Agriculture, Ecosystems and Environment 230 (2016) 315–328

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Why do farmers plant more exotic than native trees? A case study from the Western Ghats, India

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ARTICLE INFO

Article history:
Received 15 November 2015
Received in revised form 26 April 2016
Accepted 10 May 2016
Available online xxx

Keywords:
Kodagu
Multipurpose utility
Redeemed land tenure
Tree rights
Timber
Non timber forest produce

ABSTRACT

Farmers worldwide regularly plant trees to obtain provisioning and other ecosystem services. This practice has come under scrutiny by conservationists who perceive a reduction of biodiversity due to preferential planting of exotic trees. In order to reverse this preference for exotic trees it is necessary to identify the key drivers of exotic species planting and propose alternative species of interest to farmers. We examined this question in a coffee agroforestry landscape of the Western Ghats, India, a global biodiversity hotspot. We interviewed farmers regarding tree planting behaviour, preferences and constraints, and assessed the relative performance and value of native versus exotic species. Multivariate analyses were used with six species-level characteristics and four farm-level characteristics, to reveal the most significant predictors of planting frequency.

The exotic species *Grevillea robusta* was planted 5.4 times more often than native trees. Individual species' planting frequencies were most strongly related to their realised economic values, which was highest for *G. robusta*. Native trees with greater multipurpose utility value and stature were also more likely to be planted. Farm-level characteristics related to increased planting efforts were increasing climatic dryness, increased land area with native tree tenurial rights and farm size. However, farmers with a greater proportion of land under secure tree tenure planted fewer trees.

We conclude that although native trees had higher multipurpose utility and potential economic value than the exotic *G. robusta,* the latter is grown more often due to existing legal frameworks that restrict private ownership and realising monetary value from native species. If current laws were amended to increase the economic benefits obtained from native trees, they are likely to be planted more often by farmers. We propose that our results can help in implementation of the recent National Agroforestry Policy of India, as well as inform agroforestry policies and practice elsewhere.

1. Introduction

Agricultural landscape matrices with multi-strata agroforestry systems are recognised for their contribution to biodiversity conservation outside protected forests, provision of ecosystem services and alleviation of poverty (Perfecto et al., 1996; Schroth et al., 2004, 2011; Bhagwat et al., 2005; McNeely and Schroth, 2006; Vandermeer and Perfecto, 2007; Tscharntke et al., 2011; Dhakal et al., 2012). Farmers worldwide have contributed substantially towards this diversity by planting trees that provide economic value, food security and environmental improvement (Dewees, 1995; Scherr, 1995; Akinnifesi et al., 2006; Takaoka, 2008a; Anglaaere et al., 2011; Kehlenbeck et al., 2011; Goodall et al., 2015; Nyaga et al., 2015). However, a recent globally observed threat to farmland biodiversity is the ongoing transformation of traditional complex agroforests into simpler land use forms dominated by exotic species, which may eventually culminate in unshaded crop monocultures (Siebert, 2002; Peeters et al., 2003; Ruf, 2011; Jha et al., 2014). The increasing dominance of agroforestry canopies by fast growing exotic species is the first step in this landscape-simplification process, and this trend has been recorded across many tropical and subtropical countries. Thus, in southern Bahia, Brazil, farmers often plant non-native rubber (*Hevea brasiliensis*) and jackfruit (*Artocarpus heterophyllus*) trees rather than native timber and fruit trees for shade in their cocoa farms (Schroth et al., 2011); in Costa Rica, *Eucalyptus* species

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http://dx.doi.org/10.1016/j.agee.2016.05.013
0167-8809/

have become popular as coffee shade (Tavares et al., 1999; Schaller et al., 2003); and in Ghana, cocoa and coffee farmers wishing to diversify into timber production often prefer South American *Cedrela odorata* or Asian *Tectona grandis* to native species (Ruf, 2011). Similar preferences for planting exotic tree species on farm land have also been observed in other tropical regions (Dewees, 1995; Elouard et al., 2000; Takaoka, 2008a,b; Ambinakudige and Sathish, 2009; Nath et al., 2011; Kehlenbeck et al., 2011; Tefera et al., 2014; Nyaga et al., 2015; Valencia et al., 2015). In addition to the threat of declining environmental quality and ecosystem services caused by exotic species monocultures, diversity and continuity of the tree canopy may be compromised, thus preventing wildlife migration across agroforests and between nearby forest fragments (Perfecto et al., 1996; Vandermeer and Perfecto, 2007; Schroth et al., 2011). Therefore it may be ecologically desirable to halt and reverse this canopy-simplification process. What then, are the main drivers of exotic tree planting by farmers, and what can be done to divert their efforts towards increased retention and planting of native trees?

Farmers tend to be risk averse when deciding whether or not to adopt new farming practices (Pannell et al., 2014; Stevenson et al., 2014), which suggests that their decision to adopt new exotic species may be linked to reduction of economic, environmental and/or policy risks. In some countries, the introduction of fast growing exotic species has been promoted by government-supported agricultural extension workers who expect exotic species to be more efficient than native species in improving farm productivity and reducing poverty (Dunn, 1991; Dewees, 1995; Schneider et al., 2014). In addition, the exotic tree species themselves often possess (or may be perceived to possess) more useful attributes than native species, such as faster growth rates, higher economic value, fewer pests, and reduced competition with the main crop (Kalinganire, 1996; Tavares et al., 1999; Lott et al., 2000; Takaoka, 2008b; Anglaaere et al., 2011; Tefera et al., 2014). Finally, the local legal frameworks may also play a role in promoting exotic species by withholding farmers' rights of ownership over native trees, thus making the latter trees less attractive to propagate for the future (Van Noordwijk et al., 2003; Ruf, 2011; Schroth et al., 2011). In this paper we examine whether such global patterns are occurring in agroforestry landscapes of the Western Ghats, India, a key international biodiversity hotspot (Myers et al., 2000), and if so whether there are commonalities or unique features in the underlying drivers.

The Western Ghats is a mountain chain in southern India where biodiversity remains high despite a long history of human occupation and forest manipulation (Elouard et al., 2000; Bhagwat et al., 2005; Ranganathan et al., 2008). The focal area of our study in this region is the coffee agroforestry (CAF) dominated district of Kodagu in Karnataka State, which contains higher tree diversity than many other coffee landscapes worldwide (Table 1). The rustic CAF environment in this district has enabled migration of endangered wild fauna between protected forests, including large mammals such as elephants (Bal et al., 2011; Fig. 1A). The high tree diversity in Kodagu is mainly a result of retention and supplementation of naturally grown native trees within the CAFs for over 150 years (Haller, 1910). However, intensification of coffee production since the 1990s has resulted in gradual reduction and simplification of the complex multispecies tree cover to impoverished mixtures, sometimes dominated by fast-growing exotic species, especially *Grevillea robusta* (Proteaceae, Australian Silky oak or Silver oak, Fig. 1B) (Elouard et al., 2000; Moppert, 2000). With respect to shade management *G. robusta* costs less for maintenance than the densely leaved, thickly branched and spreading native trees (farmers' information). Previous studies have highlighted the increasing dominance of *G. robusta* in CAFs of the Western Ghats (Elouard et al., 2000; Moppert 2000; Bali et al., 2007; Garcia et al., 2010), and some possible drivers of shade tree dynamics have been proposed (Ambinakudige and Sathish, 2009; Guillerme et al., 2011; Nath et al., 2011).

G. robusta is an evergreen species native to Australia that was first introduced to South Asia in 1862 (Harwood, 1989) and promoted in India by British owners of tea and coffee estates. Although present in India for over 150 years, it is only in recent decades that concern has been raised about the increasing dominance of *G. robusta* in CAFs of the Western Ghats (Moppert 2000; Bali et al., 2007; Garcia et al., 2010). In order to reduce the current dominance of *G. robusta* in this region, a clear understanding is first required of how farmers value and utilise this species in order to suggest alternatives that they could easily adopt. In Kodagu, *G. robusta* grows faster than at least three popular native timber species (Nath et al., 2011). In addition, the lack of tenurial rights over native trees grown by farmers in the Western Ghats has been cited as a possible reason for their preference of exotic species

Table 1
Tree species richness values reported from various coffee agroforestry systems around the world.

Location	#farms/plots/sites	Min. tree size (cm dbh)	Area sampled (ha)	Total # species	Species ha^{-1}	Reference
GLOBAL						
Chinantec, Mexico	22 farms	2.5	2.2	45	20.5	Bandeira et al., 2005
Northern Chiapas, Mexico	61 farms	1	0.61	52	85	Soto-Pinto et al. (2001)
Mabira Forest Reserve, Uganda	105 farms	NA	210	238	1.1	Boffa et al. (2008)
Aberdare Mountains, Kenya	62 farms	≤ 2	39	59	1.5	Pinard et al. (2014)
East Usambara Mountains,	22 farms	2.5	13.2	139	10.5	Hall et al. (2011)
Tanzania						
West Java, Indonesia	148 farms	NA	(0.5–10 ha farms)	64 (inclu. bamboo)	NA	Parikesit et al. (2004)
Sumatra, Indonesia	3 sites/120 plots	NA	23.6	105	4.61	Philpott et al. (2008)
WESTERN GHATS, INDIA						
Chikmagalur	14 farms	3.18	1.26	49	38.9	Bali et al. (2007)
Kodagu	23 farms	10	NA	162	NA	Bhagwat et al. (2005)
Kodagu	14 plots	10	1.75	58	33.1	Ambinakudige and Sathish (2009)
Kodagu	7 farms	9.55	5.76	67	11.6	Nath et al. (2010)
Kodagu	20 farms	NA	10	129	12.9	Caudill et al. (2014)

NA = data not available.

Fig. 1. Two contrasting forms of tree cover and associated biota in shaded coffee agroforestry systems of Kodagu, Western Ghats, India. (A) A traditional rustic coffee plantation with diverse native tree cover that is also used by wildlife such as elephants; and (B) a modern, intensively managed coffee plantation dominated by straight-stemmed exotic *Grevillea robusta* that can be planted at higher densities than sinuous-stemmed native trees and also support climbing pepper vines, an additional source of income.

such as *G. robusta* (Ambinakudige and Sathish, 2009; Guillerme et al., 2011). Exotic species can be harvested freely to provide an instantaneous source of cash during financial emergencies, whereas native species require official permission to be harvested and this may not be granted under certain forms of land tenure such as "unredeemed land" where the government claims ownership rights over current and future native trees (see Box 1 for a description of local tenures and restrictions). Yet native trees

Box 1. Tree ownership and redemption of land in Kodagu.

The system of State ownership over native forest trees in the Western Ghats of India was initiated by the colonial British Government during the late 19th century, a period during which extensive exploration and documentation of native forests by European botanists had led to the discovery of valuable Indian timbers and their subsequent demand for domestic developmental works and international trade (Ramesh et al., 2009). During this period the ownership rights over all native trees on privately held lands in Kodagu (as elsewhere in India) were claimed by the Government, as detailed in the Coorg Land and Revenue Regulation of 1899, Appendix IV. Landholders were expected to redeem the value of any native timber sold, by paying a prescribed seigniorage value (State assessment rate) to the Government. Only if an entire survey number or land holding was completely redeemed at one go, it was then categorised as "Redeemed land" with rights over subsequent native tree growth devolving to the farmer (except *Santalum album,* Indian sandalwood). As most of the Indian smallholders could not afford to redeem all trees in a holding at one go, and opted to remove limited numbers of trees per felling permit, such holdings continued to be considered as "Unredeemed" and all subsequent native trees grown at those locations, whether planted by the farmer or naturally grown, continued to be considered as the property of the Government, as mentioned in the Karnataka Forest Rules (KFR-1969) 128 and 129. This system of viewing native tree growth on private lands as Government property continues to be upheld by modern forest laws, including the KFR-1969 and Karnataka Preservation of Trees Act 1976 (KPTA-1976). Currently most farmers in Kodagu do not have rights to harvest native trees as their lands are classified as "Unredeemed".

In order to encourage growing of trees, the Government allows unregulated harvest and sale of timber from 11 tree species (KPTA-1976 Section 8(7)), six of which are exotic (including *G. robusta* or "Silver Oak") and five are of native origin or naturalized species. Among the five native species on this list, only one has timber value (*Hopea wightiana,* which does not occur naturally in Kodagu CAFs) and the remaining four are commonly used for food, fodder, fuelwood or green manure but have low timber value (*Cocos nucifera* or Coconut, *Erythrina subumbrans, Prosopis cineraria, Sesbania* sp.). Furthermore, 28 native species have been placed on a "Reserved Species" list in the Karnataka Forest Act, 1963, Chapter 1, Section 2(15), which includes well-known native hardwood timbers such as *Dalbergia latifolia, Tectona grandis, Pterocarpus marsupium, Artocarpus heterophyllus Dysoxylum malabaricum, Lagerstroemia microcarpa, Artocarpus hirsuta, Terminalia crenulata, Chukrasia tabularis* and *Mangifera indica*. Some of these native timbers are valued at ten times more per unit volume than the corresponding value of the exotic *G. robusta* (according to timber rates published by the Karnataka Forest Department, http://aranya.gov.in). Reserved species cannot be sold by individual farmers without first obtaining permits for felling and transport. In practice the procedures for obtaining permits are usually carried out on behalf of farmers by the local timber merchants who act as middlemen, benefitting from the lack of transparency and accountability in the system. Furthermore, if the farmers' lands are unredeemed, reserved species can be sold only through Government Depots, which results in a small fraction of the true value of such timbers reaching the farmers. Thus, whereas farmers with redeemed lands can benefit from ownership rights over existing as well as newly planted native trees, those with unredeemed lands do not have ownership rights over either existing or planted native trees. These regulations have served to reduce the felling of native trees on private lands, but have also reduced their realised economic value for farmers, which makes them less attractive for planting. (The above-mentioned Acts and Rules are available at: http://www.aranya.gov.in/Static%20Pages/ActsRules.aspx).

are potentially more valuable in terms of timber, multipurpose and intangible values (e.g., Rice, 2008) and thus it is not clear what exactly motivates farmers to plant larger numbers of *G. robusta*. This study is the first to carry out a quantitative investigation of the relative values of different tree species in order to identify potential drivers of tree planting choices (especially native versus exotic) at the species-level and at the farm level by farmers in the Western Ghats. It is expected to identify key drivers behind the planting of exotic *G. robusta* and suggest effective means to reverse the trend of increasing exotic species' dominance.

The recently introduced National Agroforestry Policy (Government of India, 2014) has created opportunities to support and expand tree planting and management in agroforestry landscapes throughout India (Chavan et al., 2015). However, in the absence of a good understanding of why farmers plant different tree species, there is a risk that the support provided by the National Agroforestry Policy will result in a further shift towards exotic species, given recent tendencies observed in the Western Ghats. An important question is how the local species compare with exotics in terms of growth rate, key traits and perceived values, and whether farmers would opt for planting more native species if the conditions that currently disadvantage native species could be alleviated. Thus, we also explore whether there are native species with traits that are sufficiently useful to offer them as viable alternatives to *G. robusta* for planting, and which native species would most likely be adopted.

The study focuses on answering the following questions:

1. What is the proportion of exotic and native trees planted by coffee farmers in Kodagu?
2. What constraints and utility values are associated with native and exotic species, in the opinion of farmers?
3. What are the key factors associated with preferential planting of *G. robusta* at the species level?
4. What are the key factors associated with total tree planting frequency at the farm level?
5. What improvements in policy are recommended by farmers, in order to promote native tree planting?

2. Methods

2.1. Study area

The study was conducted in Kodagu district, Karnataka state (approximately 75°22′–76°08′ E, 11°55′–12°49′ N), situated on the leeward (eastern) slope of the central Western Ghats mountain chain (Fig. 2). The altitude declines from West to East, with corresponding gradients in rainfall from 5000 mm yr^{-1} to < 800 mm yr^{-1} and dry season length from four to six months (Elouard, 2000). There is also a latitudinal gradient of declining rainfall and increasing dry season length from South to North, as well as a temperature gradient related to altitude. Temperatures range from a minimum of approximately 10 °C during December–February, to a maximum of approximately 31 °C in March (records maintained during 2002–2009 in Madikeri, at an altitude of 1061 m). The most common vegetation types are wet evergreen forests in the west, grading into moist semi-evergreen forest in the central region and dry deciduous forest in the east, with the driest vegetation types in

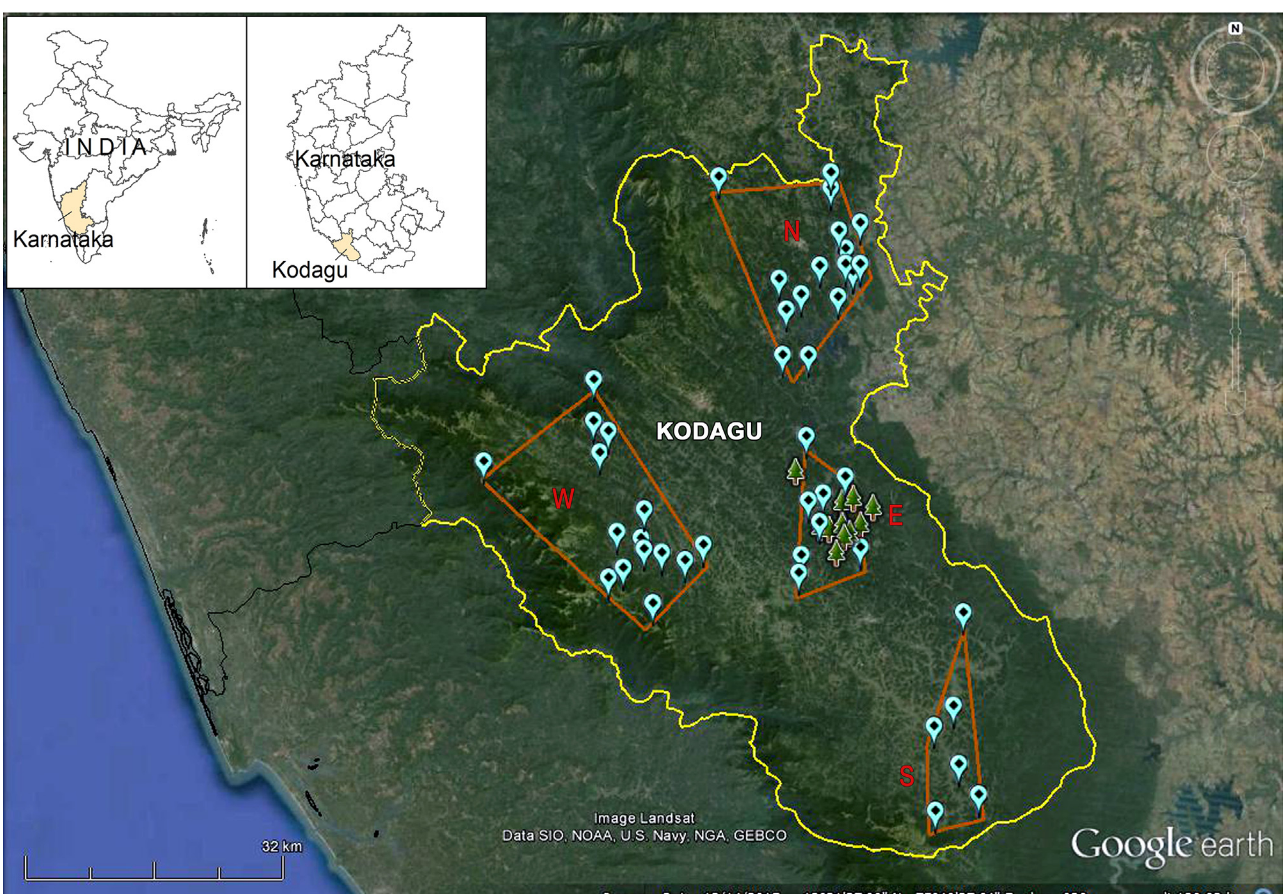

Fig. 2. Map prepared from Google Earth showing the locations of 48 villages at which farmers (one to six per village, see balloon-shaped icons) were interviewed in Kodagu district, Western Ghats, India. Also shown are 12 coffee plantations on the east of the district where tree growth was monitored (tree icons). The interviewees were grouped (see polygons) in relation to location as East (E), West (W), North (N) and South (S), respectively, for analysis.

the northeast (Pascal, 1988; Elouard, 2000). Protected state forests cover 35% of the district, while the remaining 65% of the area is used for agriculture (Ramesh et al., 2009).

Kodagu is a hilly district 4102 km^2 in area with a relatively low human population of approximately 554,500 in 2011 (www.census2011.co.in). Historically, rice paddy (*Oryza sativa*) cultivation in low-lying wetlands during the monsoon season was the dominant form of agriculture, but this has declined to cover 21% of the district currently, while coffee agroforestry systems (CAFs) have increased to cover 29% to 33% of the land area (Elouard, 2000; Garcia et al., 2010). CAFs are established on hillslopes adjacent to paddy fields and contain two species of coffee, Arabica (*Coffea arabica*) and Robusta (*Coffea canephora*), which both require tree shade. Additional crops grown include trees (coconut – *Cocos nucifera,* areca nut – *Areca catechu*), understorey crops (cardamom – *Elettaria cardamomum*, banana – *Musa* spp.) and scandent vine crops on tree trunks (e.g., black pepper – *Piper nigrum*, vanilla – *Vanilla planifolia*).

2.2. Field data collection

2.2.1. Socio-economic data

To obtain the opinions of local people regarding tree species planted, preferences and constraints, during 2012–2013 we carried out 93 interviews with farmers whose farms were classified as follows:

1) Three socioeconomic groups: Small (<4 ha of land), Medium (4–10 ha) or Large land holdings (>10 ha, which correspond to similar classifications used by the Coffee Board of India (Coffee Board, 2015)) with 34, 28 and 31 interviews, respectively.
2) Four geographic/bioclimatic zones: East, West, North and South of the district, with 19, 26, 31 and 17 interviews, respectively, representing the afore-mentioned climatic gradients (Fig. 2).

Villages were selected randomly per bioclimatic zone and most of the interviewed farmers were approached directly while driving along village roads or by selecting names at random from local revenue or village post offices (63% of interviews). We also used referrals by previous interviewees (28%), and a small number of farmers who had been involved in our earlier studies (9%) (Nath et al., 2010, 2011). Most of the interviewees were male (89%) due to the traditionally patriarchal nature of land ownership in this region, and all interviewees were actively managing their farms. Interviews lasted from 1 to 5 h and had a semi-structured format wherein a questionnaire was used to ask preset questions, but interviewees were also encouraged to provide additional information and opinions. Vernacular names of tree species mentioned by farmers were matched to corresponding botanical names with the help of published information (www.biotik.org, Murthy and Yoganarasimhan, 1990; Rani et al., 2011; Kavitha et al., 2012) and local resource people.

2.2.2. Tree growth and mortality rates

In order to obtain field growth rates of trees we selected 28 native and two exotic species based on their utility and conservation values. For each species, 30–50 individuals were selected (girth range: 4–456 cm; except three species with <10 individuals) within CAFs of two large private coffee companies on the eastern side of the district (800–1500 mm rainfall and a five-month dry season annually). Diameter measurements were obtained at 1.3 m above the ground (i.e., dbh, diameter at breast height, avoiding buttresses and trunk deformations). In total 950 living trees were marked with paint and measured with aluminium measuring tape annually from April 2012 to June 2014. An additional 163 trees on the same farms (girth range: 40.9–412.8 cm), which had steel dendrometer bands fixed on the stems during a pilot study (Nath et al., 2011), were also measured annually for this study from September 2011 to November 2013. From this total of 1113 trees, 26 trees were excluded due to development of anomalies at the point of measurement (damage, bark peeling, swelling, etc). An additional 81 trees (7%) died or were lost during the study period due to tree cutting and harvest (43% of total mortality events or 3% of standing trees, affecting 16 species with an average diameter of 14 cm; this included loss of some medium sized trees to timber thieves, use of small trees by estate workers, and harvest of large trees by the owners), natural causes such as disease, falling or breakage due to storms/winds, etc. (40%, 20 species, average diameter: 23 cm), and elephant damage (23%, seven species, average diameter: 13 cm). In a few cases tree mortality appeared to be due to more than one cause.

2.3. Data organisation and analysis

2.3.1. Species-level variables

To test the hypothesis that farmers have a preference for fast growing species, we collected growth rate data from 30 species (see Section 2.2.2 above). In addition, we obtained data on the maximum height and wood specific gravity from published sources and websites (www.biotik.orgwww.biotik.org, Pascal, 1988; Murthy and Yoganarasimhan, 1990; Ramesh and Pascal, 1997; Chave et al., 2009; Zanne et al., 2009). Multiple utility values were ascertained by asking farmers to name all tree species used currently or previously, in 15 usage classes (see online supplementary material S1).

Realised economic value was the average annual economic value obtained per species per farmer during the previous five years from sale of timber and other tree products (i.e., non-timber forest products, or "NTFP', excluding regular tree crops such as coconut, areca, coffee, cocoa and banana). "Bona fide' timber and NTFPs that were consumed at the homestead level without obtaining a cash income were not considered in this calculation as personal requirements for timber (i.e., for house building, repairs, furniture, etc.) are expected to arise approximately once in 5–10 years, and domestically consumed NTFPs (e.g., fruit consumption) comprise a small proportion of total farm production, especially for Large and Medium farmers (farmers' information). Also not included in the calculation is the value of standing timber volumes not sold or realised through harvesting.

We examined whether the reserved or restricted status of native trees versus the non-restricted status of exotic *G. robusta* (Box 1) had an influence on tree growing efforts. Relevant information on the reserved or permitted status of species was obtained from the Karnataka Forest Act (1963) and Karnataka Preservation of Trees Act (1976). We used an ordinal scale to represent the legal permission status of species as follows: reserved = 0, permitted = 2, neither = 1.

2.3.2. Farm-level variables

The size and socioeconomic grouping of farms were recorded and used as indicators of available space and access to capital. This is because large farms were more likely to contain more 'redeemed' area (see Box 1), thus increasing their possibilities for ownership rights over native trees. It was also expected that there would be differences across bioclimatic zones in terms of frequency of trees planted, related to water availability (i.e., the Western zone with highest rainfall may support faster tree growth and therefore higher frequency of tree planting).

2.3.3. Data analysis

Annual diameter growth rate (cm yr^{-1}) per individual was calculated as the difference in successive diameter measurements divided by the time interval in years. Age-size trajectories were developed from these growth rates for 27 species with ≥30 monitored stems, using the following two-parameter model that was found to be effective for representing forest tree lifespans (unpublished analysis):

$$dD/dt = sD^k$$

where D is tree diameter, t is time in years, s is a species-specific multiplier and k is a scaling constant. The constants s and k were estimated by fitting the model to field data for individual species.

Differences in opinions across socioeconomic groups were tested with the Chi-square goodness of fit test and differences in tree planting efforts across bioclimatic zones were tested with the non-parametric Kruskal-Wallis rank sum test (KW), thus avoiding assumptions of normal distributions due to the low sample sizes per group or zone (Zar, 1984). The non-parametric Mann Whitney *U* test was used to assess differences between planted versus non-planted species, in relation to farm- and species-level factors.

We also used multiple linear regression models based on generalized least squares (GLS, Crawley, 2007) estimation by maximum likelihood to identify key variables associated with tree planting frequency during the previous five years at the species-level and at the farm-level. In the first model, the number of trees planted per species was examined quantitatively in relation to the following six species-level independent variables:

1. Three intrinsic functional traits or qualities: growth rate, maximum height and wood specific gravity.
2. Economic value realised during the previous five years across all farms.
3. Multipurpose utility value citations by farmers.
4. Legal restrictions or requirement of permits for harvest.

In the second model, we examined the relationship between total tree planting efforts per farm and the following four farm-level independent variables:

1. Farm size.
2. Two variables representing the extent of the redeemed land tenure in a farmer's land holdings (see Box 1 for explanation): total area and proportion of redeemed land owned.
3. Bioclimatic zone.

The six species-level factors and four farm-level factors included in the respective models were checked for multi-collinearity by examining their variance inflation factors (VIF), which were negligible (<2.5) in all cases (Pedhazur, 1997; Zar, 1984). In order to avoid overfitting the models, we implemented a model selection procedure by stepwise deletion of unimportant variables, which maximized the reduction of the Akaike Information Criterion value (AIC) with each variable deleted (Crawley, 2007). In both of the final models the dependent variable was square-root transformed to ensure normality of residuals, which was confirmed by examining the histogram and quantile–quantile plots of residuals from the final models as well as ensuring that a non-significant result ($p > 0.05$) was obtained with the Shapiro-Wilk and Kolmogorov-Smirnov tests of normality (Zar, 1984; Crawley, 2007). All statistical analyses were carried out using R version 3.2.1 (R Core Team, 2015).

3. Results

3.1. Exotic and native tree planting frequency

During the previous five years, 78 of 93 interviewed farmers (84%) had planted at least one tree. On average a farmer planted 237 trees annually (median: 101) and the maximum was 2001 trees planted annually by a single farmer. The 93 farmers together accounted for 21389 trees annually and expressed intentions to plant 25765 trees during the following year. Trees of 53 species had been planted, and 11 species had been subjected to timber extraction. For nine species in which trees were planted as well as extracted, the ratio of planting to harvesting ranged from 0.34 (*Acacia mangium*) to 153 (*Eucalyptus sp.*). Only three species were harvested (for timber sale) in larger numbers than they were planted: *Acacia mangium* (exotic species, 50 trees planted versus 145 harvested on average annually across all farms), *Tamarindus indica* (none planted, 1 harvested) and *Maesopsis eminii* (exotic, none planted, 1 harvested). Overall the ratio of trees planted versus cut was 8.6. These results indicate that many more species and trees were planted than harvested by the farmers.

G. robusta represented 78.0% of all tree planting efforts, whereas the 35 native species that were also planted during the same period accounted for only 14.4%, and the remaining 7.6% of effort was distributed among 17 other exotic species (Fig. 3). On average a farmer planted 183 *G. robusta* trees annually compared to only 9 each of the native *Erythrina subumbrans* and *Citrus reticulata*, which were the next most commonly planted species. The median number of trees planted annually per farmer was zero for all species except *G. robusta*, which had a median of 75. Farmers showed a similar bias in their future tree planting plans (81.9% *G. robusta*, 14.7% native trees, 3.4% other exotic trees).

3.2. Constraints and multiple use values associated with exotic and native trees

G. robusta was associated with negative attributes, but its various positive aspects, especially direct economic gains (cited by

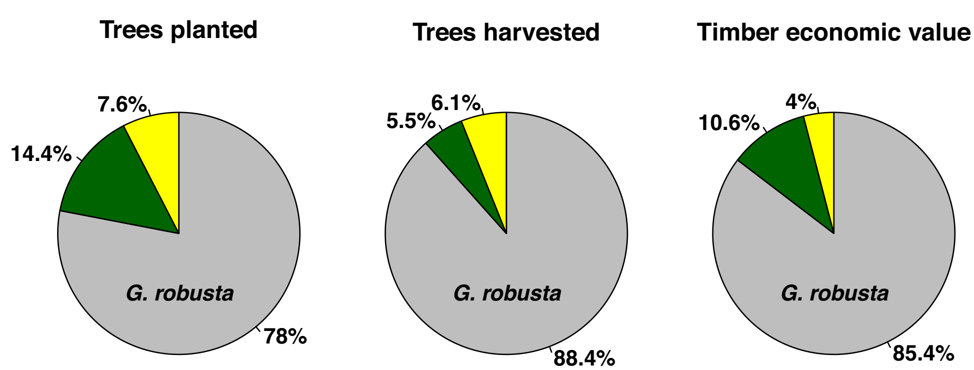

Fig. 3. Relative importance of *G. robusta* (light grey sections), native species (dark sections) and non-*Grevillea* exotic species (light sections) in CAFs of Kodagu, Western Ghats, India, in relation to total number of trees planted by farmers, trees harvested for sale as timber, and total economic value obtained from timber during the previous 5 years.

93% of interviewed farmers), fast growth (56%), suitability for black pepper vines (49%) and lack of legal restrictions (28%, Table 2) combined to make it the most popular species for planting (Fig. 3). By comparison, the difficulties associated with planting native species included mainly economic losses and legal constraints (reported by 39% of farmers for both categories), followed by deleterious effects on coffee and logistical constraints (Table 2).

Across different socioeconomic groups, large farmers were least likely to report economic loss as a constraint against growing native trees compared to the other two groups (Chi-square test,

Table 2
The main advantages (+) and constraints (−) of the exotic species *Grevillea robusta* ("GR") that were mentioned by interviewed farmers of Kodagu district, Western Ghats of India (percentage of farmer citations is provided in parentheses), in comparison with constraints against growing native trees. Details include typical reasons cited by farmers that have been grouped under 5–8 main categories of advantages and constraints that are vertically ranked by importance.

GR (+)	Details	GR (−)	Details	Native trees (−)	Details
Direct economic benefit (93%)	Good investment for future and children; Timber/plywood market value; Pole-sized trees provide economic value	Coffee damage or loss (88%)	Leaves shed on coffee plants are a nuisance during blossom and picking season, need to clear fallen leaves from coffee bushes to avoid coffee rotting (*Kole roga*); Coffee production is reduced; Thick shade is not good for coffee; Competes with coffee for water via roots; Generates heat.	Economic loss (39%)	Future risk if no permit is guaranteed at the time of planting; No guarantee of returns later; Labour charges are higher for lopping; Less useful for pepper vines (bark is generally too smooth); No commercial benefit as Government rates are used when selling the timber; only 20% of value is given by Govt.; Risk of timber thieves stealing valuable trees (*Santalum album, D. latifolia, Tectona grandis*); Slow to give profit
Fast growth (56%)	Fast growth produces quick development of shade; Short harvest rotation	Environment harm (25%)	Decomposition of fallen leaves absorbs Nitrogen from soil; Monoculture is bad; Not good for environment and soil	Legal constraints (39%)	Need license to collect and sell NTFP (e.g. soapnut "Seegai"); No permit to harvest timber, very difficult to get permit
Pepper support (49%)	Very good supporting tree for pepper vines (added economic benefit)	Pepper harm or loss (13%)	Termites make pepper vines slide down; Pepper yield is less good than on native trees	Coffee loss or disease (23%)	When native trees (*Ficus racemosa, Bombax ceiba*) die or dry up, worms infest them and nearby plants; White stem borer, a major coffee pest, is hosted by native trees (especially *Tectona grandis*); *Kole roga* (coffee dropping) is caused by *A. heterophyllus* shade; Root diseases are caused by native tree species (e.g., "kaimara" (*Apodytes dimidiata*), "budkoni" (species not identified)); Thick shade reduces coffee growth and yield
Legal advantage (28%)	No permit required for harvest and/or sale; No minimum age or size limit on harvest; Can sell any time, at any size	Maintenance/ pest problems (10%)	Termites cause tree death; Short life due to soft wood; Not good for cardamom as tree will not grow in heavy shade	Logistical constraints (23%)	No local factory to process collected NTFPs; No space available; Sapling purchase and maintenance costs are high; Shade maintenance is more than required for *G. robusta*; Lack of skilled lopping workers; Native trees already are available in the estate, no space for additional trees, lack of irrigation facilities
Coffee shade (21%)	Straight trunk, short branches, less space required between trees; Leaves small, narrow crown, which produces moderate shade; Low wood density, soft wood, therefore easy to lop; Soil fertilisation: fallen leaves decompose to produce manure; Tall stature provides high shade	Other economic losses (2%)	Orange crops affected negatively by *G. robusta* deaths nearby	Slow growth rate (20%)	Native trees grow very slowly
Low maintenance (18%)	No maintenance after planting; Easy to grow; hardy and disease resistant; Minimal pruning			Wildlife/ pest problems (17%)	Some trees attract and are damaged by wild elephants (e.g., *A. heterophyllus, F. racemosa, A. fraxinifolius, Erythrina subumbrans*); *F. racemosa* (Athi) fruiting season attracts many wild animals (Gaur, deer, wild pigs) causing risk to humans and coffee damages nearby; Feral cattle eat seedlings; Hairy caterpillars are hosted by wild trees, making plantation work difficult (e.g., *Toona ciliata, Lagerstroemia microcarpa,Olea dioica*); Biting ants cause problems for workers
Indirect economic benefit (10%)	Fuelwood economic value			Availability (16%)	Native tree seedlings/saplings are not easily available
Non-economic benefit (2%)	Multiple domestic uses; construction of temporary shelters; poles are useful			Biological drawbacks (3%)	Trees shed their leaves in summer (*L. microcarpa*); Native trees have wide crowns and require wider spacing between trees compared to *G. robusta*

$p = 0.047$). Large farmers had a median expected harvest cycle for *G. robusta* of 22.5 years (average: 25.5 years), which was significantly longer (Kruskal-Wallis rank sum test (KW) $p = 0.013$) than the corresponding values for medium and small farmers (medians, 15 and 12.5 years; means, 17.5 and 14.6 years, respectively). In the northern dry deciduous zone farmers harvested *G. robusta* at a median rate of 15 years (mean: 16.6 years), but not significantly different from the corresponding value for the southern moist deciduous zone where the median harvest cycle was 22.5 years (mean: 26.9 years) (KW test, $p = 0.46$, lack of significance may be due to limited sample size). Valuable native species were associated with a longer harvest rotation cycle than exotic species. Thus, while the median or mean expected harvest cycles reported by farmers for exotic species were <30 years, the corresponding values for valuable native timber species were generally >30 years.

Farmers recognised numerous native trees for providing numerous benefits and multipurpose utility values (Table 3). At least 131 species were cited with one or more utility values (online supplementary material S1; the actual number of useful species is likely to be higher as 98 additional vernacular names could not be matched to verified scientific names). Farmers in the western wet evergreen bioclimatic zone cited the highest number of useful species (102 species in total), while those in the southern dry deciduous zone cited the lowest (59 species). *G. robusta* was ranked 23rd in terms of multipurpose utility (Table 3), and was not among the top ten species named for high value purposes such as timber, furniture, NTFP (non-fuelwood), processed food or coffee shade.

3.3. Species planting frequencies in relation to functional traits and market-related qualities

Average annual diameter growth rates of monitored trees ranged from 0.1 cm yr^{-1} (*Radermachera xylocarpa*, native species) to 1.8 cm yr^{-1} (*Acacia mangium*, exotic). *G. robusta* was relatively fast growing, at 1.1 cm yr^{-1}, although four native species had similar or higher growth rates: *Persea macrantha* (1.7 cm yr^{-1}), *Chukrasia tabularis* (1.4 cm yr^{-1}), *Toona ciliata* (1.3 cm yr^{-1}) and *Michelia champaca* (1.2 cm yr^{-1}). Based on these measurements, at least ten native species appeared capable of attaining diameter sizes similar to or larger than that of *G. robusta* during the first 30 years (Fig. 4). *G. robusta* also had equivalent or lower maximum height and wood specific gravity values than 7 and 12 native species, respectively, and thus was not outstanding compared to native species in terms of functional trait values that are relevant for productivity.

Economic value was obtained from the timber of 11 tree species, and from NTFPs collected from 17 species. *G. robusta* constituted 88.4% of all timber trees harvested and provided 85.4% of the total economic returns from timber (i.e., 687 US Dollars (USD) on average per year per farmer; one USD = approx. 66.7 Indian Rupees). By comparison, the seven native timber species harvested during the same interval together constituted only 5.5% of total timber harvested and provided only 10.6% of economic returns from timber (USD 79.9 on average per farmer annually) (Fig. 3).

Among NTFPs, *C. reticulata* provided the highest average annual value of USD 251.1 per farmer annually, but by comparison, the

Table 3
Top 30 multiple–use tree species, ranked according to total number of citations received from 93 interviewed farmers in coffee agroforestry systems of Kodagu, Western Ghats, India. Individual cell values represent total citations per usage category. Total number of species per usage category (last row) includes additional species not listed here (see online supplementary material S1). Multiple-use citations received for the exotic *Grevillea robusta* (ranked 23rd in this table) are highlighted in bold font.

Species	Origin, Distrib	FR	CT	CO	FN	RE	PF	IM	FW	HO	FD	MD	NT	WA	SO	Total citns.
Artocarpus heterophyllus	W	47	42	26	38	32	8	3	5	0	28	0	3	0	4	236
Syzygium cumini	I	77	14	22	2	2	6	3	14	11	0	6	0	0	2	160
Lagerstroemia microcarpa	W	0	74	16	26	0	0	10	18	8	0	0	0	0	1	153
Mangifera indica (wild ssp)	W	42	0	5	0	34	27	3	6	5	1	1	2	0	0	128
Dalbergia latifolia	I	0	35	16	63	1	0	5	2	2	0	1	0	0	1	127
Tectona grandis	I	0	36	3	39	0	0	3	1	0	0	0	0	0	0	82
Ficus racemosa	I	9	0	31	0	6	2	1	1	4	14	0	0	0	9	77
Pterocarpus marsupium	I	0	35	9	9	1	0	3	5	6	0	3	0	0	1	72
Citrus reticulata (native ssp.)	W	29	0	0	0	0	11	1	0	1	0	0	17	0	0	59
Acrocarpus fraxinifolius	I	0	15	21	1	0	0	6	5	5	0	0	0	0	2	56
Sapindus laurifolius	I	0	0	0	0	0	0	0	0	1	0	0	2	51	0	55
Toona ciliata	I	0	15	8	5	0	0	20	4	2	0	0	0	0	1	55
Terminalia crenulata	I	0	29	4	2	1	0	1	7	6	0	2	0	0	1	53
Grewia tiliifolia #	I	17	7	2	4	0	0	17	3	1	0	0	0	0	0	52
Chrysophyllum roxburghii	W	38	0	0	0	0	1	0	0	1	1	1	0	0	0	42
Phyllanthus emblica	I	17	0	0	0	1	18	0	0	0	0	6	0	0	0	42
Garcinia gummi-gutta	W	13	0	2	0	0	6	0	0	1	0	2	16	0	0	41
Artocarpus hirsutus	W	15	14	3	7	0	0	0	0	0	0	0	0	0	0	39
Mimusops elengi #	W	33	0	0	0	2	0	0	1	3	0	0	0	0	0	39
Psidium guajava	E	16	0	1	0	0	9	5	0	0	1	5	0	0	0	37
Dimocarpus longan #	W	20	1	0	0	0	1	1	10	1	0	0	0	0	0	35
Erythrina subumbrans	I	0	0	8	0	0	0	0	1	0	21	0	0	0	3	35
Grevillea robusta	**E**	**0**	**2**	**7**	**0**	**0**	**0**	**10**	**12**	**0**	**0**	**0**	**0**	**0**	**0**	**32**
Canthium dicoccum #	I	25	0	2	0	0	2	0	2	0	0	0	0	0	0	31
Spondias pinnata #	I	12	0	3	0	0	14	0	0	0	1	0	0	0	0	30
Citrus aurantiifolia	I	3	0	0	0	0	21	0	0	0	0	2	1	2	0	30
Syzygium jambos #	I	23	0	1	0	0	1	0	1	0	1	0	0	0	0	27
Manilkara zapota	E	18	0	0	0	0	2	0	0	0	0	0	6	0	0	26
Aporosa lindleyana #	W	19	0	3	0	0	0	1	2	0	1	0	0	0	0	26
Gmelina arborea	I	0	1	1	7	12	0	3	0	0	2	0	0	0	0	26
Total species named per usage category:		53	32	48	22	27	27	34	33	35	22	30	17	3	17	

Origin, Distribution categories: W: Western Ghats endemic or native; I: India native or naturalized since > 500 years; E: Exotic (i.e., introduced to India during past few centuries, mainly cultivated on farms).
Usage categories: FR: fruits, CT: construction/timber, CO: coffee shade, FN: furniture, RE: religion, PF: processed food, IM: implements, FW: fuelwood, HO: honey, FD: fodder, MD: medicine, NT: NTFP economic value received, WA: washing, SO: soil enrichment and conservation.
Species that were not planted by the 93 interviewed farmers during the previous 5 years, but cited by them during interviews.

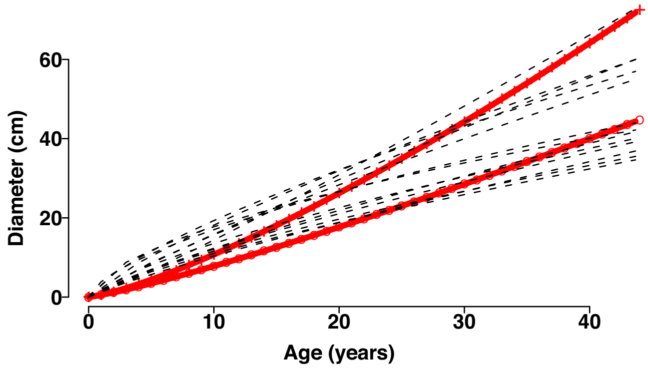

Fig. 4. Age-diameter size trajectories obtained by fitting allometric models to growth rate measurements from the field for the 15 fastest growing species in coffee plantations of Kodagu. Trajectories include two exotic species (*Acacia mangium* (+), upper solid line, and *Grevillea robusta* (O), lower solid line) and 13 native species (dashed lines without symbols).

annual economic value gained from *G. robusta* timber (see previous paragraph) was almost three times higher than that from the most valuable NTFP. In general, timber provided higher economic returns than NTFPs for almost all farmer groups and bioclimatic zones, except the southern zone, which largely depended on the sale of *C. reticulata* fruits (Fig. 5).

When species characteristics were tested individually, the species selected for planting had significantly higher multipurpose utility value, economic value and stature than non selected species (Mann-Whitney *U* test, $p < 0.05$, Table 4). In addition, multiple regression with backward selection produced a reduced parsimonious GLS model, which retained only three variables and fit the data significantly better than a null model (Table 5). The final model revealed that realised economic value of individual tree species was the most significant factor determining the number of trees planted per species, with a standardized effect size (β-value) approximately ten times higher than that of the other two variables retained in the model. The other two significant variables were multipurpose utility value and species maximum height (Table 5). When the same model was run after excluding data from *G. robusta*, only multipurpose utility value and maximum height were significant (estimates: 2.2 and 11.0, β-values: 0.48 and 0.39, $p = 0.002$ and 0.008, respectively), while economic value was non-significant although retained in the final model, (estimate: 0.1, β-value: 0.20, $p = 0.16$).

Table 4
Results of Mann-Whitney *U* test (*p*-values) for differences in functional traits and other characteristics across 30 – 134 tree species in relation to whether trees of these species were planted (Group 1) or not planted (Group 2) and differences in characteristics across 89–93 farms in relation to whether one or more trees were planted during the previous five years (Group 1) or none were planted (Group 2), by farmers in Kodagu, Western Ghats, India. The first two columns provide the average value per group (with sample size, N).

Explanatory variables	Group 1 Av. value (N)	Group 2 Av. value (N)	p-value
Species characteristics:			
Growth rate (cm/yr)	0.9 (18)	0.7 (12)	0.498
Maximum height (m)	35.3 (18)	27.9 (12)	0.023*
Wood Specific Gravity	0.6 (18)	0.6 (12)	0.309
Multipurpose utility value citations	37 (51)	8 (83)	0.0000***
Economic value received (US$ yr^{-1})[a]	22 (51)	0.02 (83)	0.0000***
Legally permitted/restricted[b]	0.9 (51)	1 (83)	0.118
Farm characteristics:			
Farm size (ha)	10.7 (76)	12.8 (17)	0.409
Redeemed area (ha)	3.0 (73)	1.5 (16)	0.325
Proportion redeemed area	0.3 (73)	0.3 (16)	0.532
Bioclimatic zone[c]	1.3 (76)	2.1 (17)	0.018*

[a] One US Dollar = approximately 66.7 Indian Rupees.
[b] Legally restricted species were given the value 0, legally permitted species (i.e., those allowed direct market access and unrestricted sales) were given the value +2, and the remaining species were given the value +1 (i.e., no restriction nor direct market access).
[c] Bioclimatic zones were assigned scores in relation to the relative amount of annual rainfall as follows: North (lowest rainfall) = 0, East = 1, South = 2, West (highest rainfall) = 3.
* MWU test significance: $p < 0.05$.
** MWU test significance: $p < 0.01$.
*** MWU test significance: $p < 0.001$.

3.4. Total trees planted in relation to farm qualities

Small farmers planted fewer trees on average than Large and Medium farmers, but in terms of trees per hectare small farmers planted more on average than large farmers (mean (and median) number of trees ha^{-1}: Small: 43.3 (32.3), Medium: 42.5 (11.0), Large: 13.8 (13.5); KW $p = 0.075$). Significantly more trees were planted annually per hectare in the dry northern zone than in the other three zones (mean (and median) number of trees ha^{-1}: North: 63.7 (45.4), East: 23.7 (15.0), West: 15.9 (7.4), South: 14.7 (3.3); KW $p = 0.00002$).

Farms where trees were planted during the previous five years were significantly more associated with dry bioclimatic zones than farms where trees were not planted (Mann-Whitney *U* test,

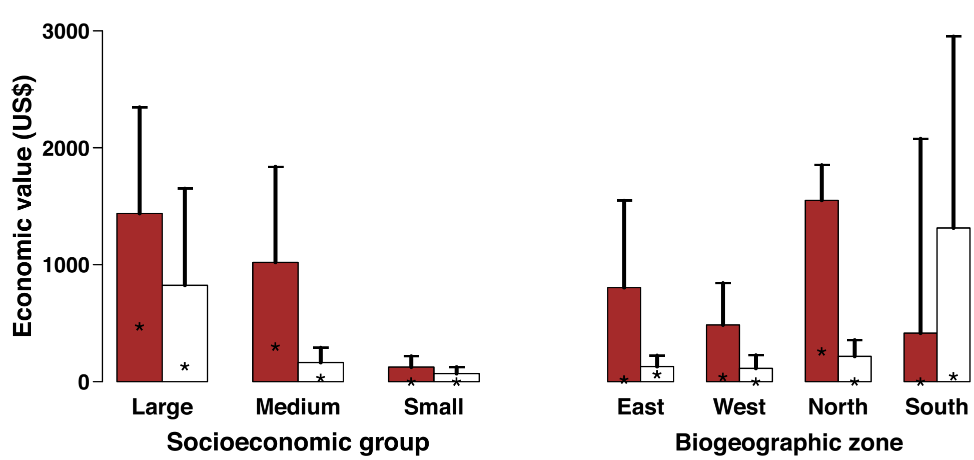

Fig. 5. Average annual economic value of timber (dark bars) and NTFPs (light bars) in US Dollars (one USD = approx. 67 Indian Rupees) accruing to individual farmers of different socioeconomic groups and biogeographic zones in Kodagu, Western Ghats, India. Asterisks (*) indicate the median economic value received per farmer (which is often zero), and vertical lines represent 95% confidence limits.

Table 5
Coefficients from generalized least squares (GLS) linear regression models used to explain tree planting frequencies across 89 farms and across 30 species during the previous five years by farmers in Kodagu, Western Ghats, India. The two models tested six species-level characteristics and four farm-level characteristics as independent predictor variables, respectively, and each model was subjected to backward selection of predictors based on minimizing the AIC value. The last column shows the AIC value, the *p*-value of the ANOVA between the initial full model and the final reduced parsimonious model or between the null model (no variables included) and the final model, and the residual standard error of the final model, "SE". The dependent variable (total number of trees planted per species or per farm during previous five years) was square root transformed in both models. Bioclimatic zones and permit/restrictions are described in Table 4.

Model		Independent variables tested; Parameter estimates (and *p*-values) of final model					AIC (*p*-value, Resid. SE)
Species level (six variables tested):							
Initial:	Growth rate	Max. height	Wood SG	Econ. value	Multi-utility	Permit	201.8
Final:	NR	0.41 (0.0027**)	NR	0.006 (0.0000***)	0.091 (0.0001***)	NR	198 (p = 0.52, SE = 5.6)
β-values:	–	0.07	–	0.98	0.1	–	
Null model:							325 (p <0.0001)
Farm level (four variables tested):							
Initial:		Farm size	Redeemed area	Propn. redeemed	Zone		779
Final:		0.43 (0.0095**)	1.36 (0.012*)	−18.3 (0.0064**)	−7.4 (0.0000***)		779 (SE = 18.0)
β-values:		0.28	0.34	−0.36	−0.41		
Null model:							804 (p <0.0001)

NR: Variable not retained in final reduced parsimonious model.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

$p < 0.05$, Table 4). Multiple regression with GLS modeling and stepwise deletion of factors produced a final model that retained all the four variables tested, and had a highly significantly better fit to the data than the null model (Table 5). The final model confirmed that farmers in drier bioclimatic zones, and those with more redeemed land and larger farms were associated with higher total planting efforts. However, lower proportions of redeemed area were also associated with more tree planting. Among the four variables tested, bioclimatic zones showed the highest standardized effect size (β-value) on total tree planting efforts across farms (Table 5).

3.5. Policy improvements suggested by farmers

When asked whether they desired greater rights over trees to encourage increased tree planting, 66% of interviewed farmers said that they should be guaranteed *a priori* rights to harvest and sell all trees that they grow. Some farmers also wanted better access to farm timber for personal use (bona fide usage), better economic value for timber from Government Depots (50%–100% of market value), and wished that the issue of permits and payments by the Government would be carried out immediately rather than after a delay of several months or years, as is currently the case. If given the appropriate legal rights over planted trees, 59% were willing to plant more native trees in future. However, 34% of the interviewees were opposed to allowing farmers unrestricted harvest rights as they believed that it would be misused by corrupt individuals (including some timber merchants, timber thieves, forestry officials and/or farmers).

During open discussions several farmers also voluntarily suggested that appropriate regulations would need to be put in place to ensure that tree harvesting rights do not lead to endangerment of native species populations by increased market demand. In this regard they suggested forbidding clear-felling or harvest of young trees (<40–50 years old), or maintaining reasonable and appropriate restrictions that could be implemented in terms of tree number (e.g., from one tree every 5 years to 4 trees yr^{-1} per farm), timber volume (e.g., 1.4–5.4 cubic metres every 5 years) or specified location (e.g., 10% harvest permit or 12 trees ha^{-1} per survey number every 30 years). In addition, they suggested a mandatory requirement to replant 1–10 saplings of the same species for every tree cut, and wished that the regulations should be applied uniformly across CAFs, regardless of size or tenure type.

4. Discussion

4.1. Farmers' tree planting efforts in the Western Ghats: potential drivers and effects

Deciding which trees and how many of them to plant on farms was revealed to be a complex process subject to varied needs and motivations of farmers in the Western Ghats. The following influences chiefly determined which species were preferentially planted by farmers:

1. Economic value (especially for timber) was the most influential and highly significant variable influencing which species were planted most often.
2. Multipurpose utility value (especially for non-*Grevillea* species).
3. Species maximum height.

At the level of farms, the following important influences on total tree planting efforts were identified:

1. Climatic dryness was the most influential and highly significant variable.
2. Total redeemed area was positively related to total tree planting frequency, but as the proportion of redeemed area per farm increased farmers planted fewer trees.
3. Farm size had a positive effect on the total number of trees planted.

Our study is the first attempt to quantify the extent of tree planting by coffee farmers in the Western Ghats of India. Assuming that the conservative median number of trees planted (101 trees per year) is representative of long term behaviour, the 93 interviewed farmers plant approximately 9393 seedlings and saplings in Kodagu every year (or 22041 trees at the average rate of 237 per year). This represents 9.1 saplings ha^{-1} planted annually within their collective land holdings (or 21.4 saplings ha^{-1} with the mean number of trees planted). Extrapolated for the entire coffee plantation area of Kodagu (104890 ha, Coffee Board, 2015), potentially between 1 million and 2.2 million seedlings and saplings are added to the Kodagu landscape every year by local farmers (at the median and mean effort, respectively). This estimate is conservative as it excludes planted tree crops such as coconut and arecanut, as well as the contributions from private coffee companies that have higher tree planting densities (median tree planting density: 26.8 trees ha^{-1}, mean: 36.9 trees ha^{-1}, based on interviews with six managers) and a longer harvest rotation cycle than individual farmers.

As the great majority (80%) of these added trees are of the exotic species *G. robusta*, it is not surprising that environmental conservationists have the impression that farmers are "replacing native species with exotic trees" (Garcia et al., 2010; Nath et al., 2011). The current study suggests that it is more appropriate to state that farmers have been "replacing the natural native regeneration" with exotic saplings for several decades, as there appears to be very little harvest of standing adult native trees and most of the replacement is happening at the juvenile level.

It is not yet clear if the large number of seedlings and saplings planted are sufficient to offset natural mortality of standing trees, or if such plantings may augment the original tree density. Augmentation is possible with *G. robusta* as the columnar architecture of this exotic species allows it to be planted closer together and at higher densities than most native trees (e.g., Table 3 in Caudill et al., 2014). An estimate of trees lost from the landscape obtained by applying the background mortality rate (7%, due to natural causes, timber harvest, local worker use and timber theft) to the average standing tree density of 165 trees ha^{-1} (calculated for trees >10 cm dbh averaged over eight CAFs in Kodagu; Nath et al., 2010) suggests that approximately 11.6 standing trees ha^{-1} are lost annually. This estimated mortality rate is higher than the median number of trees planted ha^{-1} by farmers, but less than the average number of trees planted (see above). The scaling effects of these ongoing canopy modifications (i.e., shift towards exotic trees, loss of cover and/or augmentation) on carbon sequestration, ecosystem services and climate change mitigation require further investigation (e.g., Kirby and Potvin 2007).

4.2. Reasons for preferential planting of the exotic G. robusta

The strong preference for planting exotic *G. robusta* trees in the Western Ghats has been reported earlier (Elouard et al., 2000; Moppert 2000; Bali et al., 2007; Garcia et al., 2010; Nath et al., 2011), and we have now identified the key reasons for its popularity in this region. Elsewhere, *G. robusta* is widely planted due to its fast growth, high economic value and low competition with nearby crops (Harwood, 1989; Kalinganire, 1996; Lott et al., 2000; Takaoka, 2008a, 2008b). However, according to our data this exotic species was not faster-growing than all other native species in Kodagu, and growth rate does not appear to be the key cause of its popularity. The other functional trait and multipurpose utility values of this species were also not clearly superior to those of native species. Thus, the only factors consistently associated with *G. robusta* preference over native species were its economic and legal benefits to farmers. These results agree with qualitative opinions expressed by farmers (Table 2). Although *G. robusta* is less valuable per unit volume in the market than many native species, farmers were able to legally sell much higher volumes of this exotic species on the open market, thus making it the most valuable in practical terms. The reported harvest cycle of native trees was also longer than that of exotics, due to a minimum harvest size of 150 cm girth required for the former, and delays of several months or years associated with obtaining felling permits for native trees. Similar experiences of farmers with native species restrictions and reduced economic value in other countries have been linked to their planting of exotic species (Van Noordwijk et al., 2003; Ruf, 2011; Schroth et al., 2011; Nyaga et al., 2015).

Government extension agencies may also influence the availability and choice of species to plant (Dunn, 1991; Dewees 1995; Schneider et al., 2014; Valencia et al., 2015), and in Kodagu a few government agencies such as the Forest Department and Coffee Board have previously disseminated free *G. robusta* seedlings in large numbers to farmers (farmers' information). In addition, seedlings of the exotic *G. robusta* are easier and cheaper to obtain than tree seedlings of native species in the market. However, farmers were extremely conversant with the presence and utility of over 130 locally available native tree species, perhaps because the majority of farmers are not recent migrants but have ancestral lineages that settled in this landscape centuries ago (Haller, 1910). Thus lack of awareness or appreciation of native species value was clearly not a reason for promoting exotic species, as has been reported from other agroforestry regions (Takaoka, 2008a; Ruf, 2011). This underscores the importance and need for improved two-way communication between farmers and extension agencies (Dewees, 1995; Pfund et al., 2011; Valencia et al., 2015).

4.3. Suitable native species for promotion

Popular multipurpose native trees cited by farmers (Table 3, online supplementary material S1) can be considered for agroforestry promotion in this region. Those with high multipurpose utility value, relatively fast growth rates and good timber value include *Artocarpus heterophyllus*, *Lagerstroemia microcarpa*, *Mangifera indica*, *Toona ciliata*, *Spondias pinnata*, *Syzygium cumini*, *Tectona grandis*, *Pterocarpus marsupium*, *Acrocarpus fraxinifolius*, *Terminalia bellirica*, *Michelia champaca*, *Chukrasia tabularis* and *Persea macrantha*. In addition, slow growing and highly valuable timbers such as *D. latifolia* and *Terminalia crenulata* are not expected to be harvestable within 20 years, but can be planted as a form of long term economic security for the next generation if farmers are assured of the corresponding rights of harvest for such species. Farmers in the Western Ghats are likely to plant these species in large numbers if they are assured of the ownership, harvest and selling rights over the trees they plant, as has been suggested by others (Van Noordwijk et al., 2003; Scherr, 2004; Chavan et al., 2015). Farmers are aware that the timber value of *G. robusta* is one-tenth that of the most highly valued native species, *Dalbergia latifolia* and *T. grandis* (according to timber rates published by the Karnataka Forest Department, http://aranya.gov.in). This underscores the potential long term economic loss associated with planting large numbers of *G. robusta*.

Trees do not need to be harvested to provide economic value to farmers (e.g., Scherr, 1995; Akinnifesi et al., 2006). In addition to timber value, farmers appreciated NTFPs for their economic and domestic consumption value. Popular NTFP species can be promoted by providing saplings, deregulating NTFP harvest or minimizing the bureaucracy involved in obtaining permits for harvesting tree products non-destructively, and improving the processing and marketing of products such as the fruits from *Sapindus laurifolius* (soapnut), *Cinnamomum* spp. bark (spice), *Persea macrantha* bark (for incense sticks), etc. Fruit, food and health products can be promoted by developing appropriate marketing strategies for copiously produced indigenous edible fruits such as *Syzygium cumini*, *Artocarpus heterophyllus*, *Mangifera indica* (local wild variety), *Garcinia gummi-gutta*, *Phyllanthus emblica*, *Spondias pinnata*, and the lesser known *Chrysophyllum roxburghii* and *Mimusops elengi*. Native species that are appreciated by farmers as shade trees for coffee (including *Ficus racemosa*, *A. heterophyllus*, *D. latifolia*, *L. microcarpa*, *P. marsupium*, *A. fraxinifolius*, *T. ciliata* and *S. cumini*) should also be promoted by propagation and distribution of saplings from local nurseries.

4.4. Recommendations for implementation of National Agroforestry Policy

Among the significant influences identified by our study, important implications for the National Agroforestry Policy in

India (Chavan et al., 2015) are economic value improvements for native species and reducing the legal impediments (e.g., classification of private lands as redeemed versus unredeemed, reserving valuable timbers as Government property, etc.) that restrict farmers' ownership rights over native trees. The results also suggest that farmers in relatively dry zones and those with larger farms may be more willing and/or capable of participating in Government tree-growing initiatives that offer minimal incentives.

Farmers are likely to respond favourably to agroforestry schemes that are aligned with their own interests (Dewees, 1995; Scherr, 1995; Pannell et al., 2014). Thus, the Government should consider amending tree preservation laws to guarantee farmers the ownership rights over trees that they grow, and to permit harvest and sale of native trees grown by them regardless of the redemption status of their lands, as desired by the farmers. Exploitative harvesting of standing and naturally grown native trees could be prevented by implementing harvest and replanting regulations similar to those suggested by the farmers (see Section 3.5), and by promoting or developing ecofriendly wood certification programs such as the Forest Stewardship Council certification (FSC, https://ic.fsc.org/) that provide economic incentives for responsible forest stewardship. This approach necessitates the development of a spatially digitized registration and monitoring system to facilitate subsequent differentiation of trees that were grown by farmers versus those that previously existed in the landscape.

Under the existing legal framework large farmers and private coffee companies who are willing to wait longer to harvest trees could be targeted with schemes that do not guarantee substantial economic gains (farmers' information) but are useful as international marketing strategies (e.g., ecofriendly coffee certification, etc). Small farmers' constraints with regard to tree planting such as lack of access to water, capital, space, market access and tenurial rights need to be given greater consideration. In this context *G. robusta* is favoured as it has the shortest harvest cycle and presents the least risk for harvesting. As smaller farm size was associated with increased tree planting effort per unit area, it is possible that small farmers prefer species with a columnar architecture (such as *G. robusta*) to plant at high density with relatively close spacing on limited farm space. Diversifying their income and potential utility values by planting more native species may become feasible after they have secured a baseline economic value from the exotic trees. Improved access to credit and NTFP marketability may improve their interest in native species, however, improvement of ownership and harvesting rights would be likely to generate the greatest response from small farmers as timber generally provides higher value than NTFPs. Moreover, farmers in the drier northeastern areas of the district planted more trees per hectare as many of them had been allotted cleared and treeless lands when resettled by the Government from their original villages that were submerged by the creation of the nearby Harangi dam in the 1970s and 1980s (farmers' information). Further research supported by the National Agroforestry Policy should therefore focus on identifying native species with a high capacity for growing fast and surviving drought, as well as those with a high packing density when targeting dry land agricultural areas and small farmers with agroforestry projects.

Marketability of NTFPs by farmers can be improved by eliminating or simplifying the use of permits and quotas. As farmers are already aware of numerous locally available edible native fruit species, local enterprises should be empowered to carry out seed collection and sapling development with involvement of farmers. Seedling cultivation information is available for most of these species (e.g., Rani et al., 2011; Kavitha et al., 2012), many of which have been raised in nurseries maintained by the local Forest and Horticultural Departments. Species-site matching trials or follow-up monitoring also need to be carried out to establish the compatibility of various species with local soil types (e.g., Schneider et al., 2014). Improved processing and sustainable marketing of these dwindling natural resources could be promoted via development of local Geographical Indications or Organic Certifications. Boosting the economic and non-economic values of native tree products also may improve local communities' self-reliance and resilience (Scherr, 2004), and they are entitled to benefit from native species under provisions of the Convention on Biodiversity (1993), rather than remain economically dependent on a small number of exotic species.

Finally, it needs to be mentioned that native tree species with few or no utility values are unlikely to be planted by farmers (Valencia et al., 2015), and these economically "valueless" species will require special incentives such as distribution of free seedlings and saplings under Government-sponsored programs, introduction of conservation payments to reward farmers for protecting critically endangered species, mandatory inclusion in ecofriendly wood certification programs, etc. Similarly, many native tree species are associated with ecosystem disservices such as attraction of dangerous wild animals including elephants, gaur and tigers (e.g. Bal et al., 2011), hosting frugivores such as monkeys, bats and birds that compete for economically valuable fruits, and hosting pest and nuisance species such as coffee borers, hairy caterpillars and stinging ants. Among the trees monitored by us, 12 species showed evidence of wild elephant browsing (debarking, branch or stem breaking, etc). Side effects of conserving native trees could be compensated by Ecofriendly Certification programs or pest and wildlife damage insurance schemes.

5. Conclusions

In this paper we have shown that preference for the exotic tree species *G. robusta* in the Western Ghats is not driven by farmers' ignorance or lack of appreciation for native species, but is artificially maintained by the economic and legal advantages conferred on this exotic species by the existing policy framework. While we do not question the farmers' right to include exotic species in their land use systems, we have tried to highlight the problem of increasing dominance of exotics across the landscape, and most of all the distortions in tree species selection created by complex legislation over native trees. Our study highlights an issue that is relevant for agroforestry landscapes worldwide and is also timely in the regional context, as addressing legal obstacles against tree planting and facilitating access to the right native species are key objectives of the new National Agroforestry Policy of India.

In order to encourage farmers to participate in protecting species diversity a broad-minded, flexible and participatory approach is required (McNeely and Schroth, 2006; Pfund et al., 2011; Pannell et al., 2014), which accepts farmers as nature-based entrepreneurs whose immediate survival may depend more on economic than on ecological considerations. Due to variations in farming practices, the incentives offered should avoid a one-size-fits-all approach and offer farmers the flexibility to increase on-farm biodiversity according to their own capacities in order to achieve stable long-term improvement of tree planting practices and protect the natural basis of their livelihoods in the Western Ghats.

Acknowledgments

This study was funded by the Rufford Small Grants Foundation, UK. We thank farmers and private companies in Kodagu for providing detailed information, and Tata Coffee Limited and BBTC

Limited for facilitating the collection of tree growth data. We are also grateful to S. Aravajy and N. Barathan for assistance with botanical identifications and data management, Profs. B.C. Uthaiah and I. Kalyanasundaram for assistance with vernacular names, and A. Prathap, S. Shiva, B. Saravanan and others for able field assistance. The views expressed in this document are those of the authors and do not necessarily reflect the views of the United Nations Development Programme.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agee.2016.05.013.

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