CEPF SMALL GRANT FINAL PROJECT COMPLETION REPORT

Organization Legal Name:	*-*
Project Title:	*Conserving native trees in the coffee agroforestry landscape of Kodagu*
Date of Report:	*25 October 2010*
Report Author and Contact Information	*Cheryl D. Nath* *French Institute of Pondicherry, 11 St. Louis Street, P.B. 33, Pondicherry 605001*

CEPF Region: *Malnad-Kodagu corridor, Western Ghats*

Strategic Direction: *S.D. 1, Building cooperation between local communities to promote biodiversity conservation and enhance connectivity*

Grant Amount: *$ 9,979.00*

Project Dates: *1st October 2009 – 31st August 2010*

Implementation Partners for this Project (please explain the level of involvement for each partner):

1) *French Institute of Pondicherry, India: Provided financial, intellectual, technical, logistical and administrative support*
2) *Botany and computational plant architecture group (AMAP), France: Collaborated for data analysis and provided supporting funds*
3) *National Museum of Natural History, France: Collaborated for wood analysis*

Conservation Impacts

Please explain/describe how your project has contributed to the implementation of the CEPF ecosystem profile.

1. *The interactions with farmers and their involvement in different phases of the project improved local awareness of the need for long term biodiversity planning in their landscape*
2. *The project also improved awareness of the urgent need to promote native trees rather than exotics in coffee plantations. Farmers who attended the consultative meetings articulated their interest in planting native trees if saplings were made available through government or private institutions*
3. *Awareness of the role of policy in conserving native tree species on private lands was enhanced among Forest Department officers*

Please summarize the overall results/impact of your project against the expected results detailed in the approved proposal.

Outputs achieved: A paper on native tree growth rates in coffee plantations is published online (http://dx.doi.org/10.1007/s10457-011-9401-8); a conference presentation was made based on this project

Outputs in progress: Manuscripts and reports are currently being prepared

(See Appendix 1 for citation and brief summary of outputs)

Please provide the following information where relevant:

Hectares Protected: *NIL*

Species Conserved: ***Improved local appreciation for and therefore anticipate greater future propagation of native tree species***

Corridors Created: ***NIL***

Describe the success or challenges of the project toward achieving its short-term and long-term impact objectives.

> ***Successes: The monitoring of tree growth in private coffee plantations revealed that at least one native species had the potential to grow as fast as the popular exotic silver oak. This species thus can be promoted among farmers while also pursuing options to increase its remunerative value by recommending appropriate policy modifications. A published scientific paper has resulted from this finding (See Appendix 1). In addition, three consultative meetings were conducted to publicise interim results and solicit inputs from farmers and others (Appendix 2). Farmers cooperated and participated in all phases of the project, by permitting the monitoring of trees and acquisition of botanical samples from their estates, by participating in interviews and by attending meetings held at central locations of the district. Their sustained interest and voluntary participation are likely to lead to long-term conservation gains in the district.***
>
> ***Challenges: Getting the Forest Department on board and involved seriously in the project has been a challenge. It was difficult to obtain interviews in the early months of the project, as many officers were transferred out of the district and had to be replaced by new officers. The short duration of my project thus did not permit me to identify officers with a long-term commitment to this issue, nor to develop relevant linkages between the FD and farmers.***

Were there any unexpected impacts (positive or negative)?
Nil

Lessons Learned

Describe any lessons learned during the design and implementation of the project, as well as any related to organizational development and capacity building. Consider lessons that would inform projects designed or implemented by your organization or others, as well as lessons that might be considered by the global conservation community.

Project Design Process: (aspects of the project design that contributed to its success/shortcomings)

> ***This project further developed the results of an earlier project on tree growth that I initiated with support from the CAFNET project in Kodagu, The CEPF project enabled analysis of data collected during the ongoing tree growth project, as well as facilitated further scientific studies that were not possible within the framework of CAFNET's agenda. I also utilised my associations with farmers that had been established previously during my work on elephant-human conflict in Kodagu district (1995-1997). These features probably helped produce tangible results in a short time period***

Project Implementation: (aspects of the project execution that contributed to its success/shortcomings)

Associations with scientists at the French Institute of Pondicherry and in France were important during project development, data analysis and manuscript writing. A possible reason for lack of success with involving the Forest Department was the absence of prior contacts with relevant officers. Building a relationship to enable their participation might require a longer engagement than 1 year.

Other lessons learned relevant to conservation community:

An important issue that needs to be explored in relation to long-term biodiversity conservation in agroforestry landscapes is the devolution of (at least partial) rights enabling farmers to harvest and sell native trees as timber. This is particularly relevant in Kodagu, as perhaps also in other similar areas of the Western Ghats. Under the current tenure system farmers gain little in terms of timber value from native species and thus prefer to plant exotic species that give them returns on their investment of time, money and effort. This preference for exotic species is a common phenomenon in many tropical countries with protectionist conservation policies, and prevents the farming community from becoming natural allies of conservation in agricultural landscapes. Policy changes that enable farmers to profit from native trees could help increase the conservation value of such trees to farmers. Without such enabling mechanisms, conservation efforts outside formally protected areas might remain isolated, ineffective and dependent on external funding or other top-down mechanisms for sustainability.

ADDITIONAL FUNDING

Provide details of any additional donors who supported this project and any funding secured for the project as a result of the CEPF grant or success of the project.

Donor	Type of Funding*	Amount	Notes
French Institute of Pondicherry, India	*A*	*Approximately Rs. 80,000 (for field work)*	*Additional unquantifiable support includes technical expertise, logistical and administrative facilities*
Botany and computational plant architecture group UMR AMAP (INRA and IRD), France	*A, B*	*Approximately Rs. 340,000*	*Enabled laboratory analysis and conference participation*

***Additional funding should be reported using the following categories:**

A Project co-financing (Other donors contribute to the direct costs of this CEPF project)

B Grantee and Partner leveraging (Other donors contribute to your organization or a partner organization as a direct result of successes with this CEPF project.)

C Regional/Portfolio leveraging (Other donors make large investments in a region because of CEPF investment or successes related to this project.)

Sustainability/Replicability

Summarize the success or challenge in achieving planned sustainability or replicability of project components or results.

Challenges: Sustainability will depend on continued support from researchers and the conservation community with respect to information sharing on native species value and availability. Local capacity building also is important to develop resilient systems for supply of native seedlings at nominal rates. Finally, farmers will require incentives such as rights to sell native timber freely or at higher rates of return than they currently receive from the Government.

Summarize any unplanned sustainability or replicability achieved.

Based on the positive interactions with farmers, I plan to follow up the recommendations resulting from this project,.

Safeguard Policy Assessment

Provide a summary of the implementation of any required action toward the environmental and social safeguard policies within the project.

Not applicable

Performance Tracking Report Addendum

CEPF Global Targets

(Enter Grant Term)

Provide a numerical amount and brief description of the results achieved by your grant.
Please respond to only those questions that are relevant to your project.

Project Results	Is this question relevant?	If yes, provide your numerical response for results achieved during the annual period.	Provide your numerical response for project from inception of CEPF support to date.	Describe the principal results achieved from October 1, 2009 to August 31, 2010. (Attach annexes if necessary)
1. Did your project strengthen management of a protected area guided by a sustainable management plan? Please indicate number of hectares improved.	*No*			Please also include name of the protected area(s). If more than one, please include the number of hectares strengthened for each one.
2. How many hectares of new and/or expanded protected areas did your project help establish through a legal declaration or community agreement?	*No*			Please also include name of the protected area. If more than one, please include the number of hectares strengthened for each one.
3. Did your project strengthen biodiversity conservation and/or natural resources management inside a key biodiversity area identified in the CEPF ecosystem profile? If so, please indicate how many hectares.	*No*			
4. Did your project effectively introduce or strengthen biodiversity conservation in management practices outside protected areas? If so, please indicate how many hectares.	*Yes*	*At least 50 - 100 farmers are likely to plant more native trees in the future, potentially affecting @ 1000 ha*	*(Same)*	***Results achieved during October 2009 to August 2010:*** ***1. A native species with relatively fast growth was identified and a scientific manuscript was submitted for publication*** ***2. Farmers were sensitized to the need for planting more native trees and have stated their interest in doing so*** ***3. Three consultative town meetings were conducted, in which farmers and others participated and provided practical suggestions for increasing the availability and promotion of native saplings in the future (See Appendix 2 and Project report)***
5. If your project promotes the sustainable use of natural resources, how many local communities accrued tangible socioeconomic benefits? Please complete Table 1below.	*(Expected future result)*	*Promotes but no tangible benefit accrued as yet*		

If you answered yes to question 5, please complete the following table.

Table 1. Socioeconomic Benefits to Target Communities

Please complete this table if your project provided concrete socioeconomic benefits to local communities. List the name of each community in column one. In the subsequent columns under Community Characteristics and Nature of Socioeconomic Benefit, place an X in all relevant boxes. In the bottom row, provide the totals of the Xs for each column.

Name of Community	Community Characteristics								Nature of Socioeconomic Benefit												
									Increased Income due to:												
	Small landowners	Subsistence economy	Indigenous/ ethnic peoples	Pastoralists/nomadic peoples	Recent migrants	Urban communities	Communities falling below the poverty rate	Other	Adoption of sustainable natural resources management practices	Ecotourism revenues	Park management activities	Payment for environmental services	Increased food security due to the adoption of sustainable fishing, hunting, or agricultural practices	More secure access to water resources	Improved tenure in land or other natural resource due to titling, reduction of colonization, etc.	Reduced risk of natural disasters (fires, landslides, flooding, etc)	More secure sources of energy	Increased access to public services, such as education, health, or credit	Improved use of traditional knowledge for environmental management	More participatory decision-making due to strengthened civil society and governance.	Other
Total																					

If you marked “Other”, please provide detail on the nature of the Community Characteristic and Socioeconomic Benefit:

Additional Comments/Recommendations

Through this project we were able to achieve a good understanding of farmers' constraints and have identified possible solutions. Farmers and other local stakeholders were sensitized to the need for planting more native species. Certain recommendations, such as increased availability of native saplings, can be addressed locally. Future work also should include the development of a supportive and farmer-friendly conservation policy.

Information Sharing and CEPF Policy

CEPF is committed to transparent operations and to helping civil society groups share experiences, lessons learned, and results. Final project completion reports are made available on our Web site, www.cepf.net, and publicized in our newsletter and other communications.

Please include your full contact details below:

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List of appendices:

Appendix 1: Project outputs

Appendix 2: List of meetings with local stakeholders

Appendix 3: Published paper: Nath, CD, Pelissier, R, Ramesh, BR, Garcia, C. (Published online 21 April 2011). Promoting native trees in shade coffee plantations of southern India: comparison of growth rates with the exotic Grevillea robusta. Agroforestry Systems (Nath et al.2011-AgroSyst.Promoting native trees.pdf)

Appendix 4: Detailed Project Report (CNath_Detailed_Project_report_CEPF-ATREE.pdf)

<u>Appendix 1: Project outputs</u>

1. Published paper: Nath, CD, Pelissier, R, Ramesh, BR, Garcia, C. (Published online 21 April 2011). Promoting native trees in shade coffee plantations of southern India: comparison of growth rates with the exotic Grevillea robusta. Agroforestry Systems. DOI 10.1007/s10457-011-9401-8
Summary: The paper compares growth performance of four common native species against that of the exotic species, Grevillea robusta. Results showed that G. robusta had the fastest growth rates, but large trees of the native Acrocarpus fraxinifolius had faster growth in the wet western side of the district. The results provide a basis for recommending appropriate changes in public policies that would improve native tree tenure security.

2. Conference presentation: Nath CD, De Franceschi, D, Boura, A, Pélissier, R, 2011. Tree age estimation for tropical tree species by direct and indirect methods. Oral presentation at the Annual Symposium of the British Ecological Society, Cambridge, UK, 28-30 March 2011. http://abstracts.britishecologicalsociety.org/exports/18-bulletin.html

3. Manuscripts and a technical report detailing further results of the tree growth studies and stakeholder views are under preparation

Appendix 2: List of meetings with local stakeholders

Date	***Location***	***Attendees***
8 July 2010	***Napoklu***	***Approximately 12 farmers, including a Panchayat member and members of a local NGO (Nalnad Progressive Farmers Association)***
12 July 2010	***Sidapur***	***Approximately 15 farmers, including members of local farmers' organizations (Kodagu District Small Growers' Association, Codagu Planters Association, Maldare Badaga Primary Agricultural Credit Cooperative Society)***
30 August 2010	***Kakkabe***	***Approximately 25 farmers, including a Panchayat member and members of local farmers' organizations (Kodagu Growers Federation, Yevakapadi Farmers Association, Nalnad Coffee Growers Association)***

PROMOTING NATIVE TREES IN SHADE COFFEE PLANTATIONS OF SOUTHERN INDIA: COMPARISON OF GROWTH RATES WITH THE EXOTIC *GREVILLEA ROBUSTA*

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Citation for this article:

Nath, CD, Pélissier, R, Ramesh, BR, Garcia, C (2011). Promoting native trees in shade coffee plantations of southern India: Comparison of growth rates with the exotic *Grevillea robusta. Agroforestry Systems.* DOI 10.1007/s10457-011-9401-8

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Abstract

Traditional shade coffee plantations of Kodagu district, in the Western Ghats of southern India, harbor a high density and diversity of trees. Local farmers appreciate native biodiversity, but plantation economics and public policies drive them to gradually replace the original diversified cover with exotic shade trees such as *Grevillea robusta*, which grows fast and can be easily traded as timber. In order to identify and recommend native timber trees with fast growth rates, we compared the growth performance of four common native species against that of *G. robusta,* by fitting steel dendrometer bands on 332 shade trees.

Results showed that in general *G. robusta* had the fastest growth rates, but large trees of the native *Acrocarpus fraxinifolius* had faster growth in the wet western side of the district. Computer projections of long term performance showed that most species were influenced by bioclimatic zone. Species-specific local environmental effects also occurred, including competition from coffee bushes for *A. fraxinifolius*, influence of aspect for *G. robusta*, and management block effects for *Lagerstroemia microcarpa*.

Our results show that native species can potentially produce timber at rates equivalent to those of exotic species. However, as in many tropical countries, data on growth rates of native trees within mixed-cover plantations are scarce and this study underlines the urgent need to screen for fast-growing species. Such information provides a

strong basis for recommending appropriate changes in public policies that would improve tree tenure security and encourage farmers to grow more native species.

Keywords: Silver oak, bioclimatic zone, mixed effects model, topography, competition index, tropical

Abbreviations: KFD = Karnataka Forest Department; LME = Linear mixed effects; NCI = Neighbor competition index; BA = basal area

Introduction

Traditional shade coffee plantations of Kodagu district in southern India contain 70 - 1200 trees ha^{-1} and a relatively high diversity of species (Elouard et al. 2000; Nath et al. 2010). This diversity includes a high proportion of native species that were retained for shade in traditionally managed coffee plantation systems (Haller 1910) that have persisted until modern times (Neilson 2008). Located in the Western Ghats, a world biodiversity hotspot, the conservation significance of this agroforestry-dominated landscape is high (Bhagwat et al. 2005) and the current priority is to prevent depletion of existing diversity (Garcia et al. 2010). Local farmers appear conscious of the biodiversity value of their plantations, which may be linked to their traditional cultural practices of conserving sacred forests and species (Bhagwat et al. 2005; Neilson 2008). However, international coffee price fluctuations and public policies are driving them away from traditional land management practices towards modern practices favoring shade tree monocultures and sun-intensive cultivation (Elouard et al. 2000; Ghazoul 2007; Ambinakudige and Satish 2009; Garcia et al. 2010).

The dismantling of protectionist policies in 1993-94 improved economic returns for Indian coffee farmers, but also exposed them to international dynamics that destabilize prices (Neilson 2008). Coffee yields are generally unpredictable as different stages of the production cycle depend on timely and appropriate rainfall. Despite these risks farmers are obliged to invest heavily in annual plantation maintenance, which creates the need for economic buffers (unpublished farmer interviews). Thus farmers usually turn to timber from shade trees when the coffee market is down. Farmers, however, report difficulties in maintaining high diversity due to the protectionist policies behind land and tree tenures, which demand heavy duties and permits for felling, transport and selling of native timbers. This preventive strategy has paradoxically encouraged farmers to plant exotic trees instead (Elouard et al. 2000; Ambinakudige and Satish 2009; Garcia et al. 2010). In this paper we focus on addressing farmers' concerns while promoting native species' conservation by identifying fast-growing native timber trees that could serve as short term economic buffers.

A census of over 20,000 trees in 2008 revealed that the exotic Australian species, *Grevillea robusta* A.Cunn. ex R.Br. (family Proteaceae, commonly known as "silver oak"), was the most dominant species in coffee plantations of Kodagu, constituting 20% of all trees censused (unpublished data). The most commonly cited advantages of using *G. robusta* in agroforestry plantations worldwide are its fast growth rate and minimal competitiveness with crops (Harwood 1989; Jama et al. 1989; Okorio et al. 1994; Kalinganire 1996; Baggio et al. 1997; Lott et al. 2000a; Takaoka 2008; but see Lott et al. 2000b regarding competition with crops). In Kodagu, there are additional incentives to plant *G. robusta*, such as the absence of administrative constraints on marketing its timber and easy availability of saplings. In addition, *G. robusta* is considered the best support for black pepper (*Piper nigrum)* vines (Elouard et al. 2000; Ghazoul 2007; Garcia et al. 2010). The association between coffee, pepper and *G. robusta* diversifies farm incomes, thus improving their economic resilience. However, a few drawbacks associated with *G. robusta* (fallen leaves do not decompose easily and often accumulate atop coffee branches, preventing fruit set or causing berries to drop) and the general value attached to native trees have led local farmers to express interest in planting native trees.

In this context, the current study provides a field-based comparison of growth performance of four common native timber species versus *G. robusta*, in order to determine if native species can produce comparable growth rates within the coffee plantation environment. Similar studies have been carried out elsewhere with the aim of recommending native species for afforestation and agroforestry (Jama et al. 1989; Okorio et al. 1994; Dhyani and Tripathi 1999; Yamada and Gholz 2002; McDonald et al. 2003; Takaoka 2008; Park et al. 2010). However, whereas most previous comparisons used sapling cohort growth trials, we studied growth in established standing trees with a large range of diameters. This sampling design enabled us to incorporate ontogenetic changes in growth (cf. Nath et al 2006), based on the assumption that diameter effects are generally correlated with age effects over the lifetime of a tree.

Given that growth varies with size, and can be influenced by environmental factors (Uriarte et al. 2004; King et al. 2005; Nath et al. 2006; Park et al. 2010), we included a range of different tree sizes and environmental conditions. We selected four widely occurring native species with medium to high timber value, and compared growth between the eastern and western sides of the district, which represent two different bioclimatic zones. To our knowledge this is the first study to incorporate ecological principles of tree growth in developing management guidelines for native species conservation in tropical shade coffee plantations. The specific questions asked in this study were:

1) Do native shade tree species have similar growth rates as the fast-growing *G. robusta* in the two bioclimatic zones within the coffee plantation environment?

2) Do local environmental factors, such as topography and neighbors, significantly affect the growth of these species?

Methods

<u>Study area and species selection</u>

The study sites are situated in the Cauvery watershed area of Kodagu district, Karnataka state, India (Fig. 1), on the leeward side of the Western Ghats mountain chain. The altitude ranges from 850 m to 1875 m across the district. Rainfall is strongly seasonal with maximum precipitation deposited by the southwest monsoon in June-August, and a steep geographical gradient from west (>5000 mm yr^{-1}) to east (<800 mm yr^{-1}) in about 50 km (Elouard 2000). The study area has medium to low elevation wet evergreen forest in the western and central regions and moist to dry deciduous forest in the east (Pascal 1988; Elouard 2000; Fig. 1). Landscape studies have shown gradual conversion of privately owned forests into coffee plantations, opening of the canopy, and increase of exotic trees (Elouard 2000; Garcia et al. 2010).

Four locally widespread and common native species, with differing growth rates, growth forms economic values and uses, were selected for monitoring based on published literature and earlier studies (Garcia et al. 2010, Nath et al. 2010). Species were classified as native if their original distribution range included the Western Ghats (Gamble 1935; Pascal 1988). These species are the following (with identification and nomenclature as defined by the French Institute of Pondicherry Herbarium, HIFP):

1. *Acrocarpus fraxinifolius* Wight & Arn. (locally known as “Balanji”, family Fabaceae), a lofty emergent (often >

40 m in height) deciduous softwood species, often with buttressed roots, occurring in evergreen and moist deciduous forests. The wood is of low to medium economic value and used for making furniture, plywood, planks, rafters, etc.

2. *Dalbergia latifolia* Roxb. (“Beeti”, family Fabaceae), a tall canopy (occasionally 40 m) deciduous to evergreen hardwood species occurring in deciduous forests. This species is considered “Vulnerable” by the International Union for Conservation of Nature. The wood is of high economic value and among the finest for making high quality furniture.

3. *Lagerstroemia microcarpa* Wall (“Nandi”, family Lythraceae), a medium canopy (< 40 m) deciduous hardwood species, sometimes with buttressed roots occurring in moist deciduous and disturbed evergreen forests. The wood is of medium to high economic value and used for house construction, agricultural implements, bridges, ships, wagons, etc.

4. *Syzygium cumini* (L.) Skeels (“Nerale”, family Myrtaceae), an understory or canopy (< 40 m) evergreen hardwood species, rarely with buttressed roots, occurring widely from deciduous to evergreen forests. The wood is of medium economic value and used for house construction, agricultural implements, ships, railway sleepers, mine props, etc.

In addition to these, the fast-growing exotic species, *G. robusta*, was monitored for comparison. This is a tall canopy to emergent (sometimes 40 m) evergreen softwood species native to the coastal rainforests and inland mountain ranges of eastern Australia (Harwood 1989). The wood is of low to medium economic value and used for paneling, plywood, furniture, paper pulp, etc.

The native trees above generally sprouted naturally from seeds or coppices within the coffee plantations, but the exotic trees always were planted by farmers.

Data collection

Between April and October 2008, 345 stainless steel dendrometer bands (Pélissier and Pascal 2000) with Vernier scales of 0.02 cm measurement accuracy, were affixed on trees (in the girth range 23 - 400 cm) at a height of 1.3 m from the ground, and approximately 30 cm above any buttresses that were present at this height (cf. Clark and Clark 1996). A minimum of 60 trees were monitored per species, with at least 30 each on the eastern and western sides, and approximately 30 each in the “small” (trees 23-120 cm gbh or girth at breast height, 1.3 m above the ground) and “large” (trees ≥ 120 cm gbh) size classes. The trees were spread out across three or more management blocks in each of 13 coffee plantations. Six plantations were located on the eastern side and seven on the western side of the district (Fig. 1), corresponding to the two main bioclimatic zones of the district. By sampling trees of various sizes at each estate, we expected the different environmental influences to be spread across all ontogenetic stages of tree growth.

Most of the dendrometer bands were fixed during April – June 2008, prior to the onset of monsoon rains. Data analyzed in this paper represents the interval November 2008 – November 2009, commencing approximately six months after installation of the bands. A few trees were lost or eliminated from the dataset due to death, felling or excessive disturbance, and overall a total of 332 healthy and undamaged trees provided one year of growth records for analysis.

For analyzing the influence of local biotic and abiotic environmental factors a subset of 116 trees located in four plantations of the eastern bioclimatic zone were used. Neighbor tree data were collected on identity, distance from the focal tree, girth of all stems ≥ 10 cm gbh and relative height (i.e., whether or not taller than the focal tree), from 1260 trees (with largest stem ≥ 20 cm gbh) within 10 m distance from the focal trees. In addition we counted the numbers of the two main species of coffee bushes (i.e., *Coffea canephora* or Robusta coffee, and *Coffea arabica* or Arabica coffee) growing within a circle of 10 m radius from focal trees to assess below-ground resource competition, which could affect the growth of large trees (York et al. 2010). Topographical data were collected at the management block level, including elevation (meters above sea level), slope gradient (degrees) and aspect (i.e., the direction the stand faces, averaged across multiple readings per block and classified as southwest (SW) or northeast (NE)). For large blocks an average of more than one value of topographical data was used.

Data analysis

Tree growth rates were calculated as $(D_1\text{-}D_0)/T$, where D_0 is the starting diameter (in cm), D_1 is the ending diameter and T is the intervening time in years.

Differences across species, sizes and bioclimatic zones

Multilevel linear mixed effects models were used (LME, Pinheiro and Bates 2000) to assess the magnitude of influence on growth rates due to the fixed effects of species identity, size and bioclimatic zone. Stepwise deletion of fixed effects was carried out to obtain the most parsimonious model. Random errors were modeled hierarchically as management block effects nested within plantation effects, and were retained in all the models, from initial to final step. Stepwise deletion of fixed effects was carried out by serial removal of non-significant terms that produced maximum reduction of the Akaike and Bayesian Information Criteria per step. LME modeling was implemented with the package ''nlme'' (Pinheiro et al 2008) on the R platform version 2.11.1 (R Development Core Team 2010).

This modeling procedure was carried out for all species together, and also on restricted datasets containing *G. robusta* paired with each native species. The analysis also was carried out for small trees or large trees. Diameter was checked for normal frequency distribution with the Shapiro-Wilk test, Kolmogorov-Smirnov test and histogram plot. Most diameter distributions were right skewed and thus square root transformation was used when modeling all species together or for the species pairs, *G. robusta - A. fraxinifolius* and *G. robusta - D. latifolia*; natural log transformation for *G. robusta - L. microcarpa* and *G. robusta - S. cumini;* and negative inverse transformation for large stems. Residuals of all final models were subjected to tests for normality, homoskedasticity and linearity (Pinheiro and Bates 2000). In all cases (except for *G. robusta - A. fraxinifolius*) square-root transformation was used on the dependent variable, growth rates.

In order to study long term cumulative effects of differences between species, empirical age-size trajectories were developed from dendrometer data by stochastic computer simulations (cf. Lieberman and Lieberman 1985). The use of stochastic simulations enabled projections to mimic empirical patterns and avoid potentially biased or unwarranted assumptions about growth limitations. For this, the starting diameter size was 0.05 cm, and each stem was allowed to grow by a randomly selected amount per growth step representing one year. The annual growth rate per step was selected randomly from among empirically recorded growth rates within the diameter size class ± 3 cm from the diameter of the simulated stem. Each simulation was terminated in the 80^{th} year, and for each species 10,000 such trajectories were generated. This distribution of trajectories was used to obtain the average trajectory and 95% confidence intervals per species. Where growth rates were unavailable in a size class (for e.g., all small stems < 7 cm dbh) corresponding average growth rates were substituted, which were calculated for four quarter sections of the diameter distribution per species. This substitution was used in < 25% of simulated trajectories, except in the case of *G. robusta* on the western side, in which case this substitution was used 46% of the time due to paucity of large tree data). During simulations, successive years that cumulatively produced zero or negative net growth were terminated in the third successive year, by using the average growth rate of the corresponding diameter size section.

Influence of local environmental factors on species growth rates

In order to assess the competitive effects of neighboring trees, a suitable neighbor competition index (NCI) was first identified (cf. King et al. 2005). Distance and size of neighbors often has a bearing on the strength of competitive effects (Condit et al. 1994; King et al. 2005; Uriarte et al. 2004). In addition, competitive effects may be considered symmetric (all neighbors compete) or asymmetric (only taller or larger trees compete, Pélissier and Pascal 2000). In order to identify the most suitable index of competitive influences relevant to our study, we tested different ways of combining the distance effect with the neighbor size effect.

Three different NCIs were tested, which model the effect of neighbor distance (up to 10 m) in different ways:

1. NCI-1 (cf. Condit et al. 1994): All neighbors located within a fixed distance of 5 m or 10 m were considered as competitors. Thus, NCI-1 = ΣN_i, where N_i represents the ith neighbor.
2. NCI-2 (cf. Uriarte et al. 2004): Competition by each neighbor was weighted by the inverse of its distance from the focal tree. Thus, NCI-2 = $\Sigma (N_i / D_i)$, where D_i represents the ith neighbor tree's distance.
3. NCI-3 (cf. King et al. 2005): Competition by each neighbor was weighted by its relative proximity to the focal tree, with a (theoretical) minimum distance of 0 m weighted as one (maximum proximity and competitive effect), and the furthest possible distance, 10 m, weighted as zero (minimum proximity, no competitive effect). Thus, NCI-3 = $\Sigma N_i * ((10 - D_i) / 10)$

Within all the above NCIs, N_i was unweighted for size effects (wherein N_i = 1), or weighted as follows by neighbor stem thickness:

1. Total count of neighbors (i.e., not weighted by stem thickness)
2. Neighbors weighted by diameter ($N_i = Dbh_i$)
3. Neighbors weighted by basal area ($N_i = BA_i$, inclusive of all stems ≥ 10 cm gbh)

In addition, the relative height effect was accounted for as follows:

1. All neighbors included in calculation of NCI (symmetric competition)
2. Only taller neighbors included in calculation of NCI (asymmetric competition)

The different combinations of weighting schemes were compared by non-parametric Spearman rank correlation between focal tree growth and NCI, in order to select the best NCI. The most sensitive NCI obtained in the above analysis was then used to assess the influence of neighbor tree competition on growth by Spearman rank correlation.

In order to assess the influence of topography and below-ground competition, an initial LME model was used to test tree growth as a function of tree dbh, slope, aspect and total number of coffee bushes within 10 m distance (except in the case of *L. microcarpa*, where there was insufficient variation to include slope and aspect). Interactions between focal tree diameter and each of the other factors also were included. The most parsimonious model was obtained by deleting unimportant variables (as described above).

The variables diameter, slope and number of coffee bushes were checked for normal frequency distribution and transformed as required. In addition, residuals were subjected to tests for normality, homoskedasticity and linearity (described above) and appropriate transformations were applied. All analyses were carried out using R, version 2.11.1 (R Development Core Team 2010), and results were considered significant at $P < 0.05$.

Results

Differences in relation to species, size and bioclimatic zone

Relative importance of factors with LME

Across all trees, the average diameter growth rate in the eastern and western bioclimatic zones were similar (East: 0.92 cm yr^{-1}, West: 0.96 cm yr^{-1}). However, the following differences were observed between species:

- East: *G. robusta* (1.37 cm yr^{-1}), *A. fraxinifolius* (1.13 cm yr^{-1}), *L. microcarpa* (0.79 cm yr^{-1}), *S. cumini* (0.70 cm yr^{-1}), *D. latifolia* (0.57 cm yr^{-1})
- West: *A. fraxinifolius* (1.36 cm yr^{-1}), *G. robusta* (1.24 cm yr^{-1}), *L. microcarpa* (0.88 cm yr^{-1}), *S. cumini* (0.82 cm yr^{-1}), *D. latifolia* (0.44 cm yr^{-1})

The exotic *G. robusta* had the highest overall average growth rate (1.31 cm yr^{-1}), followed by the native *A. fraxinifolius* (1.25 cm yr^{-1}). However, *A. fraxinifolius* grew faster than *G. robusta* in the western zone, as large trees of *A. fraxinifolius* had very high growth rates (Fig. 2, Appendix 1). Among the top five fastest growing individuals were two small *G. robusta* trees in the east (4.02 and 2.94 cm yr^{-1}, respectively), two large *A. fraxinifolius* trees in the west and east (2.86 and 2.68 cm yr^{-1}, respectively) and one small *L. microcarpa* in the west (2.76 cm yr^{-1}). Three of the four native species had higher growth on the wet western side, but the most valuable timber species, *D. latifolia*, which had the lowest growth rate in both bioclimatic zones, showed very poor growth in the west (Fig. 2).

Species identity was the only significant factor in LME models (Table 1). However, when modeling small and large stems separately, none of the fixed effects was significant. Variation at the block level was important for small stems (explaining 26% of random variation), and variation at the plantation level was important for large stems (18%, Table 1). Pair-wise comparisons of *G. robusta* with each of the native species showed that *G. robusta* growth rates were significantly faster than all native species except *A. fraxinifolius* (Table 1).

Age-size trajectories

G. robusta showed the best long term growth performance in both bioclimatic zones (Fig. 3). However, in the western zone *A. fraxinifolius* had an average growth trajectory and 95% confidence intervals closely overlapping those of *G. robusta*.

The two intermediate growth rate species, *L. microcarpa* and *S. cumini,* showed similar trajectories with overlapping 95% confidence intervals. However, as expected, the highly valuable *D. latifolia* had significantly slower growth trajectories than all other species, especially in the western zone (Fig. 3).

Influence of local environmental factors

Competition from neighboring trees

All the competition indexes tested showed higher correlation coefficients for asymmetric than symmetric competition (Table 2). Within the results for asymmetric competition, values were highest when taller neighbors were weighted by BA, and among these, NCI-1 using a 10 m annulus produced the highest correlation (Spearman rank correlation coefficient = -0.2680, $P < 0.001$, Table 2). These results suggest that in a coffee plantation environment height of neighbors, followed by BA, is important for competing effectively. Thus the index NCI-1, using taller neighbors weighted by BA within a 10 m radius, was selected to assess the influence of neighbor effects per species.

There was a weak negative correlation between growth and NCI for *A. fraxinifolius* (Spearman rank correlation = -0.2948, N = 24, non-significant), *G. robusta* (Spearman rank correlation = -0.2304, N = 25, non-significant) and *S. cumini* (Spearman rank correlation = -0.1966, N = 23, non-significant), suggesting that neighboring trees exert weak competitive influence within the coffee plantation environment.

Topography and below-ground competition

Only the two fastest growing species were influenced by topography and below-ground competition. *A fraxinifolius* growth was significantly reduced by coffee bush density (Fig. 4), while *G. robusta* had significantly lower growth on southwest-facing slopes (Table 3). In addition, local site differences across management blocks explained 55% of random variation in *L. microcarpa* growth rates (Table 3).

Discussion

Comparison of species' growth rates and trajectories

After a year of monitoring we have found that in general the exotic *G. robusta* had the highest growth rates, and that a comparable rate was produced by the native *A. fraxinifolius* in the high rainfall western zone. We checked if buttresses of *A. fraxinifolius* trees were responsible for high growth rates, by excluding trees with moderate to large buttresses (10 trees of *A. fraxinifolius*) from the analysis. However, the average growth rate of this species slightly increased, leaving the general conclusions unchanged. Thus we may conclude that this native species grows as fast as the exotic silver oak in the western zone where large *A. fraxinifolius* trees have the highest growth rates and *G. robusta* stems may find it difficult to withstand strong monsoon winds (farmer interviews), perhaps due to the lack of buttresses.

High growth rates of *A. fraxinifolius* in the western zone may be related to its native occurrence in low and medium elevation wet evergreen forests of the Western Ghats (Gamble 1935; Pascal 1988). Similarly, *D. latifolia* does not occur naturally in evergreen forests, which might explain its poor performance in plantations of the humid western zone (where its presence may be due to introduction by humans). The other two native species, *L. microcarpa* and *S. cumini*, are naturally widespread across deciduous to disturbed evergreen forests of the Western Ghats. Their growth rates suggest an ability to adapt to dry as well as moist conditions, resulting in medium growth rates under both types of climatic regimes. Our results accord with the knowledge of local farmers, who were aware of the fast growth of *A. fraxinifolius* and the slow growth of *D. latifolia,* especially on the western side of the district.

The projection of empirical growth rates to produce age-size trajectories greatly improved the visualization of species performance and revealed long-term variations resulting from cumulative effects of size and bioclimatic zone. However, there were a few uncertainties associated with the trajectories. For example, the trajectories of *A. fraxinifolius* and *G. robusta* increased without limit even at the age of 80 years. Clark and Clark (1996) found that growth rates of very large trees (> 70 cm diameter) were negatively correlated with diameter, suggesting that estimated sizes of old trees in our study might be overestimated. On the other hand, growth rates were positively related to species stature in Malaysian forests (King et al. 2006) suggesting that tall canopy and emergent species (such as *A. fraxinifolius* and *G. robusta*) might require faster growth than other growth forms in order to reach the maximum heights attainable. Finally, temporal autocorrelation of growth rates (Swaine et al. 1987; Pélissier and Pascal 2000, combined with a higher likelihood of early death in slow growing individuals (Swaine et al. 1987), could imply that the large individuals currently in existence are those that grew consistently fast and reached that size sooner than an “average” small tree would.

Given these uncertainties, estimation of age-size relationships for large trees requires more careful study and increased data collection effort (cf. Clark and Clark 1996). However, for the purpose of farm management and tree harvesting, age-size trajectories similar to ours, in the range of 20-50 years (the common rotation time) are likely to be of greatest relevance.

Tree growth in managed plantations versus natural forests

The range of diameter increments across different species in Kodagu is similar to the range obtained with species growth trials in Jamaica (McDonald et al. 2003). Diameter increment for *G. robusta* saplings ranged from 0.89 (ridge-top) to 1.32 (valley-bottom) cm yr^{-1} in Jamaica, which was similar to 1.31 (West) to 1.35 (East) cm yr^{-1} for small stems in Kodagu. However, in Rwanda, *G. robusta* diameter growth rates were higher, ranging from 0.9 to 3.4 cm yr^{-1} in monoculture plantations and from 1.1 to 3.7 cm yr^{-1} in multispecies farms (Kalinganire 1996). Another study in Africa also calculated higher growth rates of 2.15 to 2.64 cm yr^{-1} for juvenile *G. robusta* stems in multispecies farms (Takaoka 2008).

The annual growth rates recorded in plantations during the current study are higher than those in protected natural forests of southern India. For e.g., data recorded in medium elevation wet evergreen forests of Attapadi (Pélissier and Pascal 2000) and dry deciduous forests of Mudumalai (Nath et al. 2006) show that fast growing forest trees generally have average annual diameter growth rates in the millimeter range rather than centimeter range. In addition, the three medium to slow-growing species studied here (*D. latifolia, L. microcarpa,* and *S. cumini*) had higher average growth rates in Kodagu coffee plantations than in Mudumalai (Nath et al. 2006). As the variation in Mudumalai represents a larger dataset and longer time intervals, it is possible that average tree growth rates in Kodagu would reduce slightly if larger datasets or longer time intervals were used. However, trees in managed coffee plantations probably do grow faster than in natural forests because plantations offer higher resource inputs (Dhyani and Tripathi 1999) and reduced competition for light (due to artificially reduced tree density and canopy cover).

A management activity likely to negatively impact tree growth in plantations is the practice of shade lopping. This activity usually is carried out prior to the onset of monsoon rains, when many trees naturally shed their leaves. The following monsoon usually stimulates leaf flush, which restores the canopy cover. However, wet-season deciduous species such as *A. fraxinifolius,* and evergreen species such as *S. cumini* could be negatively affected by this practice. In our study two small and one large tree showed stem diameter shrinkage apparently related to severe lopping, of which, the two small trees (one each of *A. fraxinifolius* and *S. cumini)* appeared to be irreversibly shrinking towards death. Farmers also have observed that severe lopping often causes stem rot and death in *A. fraxinifolius*.

Implications of local environmental effects

Significant effects due to neighbors and topography were observed in the two fastest-growing species. *A. fraxinifolius* growth was negatively affected by coffee bush density, suggesting that farmers could face a tradeoff between increased production of timber or coffee. This may be more common for Arabica coffee, which occurred at higher densities (> 60 bushes in 10 m radius) than Robusta bushes.

G. robusta had slower growth on southwest-facing slopes, possibly due to dense cloud cover of the southwest monsoon reducing growth on these slopes, or due to strong monsoon winds that are reported to cause breakage of *G. robusta* trees and branches. Thus, it is probably not economical to grow *G. robusta* trees in plantation blocks facing southwest.

Local site effects, probably related to management practices (for e.g., fertilizer application, weeding, pesticide treatment and shade lopping) or soil properties, were observed at the block level in *L. microcarpa* and more generally for small rather than large trees. Thus, management actions to improve tree growth probably should be targeted at young trees.

Management and policy applications

This study revealed that despite its generally fast growth rate, the popular exotic species, *G. robusta*, grows slower in the wet western bioclimatic zone, especially on southwest facing slopes. Thus we do not recommend the planting of *G. robusta* on windy southwest facing slopes, especially in the humid western zone. For these areas the native *A. fraxinifolius* can be recommended instead.

The identification of a fast-growing native species (*A. fraxinifolius*) by our study demonstrates that there is potential for native timber production to compare favorably with that of exotics under appropriate ecological conditions. However, we do not recommend replacement of all *G. robusta* trees by *A. fraxinifolius*. Similar studies to screen large numbers of locally growing native species *in situ* are urgently required in order to inform future afforestation projects in the region, and to provide a wide range of alternatives.

In the past the Karnataka Forest Department (KFD) and the Coffee Board of India have played a substantial role in supplying exotic tree seedlings at low cost to local farmers (farmer interviews). Based on this study it is recommended that seedlings of native species, such as *A. fraxinifolius*, should be supplied at lower cost or free by the Government or other agencies, in order to make these species more accessible and attractive to farmers. The decision on what species to plant is a complex one, resulting from a balance between the economic value of timber, accessibility to the supply chain, seedling availability, agronomic properties, other uses (fruits, medicinal properties) and immaterial values. By showing there are potential alternatives, we advocate a more balanced choice of species to plant in the coffee estates, acknowledging that for this to happen, the constraints that currently drive the farmers need to change.

Ultimately, the coffee farmers require fast-growing shade trees that can be harvested for timber during economic crises. In this regard, the lack of legal rights to harvest native trees has been identified by farmers as a key problem constraining environment-friendly practices, as the majority of farms fall under the “Unredeemed” tenure category, which restricts farmers from legally harvesting their native timber (Vijaya 2000). However, in certain cases where the unredeemed lands have been assessed for revenue, the landowners are entitled to extract native trees that grew on their property after the date of revenue assessment. In this context, correct identification of a tree as farmer’s property (relatively new growth) versus Government property (old growth) can be facilitated by studies such as ours, which provide age-size trajectories based on *in situ* studies that are appropriate for the coffee plantation environment.

An appropriate Government policy modification that encourages and enables farmers to market native timber is a common problem worldwide. The relationship between tree tenure security and willingness to plant trees has been well documented and the need for reforms in land and tree tenure security has been highlighted in the Indian context (Puri and Nair 2004) and elsewhere in the tropics (Russell and Franzel 2004; Kusters et al. 2007). An option for Kodagu could be to allow farmers limited felling, transport and selling rights for some common, widespread and fast growing native species (such as *A. fraxinifolius*), which would allow farmers to benefit economically without depleting the native diversity and cover. It is therefore necessary to identify fast growing native tree species suited to this purpose.

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Table 1. Results of stepwise deletion of factors from initial LME models of tree diameter growth as a function of species identity, diameter and bioclimatic zone, for trees in coffee plantations of Kodagu, Western Ghats of India. Diameter and bioclimatic location were excluded or non-significant in all final models (non-significant F and P-values for species identity are in parentheses). Variance components analysis ("% of random variation explained") indicates the importance of local effects (plantation or management block) at different scales. Growth rates were square root transformed in all cases except for the species pair *Grevillea robusta-Acrocarpus fraxinifolius*

Dataset	Sample size	Significance of species identity		% of random variation explained		
		F-value	*P-value*	*Plantation*	*Block*	*Total*
All trees	332	17.96	<0.0001	8.7	12.1	20.8
Small trees	172	(not incl.)	(not incl.)	4.6	26.3	30.9
Large trees	160	(1.97)	(0.1058)	17.7	0.00	17.7
Species pairs [a]*:*						
Gr-Ac	135	(not incl.)	(not incl.)	1.6	29.5	31.2
Gr-Da	127	48.44	<0.0001	12.5	13.4	25.9
Gr-La	135	12.24	0.0007	3.0	22.4	25.4
Gr-Sy	136	26.86	<0.0001	16.2	11.7	27.9

[a] Gr-Ac = *Grevillia robusta - Acrocarpus fraxinifolius*; Gr-Da = *G. robusta – Dalbergia latifiolia*; Gr-La = *G. robusta – Lagerstroemia microcarpa*; Gr-Sy = *G. robusta - Syzygium cumini*

Table 2. Results of nonparametric Spearman rank correlation tests between tree growth rate (all species together, N = 116) and three kinds of local neighborhood competition indexes (NCI-1, NCI-2 and NCI-3) that model the effect of neighbor tree distances differently, within coffee plantations of Kodagu, Western Ghats of India. Each NCI was tested with different kinds of weightings for stem thickness (count, dbh or basal area) and for symmetric (all neighbors) or asymmetric (taller neighbors) competition

Weighting	Competition type	NCI-1		NCI-2	NCI-3
		0-5 m	*0-10 m*		
Count	Symmetric	-0.1608	-0.1905*	-0.1889*	-0.2064*
	Asymmetric	-0.1909*	-0.2176*	-0.2187*	-0.2203*
Dbh	Symmetric	-0.1341	-0.1765	-0.1783	-0.2000*
	Asymmetric	-0.1764	-0.2578**	-0.2439**	-0.2388**
Basal area	Symmetric	-0.1187	-0.1261	-0.1563	-0.1666
	Asymmetric	-0.1739	-0.2680**	-0.2645**	-0.2395**

* = significant at P < 0.05; ** = significant at P < 0.01

Table 3. Variables retained in the most parsimonious model per species, after stepwise deletions from an initial LME model of tree growth as a function of slope, aspect and number of nearby coffee bushes, in coffee plantations of Kodagu, Western Ghats of India

Species	Retained variable	Coefficient	P-value	% random variation explained		
				Plantation	*Block*	*Total*
A. fraxinifolius	Coffee density[a]	-0.81	<0.0001	5.43	0.03	5.45
D. latifolia	(Nil)	-	-	0.01	0.02	0.02
L. microcarpa	(Nil)	-	-	0.04	54.78	54.83
S. cumini	(Nil)	-	-	11.59	19.94	31.53
G. robusta	Aspect	-1.63	0.0385	0.66	11.40	12.06

[a] natural log transformed

Appendix 1

Mean annual diameter growth rate of five tree species in coffee plantations of Kodagu, Western Ghats, India (sample size in parentheses). Values are calculated for all stems together ("All"), small stems ("Small", < 120 cm gbh) or large stems ("Large", ≥ 120 cm gbh)

Location	Size	Diameter growth rate (cm yr^{-1})				
		A. fraxinifolius	*D. latifolia*	*L. microcarpa*	*S. cumini*	*G. robusta*
East	All	1.13 (32)	0.57 (31)	0.79 (33)	0.70 (31)	1.37 (35)
	Small	0.93 (16)	0.59 (14)	0.68 (16)	0.84 (15)	1.35 (20)
	Large	1.33 (16)	0.55 (17)	0.89 (17)	0.58 (16)	1.39 (15)
West	All	1.36 (36)	0.44 (29)	0.88 (35)	0.82 (38)	1.24 (32)
	Small	1.11 (19)	0.55 (15)	1.08 (18)	1.00 (18)	1.31 (21)
	Large	1.64 (17)	0.33 (14)	0.68 (17)	0.66 (20)	1.13 (11)

Fig. 1 Locations of 13 coffee plantations where dendrometer bands were fitted on trees, in the eastern dry to moist deciduous bioclimatic zone (6 plantations) and the western wet evergreen bioclimatic zone (7 plantations) of the Cauvery watershed area of Kodagu district, Karnataka state, Western Ghats of India. Inset shows location of Kodagu in southern India

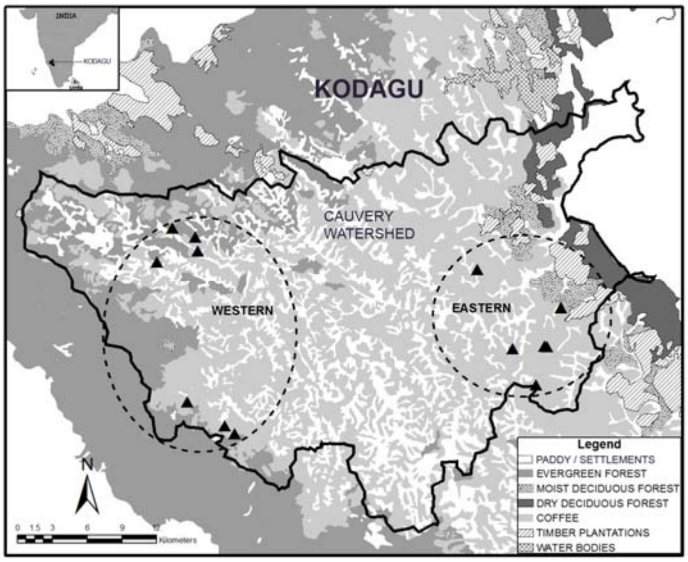


Fig. 2 Box plots of annual diameter growth rates for small (< 120 cm girth) and large (≥ 120 cm girth) stems of four native (*Af*: *Acrocarpus fraxinifolius*, *Dl*: *Dalbergia latifolia, Lm: Lagerstroemia microcarpa* and *Sc: Syzygium cumini*) and one exotic (*Gr*: *Grevillea robusta*) tree species, in coffee plantations on the western (gray boxes on the left) and eastern (white boxes on the right) sides of Kodagu district, Western Ghats of India. Horizontal dashed lines represent average growth for western trees and horizontal dotted lines represent average growth for eastern trees.

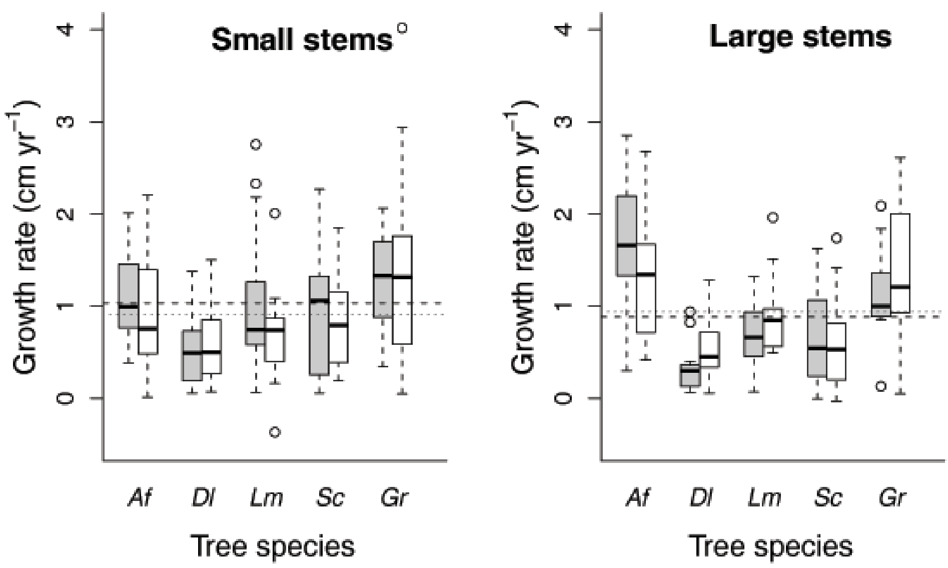


Fig. 3 Expected average age-size trajectories, with 95% confidence envelopes, obtained by computer simulation of growth rates for five tree species in coffee plantations of the eastern and western bioclimatic zones of Kodagu, Western Ghats of India

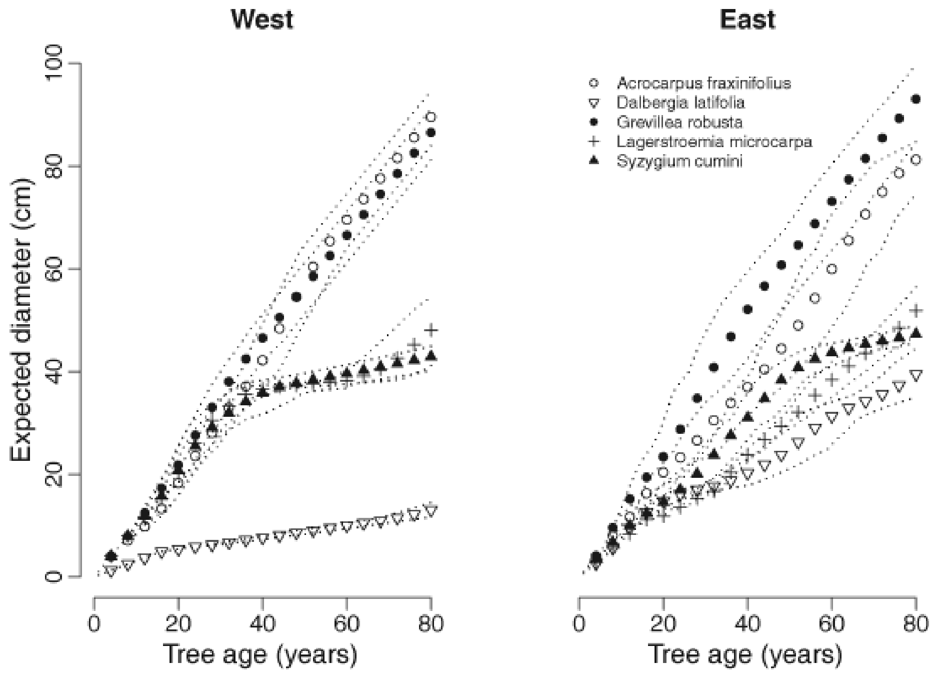
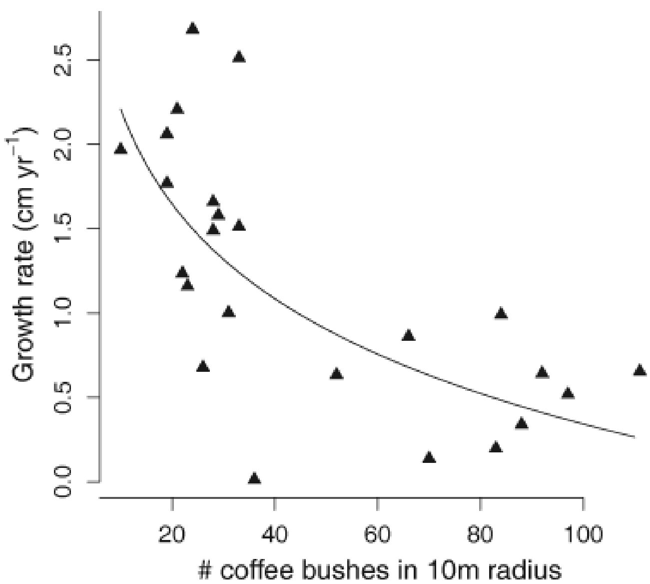


Fig. 4 Observed (▲) and predicted (fitted curve) tree growth rates for *A. fraxinifolius* under different densities of nearby coffee bushes in Kodagu, Western Ghats of India. The random factor levels used in the predictive model were the plantation and block with growth rates closest to the average species rate



Conserving native trees in the coffee agroforestry landscape of Kodagu

Project report submitted to CEPF-ATREE

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Introduction

Kodagu district, in the Western Ghats of southern India, is a coffee-dominated region characterized by high diversity in terms of topographic features, climatic conditions and biodiversity. The privately owned coffee plantations, which contain 70 to 1200 trees/ha (Elouard et al. 2000, Nath et al. 2010) and almost 280 species of trees (Garcia et al. unpublished survey data), are far more dense and diverse than most other coffee plantation landscapes elsewhere in the world (e.g., Soto-Pinto et al. 2001, Bandeira et al. 2005). Interviews with local farmers reveal them to be aware of the significance of biodiversity in their plantations, which is probably due to their traditional cultural practices promoting conservation of sacred forest patches and species (Bhagwat et al. 2005a, b, Neilson 2008). Thus Kodagu is a good location in which to develop and nurture civilian conservation initiatives (Nielson 2008).

Although there is potential for biodiversity conservation in coffee plantations, modern plantation economics cannot be ignored. A large majority coffee plantations in the district are small (< 10 ha) and fluctuations in coffee prices, labour shortages and legal constraints often drive these farmers to intensify production. A project, funded by CEPF-ATREE, was carried out between October 2009 and August 2010 to identify viable means to encourage farmers to grow more trees of native species and thereby reduce biodiversity loss. The project involved assessment of native species' growth rates and age-size trajectories, interactions to educate local farmers about the ill effects of exotic species dominance and to solicit their suggestions for participatory conservation efforts, as well as development of acceptable diversity-enhancing guidelines that local farmers would be willing to implement. The interactive nature of project development also was expected to promote dialogue between coffee farmers, the Karnataka State Forest department (FD) and other stakeholders.

Geographical context

Kodagu district in the southern Indian state of Karnataka is located on the leeward side of the Western Ghats, dominated by the valley of River Cauvery at the centre and bordered by the Western Ghats to the west and south. The altitude ranges from 850 m to 1875 m across the district, which covers an area of 4106 sq. km (Elouard 2000a). The eastern margin is relatively low in elevation compared to the west, and is lined with government protected forests including Yedavanad and Anekad reserved forests to the northeast, Devamachi and Dubare reserved forests to the East and Nagarahole National Park to the southeast. The presence of a high percentage of land with some form of tree cover, (approximately 80%, Elouard et al. 2000, Garcia et al 2010), which includes government protected forests (46%), ensures that floral and faunal diversity is very high within this small district.

Biodiversity and coffee cultivation

Natural vegetation in the district has been classified into several floristic types ranging from wet evergreen forests through intermediate forms to dry woodlands and thickets (Pascal 1988, Elouard 2000a). However, landscape studies have revealed a gradual conversion of privately owned forests into coffee plantations, opening of the canopy, and increase of exotic trees during the last few decades (Elouard 2000b, Garcia et al. 2010). Despite these changes, the biodiversity harboured in the district remains higher than in most coffee cultivating areas of the world. A recent survey of coffee plantations in central Kodagu recorded almost 280 species of trees (Garcia et al. unpublished data). In addition other studies have recorded good numbers of other wildlife, including elephants, tigers, birds and fungi within the coffee estates of Kodagu (Nath & Sukumar 1998, Mahanty 2003, Bhagwat 2005a, b, Kulkarni et al 2007, Bal et al, *2011*).

The high density and diversity of native trees in coffee plantations of Kodagu has been attributed to the existence of high indigenous diversity (Elouard et al. 2000) as well as the tough forest protection laws in the district (Ambinakudige and Satish 2009). However, farmers in Kodagu have expressed dissatisfaction with the existing laws and public policies, which prevent most of them from directly marketing their native timber. As a result, many farmers prefer to plant exotic trees rather than native ones (Elouard et al. 2000, Ambinakudige and Satish 2009, Garcia et al. 2010).

The popularity and problem of Silver oak

The Silver oak is favoured by agroforesters around the world in modern times due to its relatively fast growth rate and lack of competition with crops. Its high growth rate makes it useful (along with Dadups) for providing shade quickly when paddy fields and other open areas are converted to coffee plantation (farmers' information). In Kodagu, however, farmers also mentioned the local land tenure system, which favours promotion of exotic species.

Despite its clear contributions to agroforestry, the Silver oak is viewed negatively by environmentalists, who tend to be concerned about its non-native status and invasive potential in coffee agroforestry landscapes of the Western Ghats (Elouard 2000b, Elouard et al 2000, Moppert 2000, Bali et al 2007). In response, local farmers have expressed interest in planting native species instead of Silver oak, provided the existing tree ownership and utilisation laws are modified to facilitate the legal sale of native timbers

This report summarises the results of interviews and consultative meetings with farmers to identify biodiversity-friendly tree management practices.

Stakeholder views

Farmers contributed to project development and implementation from the inception of this project. A series of semi-structured interviews were conducted during October 2009 – June 2010 under the CEPF project, which involved 49 farmers in the district. These interviews made use of a formal questionnaire, which allowed discussions on related topics. Interviewees were located across the eastern and western sides of central Kodagu, covering 16 different villages. The following section summarises opinions and insights on issues related to tree recruitment and growth that were gained by interviewing farmers.

Table 1. Distribution of farmer interviews across different farm size groupings in 16 different villages of Kodagu district, southern India. Farm sizes used for stratifying the interviews were: Small: < 10 acres (< 2.5 Ha); Medium: 10 to 25 acres (2.5 to 10 Ha); and Large: > 25 acres (> 10 Ha).

Village		Farm size	
	Small	Medium	Large
East			
Andagove	1	1	2
Bilugunda	1	1	1
Guhya	1	1	1
7th Hoskote	1	1	2
Karadigodu	0	2	1
Kudlur-Shettalli	1	1	1
Rangasamudra	1	2	0
Siddapur	2	0	1
West			
Bengoor	0	1	2
Bettathur	3	0	0
Kokeri	1	1	1
Kolagadalu	0	1	1
Kolakeri	1	0	2
Nariandada	1	2	0
Sannapulikotu	2	0	1
Yevakapadi	1	0	2
Total:	*17*	*14*	*18*

Why plant trees in coffee plantations?

Small farmers (i.e., those with farms < 10 acres) generally mentioned timber production (expected harvest in 15 years), shade for coffee, firewood and house construction as major reasons to plant trees. In addition, they used tree planting as a means to secure long term economic returns, keeping in mind the future generations of their family. Medium farmers (10 - 25 acres) mentioned timber sale (expected within 21 years), pepper cultivation, coffee shade, and planning for future generations most often as the reasons for planting trees. Large farmers (> 25 acres) did not appear to require trees for immediate benefits, but more often mentioned the gains for the future, timber harvest on long harvest cycles (generally 20 – 30 years) or shade for coffee plants.

Tree planting efforts by farmers

The farmers recalled over 100 instances of tree planting in their estates during the last two decades (in some cases they recalled trees planted by older members of their family). Of these, the exotic Silver oak was the most frequently mentioned species, while only 19 instances involved planting the native Balanji (*A. fraxinifolius*), the next most frequently mentioned species, followed by 14 instances involving Dadups or Palwan (*Erythrina subumbrans,* another exotic species used for quick shade production).

Farmers had a strong idea of the optimal shade requirements for their plantations, and listed the problems associated with having too many or too few trees. In general, too many trees, or excess shade was expected to cause reduced coffee yield, increased incidences of black rot and vulnerability to borer attacks. Similarly, most farmers also agreed that too few trees or excessively reduced shade could be bad for plantations, by causing scorching of coffee and reduction in production of pepper.

Opinion regarding Silver oak

Generally seedlings of Silver oak and other fast growing exotic species were preferred by farmers. Compared to slow-growing hardwood species such as Teak (*Tectona grandis*) or Rosewood (*Dalbergia latifolia)*, However, several planters considered Silver oak shade unsatisfactory for coffee due to the limited amount of shade manipulation possible. The species also is susceptible to high winds and fungus attack. Farmers also reported very slow decomposition rates for its leaves, which prevents their use in organic litter compost.

Rights over trees

Most planters were unhappy with the need to obtain permits to sell native trees from their estates. This system usually involves several trips to different Government offices. In addition, the system of selling native trees through the government auction generally results in lower value for timber than can be expected on the free market. Thus, the net value of native timbers for farmers is generally unfavourable when compared with the open market prices that can be obtained for the exotic Silver oak. Thus, although of lower quality timber, Silver oak continues to be favoured for planting by farmers of Kodagu.

Tree growth studies

A field-based study of diameter growth rates of four common native timber species in comparison with the fast-growing exotic species, Silver oak (*Grevillea robusta*), was initiated by me in February 2008 (with funding from the CAFNET program of the European Union) in order to identify native species with growth rates as fast as the latter, within the coffee plantation environment. The species were: *Acrocarpus fraxinifolius* (locally known as “Balanji”), *Dalbergia latifolia* (“Beeti”), *Lagerstroemia microcarpa* (“Nandi”) and *Syzygium cumini* (“Nerale”). Growth performance was assessed for standing trees *in situ*, in order to develop guidelines regarding native shade trees.

In October 2009, while continuing to monitor standing tree growth for an additional year, I also examined wood anatomy in an attempt to validate the growth rates obtained earlier, with the aim of establishing long term age-size relationships for different species. Such relationships are required for developing predicting long term timber yield, which are of use in shade tree management.

Results

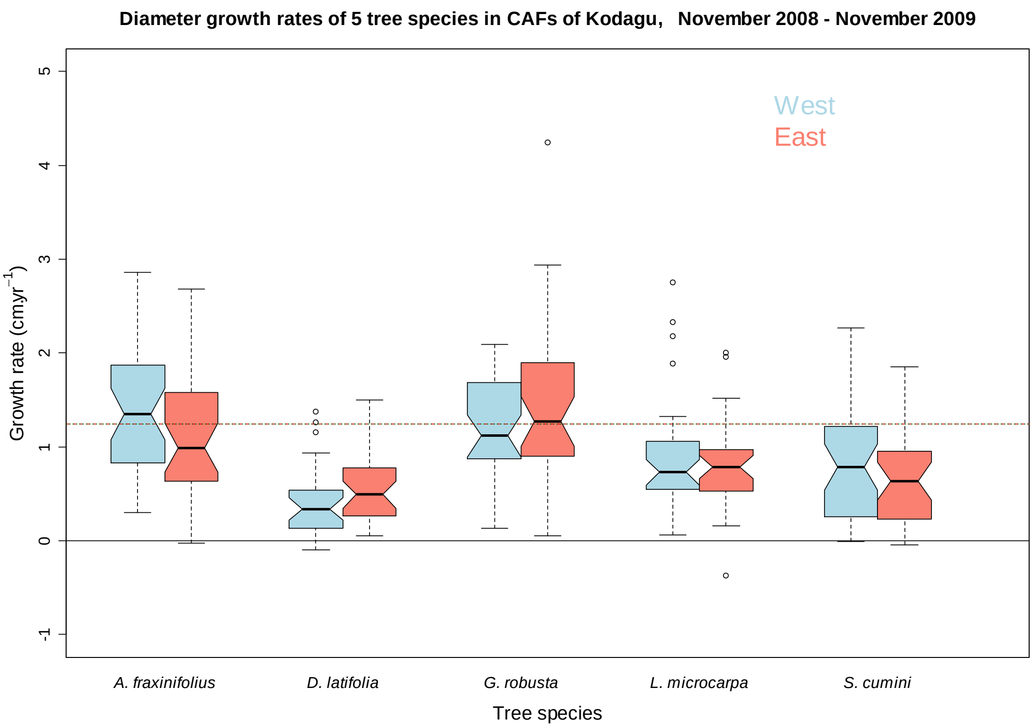
Across all trees, the average diameter growth rate in the eastern and western bioclimatic zones were similar (East: 0.92 cm yr-1, West: 0.96 cm yr-1). However, the following differences were observed between species:

East: *G. robusta* (1.37 cm yr-1), *A. fraxinifolius* (1.13 cm yr-1), *L. microcarpa* (0.79 cm yr-1), *S. cumini* (0.70 cm yr-1), *D. latifolia* (0.57 cm yr-1)

West: *A. fraxinifolius* (1.36 cm yr-1), *G. robusta* (1.24 cm yr-1), *L. microcarpa* (0.88 cm yr-1), *S. cumini* (0.82 cm yr-1), *D. latifolia* (0.44 cm yr-1).

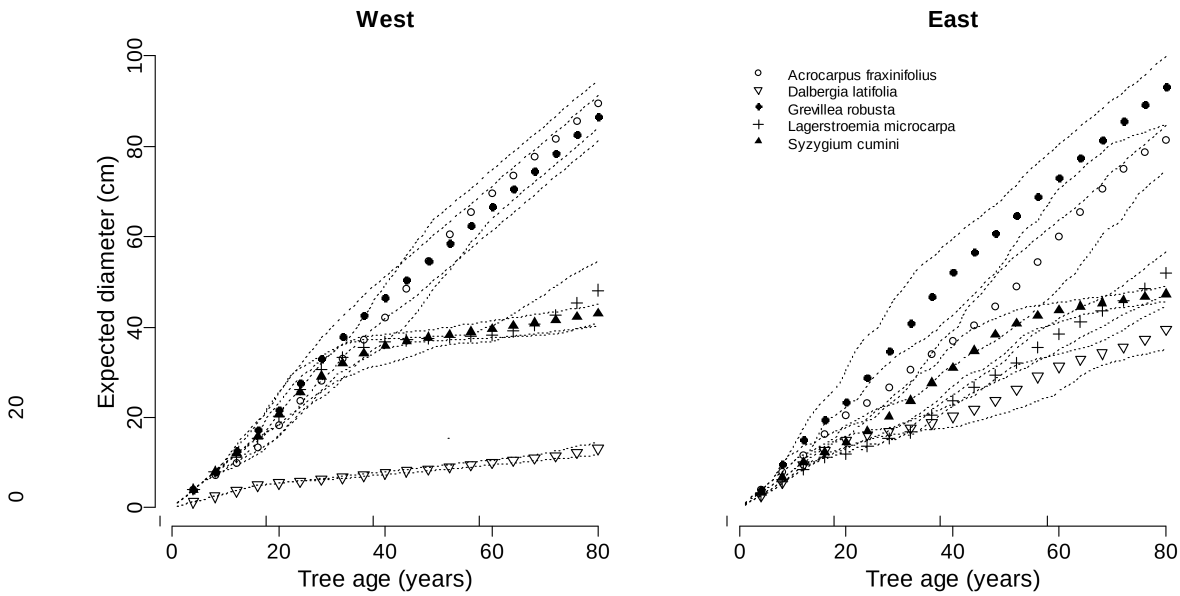
The exotic *G. robusta* had the highest overall average growth rate (1.31 cm yr-1), followed by the native *A. fraxinifolius* (1.25 cm yr-1). However, *A. fraxinifolius* grew faster than *G. robusta* in the western zone, as large trees of *A. fraxinifolius* had very high growth rates (Fig.1).

Fig. 1. Box plot of diameter growth for four native and one exotic (*Grevillea robusta* or Silver oak) in coffee plantations of Kodagu.



G. robusta showed the best long term growth performance in both bioclimatic zones (Fig. 2). However, in the western zone *A. fraxinifolius* had an average growth trajectory and 95% confidence intervals closely overlapping those of G. robusta. Tree rings identified in *A. fraxinifolius* also confirmed the general trajectories obtained from dendrometer studies.

Fig. 2. Expected average age-size trajectories obtained by computer simulation of girth increments for five tree species in the eastern and western bioclimatic zones of Kodagu. Species are represented as follows: *A. fraxinifolius* (○), *D. latifolia* (◊), *L. microcarpa* (△), *S. cumini* (▽) and Silver oak (●). Dotted lines represent 95% confidence intervals (Further details are provided in Nath et al *in press*)



Consultative town meetings

Three interactive consultative town meetings were organized during the final quarter of my CEPF project, in order to facilitate a two-way interaction with the farmers and other stakeholders. A key aim of these consultations was to obtain feedback on key points raised during the individual interviews. The meetings were held at three different locations within the Cauvery watershed area of Kodagu (Napoklu - 8 July; Siddapur - 12 July; and Kakkabe - 30 August, 2010), and involved the participation of local farmers, representatives of local Panchayats, local farmers' groups and non-governmental organizations (NGOs). The agenda included the following activities:

1. Dissemination of results obtained from my studies on tree growth in Kodagu coffee plantations
2. Sharing of information collected regarding farmers' constraints and tree preferences
3. Obtaining feedback and suggestions for improving native tree conservation efforts by farmers

The meetings were attended by 12 – 25 people (Table 2), and several useful suggestions were raised. The meetings generally began with a short introductory speech by a local well-known farmer, summarizing local attitudes towards native and exotic trees in the Kodagu landscape, economic constraints and other problems such as tree ownership policies. This was followed by a detailed presentation of my work on shade trees, showing the most updated results and conclusions, as well as constraints on native tree uptake that had been identified earlier in the project. At least half of the meeting time was devoted to an open-house session promoting frank and open discussions with farmers, in order to obtain individual views and suggestions for tackling the different constraints. In particular, the discussions were aimed at obtaining practical and viable suggestions for ameliorating the bottlenecks in native species distribution as well as identifying long-term strategies for tree management in the district. During the discussions different solutions, some of which were raised earlier during personal interviews, were explored for acceptability and relevance in the larger community.

At the end of the first two meetings, the farmers were presented with native tree seedlings and saplings that had been either donated by the Karnataka Forest Department nursery at Thithimathi, or bought with project funds from the Horticulture Research Station at Chettalli. The saplings included Balanji (*Acrocarpus fraxinifolius*), Nerale (*Syzygium cumini*), Nandi (*Lagerstroemia microcarpa*), Honne (*Pterocarpus marsupium*), Mandarin orange (*Citrus reticulata*), Sampige (*Michelia champaca*), Amla/Nellikai (*Phyllanthus emblica*), Bevu (*Azadirachta indica*), Karadi (*Chukrasia tabularis*), Kooli/Shivane (*Gmelina arborea*), Karmanji (*Carissa carandas*), Punarpuli/Kokum (*Garcinia indica*), and Antuwala (*Sapindus emarginatus*). The farmers were pleased to receive these seedlings/saplings and expressed their intentions of planting more such native species on their farms in the future.

Table 2. Details of consultative meetings held in Kodagu to discuss results of native tree growth studies and discuss options for conservation:

Date	Location	Attendees
8 July 2010	Napoklu	Approximately 12 farmers, including a Panchayat member and members of a local NGO (Nalnad Progressive Farmers Association)
12 July 2010	Sidapur	Approximately 15 farmers, including members of local farmers' organizations (Kodagu District Small Growers' Association, Codagu Planters Association, Maldare Badaga Primary Agricultural Credit Cooperative Society)
30 August 2010	Kakkabe	Approximately 25 farmers, including a Panchayat member and members of local farmers' organizations (Kodagu Growers Federation, Yevakapadi Farmers Association, Nalnad Coffee Growers Association)

The following are key suggestions to improve conservation efforts, which were raised at the meetings:

1. Farmers should not be treated as if they will not look after the land. Ownership rights over native trees should be given to farmers at the earliest
2. Rights to use native trees for bonafide uses should be given
3. There should be a mutual benefit, - local farmers should be allowed to profit from the native trees that they help to conserve (for e.g., sandalwood) in order to encourage them to grow more native species.

4. Education of farmers (by Government, NGOs, researchers) is important, in order to get them to think about planting native trees.
5. There is a need to supplement the currently scarce labour with mechanized farm equipment (along with adequate service support)
6. The problem of inadequate availability of cheap native seedlings should be addressed by setting up local nurseries (private or cooperative) with Government subsidies, or distribution of native seedlings by the Forest/Social Forestry Departments or Panchayats.

Fig. 3. Consultative meetings with farmers and other stakeholders, held at different locations of Kodagu, Western Ghats of southern India. a, b: Meeting at Napoklu, c. Sidapur, d. Kakkabe

Conclusions

This project makes an important contribution to the Western Ghats by encouraging farmers to consider alternative ways to improve native species conservation in private lands of Kodagu. It is imperative to promote the efforts of local farmers as Government-protected areas alone may be insufficient to conserve all the landscape biodiversity (Bhagwat et al. 2005a, b, 2008). Also, under the impact of climate change, species' distribution ranges might shift in coming years, resulting in some species surviving better outside the protected area network. Thus, it is important to promote native species' survival across their entire current range. This implies providing novel schemes and incentives, along with the appropriate policy framework, to enable large numbers of private individuals to contribute towards long-term species conservation (McNeeley & Schroth 2006).

Previous examples are available from other regions where farmers were given incentives to conserve diversity or grow more trees (although the latter rarely emphasized native species). Documented case studies generally include payment of conservation concessions for "setting aside" land parcels or incentives for planting trees. Factors generally linked with success include involvement of farmers in planning and decision-making, identification of appropriate tree species, availability of seedlings, provision of incentives, appropriate policy and institutional support, coordination between different institutions and policies, education of farmers, and existence of legally binding agreements regarding tree ownership rights and stewardship responsibilities.

By identifying at least one fast-growing native species (*A. fraxinifolius* or Balanji) my study demonstrated that there is potential for native timber production to compare favorably against that of exotics, given that under appropriate ecological conditions (Nath el al *in press*). However, replacement of all *G. robusta* trees with *A. fraxinifolius* trees is not an appropriate solution. Similar studies to screen large numbers of locally growing native species *in situ* will need to be carried out in order to provide a wide range of alternatives to farmers. This is a critical contribution that the scientific community needs to deliver in the future.

In the past the Karnataka Forest Department (FD) and the Coffee Board of India have played a substantial role in supplying exotic tree seedlings at low cost to local farmers (according to farmers' information). Based on this study it is recommended that seedlings of several native species, such as *A. fraxinifolius*, should be supplied at a subsidized rate or free of cost by these or other relevant Government Departments, in order to make these species more accessible to farmers. Alternatively, farmers have suggested the setting up of private nurseries with the help of Government loans and/or subsidies to improve the supply of cheap native seedlings.

Ultimately, the coffee farmers require fast-growing shade trees that can be harvested easily and sold as timber during economic crises. In this regard, the lack of legal rights to harvest native trees has been identified by farmers as a key problem constraining environment-friendly practices. Under the current tree tenure system, most farmers of Kodagu do not benefit from the potential returns of native tree species as the majority of farms fall under the "Unredeemed" tenure category, which restricts farmers from legally harvesting native trees on their plantations (Vijaya 2000). However, in certain cases, where the unredeemed lands have been assessed for revenue by the Government and thus classified as "Alienated" lands, the landowners are entitled to extract native trees that grew on their property after the date of revenue assessment. In this context, correctly identifying a tree as farmer's property (relatively new growth) versus Government property (old growth) is a problem that has concerned the FD for the last two decades, as the only data previously available was that from either natural forests or monoculture tree plantations (FD, unpublished documents). The current study can contribute towards solving this problem by developing robust age-size trajectories for native species.

Appropriate Government policy modifications might ultimately enable farmers to market adequate quantities of native timber from their plantations, without depleting the tree cover. For example, an option would be to allow limited felling, transport and selling permits for a subset of native species (including *A. fraxinifolius*) that are common, widespread and relatively fast growing.

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