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Research article

SOCIOECONOMIC AND BIOPHYSICAL FACTORS AFFECTING TREE RICHNESS AND DIVERSITY IN MACHAKOS COUNTY, EASTERN KENYA

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ABSTRACT: Trees on farm play a vital role in providing diverse goods and services to those farmers practicing agroforestry in Kenya. Other than the environmental advantages of agroforestry such as carbon sequestration and species conservation, trees provide soil and microclimate enhancement, deliver fruits, medicines, fodder, timber and fuelwood. However, tree species richness and diversity are influenced by numerous socio-economic and biophysical factors as necessary knowledge for promotion of on-farm tree planting activities. The purpose of this study was to assess the effects of different socio-economic and biophysical factors on tree richness and diversity in smallholder farms in the study area. The study covered three broad agro-ecological zones i.e., Lower highlands, Upper midlands and Lower midlands along an elevation gradient in Machakos County, Eastern Kenya. Importance Value Index (IVI) was calculated to get the level of importance of different tree species. Correlations and stepwise multiple regression analysis were used to estimate the influence of the assessed socio-economic and biophysical variables on tree species richness, abundance and diversity. Tree diversity indices were calculated using MVSP to obtain Shannon index and Evenness. Cluster analysis based on the Minimum Variance method was used to partition samples into homogenous classes. A total of 102 tree species were recorded, including 42 exotic and 60 indigenous species. Exotic abundance was at 67% of all counted individuals while mean number of tree species was 12.7 ranging from 3-26 tree species per farm. Farm sizes ranged from 0.1 to 7.1 ha, with a mean size of 1.6 ha. Tree diversity was relatively high with a mean Shannon diversity index of 1.73 (range 0.46-2.53) and a mean Shannon evenness 0.70 (range 0.28-0.97). Based on the IVI, *Grevillea robusta* and *Eucalyptus spp* were among the top exotic timber and fuelwood species while *Acacia seyal* and *Terminalia brownii* topped the indigenous tree species for fuelwood. *Mangifera indica* and *Persea americana* presented fruit tree species with a high IVI and were all exotics. Tree species richness was positively influenced by farm size and market distance, but negatively by elevation, number of plots and gender. Tree abundance was positively influenced by farm size and number of plots. Farm size, however, had a strong negative effect on Shannon evenness. Cluster analysis resulted in six clusters and twelve (12) tree species were responsible for cluster formation. Results of this study can contribute to modify agroforestry programmes for implementing future tree planting activities for different target populations in various economic and environmental circumstances.
Keywords: Cluster analysis; Shannon diversity index; Shannon evenness; Species richness

INTRODUCTION

Machakos in Eastern Kenya like most of other parts of semi-arid sub-Saharan Africa lack detailed studies on present on-farm tree diversity and the influencing socio-economic and biophysical factors. Tree diversity help to diversify income of farmers, lower their production risks while optimising the management of tree resources. Contribution of agroforestry systems in improving tree cover is thus essential with the decline of natural forests and the high-value trees species over time [1].

The understanding of the relations between investments in agroforestry and shrinking protected areas in comparison to tree diversity patterns on farms should be clear for the realization of the potentials of agroforestry as a method for landscape biodiversity conservation [2]. Thus, biodiversity and diversity of any nature have been recently under serious threat. As agroforestry conservation is gaining popularity, tree species diversity on farms in relation to farm productivity has attracted research attention [3,4]. Research suggests that, "there is a positive relationship between species diversity and ecosystem function in farmland, which is conditional on the growth characteristics of trees, the spatial scale of intervention and the level of environmental heterogeneity" [5].

Knowledge about the types and interactions of different biophysical and socio-economic factors such as farm size, agro-climatic zone, soil fertility, mobility and importance of trees and wealth had an effect on tree species richness and diversity in India's Western Himalayas [6]. The wealth status of household and time taken during cultivation influenced diversity patterns in Ethiopian [7,8]. In Niamey, Niger, urban and peri-urban farms had high plant species richness and diversity influenced mostly by socioeconomic factors such as garden size, farmer ethnic affiliation and gender [9]. Home Gardens of Nuba Mountains in Sudan showed that Plant species and diversity were influenced mainly by location of farm, type of ethnicity, remoteness, level of market access and mobility of people [10]. Understanding the interactions of above factors is a significant step towards successful conservation programmes and sustainable utilization of tree products and services.

Studies in the Tanzania's Usambara Mountains and Kenya's Mt. Kenya region, dominance of exotics in the highlands was explained to be as a result of promotion by development projects and the lack of planting material for indigenous species [11,12]. Propagation techniques that promote *Circa situm* conservation of tree biodiversity can be developed for success in their conservation [13]. Indigenous tree species are highly threatened with extinction thus should be given priority for conservation within their natural habitats [14]. Farmers can benefit more from tree product and services by integration of more indigenous tree species into farms and providing of additional habitats for these species [15], resulting in 'conservation through use'. Farm diversification and tree conservation enticements are possible through better planning after understanding the existing diversity of indigenous and exotic trees on farms [12]. Germplasm improvement and supply, silviculture and market availability of priority species especially indigenous ones can help in the progress towards farm diversification and sustainable conservation of indigenous trees [12]. This study was to help in understanding the dynamics of on-farm tree growing in the three selected administrative divisions i.e., Machakos, Kangundo and Mwala of Machakos County covering three major agro-ecological zones. Tree richness and diversity analysis would help in selecting priority areas and right tree species for successful implementation of on-farm tree planting programmes initiated by NGO's and government agencies.

MATERIALS AND METHODS

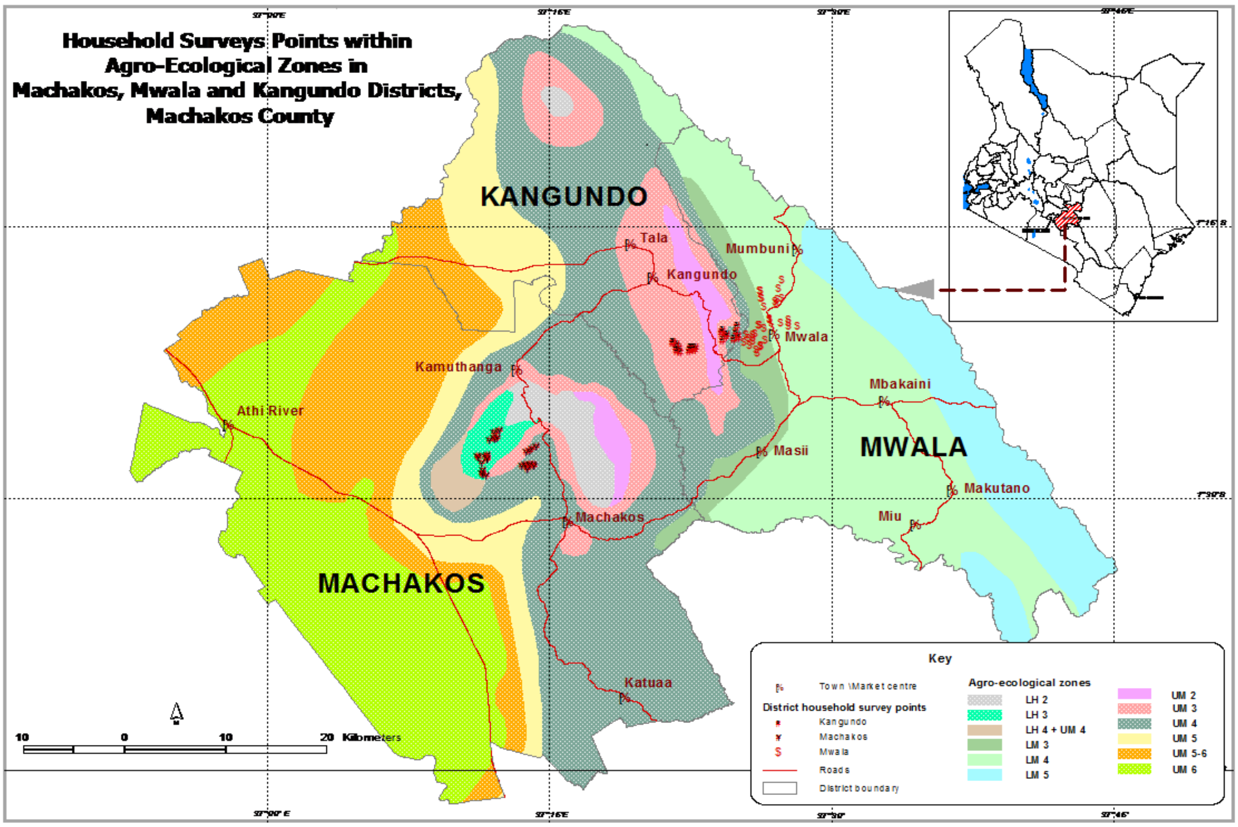
Study area

The study was carried out in three of the four districts of Machakos County (Figure 1) i.e., Machakos central, Kangundo and Mwala. The County has a population of about 1.1 million as per 2009 census with an annual growth rate is 1.7% and population density is 177 people per Km^2 [16]. The population is unevenly distributed with Kangundo division having the highest population density of 512 persons/km^2 and Athi river Division has the lowest density of 54 persons per km^2 [17].

The study area covered three broad agro-ecological zones (AEZs), namely (i) semi-humid Lower Highlands (LH3) mostly in Mua hills of Machakos central with altitudes ranging from 1800 to 2100 masl, temperatures of 16.0-16.9°C and annual rainfall of 900-1200 mm, (ii) transitional Upper Midlands (UM3 and UM4) mostly in Kangundo with altitudes of 1340-1830 m, temperatures of 17.9-20.5°C and annual rainfall of 700-1000 mm, and (iii) semi-arid Lower Midlands (LM3 and LM4) mainly in Mwala with altitudes of 1160 - 1350 m, temperatures of 17.9-0.5°C and annual rainfall of 700-900 mm (Jaetzold et al.). The county stretches from latitudes 0º 45' south to 1º 31' south and longitudes 36° 45'east to 37° 45' east [17]. Machakos is the capital of the County located 64 kilometres southeast of Nairobi (Figure 1).

The soils of Machakos reflect the largely metamorphic parent material and the rainfall regimes that contribute to their formation. In Machakos, the dominant soil groups are alfisols, ultisols, oxisols, and lithic soils [18]. A rough estimate of the agricultural quality of the region's soils indicates that less than 20 per cent of Machakos has well-drained, deep, friable red and brown clays of good fertility; more than 60 per cent of the region has very erodible, relatively shallow, sticky, red, black, and brown clays of variable fertility, on steep slopes; 20 per cent has poorly drained, shallow, stoney soils of low fertility [18].

Figure 1: Map of Machakos County, Eastern Kenya, with its three districts Machakos, Mwala and Kangundo and it different agro-ecological zones as well as the locations of the surveyed 90 farms (Source: ICRAF/ILRI GIS unit).



Sampling and data collection

Primary data was collected from April to July 2012 using a questionnaire and a tree inventory form. An interview session with the household head or his/her representative using a structured questionnaire with closed-ended questions was used to cross-check some of the farmer's basic information. The following characteristics were included: name, age, gender, education level and main occupation of the household head, as well as type of land tenure, farm size, distance to the nearest market and distance to the nearest tree nursery.

Actual farm sizes were measured by using a GPS device to compare with the approximate size given by farmers in the interviews. All tree species within each farm and their abundances were documented and a detailed tree inventory form was used to record additional information about all tree individuals. Trees were defined as follows: non climbing woody species that have the potential to grow higher than 6 m and have a distinct stem. Thus, shrubs and lianas were excluded. The following parameters were reported for each tree individual: dbh using a diameter tape, tree height (estimated) and crown diameter (roughly estimated by using steps on the ground two times at 90 degrees and the average entered in the inventory form).

The farmer assisted in providing information on the following variables for each tree individual identified on his/her farm; local name of the tree species, approximate age of the tree, source of planting material, the market values of different tree products of each tree and the individual economic and non-economic uses of the respective tree species. Trees below 5 cm dbh were regarded as 'saplings' and were only counted and recorded separately, but crown and height measurements were not taken.

Tree species were identified with their botanical names in the field and cross-checked by using different identification literature [19-21]. The mentioned literature was also used to determine scientific names for a few species not identified in the field, but only recorded with their local names. In addition, the tree databases of ICRAF assisted in getting some of the scientific names of trees [22].

Data analysis

Data collected was first entered in to Excel sheets for cleaning and then transferred to SPSS: Statistical Package for Social Scientists version 18 for analyses of both descriptive and inferential statistics. MVSP: Multivariate Statistical Package [23] was used for diversity analysis. Accumulation curves for both exotic and indigenous tree species based on farm numbers surveyed were calculated for the three altitude zones i.e., Lower highlands (LH), Upper Midlands (UM) and Lower Midlands (LM) by using Biodiversity R software [24]. Raw data on species richness and abundance was then used to calculate different other variables, including tree individual densities per ha farm area, Shannon diversity and evenness indices [25] and the Importance Value Index IVI.

Tree density was calculated as: Number of tree individuals per farm divided by the farm size in hectares. The formula used for calculating the Shannon diversity index is:

$H' = -\sum p_i \ln p_i$

Where, H'=Shannon index of diversity

p_i=the proportion of important value of the ith species ($p_i = n_i / N$, n_i is the important value index of ith species and N is the important value index of all the species).

Species evenness is often assessed by Shannon's equitability index (H'E) which is calculated by:

$H'E = H/H_{max}$

Where, H*max* is defined as *ln* S. H'E values ranges from 0 to 1, in which 1 indicates complete evenness. Shannon diversity and evenness indices were calculated using the MVSP software. The Importance Value Index (IVI) was calculated to determine the overall importance of each species in the whole sample of farms. In calculating this index, the percentage values of the relative frequency, relative density and relative dominance of each separate species were summed up and divided by three [26].

Parametric methods (T-test and ANOVA) were used to compare groups where the continuous variables met the normality and homogeneity of variance assumptions. T-tests were used for comparison of means between two groups and Analysis of Variance (ANOVA) for comparing means for more than two groups followed by post-hoc Tukey test to identify which groups were different. Non parametric methods (Mann-Whitney U-test and Kruskal Wallis H-test) were used where the continuous variables did not meet the normality and homogeneity of variance assumptions. Mann-Whitney U test was used to compare means of two groups and Kruskal Wallis H test was used to compare more than two groups, followed by pairwise Mann-Whitey U test to identify which groups were different.

Spearman correlation coefficient was used to identify relationships between ordinal variables and the tree diversity variables while Pearson correlation coefficient was used to determine the relationships between scale variables and the tree diversity variables. Stepwise multivariate linear regression analyses were carried out to assess the influence of biophysical and socioeconomic variables such as agro-ecological zones, distance to the market, distance to the nursery, farm size, economic value of trees, gender of household head, age of household head, education level of household head and income level of household head against total indigenous and exotic tree species and individuals. This helped develop models that indicated the extent to which different biophysical and socioeconomic variables affect tree species richness, density and diversity. For the above mentioned analyses, SPSS version 18 was used.

Finally cluster analysis was performed by using MVSP to classify farms into similar groups/types. This analysis was based on the log e-transformed densities of the on-farm tree species [23]. After removing outliers identified by the nearest neighbour method, minimum variance method, squared Euclidean distances using minimum variance method was applied for the final cluster analysis by using SPSS version 18. To determine the tree species that were most responsible for the cluster formation and to check the strength of the cluster separation, discriminant analysis was also performed by using SPSS version 18.

RESULTS

Socio-economic household and farm data

Inventory on the 90 farms showed that mean farm size was 1.6 ha with the LH zone having the highest at 2.04 ha. Of the 90 surveyed households, 71 (79%) had a male household head and 19 (21%) a female (Table 1). The household heads mean age was 57 years. Altitude of all farms surveyed ranged from 1,219 m to 2,103 m asl. Sixty six percent of the household heads mentioned farming as their only occupation while 34% supplemented farming with other income-generating activities such as small businesses are wage labour. Only 10% of the household heads had never gone to school, 52% finished primary school, 28% secondary school and 10% even had some post-secondary education (Table 1). Chi-square tests did not show significant differences for nominal variables of gender, occupation of the household head and education level of household head across the altitude zones.

Income from farming was above KES. 75,000 per annum for 61% of the surveyed households while only 5% had less than KES 25,000 (Table 1). The income generated from off-farm activities was lower since only 38% of the households mentioned an income above KES. 75,000 per annum but as much as 34% below KES. 25,000 however, there were no significant differences among the altitude zones (Table 1).

The overall mean distance from farms to markets was 5.4 km ranging from 0-22 km (Table 1). Mean distance in the Lower Highlands was significantly higher compared to Upper Midlands and Lower Midlands (Table 1). The overall mean distance from farms to tree nurseries was 2.3 km ranging from 0-16 km. The mean distance to markets was significantly high in the Lower Highlands as compared to Upper Midlands and Lower Midlands (Table 1).

Table 1: Household characteristics for the three altitude zones on 90 farms surveyed in Machakos County, Eastern Kenya.

Household characteristics	**Altitude zone**	**LH (n=18)**	**UM (n=37)**	**LM (n=35)**	**Total (n=90)**
Farm size (Ha)		2.04	1.22	1.76	1.6
Gender	Male	14	26	31	71
	Female	4	11	4	19
Age of household head (Years)		58.9	57.0	55.6	56.8
Altitude (m asl)		2,032	1,502	1,276	1,520
Occupation	Farmer	13	21	25	59

	Farming and business	5	16	10	31
Education level of household head	Never	0	5	4	9
	Primary	11	15	21	47
	Secondary	5	12	8	25
	Tertiary	2	5	2	9
Income from farming (KES) in ‘000	<25	1	0	3	4
	25-49	2	4	7	13
	50-74	5	7	6	18
	75-100	4	12	11	27
	>100	6	14	8	28
Income from other sources (KES) in ‘000	<25	5	14	12	31
	25-49	2	3	7	12
	50-74	6	3	4	13
	75-100	0	5	5	10
	>100	5	12	7	24
Mean distance to markets (km)		14.57	3.32	2.8.3	5.38
Mean distance to tree nurseries (km)		4.57	1.71	1.82	2.33

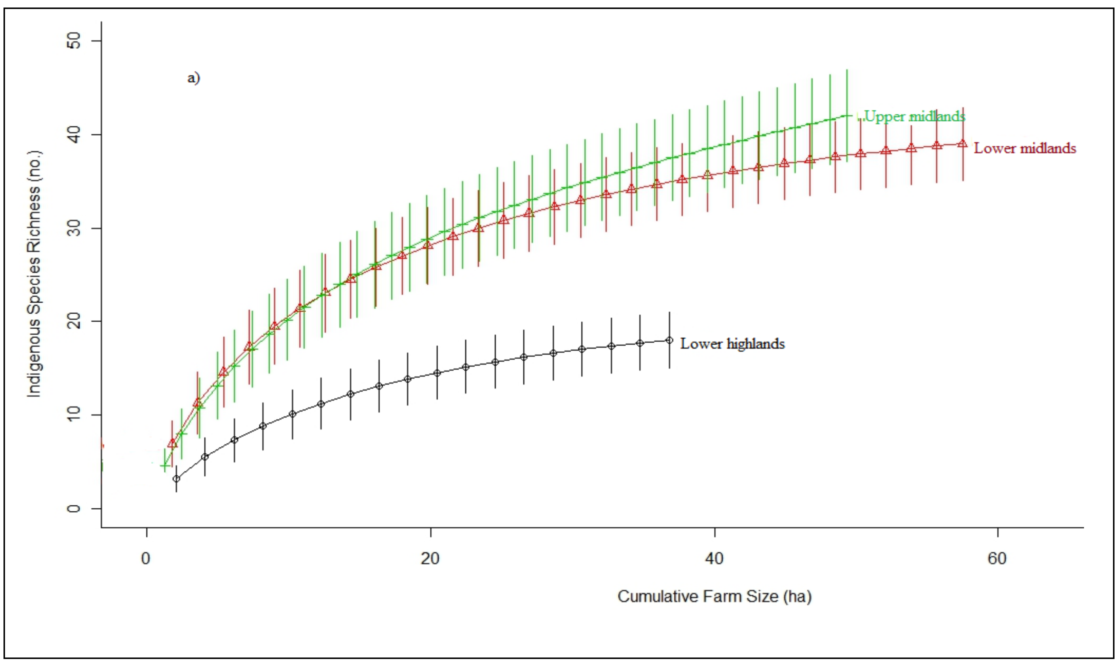
Species accumulation curves for indigenous and exotic trees

Total richness for indigenous species was significantly higher in the Lower and Upper Midland zones than in the lower highland zone (Figure 2a). However, the curve for the Upper Midland zone still increasing, indicating a possible higher total richness in UM as compared to LM if more farms were inventoried. With regard to exotic species, there were no clear differences among the altitudes, although the Upper Midlands zone showed a trend towards higher species richness than the other two zones (Figure 2b).

Species frequencies, abundance and Importance Value Index (IVI)

The four most frequent species on the surveyed 90 farms *were Grevillea robusta, Mangifera indica, Croton megalocarpus* and *Persea americana*, present in at least 50% of the farms (Table 2). Three out of these four most frequent species were of exotic origin, two of them planted for their fruits. Six more species (*Thevetia peruviana, Terminalia brownii, Citrus limon, Acacia tortilis, Psidium guajava* and *Senna siamea*), four exotic and two indigenous ones, found in at least one third of the farms (Table 2). The exotic species were even dominating the list of the 20 most frequent species, as 14 of them (70%) were of exotic origin. Six out of the 20 most frequent species were cultivated for their fruits, all of them exotic species. Similarly, the four most frequent timber species were exotic ones. The most abundant species with each more than 10% of the total individuals were *Acacia seyal*, *Eucalyptus saligna*, *Eucalyptus camaldulensis* and *Grevillea robusta* (Table 2). In terms of Species Value Index (IVI), *Acacia seyal* and *Grevillea robusta* had the highest IVI of 12.3 and 10.9 respectively (Table 2). The former was also ranked highest with regard to abundance (Table 2), basal area, and the latter highest regarding frequency (Table 3). Other species with a high IVI were *Eucalyptus saligna* (8.4%), *Mangifera indica* (7.9%) and *Eucalyptus camaldulensis* (6.9%), all of them also high in abundance (Table 2). However, there were more exotic tree species dominating the highest rank of IVI with uses such as timber and fruits unlike the indigenous trees whose main use is fuelwood.

Figure 2: Species accumulation curves for indigenous (a) and exotic tree species (b), separately for the main altitude zones Lower Highland (n=18), Upper Midland (n=35) and Lower Midland (n=35). The bars indicate the 95% confidence interval (CI) based on standard deviation.



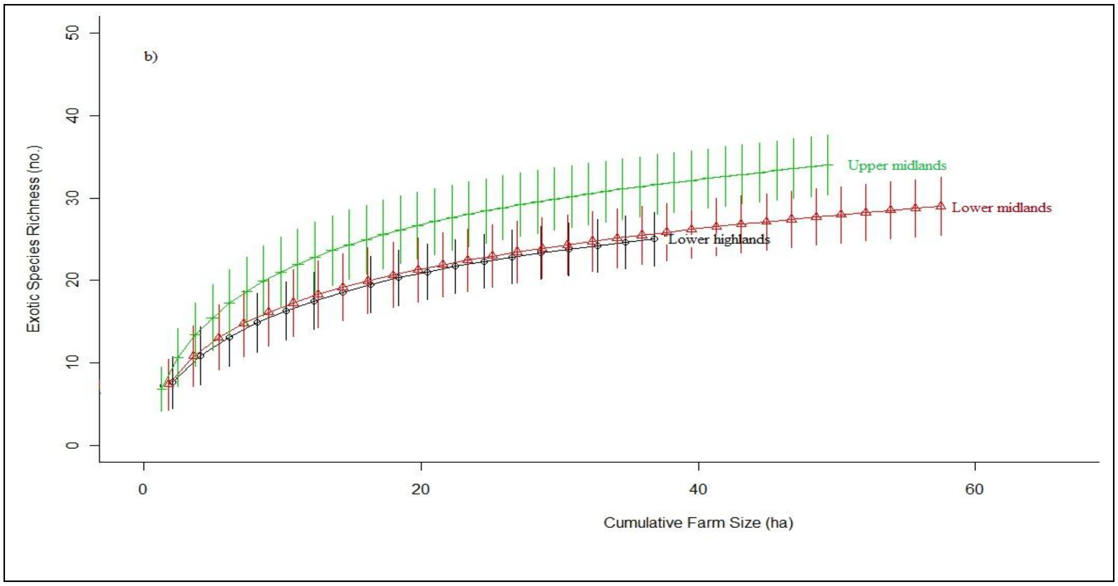


Table 2: The indigenous and exotic twenty species with the highest importance value index (IVI) on 90 farms surveyed in Machakos County, Eastern Kenya.

Rank	Tree species	Abundance	Frequency (% plots present)	IVI (%)	Main uses
(a)	**Indigenous tree species**				
1	*Acacia seyal*	3484	31.1	12.27	Fuelwood
6	*Terminalia brownii*	750	46.7	4.36	Poles, bees, medicine
7	*Croton megalocarpus*	570	65.6	3.69	Fuelwood, ornamental
9	*Acacia nilotica*	706	30.0	2.89	Fuelwood
10	*Acacia tortilis*	375	38.9	2.29	Fuelwood
18	*Combretum collinum*	305	11.1	1.13	Fuelwood
20	*Lannea schweinfurthii*	63	21.1	0.94	Fuelwood
(b)	**Exotic tree species**				
2	*Grevillea robusta*	2384	78.9	10.92	Timber, fuelwood
3	*Eucalyptus saligna*	3337	26.7	8.45	Timber, poles
4	*Mangifera indica*	1825	78.9	7.93	Fruit
5	*Eucalyptus camaldulensis*	2578	7.8	6.90	Timber, poles
8	*Persea americana*	351	60.0	3.11	Fruit
11	*Cupressus lucitanica*	1381	15.6	2.72	Timber
12	*Thevetia peruviana*	481	48.9	2.61	Ornamental
13	*Citrus sinensis*	537	15.6	2.12	Fruit
14	*Senna siamea*	259	33.3	1.77	Poles, ornamental
15	*Citrus limon*	114	45.6	1.54	Fruit
16	*Psidium guajava*	83	38.9	1.34	Fruit
17	*Eriobotrya japonica*	86	31.1	1.16	Fruit
19	*Jacaranda mimosifolia*	117	25.6	1.01	Fuelwood

Factors influencing species richness and diversity

Richness of tree species per farm ranged from 3 to 26 with a mean of 12.3 with highest richness at the LM zone at 14.3. The mean numbers of indigenous and exotic species per farm were relatively similar with 5.1 (range 0-16) and 7.2 species (range 1-13), respectively. Each farm harboured 245 tree individuals in a mean (range 9-3531), including 81 indigenous and about 165 exotic tree individuals on average (Table 3). There was a significant difference among species richness in the Lower Midlands and lowest in the Lower Highlands and Upper Midlands and for both exotic and indigenous richness at P=0.000. The proportion of exotic species was highest in the Lower Highlands (71.7%) and lowest in the Lower Midlands at 5.2% (Table 3). Species richness and diversity also differed among the three altitude zones covered in the study (Table 3). The highest species richness, indigenous species richness and portion of indigenous species were found in the Lower Midland zone (Table 3). The Lower Highland zone had the highest abundance of exotic individuals, the lowest portion of indigenous individuals and the lowest density of indigenous individuals. However, there were no significant differences for exotic species richness, total abundance, indigenous abundance, total density, exotic density, Shannon diversity, and Shannon evenness among the three altitude zones (Table 3). Shannon diversity and evenness indices were similar among the altitude zones. Mean Shannon diversity index was 1.70 (range 0.46-2.53), mean Shannon evenness 0.70 (range 0.28-0.97) as shown (Table 3).

Table 3: Mean tree species richness, abundance, tree density and diversity on 90 farms in Machakos County, Eastern Kenya.

Variable	Lower Highlands (n=18)	Upper Midlands (n=37)	Lower Midlands (n=35)	Total (n=90)	P
Total species richness	10.8^{b}	11.5^{b}	14.3^{a}	12.3	0.007
Exotic species richness	7.6	6.9	7.4	7.2	ns
Indigenous species richness	3.2^{b}	4.6^{b}	6.9^{a}	5.1	0.000
Portion of exotic species (%)	71.7^{a}	64.0^{ab}	55.2^{b}	62.1	0.003
Portion of indig. species (%)	28.3^{c}	36.0^{b}	44.98^{a}	38.9	0.001
Total abundance	291.1	277.7	180.0	245.4	ns
Exotic abundance	269.4^{a}	152.0^{b}	121.3^{b}	164.6	0.016
Indigenous abundance	21.7	125.2	58.7	80.8	ns
Portion of exotic individuals (%)	87.5^{a}	66.6^{b}	67.0^{b}	70.9	0.007
Portion of indig. individuals (%)	12.5^{b}	33.4^{a}	33.0^{a}	29.1	0.006
Density (tree individuals/ha)	136.4	171.5	106.2	141.2	ns

Density indigenous spp. (indiv./ha)	9.9[b]	45.6[a]	30.6[a]	33.1	0.000
Density exotic spp. (indiv./ha)	126.5	126.1	75.6	108.2	ns
Shannon diversity	1.594	1.638	1.829	1.697	ns
Shannon evenness	0.697	0.690	0.703	0.696	ns

Means in a row followed by different letters are significantly different at P<0.05 (Kruskal-Wallis test followed by pairwise U-tests).

The results of multivariate linear regression analyses in Table 4 had weak models since no adjusted R2 (coefficient of determination) was higher than 0.450. The strongest regression models were obtained for the dependent variables; richness of indigenous species and total tree abundance. Altitude had a negative influence on total and indigenous species richness as well as on Shannon index (Table 4). Farm size had a positive influence on species richness and abundance, but a negative one on Evenness. Farms far away from markets had higher total and indigenous species richness as well as a higher Shannon index while the distance to a nursery did not influence any species richness or diversity variable. Female-headed households had higher total and indigenous species richness on their farms while no influence of the farmer's age or main occupation was detected. Abundance of indigenous trees was lower on farms managed by respondents with rather low income from farming (Table 4). From the multivariate regression analysis in Machakos study area, biophysical factors such as altitude had strong negative influence on tree species richness as well as Shannon diversity index. This means that increase in altitude led to decreased tree species richness and diversity that could be attributed to focussing on fast growing exotic tree species, and intensive agriculture thus very little land is left fallow or unploughed land having a contribution to *in-situ* conservation (Table 4).

Table 4: Results of the stepwise multivariate linear regression analysis for selected richness, abundance and diversity variables studied at 90 farms in Machakos County, Eastern Kenya.

	Total species richness	**Indige. richness**	**Exotic rich-ness**	**Total abund.**	**Abund. Indige.**	**Abund. exotic**	**Shannon diversity**	**Shannon Evenness**
Adjusted R^2	0.280***	0.442***	ns	0.408***	0.279***	0.150***	0.113*	0.203***
Independent Variables								
Age of HH Head (years)	ns	ns	ns	ns	ns	ns	ns	ns
Altitude (m)	-0.699***	-0.827***	ns	ns	ns	ns	-0.523***	ns
Gender of HH head (0=male;	0.247**	0.211*	ns	ns	ns	ns	ns	ns

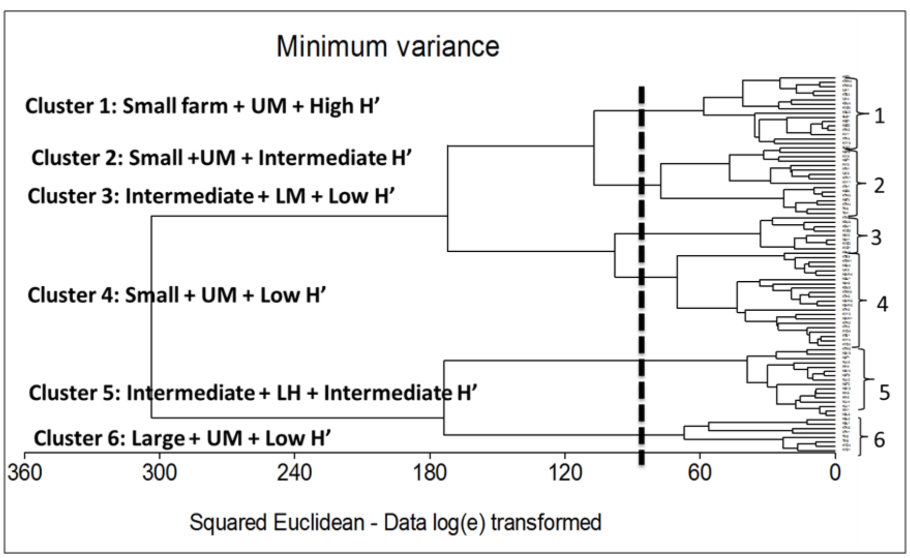
1=female)								
HH head is farmer (1=yes)	ns	ns	ns	ns	ns	ns	ns	ns
Farm size (ha)	0.344***	0.447***	ns	0.644***	0.587***	0.399***	ns	-0.460***
Distance to market (km)	0.411**	0.400**	ns	ns	ns	ns	0.331*	ns
Distance to nursery (km)	ns	ns	ns	ns	ns	ns	ns	ns
Dummy high income from farm (1=yes)	ns	ns	ns	ns	-0.206*	ns	ns	ns

Note: ns = not significant; *, **, *** = F-test (for the model) or T-test (for independent variables) significant at P≤0.05, ≤0.01, ≤0.001, respectively. For each independent variable, the standardized regression coefficient and the significance level were presented.

Classification of farms according to their species composition

The nearest neighbour clustering method resulted in the identification of four outliers which were not included in the following final cluster analysis. The final cluster analysis based on the Minimum Variance method resulted in six different clusters according to the ‘elbow criterion’ (Figure 3). Clusters were named by farm sizes, altitude zone and Shannon diversity.

Figure 3: Dendrogram resulting from a hierarchical cluster analysis (minimum variance method, squared Euclidean distances) on the basis of loge-transformed densities of 102 tree species cultivated in 90 farms in Machakos County, Eastern Kenya. The dotted line marks the cut-off point to define the correct number of clusters according to the ‘elbow’ criterion. Four farms were identified as an outlier before and were, therefore, excluded from this analysis.



Farm types were grouped together based on species density and composition and 92% of the farms were correctly classified. Discriminant analysis identified the following 12 species as most responsible for the cluster separation; *Citrus sinensis, Eucalyptus saligna, Eucalyptus camaldulensis, Grevillea robusta, Thevetia peruviana, Eriobotrya japonica, Croton macrostachys, Dolichos oliveri, Acacia seyal, Gliricidia sepium, Acacia gerrardii* and *Markhamia lutea*. These species had the highest mean densities per hectare and guided in determining their influences in cluster separation and formation.

Cluster 1 was characterised by high densities of *Thevetia peruviana* and *Grevillea robusta* among others (Table 5) while cluster 2 was characterised by high densities of *Grevillea robusta*, *Thevetia peruviana* and *Croton macrostachys*. Cluster 3 was characterised by high densities of *Citrus sinensis* and *Grevillea robusta* while Cluster 4 had high densities of *Thevetia peruviana* and *Acacia seyal*. Cluster 5 had high densities of *Eucalyptus saligna, Grevillea robusta* and *Eriobotryra japonica* while cluster 6 was characterised by high densities of *Eucalyptus camaldulensis*, *Acacia seyal* and *Gevillea robusta* (Table 5).

Grevillea robusta and *Acacia seyal* were present in all six clusters while *Citrus sinensis* (fruit tree) was present in five clusters. *Eucalyptus saligna*, *Thevetia peruviana*, *Eriobotyra japonica* (fruit tree) and *Acacia gerradii* were present in four clusters. *Eucalyptus camuldulensis, Croton macrostachys and Gliricia sepeum* were marginally low or absent in two clusters while *Dolichos oliveri* and *Markhamia lutea* (all indigenous trees) were present in only two clusters (Table 5).

Table 5: Mean densities (tree individuals per ha) of the 12 tree species responsible for cluster formation among the 6 cluster groups identified by hierarchical cluster analysis (minimum variance method, squared Euclidean distances) using tree individual density data of 86 farms surveyed in Machakos County, Eastern Kenya.

Species	Cluster 1 (n=16)	Cluster 2 (n=16)	Cluster 3 (n=8)	Cluster 4 (n=22)	Cluster 5 (n=16)	Cluster 6 (n=8)	Total (N=86)	p
Citrus sinensis	0.30^{b}	0.11^{b}	2.89^{a}	0.11^{b}	0.00^{c}	0.19^{b}	0.39	0.000
Eucalyptus saligna	0.32^{b}	0.50^{b}	0.00^{bc}	0.07^{b}	3.27^{a}	0.00^{bc}	0.78	0.000
Eucalyptus camaldulensis	0.00^{c}	0.00^{c}	0.00^{c}	0.12^{b}	0.00^{c}	2.94^{a}	0.30	0.000
Grevillea	2.38^{b}	4.10^{a}	1.18^{bc}	0.65^{bc}	1.85^{b}	2.17^{b}	2.03	0.000

robusta								
Thevetia peruviana	2.87[a]	0.88[b]	0.58[b]	0.86[b]	0.00[c]	0.00[c]	0.97	0.000
Eribotrya japonica	0.12[b]	0.32[b]	0.00[c]	0.00[c]	1.12[a]	0.43[b]	0.33	0.000
Croton macrostachys	0.23[ab]	0.71[a]	0.00[b]	0.00[b]	0.00[b]	0.00[b]	0.18	0.000
Dolichos oliveri,	0.00[b]	0.00[b]	0.00[b]	0.00[b]	0.24[a]	0.00[b]	0.04	0.008
Acacia seyal	0.49[bc]	0.08[c]	0.35[bc]	0.60[b]	0.21[bc]	2.91[a]	0.60	0.000
Gliricidia sepeum	0.22[a]	0.00[a]	0.00[a]	0.00[a]	0.00[a]	0.09[a]	0.05	0.528
Markhamia lutea	0.00[a]	0.00[a]	0.00[a]	0.05[a]	0.00[a]	0.00[a]	0.01	0.725
Acacia gerrardii	0.34[a]	0. 00[a]	0.00[a]	0.10[a]	0.04[a]	0.03[a]	0.12	0.360

Where significant difference was seen within a row ($P \leq 0.05$; one-way Kruskal Wallis test followed by pairwise Mann Whitney Test), values are lettered in descending order of size.

In addition to differences in the densities of the above-mentioned species, the clusters also differed in various variables, including both bio-physical and socio-economic household characteristics as well as tree species richness and diversity variables. Farms of Cluster 1 were of small sized, located at rather low altitudes and not far away from markets and nurseries, and were characterised by rather low species richness, abundance and density but high Shannon diversity (Table 6). In Cluster 2, small farms located on intermediate altitudes and not far from markets and nurseries were grouped together that had low to intermediate species richness, abundance and diversity. Cluster 3 grouped farms of intermediate sizes at low altitudes together, those were not far away from markets and nurseries and had high species richness and Shannon diversity, but low to intermediate abundance and low tree density (Table 6).

Farms of cluster 4 were rather small, located at intermediate altitude and not far from markets and nurseries, which had high portions of indigenous species and individuals, intermediate richness, low abundance and tree density, but high Shannon diversity and evenness indices (Table 6). In Cluster 5, farms of highest altitude, intermediate size and far away from markets and nurseries were grouped, which had low richness, abundance and tree density and intermediate diversity. Cluster 6 grouped large farms of intermediate altitude and far from nurseries but not far from markets, which had low richness and diversity, but high abundance and tree density (Table 6).

Table 6: Mean biophysical and tree species richness and diversity parameters of 86 farms grouped into six clusters, surveyed in Machakos County, Eastern Kenya.

	Cluster 1 (n=16)	Cluster 2 (n=16)	Cluster 3 (n=8)	Cluster 4 (n=22)	Cluster 5 (n=16)	Cluster 6 (n=8)	P
Altitude	1313.6^{d}	1470.2^{c}	1241.9^{d}	1364.7^{cd}	1990.8^{a}	1772.5^{b}	0.000
Farm size (ha)	1.13^{c}	0.94^{c}	2.67^{ab}	1.46^{bc}	1.95^{abc}	2.99^{a}	0.001
Distance to market	3.44^{b}	3.17^{b}	2.71^{b}	2.88^{b}	13.45^{a}	5.75^{b}	0.000
Distance to nursery	0.98^{b}	1.26^{b}	2.78^{ab}	1.85^{ab}	4.14^{ab}	5.48^{a}	0.006
Total species richness	13.4^{ab}	11.1^{b}	17.0^{a}	12.5^{ab}	10.5^{b}	10.8^{b}	0.019
Indigenous richness	5.5^{b}	4.0^{b}	9.8^{a}	6.3^{ab}	3.1^{b}	3.8^{b}	0.000
Portion of indig. spp.	40.6^{ab}	32.6^{ab}	50.9^{a}	49.6^{a}	28.8^{b}	37.4^{ab}	0.001
Total abundance	109^{b}	143^{b}	282^{b}	99^{b}	285^{b}	1022^{a}	0.000
Abund. indigenous	20^{b}	18^{b}	131^{ab}	55^{b}	22^{b}	501^{a}	0.038
Abund. exotic trees	89^{b}	125^{ab}	151^{ab}	44^{b}	263^{ab}	521^{a}	0.043
Portion indig.	20.6^{bc}	17.8^{bc}	37.2^{ab}	53.6^{a}	13.3^{c}	35.1^{abc}	0.000
Density	115^{b}	169^{ab}	105^{b}	76^{b}	115^{b}	258^{a}	0.001
Shannon diversity	1.854^{a}	1.572^{ab}	1.881^{a}	1.866^{a}	1.535^{ab}	1.318^{b}	0.009
Shannon evenness	0.720^{ab}	0.675^{ab}	0.695^{ab}	0.759^{a}	0.680^{ab}	0.565^{b}	0.042

Means in a row followed by different letters are significantly different at $P<0.05$ (one-way ANOVA followed by a Tukey test).

DISCUSSION

Socio-economic household and farm data

The mean farm size in Machakos is relatively higher as compared to Central Kenya with a mean farm size of 0.6 ha [27] but lower than in Mabira forest reserve area in Uganda with a mean farm size of 2 ha [2].

Species accumulation curves for indigenous and exotic trees

The total richness of indigenous species was markedly higher than that of exotic species. This compares with work done under coffee agroforestry systems in Central Kenya where indigenous richness was more than exotic richness [27]. Tree species richness is highest in the Upper Midlands and lowest in the Lower Highlands for both indigenous and exotic richness; however, for the exotic richness, the difference is not significant for Upper Midlands and Lower highlands (Figure 3). This is contrary to work done in Mt. Kenya region where indigenous richness was highest in Lower Midlands and lowest in Upper Highlands while exotic richness was highest in Lower Highlands and lowest in Lower Midlands [12]. This could have been due to small farm sizes of the farms in the Upper Midlands as compared to Lower Highlands and Lower Midlands since increase in farm size gave the farmer more flexibility to plant different species and had a fallow land with more indigenous species.

Species frequencies and Importance Value Index (IVI)

There are clear similarities of this study with work done in Mt. Kenya region where *Grevillea robusta, Mangifera indica, Persea americana* ranked among the most frequent exotic tree species. Only *Croton megalocarpus* was among the most frequent indigenous tree species in Mt. Kenya as well as this study though their uses were quite different [12]. Tree species such as *Mangifera indica* and *Grevillea robusta* were found in 71 farms out of 90, and this was an indication of their preference by farmers due to the trees income and ease of management attributed to farmers' knowledge learned from their neighbours over time. *Acacia seyal* topped the list of the most abundant tree species because it was highly favoured by farmers in the Upper midlands since it regenerated naturally, fast growing and good source of fuelwood and charcoal thus farmers prefer it on their farms [22,28].

Eucalyptus saligna and *Eucalyptus camaldulensis* were also preferred because of their fast growth, available market for timber, poles and fuelwood from branches thus farmers grew them for income generation. On the other hand, *Grevillea robusta* was preferred due to its multiple products such as timber, fuelwood and shelterbelt for coffee plantations. *Grevillea robusta* was a popular agroforestry tree that has minimal effect to crops if well managed under tree-crop agroforestry systems. This compared with studies done in Central Kenya where tree preference was influenced by demand for its products, proximity to markets and ease of [22,28].

Importance value index (IVI), provides knowledge on importance of a plant community. The IVI which was relatively high for *Grevillea robusta*, *Acacia seyal* and *Eucalyptus spp.* showed that these tree species had wide usage and benefits to the farmers and could be attributed to their abundance, frequency and high rate of growth across a wide range of climate zones [29]. Studies in Machakos revealed 19 tree species with an IVI>1, which closely compares with 18 tree species in Central Kenya [27]. Among some of the common species with high IVI in both Central Kenya and also in Machakos included; *Grevillea robusta, Persea americana, Mangifera indica, Eucalyptus spp, Markhamia lutea, Croton megalocarpus* and *Cupressus lucitanica* [27].

Where differences were noted was due to variations in altitude zones where trees with high IVI in this study such as *Acacia seyal*, *Terminalia brownii* and *Acacia nilotica* were only growing in Lower Midlands and some in Upper Midlands lacking in the study area of Central Kenya. *Mangifera indica* is an important fruit tree that is easy to improve through grafting, as was the case in many of the farms in Machakos where 84% were grafted mango varieties, thus return on investment could be realized as from the third year [29]. Marketability of the highly ranked trees is also a factor that contributes to their high rate of planting and conservation [28].

Factors influencing species richness and diversity

Machakos study showed that altitude had strong negative influence on tree species richness as well as Shannon diversity index compared to Southern Ethiopia where, tree abundance and density increased with altitude and tree species richness and abundance also increased significantly with increased farm size [30]. Species richness, indigenous richness and Shannon diversity was positively influenced by distance of farms far away from markets which was not the case in Southern Ethiopia where distance to markets had no influence on richness [30]. Access to markets or roads in Machakos may have contributed to depletion of tree species thus, farmers replaced indigenous tree species with fast growing exotic tree species that had high demand and marketable and a similar trend was observed in a study done in the Mt. Kenya region where there were more exotic individuals than indigenous individuals [12].

Socio-economic factors such as farm size had a positive influence on tree species richness and abundance and negative influence on evenness which compares with studies in Niamey, Niger and in Southern Ethiopia where garden size had strong positive influence on richness and Shannon [9,30]. Female-headed households had a higher total richness and indigenous tree species richness on their farms though the influence was weak, which is the opposite of studies done in Niamey, Niger where gender of the gardener only influenced evenness negatively [9]. This could be explained by variation of gender roles where female farmers have more influence on planting, tending and caring for trees in Machakos though limited. Area covered by woodlots in studies in Southern Ethiopia were considered in the overall model and had weak positive influence on tree abundance and density; then a strong negative influence on Shannon index and Evenness [30]. The models in the present study could have been different from the studies in Southern Ethiopia due to differences in altitude, farming practices and rainfall regimes.

Classification of farms according to their species composition

Farm size was a major factor in classification of farms in this study which also a factor in Central Kenya [27]. In another study in Niamey, Niger, garden size, species richness, number of individuals, species density and Shannon index had significant differences across all the clusters [9] and these contributed to the shared factors in this study. Most of these factors mentioned in the studies in Central Kenya such as farm size, percentage of individual species, percentage of indigenous individuals, density, density of indigenous individuals and Shannon index had significant differences across the clusters [27] and evidenced in this study. In the peri-urban gardens of Niamey, Niger, five clusters were detected where cluster separation was influenced by twelve (12) species and classification was based on species abundances, but large differences among clusters were also detected with respect to garden size, species richness and diversity and socioeconomic parameters such as ethnic affiliation, gender of gardener or level of market orientation [9].

CONCLUSION

The presence of indigenous trees on farms shows that farmers value them, but the number of individual indigenous trees is low as compared to exotics. This affirms that socio-economic and biophysical factors that influenced tree diversity were; farm size, altitude and distance to markets which had greater influence to tree diversity should be considered carefully before starting any on-farm tree planting campaigns.

Cluster analysis helped grouping together farms with similar characteristics such as farm size, species composition, elevation and diversity for ease of interventions in tree planting in Machakos will need a cluster approach. In addition, farmers consider profitability potential of tree species affects their choice and preference of the same. The amount of money a farmer could save by having trees on his farm played a key role total abundance of trees and this was also influenced by farm size, distance of farm from tree nursery and education level of the household head.

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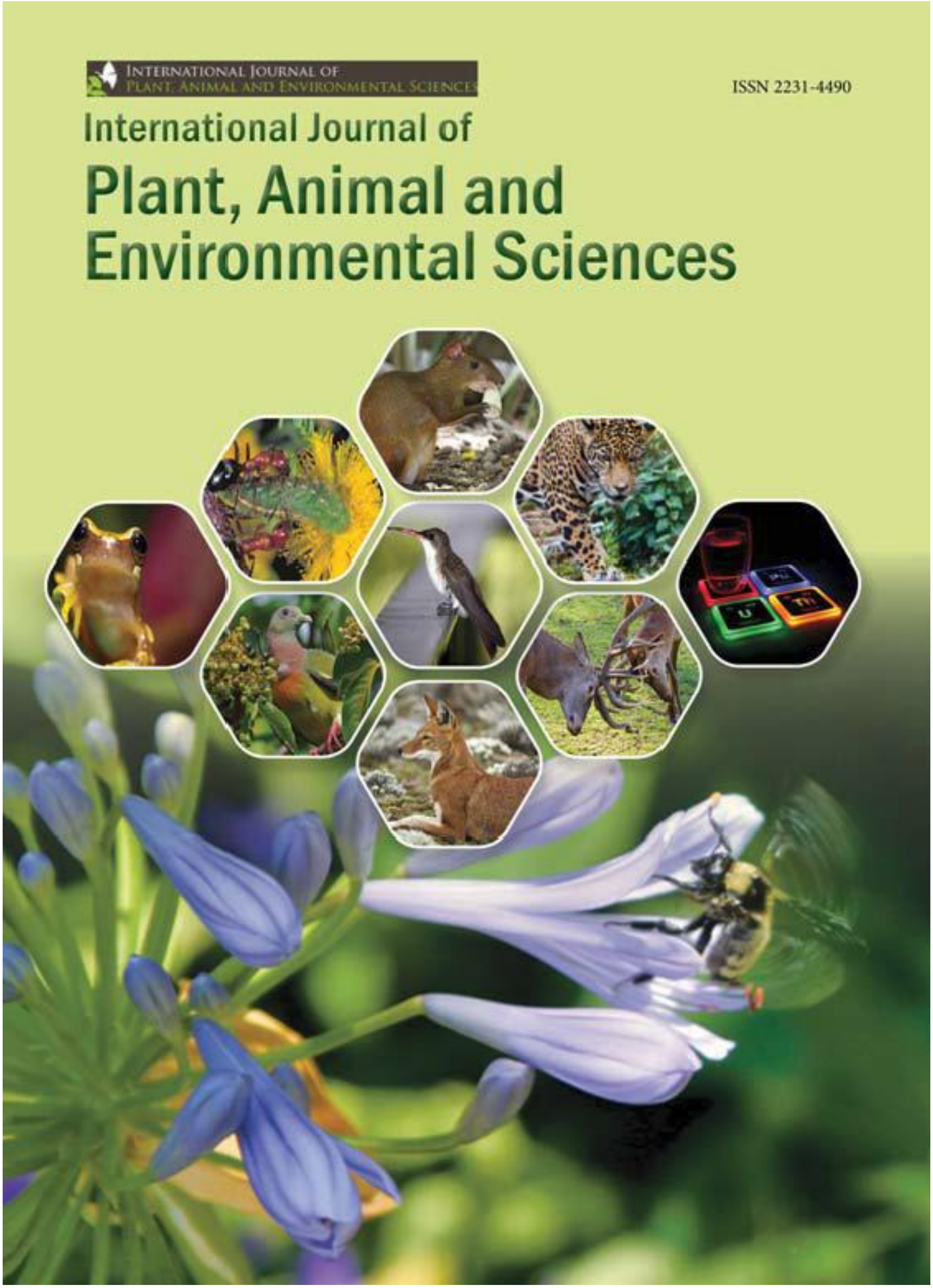
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