PARTNERSHIP FOR LAND USE SCIENCE (FOREST-PLUS) PROGRAM

Under-planting Native Tree Species in Karnataka's *Acacia auriculiformis* Stands

FOREST-PLUS

OCTOBER 2017

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PARTNERSHIP FOR LAND USE SCIENCE (Forest-PLUS) PROGRAM

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Silviculture Technique for Uneven-aged Restoration of Degraded Forestland in Karnataka

OCTOBER 2017

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SUMMARY

The forests of the Western Ghats are some of the most diverse and productive in the world. Running along the western coast of India, they traverse the States of Gujarat, Maharashtra, Goa, Karnataka, Kerala, and Tamil Nadu. However, the forests have been degraded from the extraction of high-quality timber, and more recently from fuelwood extraction and for tea and coffee plantations. In response to this, the Karnataka Forest Department embarked on a program of restoration of lands that were converted to agriculture and then abandoned. It did this using *Acacia auriculiformis*. The acacia species was chosen because the lateritic soils present in the area are unusually recalcitrant to vegetation once bare, and it is one of the few species able to thrive under those conditions. Under the expectation that these stands will eventually be transitioned back to native species, the Karnataka Forest Department established research plots in acacia plantations and planted native species in a two-aged, multi-species form of silviculture.

With the goal of guiding future silviculture, this study revisited and measured some of those plots to determine which species had been the most productive in terms of basal area. Eleven plots were established and measured. After accounting for plot-level and establishment effects, we found that of the species with replication *Pterocarpus marsupium* and *Sapindus trifoliatus* performed best and *Emblica officinalis* and *Artocarpus integrifolia* worst in terms of basal area production.

We suggest that such long-term experiments are useful for forest managers, and that though long-term management decisions can be improved with information such as from this study, they will only be successful if shared goals are clearly articulated and established based on broad-based stakeholder consultation.

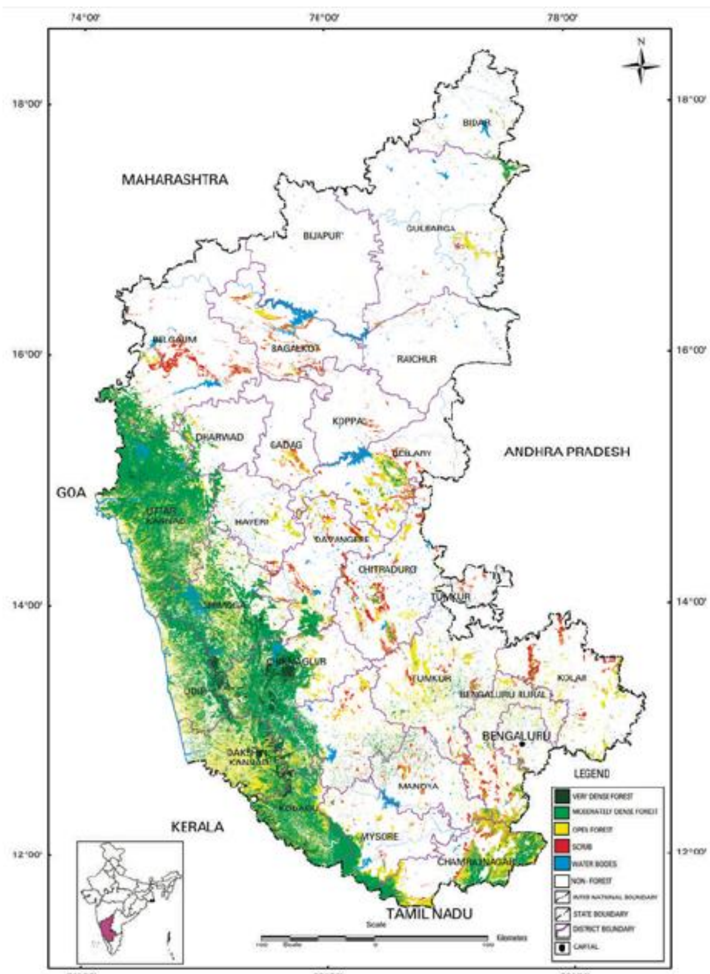
1 INTRODUCTION

1.1 GEOGRAPHY

The State of Karnataka is located in the southwest part of India. It covers an area of 191,791 km^2 and has a population of over 61 million.

According to the 1989 assessment of Forest Survey of India (FSI), the forest cover in Karnataka was 32,104 km^2 (Forest Survey of India, 1989). By 2015, that area had increased to 36,421 km^2 with a total of 19 percent of the state documented as forest cover (Forest Survey of India, 2015).

Figure 1 Forest cover map of Karnataka (Forest Survey of India, 2015)



1.1.1 CLIMATE

The year can generally be divided into three seasons: winter, summer and rainy. The majority of the rains come with the southwest monsoon from June through September, tapering heavily through October and December. Summer is from March through May, winter in January and February. The summer is severe in the eastern part of the district and moderate but humid in the west**.** The hottest months are March through May, when seasonal streams go dry. Temperatures in Karnataka range from 10^0 to 42^0 C. The highest temperatures occur in the east during summer. Humidity is generally high at night (80 to 100%) and during the rainy months and low during the day and dry months (15 to 60%).

Rainfall varies heavily throughout Karnataka. In Agumbe in the west, annual rainfall is nearly 7700 mm. Just 100 km to the east, in Honnali, the annual rainfall is 750 mm.

1.2 FOREST TYPES

Karnataka's forests are classified in the following types: southern tropical wet evergreen forests (1A/C4); southern tropical semi-evergreen forests (2A/C2); southern tropical moist deciduous forests (3B/C2); tropical dry deciduous forests (5A/C2); and southern tropical scrub forests (Champion & Seth, 1968). 'Kan' forests can also be found in certain areas in the northwestern part of the district, which contain islands of evergreen/semi-evergreen vegetation surrounded by moist deciduous forests. The percentage of different types of forests are as follows: evergreen forests-(16%), semi-evergreen-(20.28%), moist deciduous- (30.06%), dry deciduous-(25.21%) and scrub forests-(5.55%) (Bhat, Chandran, & Ramachandra, 2012).

Grassy blanks are a sub-category of forests. These are regions of the sparsely clad or bare, grassy hills with generally stunted trees found in humid areas. *Acacia auriculiformis* is being planted in many grassy blanks and open degraded areas. Much of this area has become lateritic blanks due to anthropogenic pressure, namely vegetation removal, as well as climatic factors, namely extreme seasonal rainfall, and the long stretches of hot, dry months. Over the past nearly 50 years, some of these grassy blanks near Agumbe have been slowly recovering and small patches of vegetation are developing. However, at the present rate of natural rehabilitation it appears it would take over 200 years to develop good natural vegetation.

1.3 HISTORY OF FOREST MANAGEMENT

The Forest Department in Karnataka (formerly known as Mysore state) was created in 1864. From that time until the 1970s, the forests were managed to generate revenue for the state and to meet the needs of people. As a result of intensive harvest, these forests were considerably degraded by the 1970s.

1.3.1 CURRENT FOREST MANAGEMENT

Forest management began to change in the later part of 1970s when a number of important pieces of legislation were enacted. First, the Tree Preservation Act was introduced, restricting indiscriminate felling of trees on private lands in the Malnad (humid zone) belt. Second, the Forest Development Tax was imposed on the sales of forest produce, which generated income to fund development activities to improve forests. Third, the comprehensive amendments to the Forest Act gave Deputy Conservator of Forests (DCF)-level Forest Officers the right to confiscate vehicles involved in the illicit transportation of forest produce. Fourth, entry of carts into the forests for bringing firewood on prepaid licenses was prohibited. Fifth, an amendment to the Forest Act made it mandatory for any removal of land from the Reserve Forest to get approval from both houses of the legislature.

In addition to the several legislative measures taken in the 70s, the Indian government also abolished concessions to forest industries in the mid-1980s and enacted a moratorium on green felling in 1991. In this way it could be said that 1980 marked a new era of conservation-focused forest management in Karnataka. Currently, the evergreen and semi-evergreen forests are not being harvested for timber at all. Entry is prohibited into protected areas, where not even thinning or felling for fuel wood plantations is permitted. The Moist and Dry Deciduous forest areas are being harvested on a selection system. Only the areas where basal area is more than 20 m^2 in moist deciduous forest and more than 12 m^2 in dry deciduous forests are allowed to be harvested. Felling of fuel wood plantations and thinning in teak plantations is permitted.

Over the past 30 years there has been a reduction in the pressure on the forests. While in the past, during a day's travel in well-wooded areas one would have seen over 400 head loads of wood carried by people, now that is a rarity. This change has occurred through a combination of socio-economic factors, environmental awareness and increasing the use of alternate energy sources.

1.4 AFFORESTATION AND RESTORATION OF GRASSY BLANKS IN HUMID TROPICS

The grassy blanks in the high rainfall zone of Karnataka are located in three regions: the coastal region, the Western Ghats, and the parts of the Deccan plateau adjoining the Western Ghats. The high reaches of the Western Ghats, which are steep and exposed to high velocity winds and intense rainfall, may be natural grasslands, while other areas, which at present exist as grassland at lower ranges and on undulating terrain, are man-made. In the mountainous areas, the soil is shallow and mixed with boulders. Once the vegetation cover from such sites is removed, the thin layer of organic soil gets washed away in the first rainy season, making recovery to the original vegetation state a long process, even provided the area remains protected from fire and grazing. Some young seedlings of the species in adjoining forests can be found on the fringes of these grassy patches. However, these seedlings either die during the summer months or in the recurrent annual fires. *Strobilanthes (*4-5 m tall) is invariably found bordering the forest vegetation.

Since the time required for the human induced grasslands in the humid tropics of the Western Ghats to recover to forest was undesirably long, the forest department sought a method to accelerate the process through restoration in the 1970s. Because of the poor soils and erosion, these areas required very hardy species. One of the first experimental plots was begun in Shivamogga district near Agumbe in 1976. In this plot, 38 species, including Acacia and Casuarina, were planted in 4 m long and 45 cm cube staggered trenches. Some of these areas receive rainfall of more than 6000 mm per year. Of the 38 species planted and observed for the first year, 11 showed promise. In 1977, these 11 species were planted in two locations with replications and observed further. In the third year it was observed that Casuarina did better in the grassy blanks with gentle slopes and deeper soils while Acacia did better in most other areas. These results have led to large-scale planting of *Acacia auriculiformis* across the state. Acacia is doing very well and in about 25 years it has reached nearly 25 m in height with a clear bole of about 20 m and GBH of 1-1.2 m. Although Casuarina may seem to be more desirable ecologically, due to overall growth and timber quality, Acacia has emerged a more advantageous species to plant.

1.4.1 EXPERIMENTAL UNDER-PLANTING IN *ACACIA AURICULIFORMIS* PLANTATIONS

Since 1988, there have been efforts to under-plant these areas with native species and create a mix of natural forest vegetation. Under-planting was done on an experimental basis after removing alternate rows of Acacia.

In 2016, the Partnership for Land Use Science (Forest-PLUS) and the Karnataka forest department began a study on the relative success of the native species planted on these sites under acacia. The objective of the study was to determine the species and the planting conditions that yield the best results in terms of basal area of native species. With this data, recommendations were to be made for silvicultural techniques that would be most effective in eventually transitioning these stands to native species without acacia present, without loss of forest cover.

2 METHODS

2.1 SAMPLING DESIGN

In Karnataka, in consultation with the Forest Department in 2016, potential sites for plot measurements were surveyed. The research team traveled to the different ranges where these research plots were recorded to have been established, spoke to officers about the site history of the areas, and visited the potential sites. To be included in the population, sites had to have been planted in *A. auriculiformis,* and under-planted with native species. Sites under-planted with native species less than ten years ago were excluded since the under-planted species had not had enough time to grow up into the understory or self-thin. Of the fourteen plots thus identified, eleven plots were randomly selected and measured (Figure 2).

In selected sites, for each 10 hectares (ha) of forest one 20 meter by 20 meter (m) rectangular plot was established. In the northeast corner of the main plot, a nested 5 m by 5 m plot was placed (Figure 3). In the main plot all trees with a girth of 30 centimeters (cm) or greater were recorded. Tree species, girth, and height were recorded for all trees in the full plot. In the nested plot, all trees less than 30 cm girth were counted and the species of each recorded.

Figure 2 Map of Plots in the Study

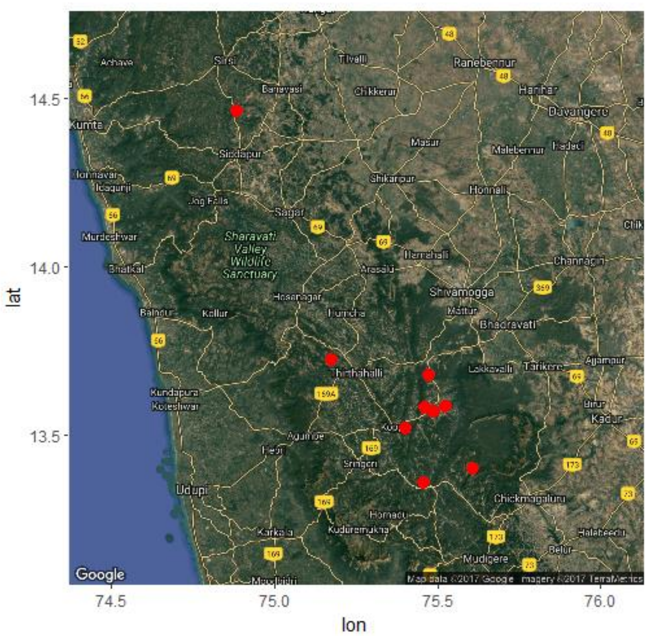
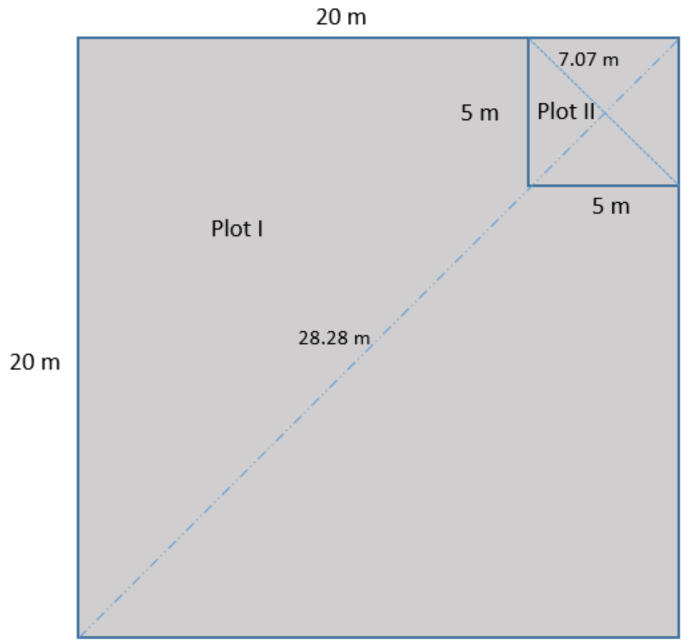


Table 1 List of Plots

Si.No	Plot name	Latitude	Longitude
86	Badagabyle N.R. Pura Range	13.67778	75.47364
89.1	Bale	13.56664	75.48911
89.2	Bale-Moodabagilu Chikkagra Hara Range	13.56786	75.48747
53	Bintravally Koppa Range	13.51819	75.40150
47	Gubbiga (Sutha)	13.57861	75.46167
F9	Hirekai Research Station Sirsi	14.46069	74.88517
175	Hornadu	13.23471	75.35888
105	Kanabur Balehonnur	13.35620	75.45837
434	Mavinakere Kalasa Range	13.23477	75.35998
72	Salur Research Range Shimoga Research	13.72094	75.17731
177	Sirigalale Chikkagrahara Range	13.58325	75.52669

The survey was supervised in the field by a retired Karnataka State Forest Department Officer. Data were recorded in predesigned data sheets against a measurement protocol. Scans of the data sheets were sent to the Forest-PLUS office for data entry. After field measurements, the APCCF Research Karnataka Forest Department and members of the Forest-PLUS office verified for a subset of the plots that plots had been laid out and measured correctly.

Figure 3 Plot Layout



2.2 ANALYSIS

Analysis of the data was done in base R and associated packages[1] (Kahle & Wickham, 2013; Lumley & Miller, 2017; R Development Core Team, 2017; Warnes et al., 2016; Wickham, 2007; Wickham, Francois, Henry, & Müller, 2017; Wickham & Henry, 2017). Data was summarized visually and checked for errors and outliers.

The analysis took a two-step approach. The goal of the analysis was to determine what best predicted the basal area of the under-planted trees at the plot level, as well as at the species level. Since many of the species were planted across several plots, plot-level factors would have confounded any analysis without first accounting for those effects in the data.

2.2.1 PLOT-LEVEL

In order to determine the correlates of basal area at the plot level, basal area was summarized for the acacia and for other species to the level of the plot. After plotting the data, forward and backward automated model selection was used with the ‘leaps’ package in R to select a linear model that best explained the variation of basal area. Predictor variables tested were: 1) years since acacia was planted, 2) the spacing of acacia when planted, 3) years since under planting occurred, 4) the spacing of the under-planted species, 5) latitude, 6) longitude, 7) the difference in years between acacia planting and

[1] R is an open-source software for statistical analysis

under planting, and 8) surviving acacia basal area. Guided testing of the best models found with automated selection was also done, and models were checked graphically (Figure 5).

2.2.2 SPECIES LEVEL

A goal of the study was to determine the species that performed best in the sample. To do this, the plot-level model was used to standardize the species basal area across plots. As well, data on the planting density by species was taken from the records of the forest department and the effect of planting density on final species density modeled using a linear model in R.

Expected species performance given plot-level factors and the species-level planting density could thus be determined. The species-level deviation from the group expectation was assumed to be a result of a species' suitability for under-planting in *A. ariculiformis* stands. For all the species, the surviving tree density was divided by the expected density to yield a proportion, with the expectation of a value of 1.

3 RESULTS

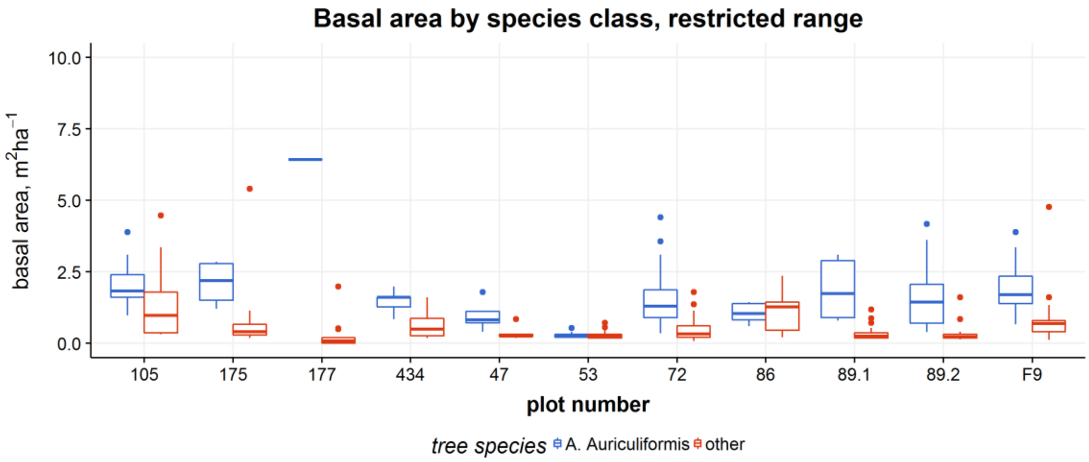
Three hundred and fifty-six trees and fifty different tree species were measured in eleven plots. The plot basal area ranged from approximately 60 m^2ha^{-1} to 4 m^2ha^{-1} in the case of acacia, and 38 m^2ha^{-1} to 1.8 m^2ha^{-1} in the case of the under planted species. In every case except one, the plot-level basal area of acacia exceeded that of the under-planted species.

The average time since acacia was planted in the study was 29 years, and the average since under-planting was 18 years.

Table 2 Plot summary statistics

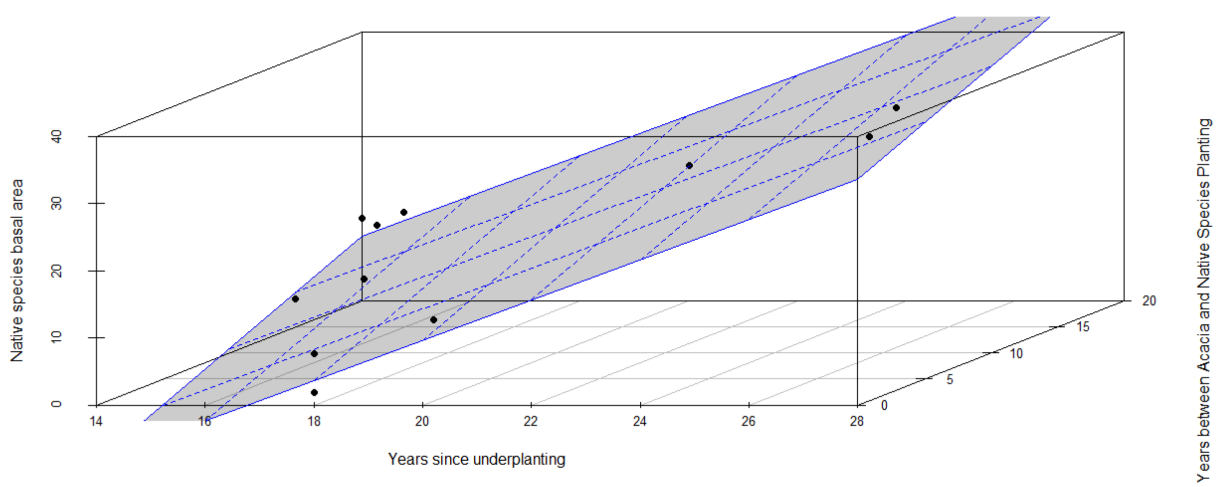
Si.No	*Acacia Basal area m^2ha^{-1}*	*Under planted Basal area m^2ha^{-1}*	*Years since Acacia planted*	*Years since under-planting*
53	4.3	5.6	27	18
177	6.4	4.1	29	14
86	8.4	7.6	18	18
89.1	11.3	6.3	31	15
47	11.6	1.8	18	18
434	13.3	12.2	34	14
105	19.0	13.5	32	15
175	20.3	13.9	34	15
89.2	26.4	36.2	32	27
F9	34.1	23.3	37	21
72	60.3	38.9	34	27

Figure 4 Basal Area by Plot (tree level)



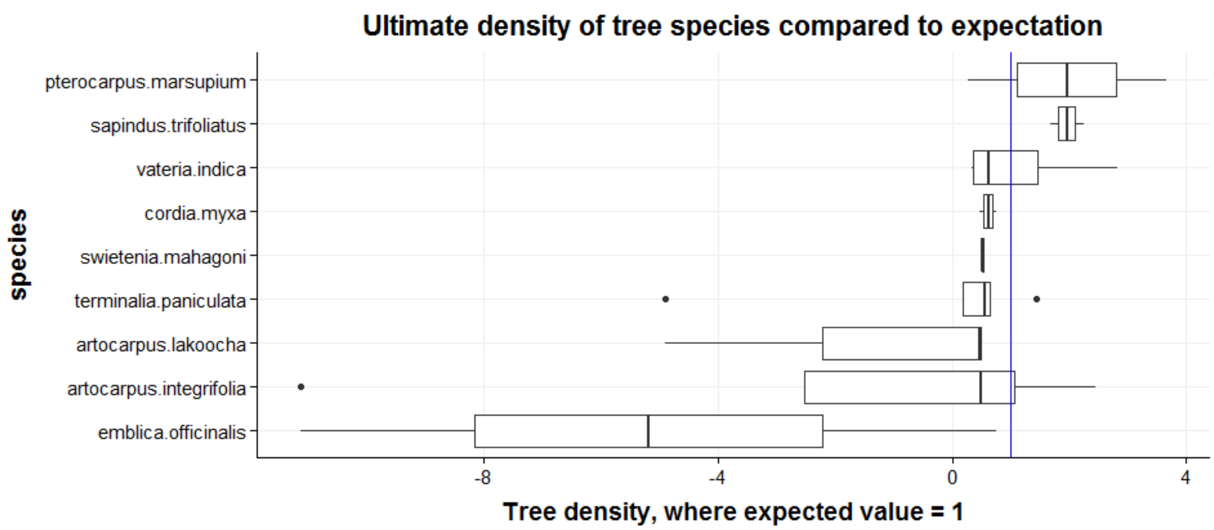
Modeling the under-planted basal area, the best predictors were found to be the number of years since under-planting, and secondarily the gap of time between the planting of acacia and of under-planting. These two predictors together explained about 92% in the plot-level variation of basal area in under-planted species (Figure 5).

Figure 5 Plot-Level Most Significant Predictor of Under planting Basal Area (m^2ha^{-1}) (adj. R^2 .92)



Taking the plot-level expectation and the planting density into account, of the fifty species measured in the plots twelve were not recorded as planted in the forest departments logs, so the species-level expectation could be determined for 38 species. Of those 38 species, only 9 appeared in more than one plot (sample size greater than one). Of the species with a sample size greater than one, *Peterocarpus marsupium* and *Sapindus trifoliatus* performed best against the pooled expectation, followed by *Vateria indica*, with a median value slightly below the expectation (Figure 6). In total, there were 15 species with a density higher than the expectation (Table 4, Figure 7).

Figure 6 Tree density, proportion of expectation



4 DISCUSSION & CONCLUSIONS

In response to the realities of forest management and the need to restore degraded lands with recalcitrant lateritic soils, the Karnataka forest department has taken the pragmatic approach of planting these areas in *A. auriculiformis*. It has further had the foresight to set up research plots to determine the most suitable species for an eventual transition of the Acacia planted to native species.

This study presents the relative success of the species planted in these plots to inform decisions about how to plan uneven-age restoration silviculture under these conditions. Key findings are:

1. At the plot-level, more time between planting acacia and under-planting is beneficial for the under-planted species[2].
2. There are clearly more productive and less productive species when under-planted, in terms of basal area relative to the expectations of the group, summarized in Table 4 and Figure 7.

With respect to the first finding, the mechanism and reasons why the gap between planting a acacia and other species is unsure; but we speculate from the general principles of silviculture and stand dynamics that the process of self-thinning that will have occurred in the acacia stand over time provides more growing space for the under-planted species in the understory (Oliver & Larson, 1996). We caution that inference should be restricted to the range of data that we have in the study, 20 to 0 years between planting of acacia and under-planting; at some point waiting to under-plant would no longer be beneficial.

With respect to the second key finding, some species tried by the forest department are clearly more productive than others. This is a useful finding for forest managers, and justifies the investment in these research plots and this study. The results should be incorporated into restoration silviculture in the future. That said, there is nuance and limitation that should be taken into account when using the results of this study. A first caution is that the findings of this study are relative – they are limited to a comparison of the performance of the species present in the plots sampled; there may be other species not present in the sample that would do better (or worse). Second, the limited number of plots in the sample (11), the large number of species (more than 50) and the variation in species planted across sites makes generalizations about all species unwarranted. We encourage limiting inference to those species with replication across plots (Figure 6) and conducting a subsequent study with more plots if decisions need to be made about planting species with only one replicate in the study. Finally, when making decisions about future under-planting and restoration silviculture the goals for species planted should be clear. In this study we are measuring success in terms of basal area – there may be other social or ecological criteria that should be taken into account when choosing species for under-planting. For example, at present acacia is commonly used as a pole wood and fuelwood species by residents near these forests. If acacia is to be completely replaced, then species with comparable wood density and growth should be planted. Other species may be useful for biodiversity conservation or human consumption and should be planted as a component of a healthy mix of species regardless of their performance in terms of basal area.

In conclusion, an effort to restore lands to productivity is subject to significant uncertainty and should be undertaken both as an exercise in learning and to allow flexibility. As forestry is a long-term endeavor, stand silviculture treatments should build in variability and flexibility so that treatments that may take decades to mature can accommodate the goals of society in the present and the future (O'Hara, 2016). In this context, we continue to call for an approach to forestry that is grounded in science-based

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[2] .9 m^2ha^{-1}/year, highly significant relationship in the final model

learning and on broad consultation with stakeholders. Such an approach will support the goals of Karnataka's citizens and of the Karnataka Forest Department.

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6 APPENDIX: BASE DATA AND SCRIPT FOR ANALYSIS

For reproducibility, the base data and script is hosted and can be downloaded at:
https://www.dropbox.com/s/3tpgh66nqmqaza4/Kar%20acacia%20 under-planting.zip?dl=0

Table 3 Plot list

Si No	*Plot*	*Acacia plant year*	*Acacia plant spacing (meters)*	*Under-plant year*	*Under-plant spacing (meters)*	*Latitude*	*Longitude*
47	Gubbiga (Sutha)	1999	2	1999	10	13.57861	75.46167
53	Bintravally Koppa Range	1990	2	1999	5	13.51819	75.4015
72	Salur Research Range Shimoga Research	1983	2	1990	5	13.72094	75.17731
86	Badagabyle N.R. Pura Range	1999	2	1999	10	13.67778	75.47364
89.1	Bale	1986	2	2002	10	13.56664	75.48911
89.2	Bale-Moodabagilu Chikkagra Hara Range	1985	5	1990	5	13.56786	75.48747
105	Kanabur Balehonnur	1985	2	2002	5	13.3562	75.45837
175	Hornadu	1983	2	2002	5	13.23471	75.35888
177	Sirigalale Chikkagrahara Range	1988	2	2003	10	13.58325	75.52669
434	Mavinakere Kalasa Range	1983	2	2003	5	13.23477	75.35998
F9	Hirekai Research Station Sirsi	1980	2	1996	4	14.46069	74.88517

Figure 7 Tree species density compared to expectation, all species

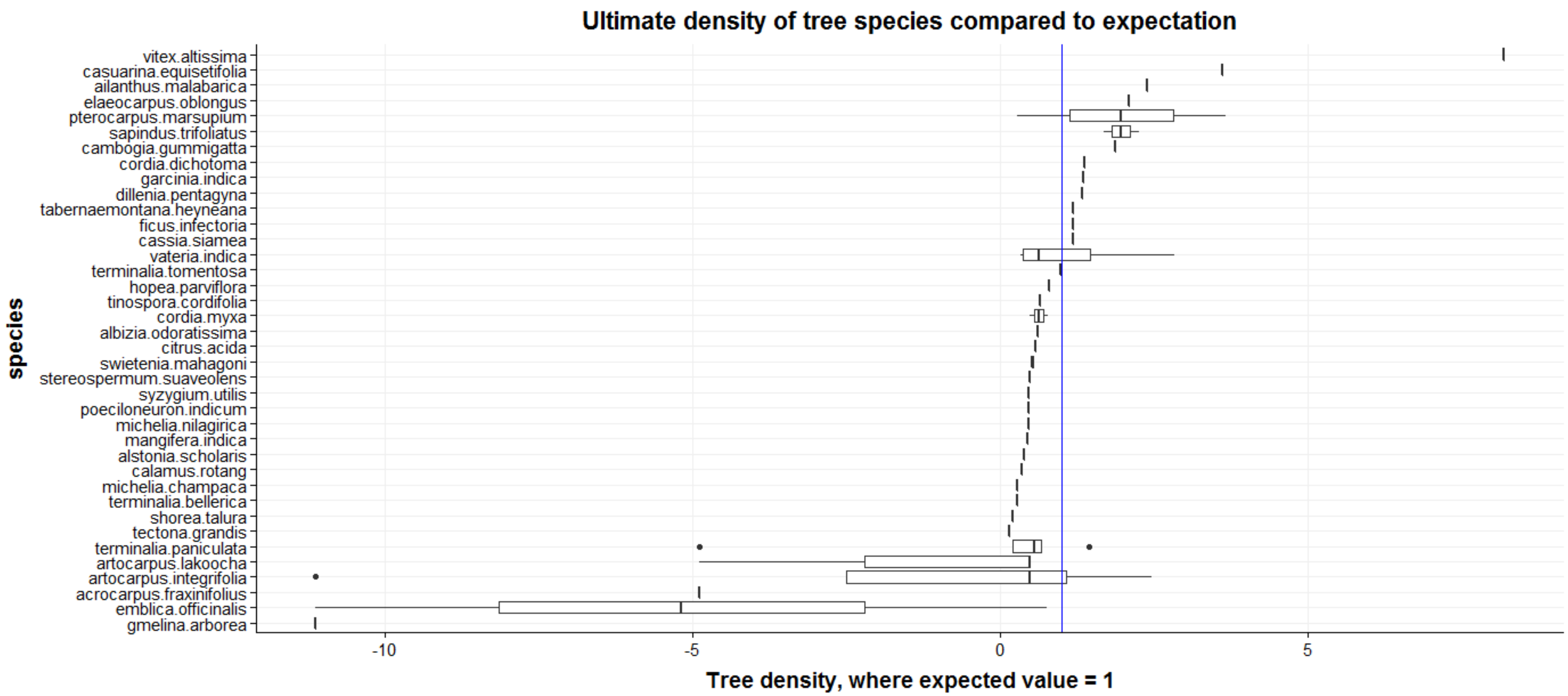

Table 4 Tree density as a proportion of the expectation, where the expectation is 1. Because of the linear form of the model, some species with very low initial planting density were modeled to have a negative expected surviving density.

Species	*Density (expectation 1)*	*Sample Size*
Gmelina arborea	-11.1	*1*
Emblica officinalis	-5.2	*2*
Acrocarpus fraxinifolius	-4.9	*1*
Artocarpus integrifolia	-1.9	*4*
Artocarpus lakoocha	-1.3	*3*
Terminalia paniculata	-0.4	*5*
Tectona grandis	0.1	*1*
Shorea talura	0.2	*1*
Terminalia bellerica	0.3	*1*
Michelia champaca	0.3	*1*
Calamus rotang	0.4	*1*
Alstonia scholaris	0.4	*1*
Mangifera indica	0.4	*1*
Michelia nilagirica	0.5	*1*
Poeciloneuron indicum	0.5	*1*
Syzygium utilis	0.5	*1*
Stereospermum suaveolens	0.5	*1*
Swietenia mahagoni	0.5	*2*
Citrus acida	0.6	*1*
Albizia odoratissima	0.6	*1*
Cordia myxa	0.6	*2*
Tinospora cordifolia	0.6	*1*
Hopea parviflora	0.8	*1*
Terminalia tomentosa	**1.0**	*1*
Vateria indica	**1.1**	*7*
Cassia siamea	**1.2**	*1*
Ficus infectoria	**1.2**	*1*
Tabernaemontana heyneana	**1.2**	*1*
Dillenia pentagyna	**1.3**	*1*
Garcinia indica	**1.3**	*1*
Cordia dichotoma	**1.4**	*1*
Cambogia gummigatta	**1.9**	*1*
Sapindus trifoliatus	**2.0**	*2*
Pterocarpus marsupium	**2.0**	*2*
Elaeocarpus oblongus	**2.1**	*1*
Ailanthus malabarica	**2.4**	*1*
Casuarina equisetifolia	**3.6**	*1*
Vitex altissima	**3.6**	*1*

7 APPENDIX: PHOTOGRAPHS

Figure 8 Review of the Study Plots by the APCCF Research Karnataka Forest Department

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