The Rufford Small Grants Foundation

Final Report

Congratulations on the completion of your project that was supported by The Rufford Small Grants Foundation.

We ask all grant recipients to complete a Final Report Form that helps us to gauge the success of our grant giving. The Final Report must be sent in **word format** and not PDF format or any other format. We understand that projects often do not follow the predicted course but knowledge of your experiences is valuable to us and others who may be undertaking similar work. Please be as honest as you can in answering the questions – remember that negative experiences are just as valuable as positive ones if they help others to learn from them.

Please complete the form in English and be as clear and concise as you can. Please note that the information may be edited for clarity. We will ask for further information if required. If you have any other materials produced by the project, particularly a few relevant photographs please send these to us separately.

Please submit your final report to jane@rufford.org.

Thank you for your help.

Josh Cole, Grants Director

Grant Recipient Details	
Your name	Sandra M. Durán
Project title	Tree diversity and aboveground carbon stocks in a tropical dry forest
RSG reference	10262-1
Reporting period	November 2011-January 2013
Amount of grant	£6000
Your email address	smduranm@gmail.com
Date of this report	February 2013

1. Please indicate the level of achievement of the project's original objectives and include any relevant comments on factors affecting this.

Objective	Not achieved	Partially achieved	Fully achieved	Comments
a) Estimate above ground carbon storage across successional stages in a tropical dry forest.			√	This objective was accomplished by sampling 18 plots in a dry forest during the wet season (November 2011-April 2012). Above ground carbon stocks were estimated in three successional stages: early, intermediate and late by estimating woody biomass of all woody plants with diameter at breast height ≥ 5 in each plot. Detailed methods and results are in section 3. and Appendix I.
b) Assess whether tree species richness or functional diversity influence above ground carbon storage in a tropical dry forest			√	To accomplish this objective, we collected information in the field of three functional traits: wood density, specific leaf area, and maximum diameter at breast height. These traits were collected in five individuals per species for a total of 43 species. See section 3 and Appendix I for results.
c) Evaluate how changes on community structure during succession influence carbon storage in a tropical dry forest			√	By using the tree data from the forest plots and using dominance-diversity models it was possible to assess the relationship of community structure and above ground carbon stocks. Results are provided in more detailed in the section 3 and Appendix I.
d) Generate a database of wood density of tree species in dry forests			√	Data on wood density were obtained in the field for 43 species in a tropical dry forest. See section 3 for more details about methods and Appendix I for the full list of species and wood density data
e) Contribute to the training of youth by including undergraduate students.			√	Four undergraduate students were included in the project, from two different local universities. They were trained throughout the field season and were able to support field and laboratory work in plant ecology.
f) Assess the potential of optical remote sensing to estimate above ground biomass in a tropical dry		√		Above ground biomass was calculated with the data taken in the forest plots. Nonetheless, the assessment of satellite data has not been performed yet due to

forest				the difficulty to obtain satellite images depicting differences across successional stages. More information on section 2.
g) Dissemination of results		√		Part of the results was presented to park managers through informal talks and seminars. A poster was also presented in a local congress conducted at Universidad de Montes Claros. Publications will be generated throughout the 2013.

2. Please explain any unforeseen difficulties that arose during the project and how these were tackled (if relevant).

- Travelling within the Mata Seca Stake Park was a bit complicated due to road and weather conditions. Since we planned on travelling to the field station throughout 6 months, we rented a small car, because renting a four-wheel truck in Brazil is really expensive. Nonetheless, we tried to rent a big car at some point to improve things, but we could not get any as there were not many big cars suitable for renting in the nearest city. We solved this problem by spending more time working in the field and doing as many trips as we needed to be able to gather all the data. Due to bad weather conditions, the car suffered some damages during the trips at the beginning of the wet season. We had to cover some of these damages, as they were not fully covered by the insurance from the rental company.
- Initially, we planned to sample 36 plots of 0.04 ha each to have a big sample size. Nonetheless, reviewing the literature and based on other forest inventory plots, sampling 0.1 ha is the minimum sample size required to work in forest plots. Thus, we sampled 0.1 ha plots that are bigger, but we sample only 18, since the effort to measure all trees within the individual plots was greater. The 18 plots of 0.1 ha provided a bigger sample area (1.8 ha instead of 1.44 ha) and allowed us the opportunity to compare with other studies in tropical dry forests that have the same sampling effort.
- The assessment of optical remote sensing to estimate above ground biomass in forests with different ages is very challenging, especially in tropical forests with great values of leaf area index. The studies in remote sensing in the tropics have shown that vegetation indices derived from satellite data tend to saturate in forests older than 15 years, which compromises the accuracy of the data to perform any analysis. More recent studies in this regard are using a combination of field measurements, satellite data, and airborne light detection and ranging (LIDAR) to increase resolution and estimates in above ground biomass and carbon in tropical environments. Nonetheless, this procedure exceeds the scope of this project and the time allotted for it as well. A solution to this issue may be to evaluate whether optical satellite data correlated with field-ground measurements of aboveground biomass for the whole forest in the study area, without differentiating across successional stages. We are currently evaluating the validity of this option and exploring which satellite data may be the most suitable to conduct this analysis.

3. Briefly describe the three most important outcomes of your project.

3a. The first outcome from this project is the quantitative estimation of aboveground carbon stocks (AGC) in a protected area of dry forest under different succession stages. On one hand this information can be used to include the study area within initiatives such as Reduction in Emissions from Deforestation in Developing Countries (REDD), since the number of carbon tons per hectare can be translated to carbon credits in the international market. On the other hand, the quantitative measurement of AGC in dry forests along a successional gradient highlights the conservation value of secondary forests and their potential for law enforcement, particularly in Brazil. Firstly, by estimating AGC in secondary forests we get an understanding of how forests recover ecosystem function after disturbance. Secondary forests currently occupy 40% of the total forest area and will likely become the dominant ecosystem in tropical regions but our knowledge of their conservation value is still incipient. Through this study, we were able to estimate that secondary forests of 11- and 31-years recover are able to store 22% and 65% respectively of the total carbon contained in old-growth or mature dry forests (Table 1, Appendix I). This highlights the value of secondary forests, and particularly the importance of early successional stages as the key step for forest recovery. Early stages in Brazil are not protected by the law for wood extraction. If exploitation continues in early stages, forest recovery and developing of later stages is jeopardised, thus impeding the forest to recovers fundamental ecosystem functions such as carbon storage.

3b. Carbon stocks in our study reflect patterns in other tropical dry forests with higher amounts in later stages of succession, and higher dominance in early stages of succession.

In intermediate and late stages, differences in species contribution to carbon stocks may be more important due to other factors such as life histories and differential rates of biomass accumulation. This conclusion is based in our analyses that indicates that both species richness and carbon storage increase along succession, and also in the positive association of these two variables (Table 2, Appendix I). This result may be expected since stands of early stages of succession tend to have greater turnover of species, while late or intermediate stages show the opposite pattern. Thus, species in early stages tend to maximise leaf production, while species in later stages tend to maximise carbon storage.

Our results are important because they highlight the role of species diversity to maintain ecosystem function in natural forests. This is also important for restoration purposes, as carbon storage will be higher in mixed species stands than stands with lower number of species. Our results suggest that niche complementarity mechanisms may be more important than dominance (mass ratio hypothesis) to explain variation in carbon storage in our study area.

3c. The third outcome of this project is a wood density database of tree species in Brazil. Wood density is a key parameter to accurately estimate above ground carbon storage in tropical forests, but there is little information on wood density of species in dry forests. In addition, there is a high number of endemic species in Brazil, which make difficult to extrapolate wood density values from other databases or other tropical dry forests. In the present project, we were able to estimate wood density from field surveys of 43 species (Table 3, Appendix I).

4. Briefly describe the involvement of local communities and how they have benefitted from the project (if relevant).

As the project was in a protected area, there was not involvement with the local communities in the area. We worked in the field with the undergraduate students, and we had support in the field from the rank managers. During the project, both rank managers and our team benefitted from each other's experience and knowledge, we benefited from rank managers experience in their knowledge of land use history of the area and learning some vernacular names for tree species. The undergraduate students also benefited from the project by getting experience working in a plant ecology project, learning the protocols for sampling forest inventory plots, collecting functional traits, and processing data.

5. Are there any plans to continue this work?

Yes, with the support of the Tropi-dry network (http://tropi-dry.eas.ualberta.ca), we have been able to work in other dry forests in order to replicate the current project. We are going to sample other tropical dry forests in Brazil using the same sampling protocol and collecting the same functional traits, in order to understand the influences of different soil, climate and vegetation structure influence carbon pools in this threatened ecosystem. This will allow us to understand how variations in previous land use also influence above ground carbon storage, essential information for ecological understanding of ecosystem function, but also to comprehend how dry forests recover from previous land uses and disturbances. Within Mata Seca State Park, Dr. Mário M. Espirito Santo and his students will continue working in the study area and using the forest inventory plots for other ecological projects until 2014.

6. How do you plan to share the results of your work with others?

So far, we have divulgated some of the information at local level through informal seminar and talks to rank managers. We have also presented some of the results in local seminars at Universidad de Montes Claros in Montes Claros, Brazil. Moreover, I will be attending to an international conference in Costa Rica on tropical biology in June 2013 where I am going to present results from this project. We are also preparing a report for a newsletter called "MG-Biota" that is published by the State Forestry Institute (administrators of the State Park) to disseminate our results to environmental institutions working in the area. We are also working to publish our results in a peer-reviewed journal, where the information from this project and other study areas will be analysed and compared. We will also make available our data on functional traits collected in this project (currently available in this report in Appendix I), and in other study areas (including other functional traits) to the academia and the scientific community through public databases and scientific journals.

7. Timescale: Over what period was the RSG used? How does this compare to the anticipated or actual length of the project?

The project was planned for 16 months. Funding from RSG was used for 10 months, and the last six months were employed for data analysis, assessing satellite data and dissemination of results as it was planned in the original project.

8. Budget: Please provide a breakdown of budgeted versus actual expenditure and the reasons for any differences. All figures should be in £ sterling, indicating the local exchange rate used.

Item	Budgeted Amount	Actual Amount	Difference	Comments
GPS	400	400	0	
Vehicle rental 6 months	3000	2500	500	For our last months we were able to rent a particular car from a plant ecology lab at Universidad de Montes Claros for a cheaper price, and this let us with some remaining money.

Vehicle fuel	1750	1750		
Field equipment and supplies (borer-tree core, plastic bags, etc.)	250	500	-250	We were required to buy more field supplies (batteries, flashlights ~$70) and another increment borer ($180) because the first one broke when we were screwing in a tree with a wasp's nest. We were able to use the money meant to buy the hypsometer to do this.
Food	600	600	0	
Unexpected expenses	0	250	-250	We used the remaining money we got from the rental to cover unplanned expenses such as paying for fixing the car due to bad road and weather conditions in the study area.
Total	6000	6000	0	

9. Looking ahead, what do you feel are the important next steps?

The important steps now that we have the data are synthesising the information and disseminated to the scientific community and park managers. We have disseminated some results already, but they included preliminary results and we have not distributed all the information to the relevant institutions. Another important step is releasing some part of our data to the scientific community, so it can be used for other purposes. We are organising our data, and these will be release in the current year (2013).

10. Did you use the RSGF logo in any materials produced in relation to this project? Did the RSGF receive any publicity during the course of your work?

We constantly acknowledge RSG as our main source of funding at any informal seminars and talks. We also provided acknowledgments in the poster presented in Brazil. We are planning to use the logo in our presentation at the international conference of tropical biology next June 2013. We will acknowledge RSG in the scientific publications that will be generated from this study as well.

11. Any other comments?

We are pleased and grateful to get funding from RSG funding, as this was our major source of funding, we could not get our objectives accomplished in this project without this support.

Appendix I.

Objective 1. Estimate above ground carbon storage across successional stages in a tropical dry forest

Forest inventory data were collected at Mata Seca Stake Park. The study is located in the state of Minas Gerais, Brazil (Figure 1). The original vegetation in this area is seasonally dry tropical forests, dominated by deciduous trees, with almost 90-95% of leaf drop in the dry season (May-October). Currently, there are three successional stages: the early stage, used as pasture for at least 20 years and abandoned in 2000, is characterised by a single stratum of trees with a canopy up to 4 m. The intermediate stage was used as pasture and abandoned in late 1980s; it is composed of two vegetation layers: one with deciduous trees of 10-15 m and the second one formed by a dense understory with a high abundance of young trees and lianas. The late stage (old-growth forest) has not been disturbed for the last 50 years; it has two strata, the first one formed a closed canopy of deciduous trees of 18-20 m high, and the second one is composed of a sparse understory with reduced light penetration and low density of young trees and lianas (Figure 2).

Figure 1. Location of the study area: Mata Seca Stake Park, Brazil

Figure 2. Photos of the three successional stages in which forest inventories were conducted at Mata Seca State Park, Brazil during the wet season of 2011-2012.

Within the study area, 18 plots were located along a 5 km transect encompassing the three successional stages: early, intermediate and late. Early with a single stratum and a canopy up to 4 m; Intermediate with two strata and canopy up to 15 m, and late with two strata and canopy up to 20 m (Figure 2). Six plots were established within each successional stage, following Gentry's plot size design of 50 x 20 m (0.1 ha each). Plots within the same successional stage were separated from each other by 200 to 1000 m. Plots were established under similar topographic, soil and microclimatic characteristics to reduce variation in physical conditions. Within each plot, all individual trees with diameter at breast height (DBH at 1.30 m) ≥ 5 cm were identified at species level and their DBH was measured.

To estimate aboveground carbon storage, an allometric equation that requires basal area was used. Basal area (BA) was estimated using the formula:

$BA = \pi \, (DBH / 2)^{2}$

Then, an allometric equation developed for dry forests was employed to estimated aboveground biomass (AGB) of all woody plants:

$AGB^{b} = 10^{(-0.535 + \log 10 \, BA)}$

AGB was estimated for each individual tree. For trees with multiple stems, AGB was calculated for each stem using individual values of DBH and sum them. Carbon content was estimated as 47% of the AGB and was summed by successional stage. We also assessed the effects of succession on the magnitude of carbon stocks using an analysis of variance.

[b] Martínez-Yrizar et al. 1992. Journal of Tropical Ecology 8:87-96

Above ground carbon stocks significantly increased along succession ($F = 42.64$, $P < 0.01$), with greater carbon stocks in late successional stages. Basal area also increased with succession ($F = 42.64$, $P < 0.01$), while stem density did not vary across stages ($F = 1.5$, $P = 2.5$) (Table 1).

Table 1. Forest structure characteristics and carbon stocks for three successional stages at Mata Seca State Park obtained during the wet season 2011-2012. Age since land abandonment for natural regeneration is indicated. Mean values ± standard error are shown.

Successional stage	Aboveground carbon storage (tons / ha)	Basal area (m^2 / ha)	Stem density (No. ind / ha)
Early (~ 11 years)	7.36 ± 1.27	5.37 ± 0.92	810 ± 152
Intermediate (~ 31 years)	21.8 ± 1.17	15.9 ± 0.85	879 ± 167
Late (> 50 years)	33.7 ± 3.05	21.6 ± 2.22	1053 ± 62

Objective 2. Assess whether tree species richness or functional diversity influence carbon storage

Species richness was estimated in each successional stage and averaged across plots. To estimate functional diversity we measured three different functional traits: wood density (is a key variable in the carbon cycle), specific leaf area (the one-sided area of a fresh leaf divided by its oven-dry mass expressed in cm^2/g), and maximum diameter at breast height (DBH in cm). We measured these functional traits in five individuals per species of 43 species in the study area. The most abundant and dominant species in each successional stage were selected to measure these traits. The traits were measured following standardized protocols[c].

We evaluated whether species richness, dominance or functional diversity explained aboveground carbon storage. Species richness was the number of species per plot. Species dominance was calculated using the Simpson Index. Functional dominance was estimated using the Community Weighted Mean (CWM), which uses information of each functional trait weighted by the abundance of each species[d]. We also used a multifunctional index of functional divergence FDiv, which varies from 0 to 1, where values closer to 1 imply large differences in functional traits[d]. We evaluated the relationship of each of these indexes with aboveground carbon storage using simple linear regression (n = 18).

[c]Cornelissen et al. 2003. Australian Journal of Botany 51: 335-380.
[d] Magurran & McGill. 2011. Biological Diversity: Frontiers in Measurement and Assessment, Oxford University Press

Table 2. Results of simple regression analyses to evaluate the relationship between aboveground carbon storage and different measurements of diversity at Mata Seca State Park. Community Weighted Mean (CWM) for specific leaf area and wood density were calculated as functional dominance paramenters. The coefficient of determination (R^2) is indicated only for significant relationships.

	Estimate	**t-value**	***P*-value**	**R^2**
Species richness	1.39	3.34	0.004	0.41
Species dominance (Simpson index)	20.62	1.07	0.29	
Functional dominance				
CWM Specific Leaf Area	0.24	2.15	0.047	0.22
CWM Wood density	-20.53	-0.77	0.45	
Functional Divergence (FDiv)	24.81	1.23	0.23	

Species richness explained 41% of the variation on above ground carbon stocks along succession in Mata Seca Stake Tark. Functional diversity did not have any influence on carbon stocks, except for the CWM for Specific Leaf Area (SLA), which showed a positive association. This result may be the effect of the high dominance of some species with high values of SLA in the early stages, such as *M. urundeuva*, which store about 50% of the carbon in early stages, but it is not the most dominant species in the intermediate and late stages.

Objective 3. Evaluate how changes on community structure along succession influence carbon stocks

Using the forest inventory data, we evaluated how changes on community attributes change along succession and how these changes affect above ground carbon stocks (AGC). Dominant species were identified by determining the contribution of each species to the total basal area within each successional stage. We described the relationship between community and functional structure within each successional stage using dominance-diversity curves of species contribution to total abundance and total carbon stocks respectively (Balvanera et al. (2005). We explored the effects of succession on community and functional structure using generalised linear models.

Our analysis included 72 species for which we had wood density data. Early stages had the lowest species richness and the highest species dominance (F = 15.37, P<0.01). Functional contribution of species to carbon stocks (functionality) was highly uneven in early stages (F = 44.8, P < 0.01), due to the dominance of *Myracrodruon urundeuva* (Anacardiaceae), which contributed to over 45% of carbon stocks in early stages. Species contribution of the most dominant species in early stages was greater than the most dominant species in late stages (Figure 3). In contrast, no differences were found between intermediate and late stages on abundance (P = 0.2) and functionality (P = 0.7) of species.

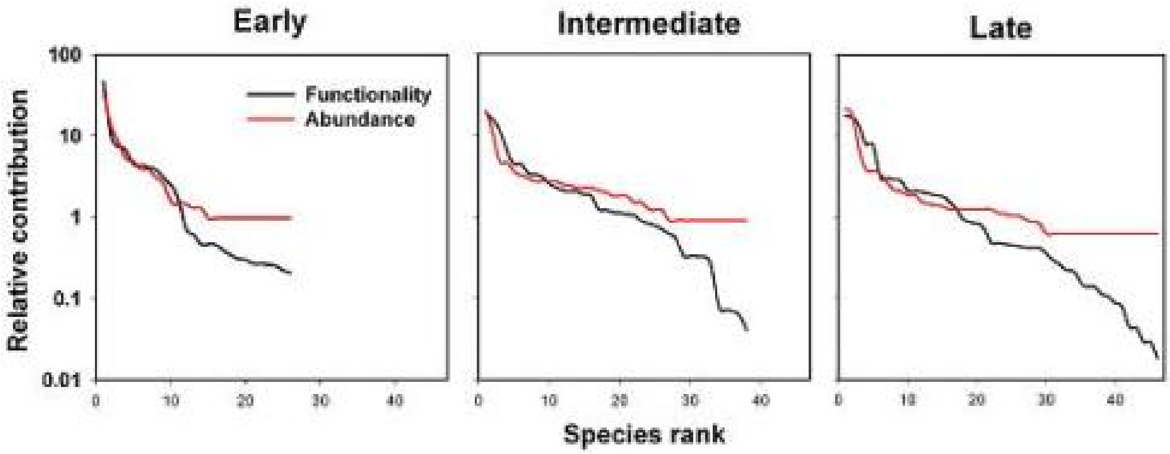

Figure 3. Comparison of community (abundance) and functional structures in three successional stages in a tropical dry forest at Mata Seca State Park, wet season 2011-2012.

Successional effects show a significant increase of carbon storage from early to late stages. The relationship between cumulative magnitude of carbon storage and species richness indicated that few species had a large effect on ecosystem function (Figure 4). Nonetheless, the number of species that make this major contribution to carbon stocks increase along succession (Figure 4), and the identity of the species also change across stages. Comparisons between early and late stages indicated a lower evenness in abundance (t= -6.93, P < 0.01) and species contribution (t= -8.75, P < 0.01) to carbon stocks in early than late stages.

Objective 4. Generate a database of wood density of tree species in a tropical dry forest
Wood samples were collected following standardize protocols[c]. We extracted wood cores for 43 species that were common in the study area. Wood cores were extracted in 5 individuals for each species (Table 3).

[c]Cornelissen et al. 2003. Australian Journal of Botany 51: 335-380.

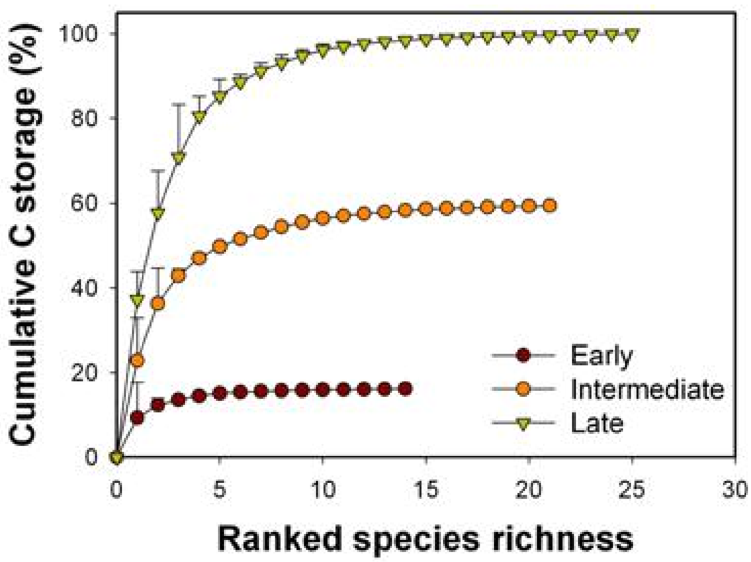

Figure 4. Relationship between aggregate carbon storage function (as percentage of total in late successional stages) and species richness (ordered by rank of decreasing contribution to the function) for all successional stages.

Table 3. Wood density (WD) values for tree species at Mata Seca State Park, Brazil.

Species name	WD g/cm3	Species name	WD g/cm3
Acosmium lentiscifolium	0.970	*Machaerium acutifolium*	1.120
Aspidosperma parvifolium	0.870	*Mimosa hostilis*	0.797
Aspidosperma polyneuron	0.734	*Myracrodruon urundeuva*	1.143
Casearia selloana	0.609	*Patagonula bahiensis*	0.880
Cavanillesia arborea	0.214	*Pereskia bahiensis*	0.664
Chloroleucon foliolosum	0.630	*Piptadenia oftalmocentra*	0.663
Cnidoscolus oligandrus	0.360	*Piptadenia viridiflora*	0.902
Coccoloba schwackeana	0.639	*Plathymenia reticulata*	0.806
Cochlospermun vitifolium	0.222	*Platysmiscium blanchetii*	0.770
Combretum duartenum	0.808	*Platysmiscium pubescens*	0.627
Commiphora leptophloeus	0.430	*Poincianella pluviosa*	0.950
Cyrtocarpa caatingae	0.615	*Prosopis sp*	0.800
Dalbergia acuta	0.809	*Pseudobombax marginatum*	0.293
Dalbergia cearensis	1.010	*Pseudopiptadenia contorta*	0.664
Enterolobium contortisiliquum	0.540	*Sapium glandulosum*	0.357
Handroanthus chrysotrichus	1.040	*Schinopsis brasiliensis*	1.230
Handroanthus heptaphyllus	0.766	*Senegalia polyphylla*	0.790
Handroanthus ochraceus	0.870	*Senna spectabilis*	0.481
Handroanthus reticulatus	0.939	*Spondias tuberosa*	0.604
Handroanthus spongiosus	0.806	*Stilingia saxatilis*	0.419
Luetzelburgia andradelimae	0.757	*Terminalia fagifolia*	1.000