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Full Length Research Paper

Applying an indirect method for estimating and modelling the aboveground biomass and carbon for wood energy in the arid ecosystems of Aïr Tenéré of Niger

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Maintaining the economic, ecological and social services provided by the oases and the valley ecosystems of Aïr, in the northern part of Niger, is important for local communities. The purpose of this study is to evaluate the supply and regulation services provided by these ecosystems through wood energy and carbon sequestration. Semi-structured surveys and dendrometric parameter measurements of woody species were carried out. In total, 9 villages were surveyed, and 558 trees of all woody species were inventoried in 65 plots. Most of the resources are distributed in lowlands and valleys along the toposequence. These topographical units are favourable for the accumulation of rainwater and also serve as resources for the wellbeing of the local population, especially their wood energy needs. Businesses have developed around the production and sale of charcoal. The carbon stock of the woody species was found significantly varied ($P \leq 0.05$) between the different topographical units. Four allometric models of carbon estimation were developed, of which the model with diameter at breast height (DBH), height and wood density as the predictor variables was the most efficient. This study can be used for the formulation of policies and strategies for the sustainable management of Aïr Massif's natural resources to benefit the welfare of local communities.

Key words: Ecosystem services, wood density, allometric models, Aïr massif, Niger.

INTRODUCTION

Niger is subdivided into 3 major ecological zones: The Sudanian, Sahelian and Saharian zones (Saadou, 1990), and the Aïr Massif belongs to the Saharian zone. The aïr massif includes the entire mountainous region and the hydrographic network that is created by and linked to the great Ténéré desert (Bruneau and Gillet, 1956), within which there is also a succession of upland and plain chains. This large structure stands on a Precambrian

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crystalline base. The ecosystems are located in valleys and inter-mountainous upland areas. Located between 600 and 1000 m; these geomorphologic units shelter relatively abundant vegetation because of the favourable water table generated by the flows coming from the mountains. These ecosystems are home to a wide range of Saharan plant species mixed with species from the Sudano-Sahelian and Mediterranean zones (Bruneau and Gillet, 1956; Sâadou, 1990; Anthelme et al., 2008). Surrounding these ecosystems are important socioeconomic activities, such as livestock and oases, for agriculture. Indeed, studies have illustrated the vital importance of these ecosystems for local communities through their annual agricultural production, which includes a high diversity of crops that supply the other communities around the southern band of the country (Anthelme et al., 2006). Other studies have highlighted the important contributions of these ecosystems in pastoral and fodder terms (Chaibou et al., 2011, 2012). Most recently, with the Aïr Ténéré natural resources co-management project (COGERAT, 2009) studies have been carried out to assess the ecosystem services provided by these ecosystems, as well as their current trends and strategies for their conservation and restoration. Similar studies were carried out on the wood energy sector and wood services (COGERAT, 2008). This study clearly approaches the sector in comparison with other areas of Niger. However, with trend towards the proliferation of invasive plants in some parts of the massif (COGERAT, 2006) and the increasing needs of the populations, the wood sector received attention from various stakeholders. Among the various studies conducted, almost none have performed forest carbon estimation. However, since the Kyoto Protocol (2005), followed by the Paris Convention (2015), forest carbon estimations have attracted considerable ecological and political interest. Aboveground biomass is a parameter that indicates the functional and structural attributes of a forest ecosystem (Chave et al., 2005). In the Sahel, the aboveground biomass of a forest is used to express its economic, agronomic, forage and biological productivity (Breman and Kessler, 1997). Estimations of aboveground biomass are also essential for the quantification of atmospheric carbon sequestered by forest vegetation through the photosynthetic cycle (Brown, 1997; Chave et al., 2005). Due to a lack of field data, especially on land use, land use changes and forestry sectors, default data have been regularly used according to the National Council for the Environment for Sustainable Development in 2014. There is little information on allometric models for estimating biomass concerns in the Sahelo-Sudanian zones of the country (Moussa, 2016; Weber et al., 2018; Moussa and Larwanou, 2018). In addition, none of the pantropic or generic models address the Saharan zone of Niger (Brown, 1997; Chave et al., 2005; Henry et al., 2011; Chave et al., 2014). Therefore, building allometric models specific to the Saharan zone of Niger is important for improving the evaluation accuracy of the biomass and sequestered carbon in the area. The overall objectives of this study are to provide reliable data and a relevant analysis that can contribute to the development of sustainable management strategies for the ecosystems of the Aïr massif. Specifically, this study's objectives are (i) to analyse the needs and the supply chain of wood energy of the massif; (ii) to assess the biomass and carbon sequestration potential of the ecosystems; and (iii) to develop reliable allometric models for estimating the biomass and carbon of the major woody species in the massif.

METHODOLOGICAL APPROACHES

Study zone

The Aïr massif is an area of high aridity characterized by very low and uncertain precipitation, high average temperatures and low atmospheric humidity (Anthelme et al., 2007). Data from the meteorological station of Agadez airport were used to characterise certain climatic parameters, particularly rainfall and temperature. The average annual rainfall is 183.02 ± 26.43 mm, the minimum annual mean temperature is 22.30 ± 0.24°C and the maximum is 37.50 ± 0.30°C. A month is considered wet if its average rainfall is less than or equal to 2 times its average temperature. Figure 1 shows that in Agadez, two months are considered wet: July and August.

The soils of the zone are regosols and lithosols that occur along the ara's rivers (Giazzi, 1996 cited by Anthelme et al., 2006). The soils are mostly sandy in the plains and shallows and rocky on the plateaus and mountains. The valleys are mostly agricultural soils of loamy, loamy-clayey or clay compositions. Water erosion caused by runoff is a major environmental challenge, as it deposits large amounts of sediment in untreated koris, plains and valleys.

Site sample

An interview was carried out with the administrative and customary authorities and the technical agents at the regional, departmental and communal levels for site selection. This interview made it possible to determine a reasonable number of villages where data collection activities would take place. Since the reliability of the results depends on the established sampling techniques (Gerville-Réache and Couallier, 2011), the choice of villages was based on criteria such as the availability of natural resources and populations and, especially, the development of activities such as forestry and domestic charcoal production. Table 1 presents the list of villages visited during this study.

Surveys

The surveys were carried out between July and August, 2018. This study adopted a focus group using a questionnaire developed for the assessment of domestic energy needs. For this purpose, a sample of 8 to 12 representative participants from each village was used. The participation criteria were gender (female and male), age (young, adult and old people), socio-professional activities (farmers, pastoralist, blacksmiths, craftsmen, loggers) and other resource persons in the village. The surveys focused on the potentialities of villages in terms of their natural resources, such as forest

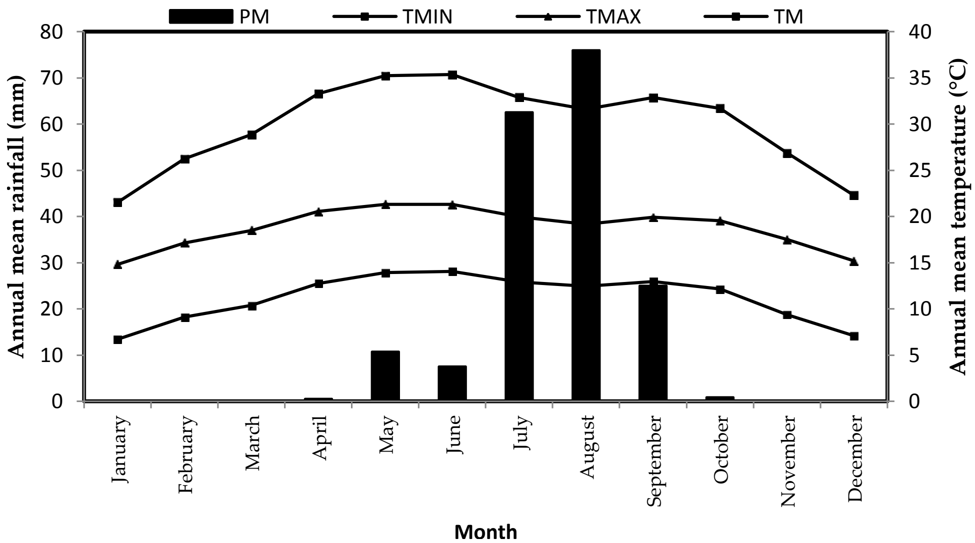

Figure 1. Ombrothermal diagram of the Agadez airport station. PM: Annual average rainfall; TMIN: Minimum annual average temperature; TMAX: Maximum annual average temperature; TM: Annual average temperature.

Table 1. Location of sites.

Site	District	Latitude	Longitude	Altitude (m)
Tassalam Salam	Dabaga	N 17°15'45.6''	E008°06'12.3''	622
Takaya	Dabaga	N17°18'26''	E008°10'24''	653
Dabaga	Dabaga			
Telwas	Tabelot	N17°39'11.8''	E008°53'47''	895
Nabaraw	Tabelot	N17°36'32.6''	E008°52'07.8''	894
Tabelot	Tabelot			
Nabalawe	Timia	N18°14'58.3''	E008°57'01.6'	975
Tefararawe	Timia	N18°00'38.9''	E008°29'45.7''	758
Timia	Timia	N18°06'50.8''	E008°46'50''	1091

resources; the different socio-economic activities related to the exploitation of these ecosystems through the practice of charcoal production; the woody species used; and the stand trends.

Woody species inventory

To evaluate forest biomass and carbon, an inventory was conducted in five different sites, namely, Tassalam Salam, Takaya, Nabaraw, Nabalawe and Tefaraou (Table 1). Satellite images from 2017 were used to guide the inventory towards the different physiographic units along the vegetation toposequence. The woody species are mainly distributed on the plateaus or uplands around water points, dry valleys, plains and agrosystems of the lowlands. In each physiographic unit, square plots of 30 m x 30 m were delineated with an equidistance of 100 m between plots to evaluate the heterogeneity of the environment (Larwanou and Saadou, 2011; Thiombiano et al., 2015). The homogeneous size of the plots also made it possible to compare different landscape units (Larwanou and Saadou, 2011). A total of 65 plots were installed as indicated in Table 2.

Within each plot, a systematic count of all woody species was carried out. For each adult tree, that is, a diameter greater or equal to 2 cm, the following measurements were made: The circumference at 1.30 m from the ground for trees and 0.20 m from the ground for shrubs, the total height, the height of the trunk and two perpendicular crown diameters (d1 and d2).

Table 2. Distribution of the inventory plots per landscape unit.

Physiographic unit	Plot
Lowland	19
Plain	22
Plateau	9
Valley	30
Total	**65**

Data analysis

Survey data were processed using IBM (International Business

Machines Corporation) SPSS 22 (Statistical Package for the Social Sciences) software to perform descriptive statistics (population citation frequency, averages, and standard deviation). Similarly, mapping of the production and supply chain of wood charcoal was carried out.

Determination of wood biomass

Determination of wood volume

Inventory data were processed and analysed using the Excel and Minitib 14 software. The following parameters were determined:
For multi-stem species, the mean root mean square diameter was calculated using the following formula (Thiombiano et al., 2015):

$$DBH = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(DBH)^2} \quad (1)$$

where DBH is the diameter at breast height and n is the number of stems.

Before determining the total volume of the tree and the volumes of the trunk, the crown was determined separately. The dendrometric parameters of each tree were used to calculate the volume of wood using the following formulas (Rondeux, 1999):

For the trunk, it was assimilated to the volume of the cylinder:

$$V_{trunk}\,(m^3) = \frac{\pi}{4} \times DBH^2 \times H_{trunk} \quad (2)$$

For the crown, the exact calculation of its external surface and its volume is, in principle, impossible (Assmann, 1970). Under these conditions, an approximation must be made by taking advantage of directly feasible measures, such as the height and diameter of the crown, to estimate the volume of the cone (Rondeux, 1999). Thus, the volume of the crown was calculated based on the following formula:

$$V_{crown} = \frac{1}{3} x \frac{\pi}{4} x Dm^2 x H_{crown} \quad (3)$$

This formula underestimates the real volume; however, if the crown was assimilated as a half-sphere, the real volume would be overestimated (Rondeux, 1999).

The total volume of the tree was calculated as follows:

$$V_{total} = V_{trunk} + V_{crown} \quad (4)$$

where, V is in m^3, DBH is in cm converted into m, H_{trunk} and H_{crown} are in m and Dm, respectively; the mean diameter, in m, was obtained using the average of two crossed diameters of the crown d1 and d2.

Determination of aboveground biomass

The total volume of each tree was used to calculate its dry aerial biomass (GBS in kg) and the biomass of the whole stand using the following formula:

$$AGB = \rho \times V_{total} \quad (5)$$

With ρ= density of wood by species.

Wood density was determined using an approach similar to that used by Peltier et al. (2007), Henry et al. (2010) and Moussa and Larwanou (2018). This approach involves taking samples of wood from each species and determining its volume by means of a graduated test tube (500 ml) in the laboratory. The following formula was used:

$$\rho = \frac{Drymassofwood\ sample}{Fresh\ volumeofwood} \quad (6)$$

where, ρ is in g/cm^3, mass is in g and volume is in cm^3.

Carbon determination

The total aboveground carbon per physiographic unit was calculated based on the following:

$$AGC = AGB \times 0.5 \quad (7)$$

With 0.5 as the default carbon factor as recommended by UNFCCC (2006); AGC is the above-ground carbon, and AGB is aboveground biomass.

Modelling the estimation of aboveground carbon

The modelling was performed using allometry. Tree allometry is defined by different measures and their relationships to the mass or volume (Lehtonen, 2005). Three types of aboveground biomass or carbon estimation models were tested based on one predictor (DBH or Total Height), two predictors (DBH and H) and three predictors (DBH, H and density). The methodological approach was based on the following sequence of steps: (i) a logarithmic transformation of the data to reduce error variances (Xiao et al., 2011; Mascaro et al., 2014); (ii) elimination of data with residuals that deviate from the global observation to further reduce error variances (Zuur et al., 2010); and (iii) testing of the following models:

i. $\ln AGC = \beta_0 + \beta_1 \ln(DBH) + \varepsilon_i\varepsilon_i \sim N(0, \sigma^2)$ (8)

II. $\ln AGC = \beta_0 + \beta_1 \ln(H) + \varepsilon_i\varepsilon_i \sim N(0, \sigma^2)$ (9)

III. $\ln AGC = \beta_0 + \beta_1 \ln(DBH) + \beta_2 \ln(H) + \varepsilon_i\varepsilon_i \sim N(0, \sigma^2)$ (10)

IV. $\ln AGC = \beta_0 + \beta_1 \ln(DBH) + \beta_2 \ln(H) + \beta_3 \ln(\rho) + \varepsilon_i\varepsilon_i \sim N(0, \sigma^2)$ (11)

where, ln is the logarithm; AGC is the aboveground carbon; β_0 ... β_3 are the coefficients of independent variables, such as DBH, H, Dc and ρ, ε_i is the error; N is the normal law with σ^2 as the deviation; and $\varepsilon_i\varepsilon_i$~ errors follow a normal distribution.

Error analysis

Error analysis was performed based on the overall significance of the equations (P-value < 0.05) and its coefficients (P < 0.05) as well as the coefficient of determination (R^2) (Sileshi, 2014). However, correlation coefficients were not enough to judge the performance of the model. For this purpose, an analysis of the percentage of root means square of error (RMSE) was made using the following formula (Yao et al., 2013):

$$RMSE = \sqrt{\frac{1}{n} \times \sum_{i=1}^{n}(Co - Cp)^2} \times 100 \quad (12)$$

This approach is widely used to assess errors related to the prediction of a biomass estimation model (Fayolle et al., 2013; Moussa and Larwanou, 2018). To avoid errors related to the back transformation, the correction factor was calculated for each model using the following formula (Chave et al., 2005; Mascaro et al., 2014):

$$CF = \exp(\frac{MSE}{2}) \quad (13)$$

Where, MSE is the mean square of errors of the model.

For models with two or more predictors, the effect of the variable multi-collinearity was analysed using the value taken by the variance of inflation factor (VIF) (Graham, 2003).

Validation of the models

The performance of each model was first assessed by checking the homogeneity and normality of the standardized residuals (Zuur et al., 2010). Second, the model was accepted when the significance of the coefficients and the regression was justified and the errors were small (Sileshi, 2014; Moussa and Larwanou, 2018).

Finally, ANOVA associated with the GLM (Generalized Linear Model) and the Tukey method was applied at the 5% significance level to compare the sequestered carbon averages per physiographic unit and the wood density per woody species.

RESULTS

Household energy sources

Figure 2 shows the organization of the domestic energy supply chain of the survey area, which is mainly based on domestic gas (70%), and firewood and/or charcoal (30%). The gas supply is mostly provided by organized entities, including state services, NGOs and, to some extent, private individuals. In the mountains, gas is most often acquired from the neighbouring countries Algeria and Libya. The energy type consumed by households is mainly firewood as well as some crop residues, represented by date and doum palms leaves or citrus twigs. Wood is most often from forest formations in plateaus or dry valleys and, sometimes, in lowlands. The main actors involved in the supply of wood energy are woodcutters (100%) according to the villages. To supply the villages with firewood, animals such as donkeys and camels are used. Similarly, wood intended for urban centres as well as charcoal is transported by trucks, small transit vehicles or motorcycles. Wood charcoal production is currently booming in the Air massif. 33.33% of the villages surveyed expressed this activity. Increasingly, private producers have settled in villages around wooded areas by planting *P. juliflora* according to 100% of the village citations and are hiring labour at a low price. However, certain species, such as *Acacia raddiana* and *Acacia ehrenbergiana*, are also used. In one of the Tefarawe sites visited, a charcoal producer can produce 250 to 400 bags of charcoal before transporting them to the markets of the nearest big cities, such as the mining towns of Arlit or Agadez, or to local markets. On average, a bag is sold to wholesalers at 4000 FCFA or 7.14 US dollars. This wood energy is most often consumed for household cooking or for the preparation of tea, which is an important cultural item for the massif community.

Assessment and modelling of the biomass and carbon stock

Assessment of the carbon stock of aboveground biomass

Dendrometric parameters measured: The dendrometric parameters of the measured trees were the diameter at breast height (DBH), total height, and average crown diameter (Dm). The mean DBH was equal to 15.96 cm, with minimum and maximum values of 2.87 and 69.75 cm, respectively. For the total height, the average was 4.47 m, with minimum and maximum values of 0.8 and 16 m, respectively. The Dm average was 0 3.30 m, with a minimum value of 0 m and a maximum of 21.25 m, and the calculated average biomass per tree was 50.64 kg, with a minimum value of 0.02 kg and a maximum of 2131.22 kg (Table 3).

Wood density: The wood densities of the eight main species were determined. These are *B. aegyptiaca* (0.66 ± 0.03 g/cm^3), *M. crassifolia* (0.68 ± 0.01 g/cm^3), *A. raddiana* (0.74 ± 0.03 g/cm^3), *A. erhenbergiana* (0.72 ± 0.03 g/cm^3), *B. senegalensis* (0.84 ± 0.06 g/cm^3), *A. nilotica* (0.77 ± 0.02 g/cm^3), *P. juliflora* (0.65 ± 0.04 g/cm^3) and *S. persica* (0.60 ± 0.01 g/cm^3). ANOVA shows a globally significant difference between the wood densities of these eight species (F = 5.74/ P = 0.001).

Carbon stock: The amount of sequestered carbon for aboveground biomass accounts for the eight most important species in the area. The amount of sequestered carbon is significantly different (F = 3.06 / P = 0.036) among the physiographic units. The amount of carbon is highest in the lowlands (2880 ± 181 kg/ha), followed by plateaus (1694 ± 556 kg/ha), valleys (1328 ± 265 kg/ha) and lowlands (1294 ± 441 kg/ha) (Figure 3). A higher variability was observed in the plateau plots with a standard error of 556 kg/ha.

Modelling carbon sequestration

Models of carbon estimation

The selection and validation parameters of the developed models were the correlation coefficient (R^2), the error (RMSE), the multi-collinearity (VIF) and the probability (P-value). The statistical parameters of the selected and validated models are presented in Table 4. For each of the four models, the error percentage shows a relatively low range from 1.7 to 3.58%. For models with more than two predictors, VIF also has a low range from 1.2 to 2.8. A strong correlation between the model variables was

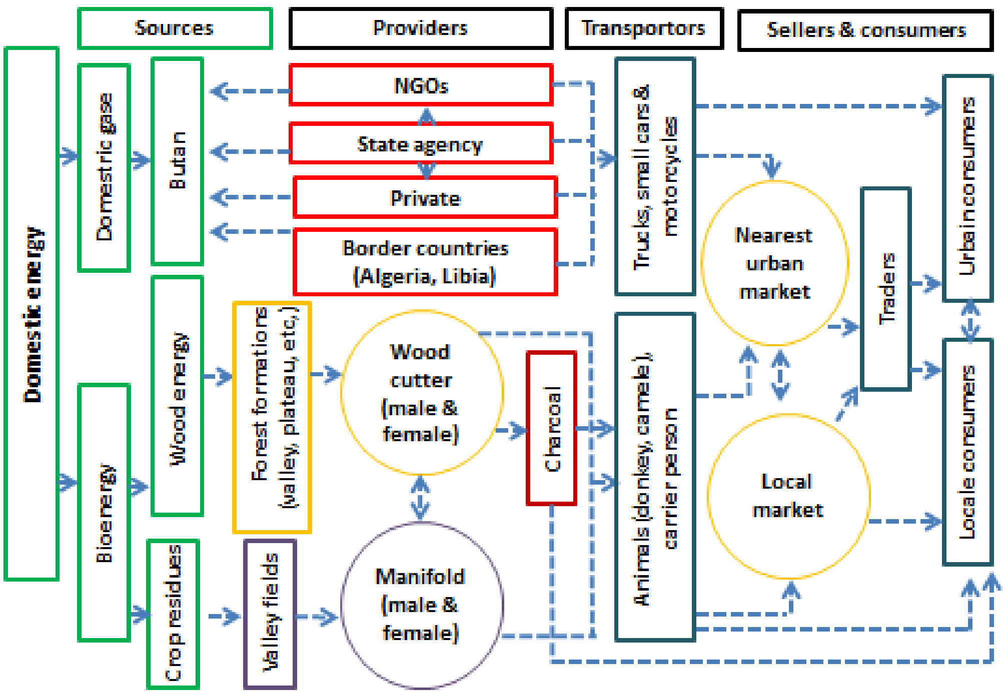

Figure 2. Mapping of the domestic energy supply pathway of the study area.

Table 3. Statistical parameters of individuals used in model development.

Species	N	DBH (cm)			Height (m)			Dm (m)			Biomass (kg)		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Acacia ehrenbergiana	132	3.18	12.7	69.75	1.1	3.54	16	0	3.58	7.50	0.02	14.8	276.28
Acacia nilotica	8	27.39	49.72	63.69	6.5	11.75	16	0	9.98	21.25	23.26	370.1	679.62
Acacia raddiana	168	2.87	22.4	63.69	0.8	5.4	14.5	0	6.68	16.00	0.02	98.26	2131.22
Balanites aegyptiaca	26	4.14	20.2	41.4	1.4	5.4	8	0	5.79	10.75	1.86	60.56	221.56
Boscia senegalensis	24	5.41	14.06	23.89	1.3	3.33	4.5	0	3.03	6.25	3.48	22.2	81.88
Maerua crassifolia	17	4.78	22.56	36.94	1.4	4.9	8	0	3.75	5.75	2.66	48.66	112.26
Prosopis juliflora	153	2.87	7.54	36.31	1.5	3.7	8.5	0	1.37	13.00	0.02	13.4	121.78
Salvadora persica	22	6.05	17.88	25.96	2.3	4.37	7	1.85	3.74	7.00	0.74	16.34	49.86
Ziziphus spina-chisti	8	9.24	34.43	57.01	3	7.69	10	1.50	4.47	6.25	4.88	186.92	368.56
Total	**558**	**2.87**	**15.96**	**69.75**	**0.8**	**4.47**	**16**	**0**	**3.30**	**21.25**	**0.02**	**50.64**	**2131.22**

N: number, Min: minimum, Max: maximum.

observed. This correlation varies from 0.75 to 0.95 depending on the model (Table 4); the correction factor is always close to 1 and is the highest in model I and lowest in IV.

Goodness of models

The performance rates of these four models were assessed and confirmed using normality testing and error variance homogeneity. Figure 4 shows a normal distribution of residuals along the diagonal. Homogeneity of standardized residuals is also observed in each of the four models (Figure 5).

DISCUSSION

Strengths and weaknesses of the methodological approach

Evaluation and mapping of the wood energy needs in the

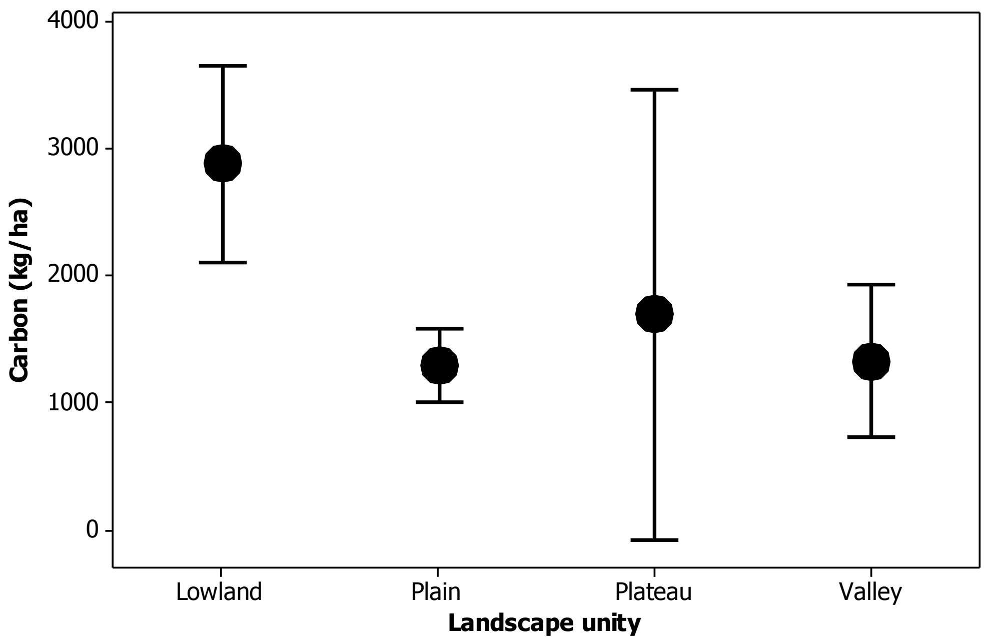

Figure 3. Sequestered carbon distribution per unit of vegetation occupancy.

Table 4. Statistical parameters and carbon estimation models of above-ground biomass for eight dominant woody species.

S/N	N	Model	R^2	RMSE (%)	VIF	CF	P-value
		One predictor					
I	504	ABC = 1.12 x exp (-3.35 + 2.10 x lnDBH)	0.91	2.18	-	1.12	0.0000
II	510	ABC = 1.37 x exp (-1.91 + 2.78 x lnH)	0.75	3.58	-	1.37	0.0000
		Two predictors					
III	510	ABC = 1.09 x exp (-3.44 +1.56 x lnDBH + 1.09xlnH)	0.93	1.86	2.3	1.09	0.0000
		Three predictors					
IV	498	ABC = 1.07 x exp (-4.23 + 1.63 x lnDBH + 1.05 x lnH - 1.89 x lnρ)	0.95	1.70	1.2 - 2.8	1.07	0.0000

R^2: Correlation coefficient; N: Number of tree samples; VIF: Variances inflation factor; RMSE: Root mean square error; CF: Correction factor.

study area were performed by using semi-structured focus group surveys. This method is widely used by researchers, especially in the social sciences, because of its cost effectiveness and its abilities to evaluate the global trends and obtain immediate answers to questions (Schmidt and Hollensen, 2006; Birch and Pétry, 2011). The purpose of the study is also one of the fundamental reasons for using this method (Baribeau, 2009; Birch and Pétry, 2011). However, there is little consensus among researchers as to the sample size that should be investigated and the approach to processing and analysing data collected in focus groups (Baribeau, 2009). Thus, the focus group provides qualitative data. As far as the context of this study is concerned, the study area is one of the most difficult places to access in Niger because the natural landscape has inaccessible roads. Moreover, the availability of the populations is very random in villages. Villagers are more concerned with field work or migrate, so maintaining a consistent population at any time was difficult during the study. This issue justified the use of our methodological approach. Additionally, in conducting similar studies in the same area, Anthelme et al. (2006) used the same methodological approach.

The study of biomass was based on the use of the indirect method that uses tree dendrometric parameters to determine the total volume and specific wood densities and thus deduce biomass. This method has the advantage of avoiding the destruction of trees in an arid environment and can also provide measurement data for many tree samples at a lower cost and over a short time to build high performance allometric models. Although no limit has been given for the construction of allometric models (Moussa et al., 2015), it is still important to have a

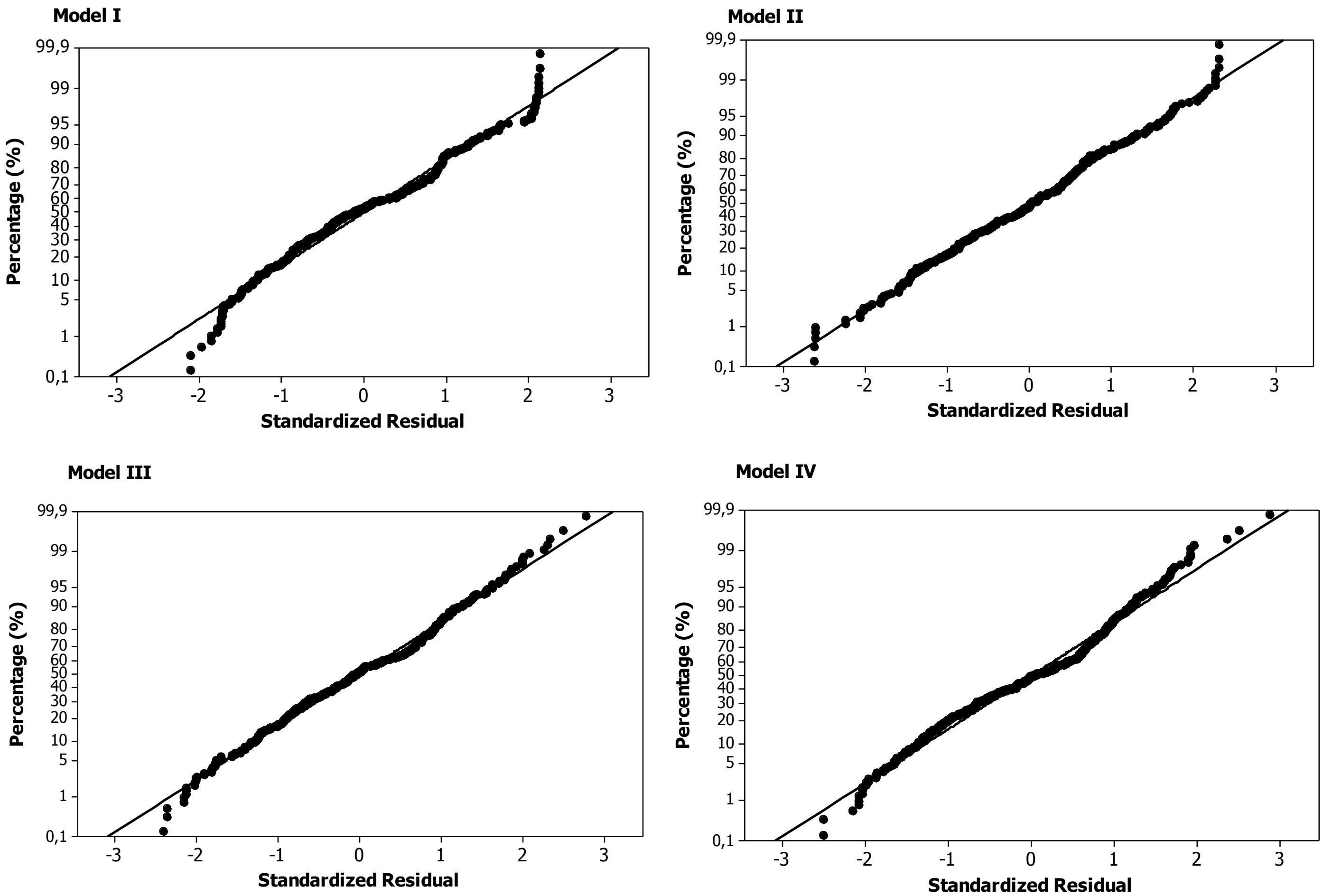

Figure 4. Normal distribution of standardized residues.

large sample size of trees with a range of dendrometric parameters to ensure the best representation of the stand (Brown, 1997; Chave et al., 2005; Chave et al., 2014). However, this method does not remain unbiased. If the volume of the crown is assimilated as a cone, the formula underestimates the actual situation, whereas if the crown is assimilated as a half-sphere, the real volume is overestimated (Rondeux, 1999). Therefore, the exact calculation of the surface and the volume of a tree's crown is, in principle, impossible (Assmann, 1970), which leads to the use of the directly feasible measures for estimating the crown height and diameter and by applying the previously mentioned geometric formulas similar to those used by Nouvellet et al. (2006).

Wood energy need

Although not well endowed with forest resources, the ecosystems of the massif offer important services in regard to wood energy for the local populations. These services mainly comprise firewood from species such as *P. juliflora* and *A. raddiana*. The first species was introduced as a part of the fight against desertification in Niger in the 1980s, and the second is a native species. The wood energy value chain is highly organized in the Aïr massif, with various actors ranging from collectors to consumers through transporters and traders. Because of the socially structured nature of the population, the actors are organized into well-defined social classes. Even though the resources are sparse in different physiographic units, they supply the major urban centres of Arlit, Agadez and Chirozerine. In Niger, firewood consumption at the national level per inhabitant in urban centres has been estimated at 1.15 m^3 / year. On this basis, the population of the region would need 651,414.05 m^3 of fire with a population of 566,447 inhabitants estimated in 2017 (COGERAT, 2008). However, the area has long been deficient in terms of the relationship between forest productivity and population consumption (COGERAT, 2009). For example, local communities are now using domestic gas to replace wood energy. However, the accessibility, availability and high price of gas limits its use in the area according to the

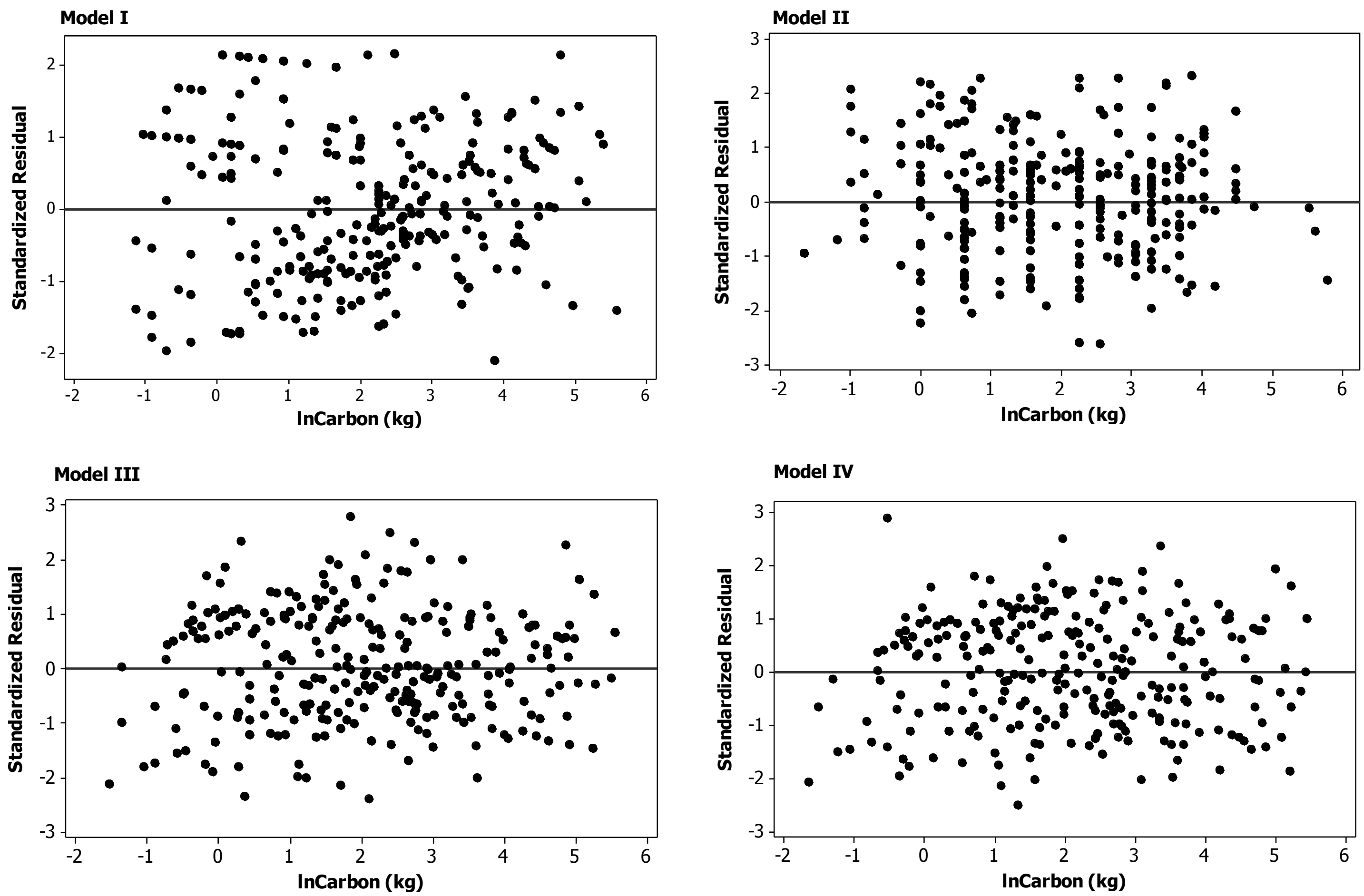

Figure 5. Homoscedasticity of the standardized residuals of the four models**.**

populations, and the use of woody biomass is still the primary energy source for poor citizens (Portner et al., 2009). Increasing trends in charcoal production due to the population are being felt not only because of economic profit but also the real needs of the market. This activity mostly occurs without control in many cases because woodcutters harvest protected species, which impacts the dynamics and, particular, the sustainability of the forest resources of the massif. Sustainability is the goal of any forest management operation. Above all, the quality of the ecosystem services provided at the ecological threshold must be reconciled (Blanco et al., 2018). The ecological threshold is defined as the moment when there is an abrupt change in the quality of an ecosystem, a property or a phenomenon, or in which small changes in an environmental factor produce important reactions in the ecosystem (Groffman et al., 2006). Safeguarding this threshold is extremely important for maintaining communities in the area by protecting the farmland around lowlands. Actions and especially interventions are needed in terms of recovering degraded lands followed by seeding or reforestation by maintaining natural regeneration. There has been substantial momentum in the Sahelo-Sudanian zone of Niger towards this aim with the active involvement of the populations (Larwamou et al., 2006), which has allowed a global return of vegetation cover (Hermann et al., 2005; Olsson et al., 2005; Brandt et al., 2018). Moreover, potentialities in terms of the valourization of crop residues exist in the areas where agriculture is highly developed by producing biogas or by setting up renewable energy production systems. This will reduce greenhouse gas emissions from forest ecosystem degradation in line with the spirits of the Kyoto Protocol and the Paris Agreement.

Carbon sequestration

The amount of biomass or sequestered carbon by woody stands is higher in the lowlands and valleys than on the plains and plateaus. This may be explained by the differential productive capacities of these landscape units where most of the vegetation is distributed. The rain water runs from the uplands through the valleys and plains to settle in the lowlands. Wherever moisture is present, vegetation occurs (Bruneau and Gillet, 1956; Sâadou, 1990). This functioning of the Sahelian ecosystems was explained by Maisharou et al. (2015) and Paxie and Larwanou (2017). Thus, the accumulation of woody biomass in these ecosystems is important because of its environmentally and socio-economically important roles in the protection of lowland agrosystems and the aboveground fodder it provides to animals, and particularly large ruminants (Chaibou et al., 2012). In the southern part of Niger, important data on the quantity of sequestered carbon in agroforestry parklands have shown that the quantity varies depending on the relative density of trees (Weber et al., 2018; Moussa and Larwanou, 2018).

Modelling

The allometric models developed in this study are the expression of carbon according to the dendrometric parameters of DBH, total height and wood density of the main inventoried species. Four models have been validated with a very precise performance. The models' errors were very low, between 1.70 and 3.58%. The assessment of the performance of the models based on this indicator does not cross any threshold in most cases (Sileshi, 2014). The assessment was made based on small errors. For VIF, this only applies to models with more than two predictors. There are also VIF values between 1.2 and 2.3. The VIF value reflects the instability or collinearity between model predictors (Zuur et al., 2010). The higher the VIF, the lower is the model efficiency. Studies have shown that inflation may occur with a VIF value greater than 5 (Sileshi, 2014), or 10 (Graham, 2003). Thus, models III and IV proved a low VIF, and hence were validated. At the current stage of biomass research in the Aïr massif, knowledge is very limited. The few equations available are those of Chaibou et al. (2012), which deal with the fodder biomass of *A. ehrenbergiana* and *M. crassifolia* with very little information on the criteria for their validation, in which an assessment was made on the correlation coefficient. The comparison of the models with those of Chaibou et al. (2012) will not be informative. When generic and pantropical models of biomass estimation (Brown, 1997; Chave et al., 2005; Henry et al., 2010; Chave et al., 2014) were taken, their use in the study area remains problematic. The same authors defined the geographical areas of their development, which are wet and dry forests and a part of the savannah. An allometric model can only be used in strict compliance with the conditions related to the geographical area and the range of dendrometric parameters that have governed its development (Rondeux, 1999). Moreover, these pantropical models are not superior to the models of this study in terms of errors. For example, Chave et al. (2005) show a variability of the error in Model II for wet and dry forests that reflects a biomass overestimation between 5.5 and 16.4%. To avoid the back transformation problem, the correction coefficient has been calculated. This coefficient is often close to 1 (Baskerville, 1972), as attested by the study's models. The most successful of the four models is IV because of its higher correlation coefficient, and its weaker RMSE and CF. The other models can be used as alternative models for the default of a given predictor.

Conclusion

This study highlighted the energy needs of the rural communities of the Aïr massif that are strongly dependent on natural resources, such as residues and woody species. The local communities depend on the light species of the landscape, specifically *A. raddiana* and *A. ehrenbergiana* and, especially, *P. juliflora*. In view of the difficulties of collecting wood, people are engaged in charcoal production, which is a practice that is increasingly becoming an income-generating activity. This activity is closely linked to the real wood energy needs of large urban centres, which are growing in proportion with the ever-increasing local demography. The charcoal economy also involves various actors and is a situation in which everyone benefits. This study also intended to evaluate the aboveground biomass and carbon stock of the woody species available in the massif. The carbon stock is more dependent on the toposequence of the massif, with rainwater runoff and valleys being more important than plateaus and plains. At the end of the study, it was possible to develop allometric models for estimating aboveground carbon, which is related to biomass. The models were developed based on an analysis of the correlation between the variables and prediction errors. Thus, model IV of the form $ABC = 1.07 \times \exp(-4.23 + 1.63 \times \ln DBH + 1.05 \times \ln H - 1.89 \times \ln \rho)$ was the most efficient. The results of this study can be used to formulate sustainable management policies in the massif, which is of paramount importance for its local communities.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Forest land use and native trees diversity conservation in Togolese mega hotspot, Upper Guinean, West Africa

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In tropics, species diversity in agricultural systems is often assessed without distinction between native and exotic species. However, the conservation value of an ecosystem depends on its richness in native species. This study was conducted to determine the conservation value of agricultural systems in Togo megahotspot, one of the species-rich sites in Upper Guinean. Specifically, the study compares fallow systems (FS), coffee systems (COFS), cocoa systems (COCS) to forest relics (FR) on the one hand, and on the other hand the agricultural systems (FS, COFS, COCS) between them base on natives tree species diversity and composition. Sites have been selected to represent different forest lands use types. Plots (n = 233) of different sizes (400, 500 and 625 m²) were used for data collection. In each plot, all living trees (DBH ≥ 10 cm) were counted. Rarefaction, generalized linear models (GLM) and ecological distance approach were used to standardized and compare the data. A total of 183 species were recorded, of which 42% were absent from the agricultural plots. Difference in diversity index were significant between the FR and agricultural systems ($p<0.001$), but not between agricultural systems ($p=0.23$). Guineo-Congolian climax and endemic species were seriously under threat. The study poses a real problem of regeneration dynamic of these species in human-dominated landscapes that requires further specific work.

Key words: Rainforests, agricultural practices, biodiversity conservation, Reducing Emissions from Deforestation and Forest Degradation (REDD+), Togo, Upper Guinean.

INTRODUCTION

Agroforestry is generally defined as association of trees with crops and livestock. There are several agroforestry practices; including shade trees with perennial crops such as coffee and cocoa. Several studies on tropical ecosystems have shown that agroforestry systems, especially traditional ones, play an important role as refuges of tropical biodiversity by providing habitat for many species of plants and animals in human-dominated landscapes (Cicuzza et al., 2011; Cassano et al., 2012; Maas et al., 2015; Gras et al., 2016). Thus, it is widely

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accepted that agroforestry is the only alternative to meet the ecological and economic challenges posed by slash-and-burn agriculture practices (Fischer and Vasseur, 2000). These ideas have contributed immensely to the growth of agroforestry projects across the tropics in the recent decades. Some of these studies have also highlighted the importance of these systems for carbon sequestration (Schroth and Harvey, 2007). Today, forest policies of many counties aim at increasing forest areas through the promotion of agroforestry systems for carbon and biodiversity. The conservation of this latest (biodiversity) is a critical component of the development and implementation of UN-led Reducing Emissions from Deforestation and Forest Degradation (REDD+) (Bustamante et al., 2016). However, in recent decades, there have been major changes in agroforestry practices in the coffee-cocoa sector around the world because of the declining productivity due to tree age, soil poverty and increased disease. In West Africa, facing declining productivity, traditional cocoa and coffee systems had been the subject of several managements by producers to make them more productive. These included the rehabilitation and replanting of fields, the use of Upper Amazon hybrid cocoa without shade, intensification by the planting of additional trees and fruit trees, and the conversion of secondary forest and fallow areas to agroforestry and monoculture plantations (Wessel and Quist-Wessel, 2015). These changes in agroforestry management practices and their potential impact on tropical biodiversity raise today the question of the conservation value of agroforestry systems that requires research, especially in Africa where the conservation value of agroforestry systems are poorly evaluated compared to Asia or Latine America (Fischer and Vasseur, 2000; Paruelo et al., 2001; Siebert, 2002; Rolim and Chiarello, 2004; Ashley et al., 2006; Harvey et al., 2007; Schroth and Harvey, 2007b; Philpott et al., 2008; Chazdon et al., 2009; Gardner et al., 2009; Wanger et al., 2009; Feeley and Silman, 2010; Hoehn et al., 2010; Williams Guillén and Perfecto, 2010; Cicuzza et al., 2011; Tscharntke et al., 2011; Cassano et al., 2012; Pelletier et al., 2012; Dawson et al., 2013; Bustamante et al., 2014; Maas et al., 2015; Sariyildiz et al., 2015; Sharma and Vetaas, 2015; Valencia et al., 2015; Barsoum et al., 2016; Gasperini et al., 2016; Gras et al., 2016; ; Farah et al., 2017; Almazán-Núñez et al., 2018; Benítez-Badillo et al., 2018; Jesse et al., 2018; Rodrãguez-Echeverry et al., 2018; Santos-Heredia et al., 2018). Few studies in Africa now compare agriculture systems to natural forests and each other to assess their conservation value based on forest species richness (Eilu et al., 2003; Augusseau et al., 2006; Bobo et al., 2006; Norris et al., 2010; Pinard et al., 2013). In Africa, several studies have been conducted on agroforestry systems for coffee and cocoa. However, these studies have rather addressed issues related to the decline in productivity and the socio-economic aspects of these systems (Wessel and Quist-Wessel, 2015). In addition, the few studies carried out on the conservation value of agroforestry systems in Africa have taken into account exotic species, that is, species richness and not forest species richness (Aerts et al., 2011). In Cameroon, for example, cocoa systems are rich with 206 species of trees while this richness included one third of exotic species with densities which double those of native species (Sonwa et al., 2007). The disadvantage is that, exotic species can greatly influence diversity index whose calculations are often based on abundance data, with as consequence the overestimation of the conservation value of these agroforestry systems. Otherwise, **human** land use causes major changes in species abundance and composition, yet native and exotic species can exhibit different responses to land use change. Native species populations generally decline in human-impacted habitats while exotic species often benefit (Jesse et al., 2018). Exotic species are often generalist species or species that adapt easily to human disturbance. It is often those taxa that are of the highest priority for conservation, such as regional forest endemics, that are the most extinction prone in modified tropical landscapes (Gardner et al., 2009). For these reasons, ecologists think that a better indicator of the conservation value of agroforest systems would be the forest species richness. Thus, to estimate accurately the value of modified landscapes for conserving regional forest biodiversity we need to know the proportion of species that inhabit human-modified systems that were also inhabitants of the original forest landscape (Gardner et al., 2009).

The Upper Guinean forests are among the 25 most important hotspots in the world (Poorter et al., 2004). They are estimated to contain 2,800 forests plant species among which 650 are endemics, and about 400 are considered rare. Within Upper Guinean, three areas of high diversity are distinguished and need protection and attention (Poorter et al., 2004). Togo megahotspot is one of the three areas of high diversity in Upper Guinean that owes its immense biodiversity to its past climate but also to the current ecological conditions of humidities and fogs which contributed to the installation of a great diversity of forest communities (Akpagana, 1989). These forests of the mountains of Togo have been assigned to agriculture, particularly for shifting, coffee and cocoa cultivation, which has led to repeated clearings. The conservation of biodiversity in this area largely depends of a deeper comprehension of the impact of forest land-use types on native species diversity. However, this information is absent today on this area. Togo Mountains vegetation was the subject of several works (Aké Assi, 1971; Brunel, 1977, 1978; Akpagana, 1989, 1992; Guelly, 1994; Adjossou, 2004, 2009; Kokou et al., 2008; Adjossou and Kokou, 2009;). Recent works have been focused on agroforestry systems in the area (Adden et al., 2016, 2018; Koda et al., 2016; Adden et al.). Nevertheless, there is an important lack of information on conservation value of forests land-use types of this area. The present study is significant in providing clear answers to questions regarding the biodiversity value of different forest land-use types in order to help policymakers and managers to conserve and manage the native trees species in most species-rich site of Togo. Togo has signed the World Bank forest carbon partnership. This study will guide the policies in the strategic choices and implementations of REDD + projects in order to conserve and manage the native tree species in Togolese meagahotspot. The aim of this study was to evaluate the conservation value of agricultural systems in the Togo Mgahotspot. Specifically, the study compares fallow systems (FS), coffee systems (COFS), cocoa systems (COCS) to forest relics (FR) on the one hand, and on the other hand the agricultural systems (FS, COFS, COCS) between them base on natives tree species diversity and composition.

METHODS

Study area

Forest growth conditions

The studied area (6°15’ N - 8°20’ N; 0°30’ E -1° E) covers 6,441 Km² in the southern part of the Atakora mountains, south-west of Togo, on the border between Togo and Ghana called Togo Mountains or Togo highlands or Ecological Zone IV (Figure 1). It is adjacent to Dahomey Gap, an extension of the woodland savannas of the Sahel to the Gulf of Guinea, which separates the Upper Guinea forests from the rest of the African rainforests (Poorter et al., 2004). The subhumid mountainous area of Togo owes its immense biodiversity not only to its past climate but also to the current ecological conditions of humidities and fogs which contributed to the installation of a great diversity of forest communities. The areas are mainly covered with deciduous forest (Akpagana, 1989) intersected with Guinean savannas (Guelly, 1994). Six types of upland semi-deciduous forest were distinguished: (1) Forest with Sterculiaceae and Sapotaceae; (2) Forest with dominant *Celtis mildbraedii*; (3) Forest with dominant *Terminalia superba*; (4) Forest with dominant *Ricinodendron heudelotii*; (5) Forest with Meliaceae and Moraceae; (6) Forests with *Parinari excelsa* (Akpagana, 1989). Adjossou et al (submitted) found that the forest vegetation of the site is rather a mixture of Guineo-Congolese forest types. The climate in this area is of Guinea Mountain type (Papadakis, 1966) characterized by a long rainy season (8-10 months). The mean annual temperatures range from 21 to 25°C and the total annual rainfall ranges from 1250 to 1900 mm.. Landforms are diverse and complex. The main geologic component is of the late Precambrian (Hall and Swaine, 1976). The main edaphic component consists of schist.

History of forest land-use

Three main forestry uses can be distinguished in the mountains of Togo, which are shifting, coffee and cocoa cultivation. Coffee and cocoa were introduced into the humid forest zone of Togo around 1945. The varieties introduced at the time were *Coffea canefera* (GNAWLUI) *Coffea robusta* (ROBOSCA) for coffee and *Theobroma* sp (TETEKOSSI) for cocoa. These traditional varieties were grown in rainforests understory and did not pose a real threat to plant biodiversity. From 1975, sun-loving hybrids (Agric varieties) were introduced into the forest zone. Until 1989, most of Togo's rainforests were converted into high-yielding coffee and cocoa fields through massive fertilizer use. Conversion was possible thanks to the introduction and use of chainsaws. Since 1990, producers could no longer buy fertilizer because of falling purchase prices following the fall in world prices causing a drastic drop in productivity. In response to the declining productivity of traditional coffee-cocoa systems in the 1990s, farmers have chosen the management method based on intensification by the planting of additional trees and fruit trees. Currently, the use of Upper Amazon hybrid cocoa without shade is emerging in the area. The conversions of secondary forest and fallow areas to agroforestry and monoculture plantations are also underway in Togo's forest zone. What remains of these forests today is very fragmented and primarily localized in the zones difficult to reach, and along the rivers. Because of a high demographic growth rate in Togo (3.3% annually), the forest remnants are also affected, contrary to those along the rivers which are still relatively saved by the local populations, partly for traditional reasons (Adjossou, 2009).

Sampling methods

The forest land-use types were identified and inventoried through reconnaissance survey in the field, involving local populations but also on the basis of available historical vegetation maps which distinguishes forest areas from savannas. This approach was used because of the unavailability of accurate geographic information on each forest land- use types in the study area. These reconnaissance survey and data collections were carried out between 2007 and 2012. Sites were selected to represent study land-use types. In each site, sampling points were selected systematically to represent the physiognomy of different land-use. Plots (n=223) of different sizes (400, 500 and 625 m²) corresponding to an area of 16 ha were used to study the native plant communities under different forest land use: FS (n= 41; 3.35 ha), COFS (n=43; 3.12 ha), COCS (n=72; 5.13 ha), FR (n=67, 4.41 ha). Plots 0.04 ha in area (20 m × 20 m) were used to study the native plant communities under forests relic land-use type. But, if the habitat of a plant community was long and narrow such as for ones located near a stream, 10 m × 50 m plots were used (Kokou, 1998; Natta, 2003). Under coffee and cocoa systems, plots 0.0625 ha in area (25 m × 25 m) were used. Under FS, plots 0.04 ha in area (20 m x 20 m) and 0.0625 ha (25 m × 25 m) were used. In these different plots, all living natives’ trees with a DBH ≥10 cm (diameter at 1.3 m height) were counted.

Data analysis

Species richness and diversity

To compare species richness and diversity between land-use types, species accumulation curves, gamma, alpha, beta, and Shannon diversity were used. According to Gotelli and Colwell (2001), if the sampling methods are not identical, different kinds of species may be over or under-represented in different samples. To solve the problem of inequality samples size in this study (400, 500 and 625 m ²), different data standardization techniques were used. Firstly, richness of different plot sizes were standardized to the same 400 m² plot following Vandermeer et al. (2000). Secondly, samples-based species accumulation curves were used to standardize and compare total species richness between the four forest land-use types based on a sampling area of 400 m². This rarefaction method is especially useful when comparing species richness between subsets of different sizes (Kindt and Coe, 2005) because it allows comparing the same number of plots for each subset. Species accumulation curves of each forest land use were calculated from

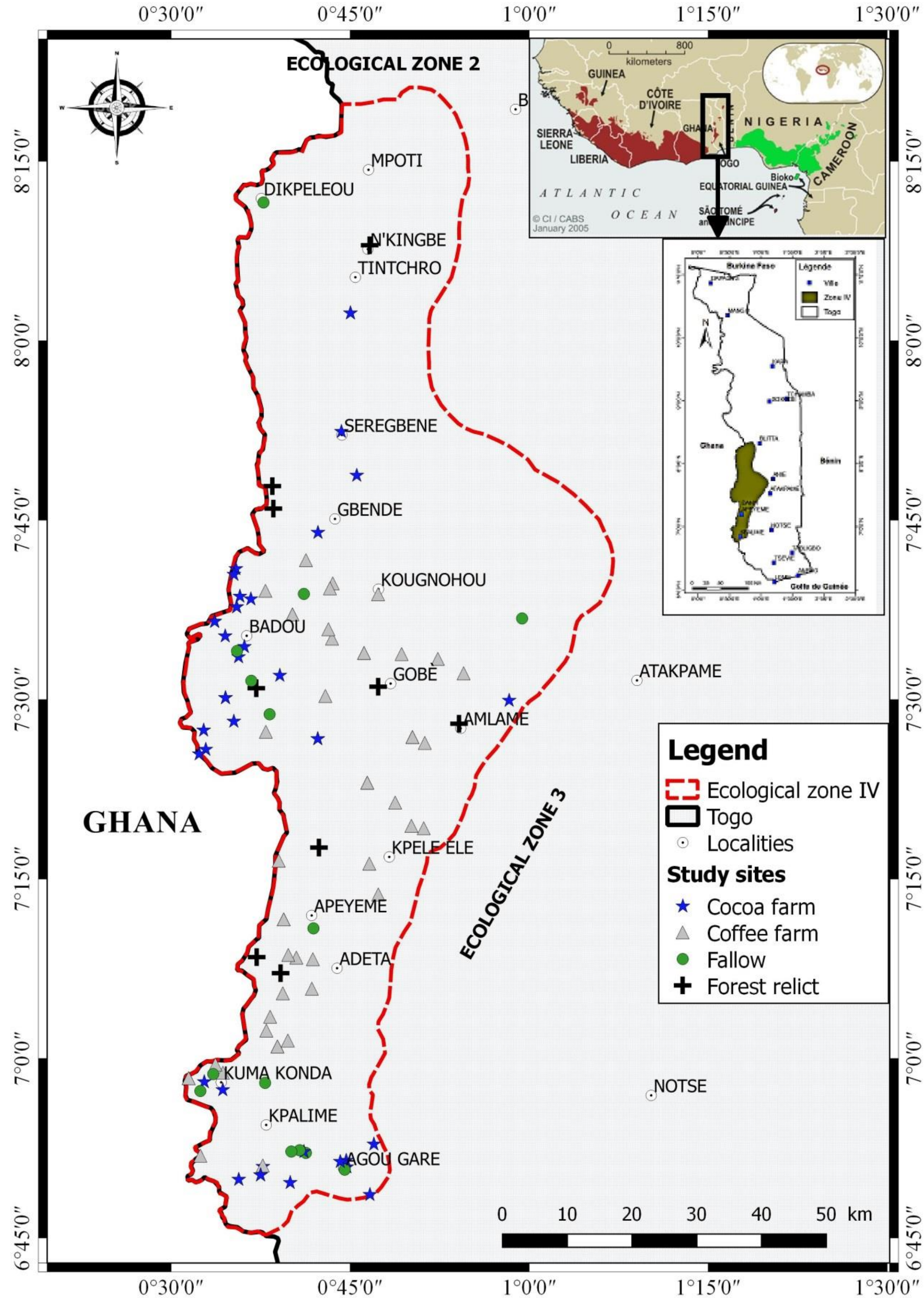

Figure 1. Map showing the location of the study sites in Togo megahotspot (Ecological zone IV).

Table 1. A comparison of total observe species number, number of unique species, number of climax species, mean species richness, mean Shannon diversity index; mean abundance of native trees species (DBH> 10 cm) on different forest land used types in Togo megahopspot mixed evergreen/semidecidous forest zone

Parameter	FR	COCS	COFS	FS
Total area sampled (ha)	4.41	5.13	3.12	3.35
Gamma diversity (Area sampled)	165	72	67	65
Number of unique species (Area sampled)	77	8	4	3
Alpha diversity per plot (400m²)	13.76 (SD=5.66)	4.15 (SD=3.11)	4.72 (SD=2.75)	4.88 (SD=4.43)
Beta diversity per plot (400m²)	10.99	16.33	13.19	12.32
Mean Shannon diversity index per plot (400 m²)	2.54 (SD=0.42)	1.15 (SD=0.79)	1.40 (SD=0.59)	1.28 (SD=0.82)
Mean abundance per plot (400m²)	10.07 (SD=5.52)	2.25 (SD=1.64)	2.55 (SD=1.30)	2.38 (SD=2.32)

FR: Forest Relics; **COCS**: Coco System; **COFS**: Coffee System; **FS**: Follow Systems.

the cumulative number of species based on the number of species present in the plot sample using bootstrap's randomization (200 times) re-sampling techniques.

Gamma, alpha and beta diversity were used as the basic diversity index (Whittaker, 1972). Gamma diversity is the landscape-level diversity estimated as the total number of species or total richness across plots. Alpha diversity is calculated as the average species richness per plot. Beta diversity is a measure of heterogeneity in the data or habitats diversity (McCune et al., 2002), defined as: $\beta w = (Sc/S)-1$, where βw is the beta diversity, Sc is the number of species in the whole data set and S is the average species richness in the sample units. The one is subtracted to make zero beta diversity correspond to zero variation in species abundance. If $\beta w = 0$, then all sample units have all of the species. The larger the value of βw, the more heterogeneous the data set is. As a rule of thumb in that context, values of $\beta w < 1$ are rather low and $\beta w > 5$ can be considered high. The maximum value of βw is Sc-1. The maximum value is obtained when no species are shared among sample units. Shannon–Wiener index (H) was computed following Magurran (1988):

$$H = - \Sigma (pi) \operatorname{Log}_2 (pi)$$

Where $pi=Ni/N$ is the proportional abundance of species i and Log_2 is the base of the logarithm.

Generalized linear models (GLM) was used with binomial (link= logit) variance functions to standardize and compare alpha and Shannon index between forests land use. This technique offer the best approach because it does not require that sample sizes to be equal, as required to compare the total number of species (Kindt and Coe, 2005). Analysis of variance is carried out to examine whether the data are consistent with a simpler ('null') model in which there are no differences.

Floristic similarity and species abundance

To assess differences in species composition among forest land use types, similarity method based on abundance of species was performed using Bray-Curtis ecological distance. Bray-Curtis distance was chosen because it is the most widely used abundance based measure, due to its strong relationship to ecological distance under varying conditions (Bray and Curtis, 1957). To diminish the influence of the dominant species, logarithmic transformation technique has been applied to the species matrix. To assess haw species abundance varied among forest land use types species abundance as the number of individuals per ha was calculated following Misra (1968). All the data supporting this paper are available at https://data.mendeley.com/datasets/kymphvj2cj/draft?a=52c6ccfd-fdb2-4c2e-8a05-daaf46d2f10d

RESULTS

Species richness and diversity

A total of 183 native tree species (Appendix S1) comprising 2485 stems were recorded. They were divided into 165 (89% of the total species recorded) species and 1759 (61% of the total stems recorded) stems, 72 (39%) and 420 (15%), 67 (36%) and 330 (11%) and 65 (35%) and 366 (12%) on FR, COCS, COFS and the FS, respectively (Table 1). It is worth noting that the largest area was sampled in the Cocoa System (COCS). However, total species richness in this system, similar to that of Coffee System (COFS) and Fallow system (FS), remains the lowest compared to forest relics.

Comparison of the accumulation curves between the four forest land use types, based on the same number of plots (40 plots of 400 m² for each type of land use), showed that FR was the richest in observed species (143 species), followed by COFS and FS (63 species each) and COCS (57) (Figure 2). Thus, the species richness of agricultural systems accounted only for 40 to 44% of forest relics. Alpha and Shannon diversity were three times higher in the RF than in the three agricultural forest land use types (Table 1). However, the beta diversity results showed a high value in the COCS (16.33; SD=3.10), followed by COFS (13.19, SD=2.74), FS (12.32, SD=4), and FR (10.99; SD=5.66). Difference in alpha (LR Chisq = 135.38; P<0.001) and Shannon diversity (LR Chisq = 142.61; P<0.001) were significant between the FR and the three agricultural systems. But, there is no significant difference in alpha (LR Chisq = 1.41 P=0.23) and Shannon diversity (LR Chisq = 2.5 P=0.11) between the three agricultural systems indicating that the studied agroforestry systems for coffee and

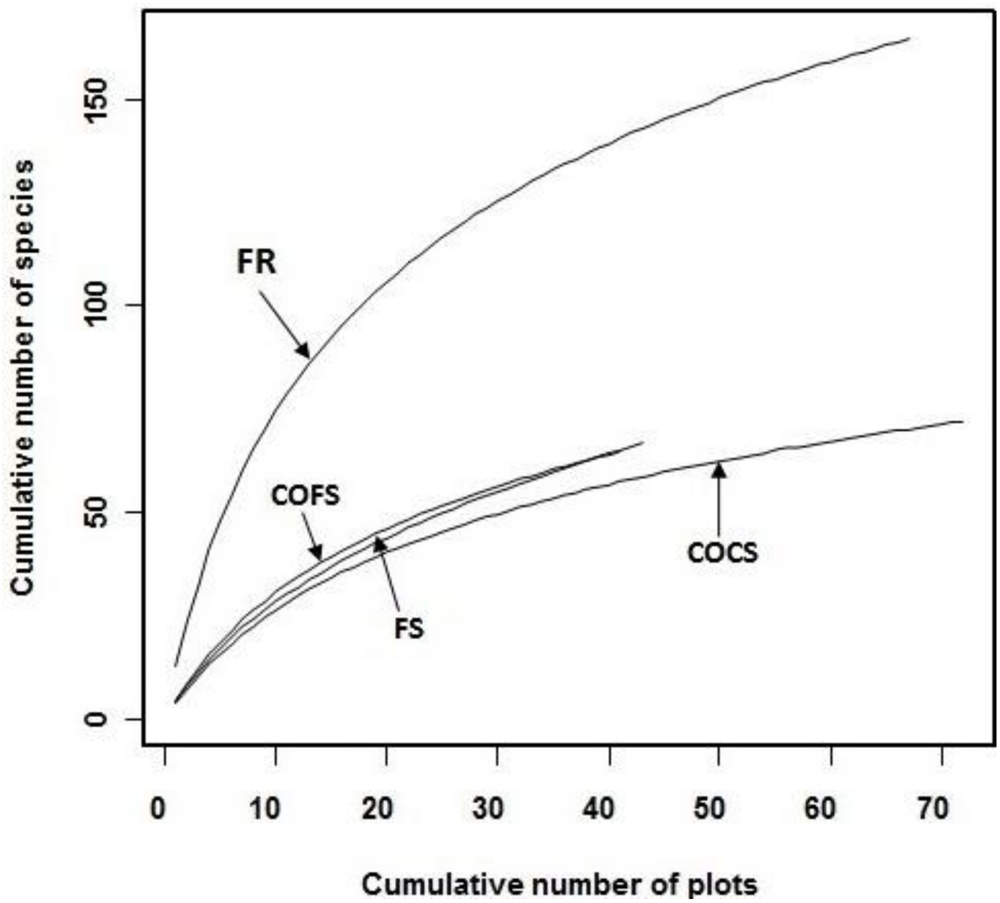

Figure 2. Samples-based species accumulation curves of the four forest land use types in the Togo Megahotspot. **FR**: Forest Relics; **COCS**: Coco System; **COFS**: Coffee System; **FS**: Follow Systems. All curves are based on a sampling area of 400 m².

cocoa system have the same conservation value as fallows systems.

Floristic similarity and species abundance distribution

The overall Bray-Curtis distance values between forest lands use types ranged from 0.39 to 0.60. Highest Bray-Curtis distance (D=0.6) was observed between FR and agricultural systems and less Bray-Curtis distance (D = 0.39) was observed between the three agricultural systems (Table 2). FR shared 32 (17.3% of total species) species with the three agricultural systems, whereas 77 (42% of total species) species occurred on FR site only. Only 8 (4%), 4 (2%) and 3 (2%) species were unique to COCS, COFS and FS site, respectively.

Abundance distribution patterns showed that species individual abundance varied between forest lands uses types. The most abundant species by number of stems recorded in the FR was *Pseudospondias microcarpa* (30 ind /ha); followed by *Celtis mildbraedii* (22.22), *Funtumia africana* (21.35), *Pycnanthus angolensis* (13.60), *Sterculia tragacantha*, *Tabernaemontana pachysiphon*, *Pterocarpus mildbraedii*, *Cola gigantea*, *Albizia adianthifolia*, and *Antiaris toxicaria* subsp. Africana. In the COCS, *Milicia excelsa* (9.55 ind/ha) was the abundant species with the highest density, followed by *Terminalia superba (*5.06*), Funtumia africana* (4.28), *Ficus mucuso*, *Sterculia tragacantha, Ficus sur, Monodora myristica, Khaya grandifoliola etc.* In the COFS, *Xylopia aethiopica* (12.17 ind/ha) was the abundant species, followed by *Milicia excelsa (9. 29*), *Albizia adianthifolia (8.65)*, *Albizia zygia* (7.05), *Khaya grandifoliola*, *Terminalia superba*, *Anthocleista djalonensis*, *Morinda lucida*, Monodora *myristica*, *Aubrevillea kerstingii etc. (*Appendix S1)

The majority of species (78%) have low abundance (density <5 ind/ha) and could be considered rare. Of these, 57% were endemic to Guneo-Congolese rainforests (*Afzelia bella, Cordia platythyrsa, Drypetes aylmeri, Entandrophragma cylindricum, Erythrina vogelii, Gymnostemon zaizou, Homalium letestui, Parkia bicolor, Pterygota bequaertii etc*.), 21% of the transition species between Guneo-Congolese rainforests and dry

Table 2. Distance matrix between forest land use types in Togo megahopspot mixed evergreen/semidecidous forest zone using the Bray- Curtis , Kulczynski and Gower distances

Distance	FR-COCS	FR-COFS	FR-FS	COCS-COFS	COCS-FS	COFS-FS
Bray- Curtis distance	0.58	0.58	0.56	0.39	0.44	0.40
Kulczynski distance	0.56	0.56	0.53	0.39	0.44	0.40
Gower distance	0.76	0.75	0.72	0.30	0.35	0.31

FR: Forest Relics; **COCS**: Coco System; **COFS**: Coffee System; **FS**: Follow Systems.

vegetation (*Afzelia Africana, Anogeissus leiocarpus, Cassia sieberiana, Eriocoelum kerstingii, Malacantha alnifolia, Manilkara multinervis* etc.) (Appendix S1),

DISCUSSION

Results showed a high species richness and diversity in the FR compared to the three agricultural systems (COCS, COFS and FS). Very few studies in the tropics have reported the impacts of cocoa and coffee agroforests practices on the richness and diversity of native tree species compared to those that included exotic species in the calculation of diversity index, or focused on the wildlife richness of these systems (Harvey and González Villalobos, 2007). Rolim and Chiarello (2004) have been reported that the cocoa agroforestry (cabruca forests) systems in southeastern Brazil were less diverse and less dense than secondary or primary forests of the region. In Densu Basin in Ghana, Attua (2003) (cited by Norris et al., 2010) showed that the plant community of existing pockets of forest are more species diverse than the vegetation associated with the cocoa or food crop farms.

Findings showed that native's tree species richness was reduced by 70, 66 and 65% and Shannon index by 55, 45 and 50% in COCS, COFS and FS, respectively compared to FR. The reduction of regional species richness by coffee systems in this study (66%) can be considered high compared to that observed in similar systems in Ethiopia (25%) (Aerts et al., 2011). This difference could be due to the fact that the two studies did not use the same methods. In this study, trees of DBH ≥10 cm were considered, exotic species were not taken into account while Aerts et al. (2011) considered species ≥ 2 m tall and exotic species. This observations, with regard to Shannon diversity Index, are in agreement with those of Rodriguez-Echeverry et al. (2018) who have shown that the land-use change decreased Shannon diversity index in the Chilean temperate forests (Rodrãguez-Echeverry et al., 2018).

The results showed a high beta diversity index in the four forest land use types (> 5) showing a great heterogeneity in the data which could be explained by the variability of species abundance within and between forest land use types, justifying the differences observed in this results (SD) (Table 1). However, this heterogeneity was more pronounced in cocoa (beta = 16) and coffee (13) systems. This could be related to the different management schemes.

Very few studies have compared the native species richness and composition between agricultural systems in tropics. In general, both plant and animal diversity within cocoa agroforests is greater than those of other agricultural land uses, but lower than in the original forest habitats (Harvey et al., 2007). It has been shown that fallows are less diversified than cocoa systems (Trimble and Van Aarde, 2014). However, based on the native species, this study has shown that agricultural systems (COCS, COFS and FS), in Togolese megahotspot, have similar species diversity and composition, hence similar conservation values. This could be justified by changes in the management practices of coffee-cocoa agroforestry systems which are causing their change close to FS.

These changes affect native species identity and abundance distribution across the study area and the types of forest land use. At the scale of the study area, very few species were abundant (22%) (Table 4), while the majority could be considered rare (78%). In addition, 42% of species recorded were absent from agricultural systems; some species have low densities on agricultural systems compared to their density in FR. Moreover, it was noted that:

1. Species abundance varied according to the types of practices. For example *Milicia excels*a and *Terminalia superba* were abundant in the COCS and COFS, while *Albizia adianthifolia* and *Albizia zygia* in the COFS and FS. *Ficus mucuso* and *Funtumia africana* were abundant in the COCS, *Xylopia aethiopica* in the COFS and *Macaranga barteri* in the FS (Table 4);
2. The most abundant species at the scale of the study area included species with high economic values belonging to the categories of timber species (*Khaya grandifoliola*, *Milicia excelsa*, *Terminalia superba etc.*), medicinal species (*Alstonia boonei*, *Anthocleista djalonensis* and *Spathodea campanulata*) and spice species (*Monodora myristica* and *Xylopia aethiopica*) and multipurpose species (fertilization, soil restoration, shading, firewood, fruits, tools, etc.) and pioneer species like: *Albizia adianthifolia*, *Albizia adianthifolia*, *Funtumia Africana*, *Ficus exasperata*, *Ficus mucuso*, *Ficus* sur,

Table 3. Pioneer and farmers' preferred dominated tree species in Togo megahopspot mixed evergreen/semidecidous forest zone. The numbers represent the density per ha.

Species	Families	FR	COCS	COFS	FS	Total
Milicia excelsa (Welw.) C.C. Berg.	Moraceae	6.12	9.55	9.29	2.38	27.35
Funtumia africana (Benth.) Stapf	Apocynaceae	21.31	4.28	0.96	0.29	26.86
Albizia adianthifolia (Schum.) W. F. Wright	Fabaceae	7.48	1.16	8.65	6.86	24.17
Albizia zygia (DC.) J.F. Macbr.	Fabaceae	2.04	1.75	7.05	11.64	22.48
Pycnanthus angolensis (Welw.) Warb.	Myristicaceae	13.6	1.55	2.24	4.47	21.88
Sterculia tragacantha Lindl.	Sterculiaceae	12.01	3.89	1.6	3.88	21.39
Khaya grandifoliola DC.	Meliaceae	7.02	2.72	4.8	3.28	17.84
Ficus sur Forssk	Moraceae	4.98	3.89	1.6	6.86	17.35
Morinda lucida Benth.	Rubiaceae	4.08	2.72	4.16	6.26	17.24
Macaranga barteri Müll. Arg.	Euphorbiaceae	5.44	0.19	1.6	8.95	16.19
Terminalia superba Engl. & Diels	Combretaceae	4.76	5.06	4.48	0.29	14.61
Cola gigantea var. glabrescens Brenan & Keay	Sterculiaceae	8.39	1.55	0.96	3.28	14.19
Xylopia aethiopica (Dural) A. Rich.	Annonaceae	0.22	0.77	12.17	0.29	13.48
Monodora myristica (Gaertn.) Dunal	Annonaceae	5.66	3.31	3.84	0.29	13.12
Ficus exasperata Vahl.	Moraceae	4.08	1.36	1.6	5.37	12.42
Ficus mucuso Welw. ex Ficalho	Moraceae	5.21	4.09	0.64	1.79	11.74
Antiaris africana Engl.	Moraceae	7.48	0.97	0.96	2.08	11.5
Aubrevillea kerstingii (Harms)	Fabaceae	6.57	0.19	3.2	0.59	10.57
Anthocleista djalonensis A. Chev.	Loganiaceae	2.49	1.75	4.48	1.79	10.52
Alstonia boonei De Wild.	Apocynaceae	4.53	1.55	0.32	3.88	10.29
Ceiba pentandra (Linn.) Gaerth.	Bombacaceae	4.98	1.94	0.32	2.38	9.64
Canarium schweinfurthii Engel.	Burseraceae	6.12	0.19	0.32	1.49	8.13
Tetrorchidium didymostemon (Baill.) Pax & Hoffm.	Euphorbiaceae	3.85	0.58	0.32	1.49	6.25
Holarrhena floribunda (G. DON.) Dur. & Schinz.	Apocynaceae	2.26	1.36	1.6	0.59	5.83
Spathodea campanulata P. Beauv.	Bignoniaceae	0.9	1.36	1.28	1.79	5.34
Harungana madagascariensis Lam. ex Poir.	Guttiferae	0.9	0.38	2.24	1.49	5.03
Vitex doniana Sweet	Verbenaceae	1.36	1.16	1.28	1.19	5
Ricinodendron heudelotii (Baill.) Pierre ex Pax	Euphorbiaceae	1.36	1.94	0.32	0.29	3.92
Margaritaria discoidea (Baiil) Webster	Phyllanthaceae	0.22	0.38	0.64	2.38	3.64

FR: Forest Relics; **COCS**: Coco System; **COFS**: Coffee System; **FS**: Follow Systems.

Harungana madagascariensis, *Holarrhena floribunda*, *Macaranga barteri*, Margaritaria discoidea, *Morinda lucida*, *Tetrorchidium didymostemon* etc.; among them, there are several pioneer species (Table 3).

These distribution patterns were a reflection of the selection of trees by farmers. These results are consistent with those of other authors. Indeed, works based on interviewed and tree inventories in coffee farms and forest sites in La Sepultura Biosphere Reserve in Chiapas, Mexico have showed that farmers are modifying agroforests according to their knowledge and tree preferences, and that the resulting agroforest is lower in tree diversity and dominated by pioneer and farmers' preferred tree species as compared to forests (Valencia et al., 2015). In Agroforestry system in southern Mexico and Central America, more than 30 native tree species are recognized and managed as potential facilitators of forest regeneration and direct human consumption of forest products. Immediate useful species were those plants that the farmers use for food, medicine, firewood, construction, or raw materials (Diemont et al., 2011). The results are also in line with those obtained by Adden et al. (2018) who studied the preference of trees by farmers in the coffee and cocoa agroforestry systems in Togo. Their study showed that Togolese farmers prefer in their plantation species like *Albizia* spp., *Khaya grandifoliola*, *Milicia excels* and *Terminalia superba*.

These patterns suggested also that agricultural systems block the natural succession of certain species especially climax and endemic species of Guineo-congolian. These results are in agreement with those of other authors. In semi-forest coffee agroforestry system in Ethiopian Afromontane rainforest fragments, climax species of the rainforest were underrepresented (Aerts et al., 2011). Waltert et al. (2011) assessed conservation values in tropical land use systems and found that

Table 4. Some Guineo-Congolian endemic and climax endangered species in Togo megahopspot mixed evergreen/semidecidous forest zone.

Species	Family	FR	COCS	COFS	FS	Total
Parinari glabra Oliv.	Chrysobalanaceae	3.4	-	-	-	3.4
Aningeria altissima (A. Chev.) Aubrév. et Pellegr.	Sapotaceae	3.17	-	-	-	3.17
Piptadeniastrum africanum (Hook. f.) Brenan	Fabaceae	2.26	0.58	0.32	-	3.17
Polyscias fulva (Hiern) Harms	Araliaceae	3.17	-	-	-	3.17
Hannoa klaineana Pierre et Engl.	Simaroubaceae	0.68	0.19	1.6	0.59	3.07
Nesogordonia papaverifolia (A.Chev.) R. Capuron	Sterculiaceae	2.72	-	0.32	-	3.04
Sterculia oblonga Mast.	Sterculiaceae	2.72	-	-	0.29	3.01
Bombax buonopozense P. Beauv.	Bombacaceae	0.22	0.97	0.32	1.19	2.71
Zanthoxylum macrophylla Engl.	Rutaceae	0.68	-	1.92	-	2.6
Holoptelea grandis (Hutch.) Mildbr.	Ulmaceae	2.26	0.19	-	-	2.46
Turraeanthus africanus Pellegr.	Meliaceae	2.26	-	-	-	2.26
Pterygota macrocarpa K. Schum.	Sterculiaceae	1.81	-	0.32	-	2.13
Distemonanthus benthamianus Baill.	Fabaceae	0.9	0.19	0.96	-	2.06
Maesopsis eminii Engl.	Rhamnaceae	2.04	-	-	-	2.04
Lovoa trichilioides Harms	Meliaceae	1.58	-	-	-	1.58
Amphimas pterocarpoïdes Harms	Fabaceae	0.22	0.38	0.64	0.29	1.55
Trichilia megalantha Harms	Meliaceae	1.13	0.38	_	_	1.52
Tetrapleura tetraptera (Schum.& Thonn.) Taub.	Fabaceae	1.13	-	0.32	_	1.45
Khaya anthotheca (Welw.) C.DC.	Meliaceae	0.45	-	0.32	0.59	1.37
Afzelia bella Harms var.gracilior Keay	Fabaceae	1.36	-	-	-	1.36
Morus mesozygia Stapf	Moraceae	0.68	-	0.32	0.29	1.29
Klainedoxa gabonensis Pierre ex Engl.	Irvingiaceae	0.68	0.38	-	-	1.07
Sterculia rhinopetala K. Schum.	Sterculiaceae	0.68	0.38	-	-	1.07
Treculia africana Decne	Moraceae	0.45	-	-	0.59	1.05
Parinari excelsa Sabine	Chrysobalanaceae	0.68	-	0.32	-	1
Gymnostemon zaizou Aubrév. & Pellegr.	Simaroubaceae	0.9	-	-	-	0.9
Homalium letestui Pellegr	Flacourtiaceae	0.9	-	-	-	0.9
Afrosersalisia afzelii (Engel.) A. Chev.	Sapotaceae	0.45	-	0.32	-	0.77
Blighia welwitschii (Hiern) Radlk	Sapindaceae	0.22	0.38	-	-	0.61
Nauclea diderrichii (de Wild. & Th. Dur. Merril.)	Rubiaceae	_	0.58	-	-	0.58
Drypetes gilgiana(Pax)(Pax)&K.Hoffm.	Euphorbiaceae	0.45	_	-	-	0.45
Entandrophragma cylindricum (Welw.) C.DC.	Meliaceae	0.45	_	-	-	0.45
Stereospermum acuminatissimum K. Schum.	Bignoniaceae	0.45	_	-	-	0.45
Tarenna pavettoides (Harv.) Sim	Rubiaceae	0.45	_	-	-	0.45
Mansonia altissima A. Chevalier	Sterculiaceae	0.22	0.19	-	-	0.42
Cordia platythyrsa Baker	Boraginaceae	0.22	-	-	-	0.22
Drypetes aframensis Hutch.	Euphorbiaceae	0.22	-	-	-	0.22
Drypetes aylmeri Hutct .& Dalz.	Euphorbiaceae	0.22	-	-	-	0.22
Drypetes leonensis Pax	Euphorbiaceae	0.22	-	-	-	0.22
Erythrina vogelii Hook. f.	Fabaceae	0.22	-	-	-	0.22
Irvingia robur Mildbr.	Irvingiaceae	0.22	-	-	-	0.22
Parkia bicolor A.Chev.	Fabaceae	0.22	-	-	-	0.22
Parkia filicoidea Welw. ex Oliv.	Fabaceae	0.22	-	-	-	0.22
Pterygota bequaertii De Wild.	Sterculiaceae	0.22	-	-	-	0.22
Rhodognaphalon brevicuspe (Sprague) Roberty	Sterculiaceae	0.22	-	-	-	0.22
Symphonia globulifera Linn. f.	Guttiferae	0.22	-	-	-	0.22
Erythrina mildbraedii Harms	Fabaceae	_	0.19	-	-	0.19

FR: Forest Relics; **COCS**: Coco System; **COFS**: Coffee System; **FS**: Follow Systems. The numbers represent the density per hectare.

agroforestry systems, even traditional, reduced by 91% endemic plant species and concluded that even ecologically friendly agricultural matrices may be of much lower value for tropical conservation than indicated by mere biodiversity value. The results of this study confirm those of Barlow et al. (2007) who quantified the biodiversity value of tropical primary, secondary, and planting and found that almost 60% of plant species were only ever recorded in primary forest.

Finally, the study showed that some species have low density in both FR and agricultural systems. These results indicated that agroforestry is not the only cause of species rarity in the area. The exploitation of the timber could explain the rarity of species. *Pseudospondias microcarpa* was the most abundant species in FR because it is not a timber species.

Implication for management and biodiversity conservation

Agroforestry systems are often presented as a refuge for tropical biodiversity, only alternative to meet the ecological and economic challenges posed by slash-and-burn agriculture practices (Fischer and Vasseur, 2000). Bhagwat et al. (2008) reviewed evidence from studies across the tropics where species richness and composition of agroforestry systems are compared with that of neighbouring forest reserves and concluded that agroforestry systems are high in species richness and more similar to neighbouring forest reserves in species composition if (i) the forest land was fairly recently converted to agroforestry plantation; (ii) the management was less intensive; and (iii) the canopy cover of native trees was high. In traditional systems where these conditions are met, significant reductions in native species could have been observed. Waltert et al. (2011) have shown that traditional agroforestry systems could reduce more than 90% of native plant species. This reduction is not only related to the management practices of these systems but also their effect on microhabitats. Tropical forest ecosystems consist of a large number of microhabitats, each of which supports a high diversity of specialized organisms. Many organisms depend upon these microhabitats for a critical stage in their life cycle. Management that removes or modifies any of these microhabitats can potentially cause critical changes in overall diversity (Greenberg, 1998).

To counter the threats caused by agroforestry practices and conserve biodiversity over the long-term, auteurs (Siebert, 2002; Harvey et al., 2007; Magnago et al., 2015) thinks that land management should focus on conserving native forest habitat within cocoa production landscapes, maintaining or restoring floristically diverse and structurally complex shade canopies within cocoa agroforests, and retaining other types of on-farm tree cover to enhance landscape connectivity and habitat availability. These measures are good except that maintaining or restoring floristically diverse and structurally complex shade canopies within cocoa agroforests are at the origin of the problems that the cocoa sector is facing today (disease, rot, yield reduction). This study showed that 78% of the native species of the Megahotspot of Togo are threatened. Of these, 57% of climax and endemic species of the Guineo-Congolian region, 21% of the transition species between Guneo-Congolese rainforests and dry vegetation. In terms of conservation, transitional species are not endangered because of their wide distribution. They can be found in other types of vegetation. But the climax and endemic species of the Guineo-Congolian region deserve special attention (Table 4). Measures will be taken to ensure the renewal of these species in both FR and agricultural systems. This study poses a real problem of regeneration and succession of tropical rainforest species in human-dominated landscapes. Of the characteristic species, it is the anthropophilic and heliophilous species that colonize our agricultural and forest landscapes. Important ecological issues are required for the conservation and sustainable management of biodiversity in this area. This requires scientific and indigenous knowledge.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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Appendix S1

Appendix S1. Species abundance in Togo megahopspot mixed evergreen/semidecidous forest zone. The numbers represent the density per ha

Species	Fam	Succession	Chie	FR	COCS	COFS	FS	Total
Pseudospondias microcarpa (A. Rich.) Engl.	Anacardiaceae	Pioneer	GC-SZ	29,93	_	_	1,79	31,72
Milicia excelsa (Welw.) C.C. Berg.	Moraceae	Climax	GC	6,12	9,55	9,29	2,38	27,35
Funtumia africana (Benth.) Stapf	Apocynaceae	Pioneer	GC	21,31	4,28	0,96	0,29	26,86
Albizia adianthifolia (Schum.) W. F. Wright	Fabaceae	Pioneer	GC	7,48	1,16	8,65	6,86	24,17
Albizia zygia (DC.) J.F. Macbr.	Fabaceae	Pioneer	GC	2,04	1,75	7,05	11,64	22,48
Celtis mildbraedii Engl.	Ulmaceae	Climax	GC	22,22	_	_	_	22,22
Pycnanthus angolensis (Welw.) Warb.	Myristicaceae	Climax	GC	13,6	1,55	2,24	4,47	21,88
Sterculia tragacantha Lindl.	Sterculiaceae	Pioneer	GC-SZ	12,01	3,89	1,6	3,88	21,39
Khaya grandifoliola DC.	Meliaceae	Climax	GC	7,02	2,72	4,8	3,28	17,84
Ficus sur Forssk	Moraceae	Pioneer	GC-SZ	4,98	3,89	1,6	6,86	17,35
Morinda lucida Benth.	Rubiaceae	Pioneer	GC-SZ	4,08	2,72	4,16	6,26	17,24
Macaranga barteri Müll. Arg.	Euphorbiaceae	Pioneer	GC	5,44	0,19	1,6	8,95	16,19
Terminalia superba Engl. & Diels	Combretaceae	Climax	GC	4,76	5,06	4,48	0,29	14,61
Cola gigantea var. glabrescens Brenan & Keay	Sterculiaceae	Climax	GC	8,39	1,55	0,96	3,28	14,19
Xylopia aethiopica (Dural) A. Rich.	Annonaceae	Pioneer	GC-SZ	0,22	0,77	12,17	0,29	13,48
Monodora myristica (Gaertn.) Dunal	Annonaceae	Climax	GC	5,66	3,31	3,84	0,29	13,12
Ficus exasperata Vahl.	Moraceae	Pioneer	GC-SZ	4,08	1,36	1,6	5,37	12,42
Ficus mucuso Welw. ex Ficalho	Moraceae	Pioneer	GC	5,21	4,09	0,64	1,79	11,74
Antiaris africana Engl.	Moraceae	Pioneer	GC-SZ	7,48	0,97	0,96	2,08	11,5
Aubrevillea kerstingii (Harms)	Fabaceae	Climax	GC	6,57	0,19	3,2	0,59	10,57
Anthocleista djalonensis A. Chev.	Loganiaceae	Pioneer	GC-SZ	2,49	1,75	4,48	1,79	10,52
Alstonia boonei De Wild.	Apocynaceae	Climax	GC	4,53	1,55	0,32	3,88	10,29
Ceiba pentandra (Linn.) Gaerth.	Bombacaceae	Pioneer	GC-SZ	4,98	1,94	0,32	2,38	9,64
Cleistopholis patens (Benth.) Engl. & Diels	Annonaceae	Pioneer	GC	6,57	2,14	_	0,59	9,31
Tabernaemontana pachysiphon Stapf	Apocynaceae	Climax	GC	9,07	_	_	_	9,07
Pterocarpus mildbraedei Harms	Fabaceae	Climax	GC	8,61	_	_	0,29	8,91
Cola millenii K. Schum.	Sterculiaceae	Climax	GC	7,48	_	0,32	0,59	8,4
Canarium schweinfurthii Engel.	Burseraceae	Climax	GC	6,12	0,19	0,32	1,49	8,13
Trilepisium madagascariense DC.	Moraceae	Climax	GC	5,89	0,58	_	0,29	6,77
Tetrorchidium didymostemon (Baill.) Pax & Hoffm.	Euphorbiaceae	Pioneer	GC	3,85	0,58	0,32	1,49	6,25
Holarrhena floribunda (G. DON.) Dur. & Schinz.	Apocynaceae	Pioneer	GC-SZ	2,26	1,36	1,6	0,59	5,83
Erythrophleum suaveolens (Guill. & Pherr.) Brenan.	Fabaceae	Pioneer	GC-SZ	2,26	_	2,56	0,89	5,72
Myrianthus arboreus P. Beauv.	Moraceae	Pioneer	GC	4,76	_	0,64	0,29	5,7
Newbouldia laevis (P. Beauv.) Seemann. ex Bureau	Bignoniaceae	Pioneer	GC	4,76	0,58	0,32	_	5,66
Spondias monbin Linn.	Anacardiaceae	Pioneer	GC-SZ	4,3	0,97	0,32	_	5,6
Lecaniodiscus cupanioides Planch. & Benth.	Sapindaceae	Pioneer	GC	4,98	0,19	0,32	_	5,5
Spathodea campanulata P. Beauv.	Bignoniaceae	Climax	GC	0,9	1,36	1,28	1,79	5,34
Trichilia heudelotii Planch. ex Oliv.	Meliaceae	Climax	GC	3,17	0,97	0,96	_	5,11
Harungana madagascariensis Lam. ex Poir.	Guttiferae	Pioneer	GC	0,9	0,38	2,24	1,49	5,03
Vitex doniana Sweet	Verbenaceae	Pioneer	GC-SZ	1,36	1,16	1,28	1,19	5
Celtis zenkeri Engl.	Ulmaceae	Climax	GC	4,98	_	_	_	4,98
Macaranga hurifolia Beille	Euphorbiaceae	Pioneer	GC	4,08	0,38	0,32	_	4,79
Dialium guineense Willd.	Fabaceae	Pioneer	GC	2,94	_	0,32	1,49	4,76
Rauvolfia vomitoria Afzel.	Apocynaceae	Pioneer	GC-SZ	2,94	0,19	_	1,19	4,33
Triplochiton scleroxylon K.Schum.	Sterculiaceae	Climax	GC	3,4	0,38	_	0,29	4,08
Uapaca guineensis Müll. Arg.	Euphorbiaceae	Climax	GC	3,17	_	_	0,89	4,07
Ricinodendron heudelotii (Baill.) Pierre ex Pax	Euphorbiaceae	Climax	GC	1,36	1,94	0,32	0,29	3,92
Margaritaria discoidea (Baiil) Webster	Phyllanthaceae	Pioneer	GC-SZ	0,22	0,38	0,64	2,38	3,64

Appendix S1. Contd.

Parinari glabra Oliv.	Chrysobalanaceae	Climax	GC	3,4	_	_	_	3,4
Aningeria altissima (A. Chev.) Aubrév. et Pellegr.	Sapotaceae	Climax	GC	3,17	_	_	_	3,17
Aphania senegalensis (Juss.ex Poir.) Radlk.	Sapindaceae	Climax	GC	3,17	_	_	_	3,17
Canthium schimperianum A. Rich.	Rubiaceae	Pioneer	GC-SZ	3,17	_	_	_	3,17
Piptadeniastrum africanum (Hook. f.) Brenan	Fabaceae	Climax	GC	2,26	0,58	0,32	_	3,17
Polyscias fulva (Hiern) Harms	Araliaceae	Climax	GC	3,17	_	_	_	3,17
Lonchocarpus sericeus (Poir.) Kunth	Fabaceae	Pioneer	GC-SZ	1,13	1,36	_	0,59	3,09
Hannoa klaineana Pierre et Engl.	Simaroubaceae	Climax	GC	0,68	0,19	1,6	0,59	3,07
Macaranga heudelotii Baill.	Euphorbiaceae	Pioneer	GC	1,58	1,16	0,32	_	3,07
Nesogordonia papaverifolia (A.Chev.) R. Capuron	Sterculiaceae	Climax	GC	2,72	_	0,32	_	3,04
Discoglypremna caloneura (Pax) Prain.	Euphorbiaceae	Pioneer	GC	0,9	1,16	0,96	_	3,03
Sterculia oblonga Mast.	Sterculiaceae	Climax	GC	2,72	_	_	0,29	3,01
Afzelia africana Sm.	Fabaceae	Pioneer	GC-SZ	1,58	_	0,64	0,59	2,82
Baphia nitida Lodd.	Fabaceae	Climax	GC	2,72	_	_	_	2,72
Bombax buonopozense P. Beauv.	Bombacaceae	Climax	GC	0,22	0,97	0,32	1,19	2,71
Zanthoxylum macrophylla Engl.	Rutaceae	Climax	GC	0,68	_	1,92	_	2,6
Holoptelea grandis (Hutch.) Mildbr.	Ulmaceae	Climax	GC	2,26	0,19	_	_	2,46
Dacryodes klaineana (Pierre) H.J.Lam	Burseraceae	Climax	GC	2,04	_	_	0,29	2,33
Manilkara multinervis (Baker) Dubard.	Sapotaceae	Pioneer	GC-SZ	2,04	_	_	0,29	2,33
Cathormion altissimum Hook.f.)Hutch. & Dandy	Fabaceae	Climax	GC	2,26	_	_	_	2,26
Pentaclethra macrophylla Benth.	Fabaceae	Climax	GC	2,26	_	_	_	2,26
Turraeanthus africanus Pellegr.	Meliaceae	Climax	GC	2,26	_	_	_	2,26
Pterygota macrocarpa K. Schum.	Sterculiaceae	Climax	GC	1,81	_	0,32	_	2,13
Distemonanthus benthamianus Baill.	Fabaceae	Climax	GC	0,9	0,19	0,96	_	2,06
Maesopsis eminii Engl.	Rhamnaceae	Climax	GC	2,04	_	_	_	2,04
Mitragyna stipulosa O. Kuntze	Rubiaceae	Pioneer	GC-SZ	2,04	_	_	_	2,04
Ficus ovata Vahl.	Moraceae	Pioneer	GC	0,45	0,38	_	1,19	2,03
Blighia sapida Konig	Sapindaceae	Pioneer	GC	0,22	_	0,96	0,59	1,78
Canthium subcordatum DC.	Rubiaceae	Pioneer	GC	1,58	0,19	_	_	1,78
Berlinia grandiflora (Valh) Hutch. & Dalz.	Fabaceae	Pioneer	GC-SZ	1,13	_	_	0,59	1,73
Spondiathus preussii Engl.	Euphorbiaceae	Climax	GC	1,36	_	_	0,29	1,65
Eriocoelum kerstingii Gilg. & Engl.	Sapindaceae	Pioneer	SZ	1,58	_	_	_	1,58
Lovoa trichilioides Harms	Meliaceae	Climax	GC	1,58	_	_	_	1,58
Sorindea juglandifolia (A.Rich.)Planch.ex Oliv.	Anacardiaceae	Pioneer	GC-SZ	1,58	_	_	_	1,58
Vitex ferruginea Schum & Thonn.	Verbenaceae	Climax	GC	1,58	_	_	_	1,58
Amphimas pterocarpoïdes Harms	Fabaceae	Climax	GC	0,22	0,38	0,64	0,29	1,55
Trichilia prieuriana A. Juss.subsp. prieuriana	Meliaceae	Climax	GC	1,36	0,19	_	_	1,55
Millettia zechiana Harms	Fabaceae	Pioneer	GC	0,45	0,19	_	0,89	1,54
Trichilia megalantha Harms	Meliaceae	Climax	GC	1,13	0,38	_	_	1,52
Tetrapleura tetraptera (Schum.& Thonn.) Taub.	Fabaceae	Climax	GC	1,13	_	0,32	_	1,45
Khaya anthotheca (Welw.) C.DC.	Meliaceae	Climax	GC	0,45	_	0,32	0,59	1,37
Afzelia bella Harms var.gracilior Keay	Fabaceae	Climax	GC	1,36	_	_	_	1,36
Anogeissus leiocarpus (DC.) Guill. & Perr.	Combretaceae	Pioneer	SZ	1,36	_	_	_	1,36
Olax subscorpioidea Oliv.	Olacaceae	Pioneer	GC	1,36	_	_	_	1,36
Morus mesozygia Stapf	Moraceae	Climax	GC	0,68	_	0,32	0,29	1,29
Ficus populifolia Vahl	Moraceae	Pioneer	SZ	_	_	1,28	_	1,28
Albizia ferruginea (Guill.& Perr.)Benth.	Fabaceae	Climax	GC	_	0,19	0,96	_	1,15
Cassia sieberiana DC.	Fabaceae	Pioneer	GC-SZ	0,22	_	0,32	0,59	1,14
Dichapetalum oblongum (Hook.f.ex Benth.) Engel.	Dichapetalaceae	Climax	GC	1,13	_	_	_	1,13
Gaertneria paniculata Benth.	Rubiaceae	Pioneer	GC	1,13	_	_	_	1,13
Hexalobus crispiflorus A. Rich.	Annonaceae	Pioneer	GC-SZ	1,13	_	_	_	1,13
Mareya micrantha (Benth.) Muell.	Euphorbiaceae	Climax	GC	1,13	_	_	_	1,13

Appendix S1. Contd.

Pachystela brevipes (Bak) Baill.ex Engl.	Sapotaceae	Pioneer	GC	1,13	_	_	_	1,13
Peddiea fischeri Engl.	Thymelaeaceae	Climax	GC	1,13	_	_	_	1,13
Pentadesma butyraccea Sabine	Guttiferae	Pioneer	GC-SZ	1,13	_	_	_	1,13
Syzygium guineense (Willd.) DC.	Myrtaceae	Pioneer	SZ	1,13	_	_	_	1,13
Klainedoxa gabonensis Pierre ex Engl.	Irvingiaceae	Climax	GC	0,68	0,38	_	_	1,07
Sterculia rhinopetala K. Schum.	Sterculiaceae	Climax	GC	0,68	0,38	_	_	1,07
Treculia africana Decne	Moraceae	Climax	GC	0,45	_	_	0,59	1,05
Parinari excelsa Sabine	Chrysobalanaceae	Climax	GC	0,68	_	0,32	_	1
Sapium ellipticum (Hochst) Pax	Euphorbiaceae	Pioneer	GC-SZ	0,68	_	0,32	_	1
Macaranga spinosa Müll. Arg.	Euphorbiaceae	Pioneer	GC	0,68	_	_	0,29	0,97
Dracaena arborea Link.	Dracaenaceae	Pioneer	GC	0,22	0,38	_	0,29	0,91
Gymnostemon zaizou Aubrév. & Pellegr.	Simaroubaceae	Climax	GC	0,9	_	_	_	0,9
Homalium letestui Pellegr	Flacourtiaceae	Climax	GC	0,9	_	_	_	0,9
Phoenix reclinata Jacq.	Palmae	Pioneer	GC-SZ	0,9	_	_	_	0,9
Canthium horizontale (Schum. & Thonn.) Hiern	Rubiaceae	Pioneer	GC-SZ	0,68	0,19	_	_	0,87
Markhamia tomentosa (Benth.) K.Schum.	Bignoniaceae	Pioneer	GC	0,68	0,19	_	_	0,87
Detarium senegalense J.F.Gmi	Fabaceae	Climax	GC	_	0,19	0,32	0,29	0,81
Afrosersalisia afzelii (Engel.) A. Chev.	Sapotaceae	Climax	GC	0,45	_	0,32	_	0,77
Bridelia atroviridis Müll. Arg.	Euphorbiaceae	Pioneer	GC	0,45	_	_	0,29	0,75
Antidesma laciniatum Mül. Arg. var. membranaceum Müll. Arg.	Euphorbiaceae	Climax	GC	0,68	_	_	_	0,68
Ficus polita Vahl.	Moraceae	Pioneer	GC-SZ	0,68	_	_	_	0,68
Ekebergia senegalensis A. Juss.	Meliaceae	Pioneer	SZ	_	_	0,64	_	0,64
Blighia welwitschii (Hiern) Radlk	Sapindaceae	Climax	GC	0,22	0,38	_	_	0,61
Albizia coriaria Welw.ex Oliv.	Fabaceae	Pioneer	GC-SZ	_	_	_	0,59	0,59
Trema orientalis (Linn.) Bl.	Ulmaceae	Pioneer	GC-SZ	_	_	_	0,59	0,59
Nauclea diderrichii (de Wild. & Th. Dur. Merril.)	Rubiaceae	Climax	GC	_	0,58	_	_	0,58
Strombosia glauscescens J.Leonard var. lucida	Olacaceae	Climax	GC	_	0,58	_	_	0,58
Vernonia colorata (Willd.) Drake	Compositae	Pioneer	GC-SZ	_	0,58	_	_	0,58
Rothmannia longiflora Salisb.	Rubiaceae	Climax	GC	0,22	_	0,32	_	0,54
Anthocleista nobilis G. Don	Loganiaceae	Pioneer	GC	0,22	_	_	0,29	0,52
Albizia glaberrima (Schum. & Thonn.) Benth.	Fabaceae	Climax	GC	_	0,19	0,32	_	0,51
Blighia unijugata Bak.	Sapindaceae	Pioneer	GC	_	0,19	0,32	_	0,51
Ficus lyrata Warb.	Moraceae	Pioneer	GC	_	0,19	0,32	_	0,51
Drypetes gilgiana(Pax)(Pax)&K.Hoffm.	Euphorbiaceae	Climax	GC	0,45	_	_	_	0,45
Entandrophragma cylindricum (Welw.) C.DC.	Meliaceae	Climax	GC	0,45	_	_	_	0,45
Ficus tesselata Warb.	Moraceae	Climax	GC	0,45	_	_	_	0,45
Ficus umbellata Vahl.	Moraceae	Pioneer	GC-SZ	0,45	_	_	_	0,45
Lannea nigritana (Sc. Elliot) Keay var.nigritana	Anacardiaceae	Pioneer	GC-SZ	0,45	_	_	_	0,45
Malacantha alnifolia (Bak.) Pierre	Sapotaceae	Pioneer	GC-SZ	0,45	_	_	_	0,45
Millettia thonningii (Schum. & Thonn.) Bak.	Fabaceae	Pioneer	GC	0,45	_	_	_	0,45
Musanga cecropioides R.Br. ex Tedlie	Cecropiaceae	Pioneer	GC	0,45	_	_	_	0,45
Napoleonaea vogelii Hook. ex Planch.	Lecythidaceae	Pioneer	GC	0,45	_	_	_	0,45
Pancovia pedicellaris Radlk.& Gilg	Sapindaceae	Climax	GC	0,45	_	_	_	0,45
Rinorea yaundensis Engl.	Violaceae	Climax	GC	0,45	_	_	_	0,45
Rothmannia urcelliformis (Hiern) Bullock.ex Robyns	Rubiaceae	Climax	GC	0,45	_	_	_	0,45
Stereospermum acuminatissimum K. Schum.	Bignoniaceae	Climax	GC	0,45	_	_	_	0,45
Tarenna pavettoides (Harv.) Sim	Rubiaceae	Climax	GC	0,45	_	_	_	0,45
Uapaca heudelotii Baill.	Euphorbiaceae	Pioneer	GC-SZ	0,45	_	_	_	0,45
Mansonia altissima A. Chevalier	Sterculiaceae	Climax	GC	0,22	0,19	_	_	0,42
Dracaena mannii Bak.	Dracaenaceae	Pioneer	GC	_	0,38	_	_	0,38
Ficus lutea Vahl.	Moraceae	Pioneer	GC	_	_	0,32	_	0,32
Garcinia afzelii Engl.	Guttiferae	Pioneer	GC-SZ	_	_	0,32	_	0,32

Appendix S1. Contd.

Zanthoxylum leprieurii Guill. & Perr.	Rutaceae	Pioneer	GC	_	_	_	0,29	0,29
Aidia genipiflora (D.C.) Dandy	Rubiaceae	Climax	GC	0,22	_	_	_	0,22
Bertiera racemosa (D. Don.) K. Schum.	Rubiaceae	Climax	GC	0,22	_	_	_	0,22
Cordia platythyrsa Baker	Boraginaceae	Climax	GC	0,22	_	_	_	0,22
Cordia senegalensis Juss.	Boraginaceae	Climax	GC	0,22	_	_	_	0,22
Dichrostachys cinerea (L.) Wight & Arn.	Fabaceae	Pioneer	SZ	0,22	_	_	_	0,22
Diospyros mespiliformis Hochst. Ex A. DC.	Ebenaceae	Pioneer	GC-SZ	0,22	_	_	_	0,22
Dovyalis zenkeri Gilg. I.c	Flacourtiaceae	Pioneer	GC	0,22	_	_	_	0,22
Drypetes aframensis Hutch.	Euphorbiaceae	Climax	GC	0,22	_	_	_	0,22
Drypetes aylmeri Hutct .& Dalz.	Euphorbiaceae	Climax	GC	0,22	_	_	_	0,22
Drypetes leonensis Pax	Euphorbiaceae	Climax	GC	0,22	_	_	_	0,22
Erythrina vogelii Hook. f.	Fabaceae	Climax	GC	0,22	_	_	_	0,22
Ficus thonningii Blume	Moraceae	Pioneer	GC-SZ	0,22	_	_	_	0,22
Flacourtia flavescens Willd.	Flacourtiaceae	Pioneer	SZ	0,22	_	_	_	0,22
Garcinia ovalifolia Oliv.	Guttiferae	Pioneer	GC-SZ	0,22	_	_	_	0,22
Grewia pubescens P.Beauv.	Tiliaceae	Pioneer	SZ	0,22	_	_	_	0,22
Irvingia robur Mildbr.	Irvingiaceae	Climax	GC	0,22	_	_	_	0,22
Mimusops kummel Hochst.	Sapotaceae	Pioneer	SZ	0,22	_	_	_	0,22
Morelia senegalensis A.Rich.ex DC	Rubiaceae	Pioneer	GC-SZ	0,22	_	_	_	0,22
Parkia bicolor A.Chev.	Fabaceae	Climax	GC	0,22	_	_	_	0,22
Parkia filicoidea Welw. ex Oliv.	Fabaceae	Climax	GC	0,22	_	_	_	0,22
Psychotria psychotrioides (DC.) Roberty	Rubiaceae	Pioneer	GC-SZ	0,22	_	_	_	0,22
Pterygota bequaertii De Wild.	Sterculiaceae	Climax	GC	0,22	_	_	_	0,22
Rhodognaphalon brevicuspe (Sprague) Roberty	Sterculiaceae	Climax	GC	0,22	_	_	_	0,22
Symphonia globulifera Linn. f.	Guttiferae	Climax	GC	0,22	_	_	_	0,22
Voacanga africana Stapf.	Apocynaceae	Pioneer	GC	0,22	_	_	_	0,22
Zanha golungensis (Hiern)	Sapindaceae	Pioneer	GC-SZ	0,22	_	_	_	0,22
Erythrina mildbraedii Harms	Fabaceae	Climax	GC	_	0,19	_	_	0,19
Ficus vogeliana (Miq.) Miq.	Moraceae	Pioneer	GC	_	0,19	_	_	0,19
Monodora tenuifolia Benth.	Annonaceae	Pioneer	GC	_	0,19	_	_	0,19
Vernonia conferta Benth.	Compositae	Pioneer	GC	_	0,19	_	_	0,19

FR: Forest Relics; **COCS**: Coco System; **COFS**: Coffee System; **FS**: Follow Systems.
GC-SZ: species encountered in several phytochoria in continental tropical Africa, **GC**: Guinean-Congolese regional centre of endemism species, mainly consists of humid forest domains, **SZ:** Sudanese-zambezian regional centre of endemism , mainly consists of savannah or dry vegetation specie.

Pioneer : First stage of natural succession ; **Climax :** last stage of natural succession

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Determinants of public preferences for Hawassa Amora-Gedel recreational park, Southern Ethiopia

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This study investigates the economic value of Hawassa Amora-Gedel recreational park and determines the factors that affect the public's willingness to pay for the quality improvement of the recreational park. A contingent valuation method was applied to measure public willingness to pay (WTP) for the quality improved recreational park. Based on random sampling technique, 390 visitors were selected to determine people's preferences on the park improvement. The Heckman selection model was used to analyze the factors affecting people's participation in the park improvement and the valuation of the quality improved recreational park. The analysis of the determinants of WTP shows that education, duration of the park users in the watershed, income, urban residents and multiple uses of the recreational park influence the park improvement positively. The valuation of the recreational park in terms of entrance fee shows that visitors are willing to pay Birr 25.77 (US$1.43) per person when the quality of the recreational park is improved, which is five times higher than the current charge for a single visitor on the status quo.

Key words: Contingent valuation method, Heckman selection model, recreational park, willingness to pay.

INTRODUCTION

Lake Hawassa has given the natural beauty to Hawassa city, which was established in 1956 with the authorization of Emperor Hailesilassie with the appropriate master plan for tourist attraction along the shore of the lake. Amora-Gedel recreational park is one of the amenity values that Lake Hawassa benefits the society. The recreational park was given the name "Amora-Gedel" with the reference to the mass of Marabou storks that exist at the park, where "Amora" is synonymous to Marabou stork (*Leptoptilos crumenifer*) and "Gedel" to downstream location. So, "Amora-Gedel" refers to the site for large number of Marabou storks. The park was earlier occupied by Princess Tenagne Teferi, who was the daughter of Emperor Hailesilassie. After 1974 it has been reserved as main recreational park for Hawassa people under Hawassa municipality.

The unique birds, beautiful wild lives in the recreational park, and the impressive and breath taking view of the sun set over the lake are some of the special memories of the recreational park. Large number of congregatory waterbirds occurs on the lake around the park, with 20,000 birds counted along less than 25% of the

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shoreline. Some wild animals that are unique to Ethiopia such as Colobus monkey and others add values to the recreational park. However, this recreational park has not been well managed and the majority of the visitors have not been satisfied with the status quo services provided at the recreational park. The aesthetic quality of the park is assumed to be valuable to society, yet few policy makers incorporate the value of the biodiversity it supports and the recreational opportunities it provides into the resource management. The decisions on the park management without incorporating the economic value of the recreational park have resulted in the resource degradation.

The benefits of investments in the recreational park improvement are not all appreciated locally as society realizes the benefit of the resource services only after it has disappeared. This limits the ability of users to invest in resource conservation. Lost recreational opportunities are understood only after the park ecosystem has been degraded. This calls for a necessary policy for the resource management on the basis of environmental valuation. Valuation forms a key exercise in economic analysis and provides important information for conservation of resources. The basic aim of valuation is to determine people's preferences how much they are willing to pay for, and how much better or worse off they would consider themselves to be as a result of changes in the supply of different goods and services. It, therefore, provides a means of quantifying the benefit that people receive from natural resources, the costs associated with their loss, and the relative profitability of resource uses which are compatible with its conservation. Attaching monetary values to recreational park goods and services aims to make them directly comparable with other sectors of economy when activities are planned and decisions are made. According to Mokhtari and Hosseinfar (2013), it is necessary to analyze the recreational parks from the economic and social point of view so as to control the balance of human-environment relationships for sustainable benefits of the recreational resources. Therefore, the idea behind assigning an economic value on the recreational benefits before ecosystem-altering decisions are made is to recognize the potential costs up front and thereby put park-related decisions on a more economically sound footing.

Unfortunately, integrated information about economic values of the recreational parks which is important for their conservation has been limited in the region. Those who would estimate the benefit of controlling the resources degradation face a dilemma because the studies that have valued local recreational parks are of limited use in determining the resources quality policy changes due to unreliable data. Unreliable results on the economic value of the recreational parks due to lack of quality and sufficient data needed for research have, therefore, contributed little value to the management of local recreational parks. This study differs from previous studies on Lake Hawassa in quantifying the resource use with reference to recreational value in monetary terms so as to reduce its degradation more effectively. Hence, it contributes to sustainable resource use providing the necessary economic information of the lake as a source of recreational benefits to develop socially acceptable, environmentally sound and financially feasible resource management. The objective of this study was to analyze the economic value of quality improved recreational park and the factors determining the visitors' willingness to pay for the recreational park improvement. The improvement program includes establishment of zoo site and manage the wild animals in the recreational park. When the recreational park is improved, the visitors are supposed to pay for the scenic value of the park. Therefore, are the beneficiaries willing to pay for the improvement of the resource quality? If yes, what are the determinants of their willingness to pay for the quality improvement? This study is limited to the use value of the lake as recreational benefit. The other use values of the lake such as fish products, potential irrigation water, and the non-use value such as the existence value and bequest value of the lake have not been considered in this study.

The remaining part of the study is organized as follows. Section two presents some reviews of theoretical and empirical literature about the recreational use of water resources and their economic valuation. With the aim of ensuring the sustainable use of resource, this section overviews the empirical literature on most widely used technique (contingent valuation) of environmental valuation in terms of recreational value describing the strength and limitation of the contingent valuation method over travel cost method in the application for recreational park. This section also briefly presents some facts about the Heckman selection model describing how it minimizes the selection bias. Section three elaborates the methodology followed in the valuation of the recreational park. This section presents the Heckman selection model with a brief discussion on why this model has been preferred to other models. Section four presents the descriptive and empirical analyses with the help of the Heckman selection model (two-step) to determine the probability of participation and the valuation of participants in support of the proposed improvement. Finally, conclusions are provided based on the results of this specific study.

LITERATURE REVIEW

Recreational use of water resources and economic valuation

Rivers, streams, wetlands, lakes and reservoirs host a vast array of aquatic ecosystems that provide many benefits to humans (National Research Council, 2004). The various recreational services provided by lakes and rivers like fishing, swimming, boating, hunting, picnicking, or nature appreciation in general are all enhanced by the body of water's natural beauty (Corrigan et al., 2007). The recreational opportunities provided by these resources generate positive impact to local economies through spending on materials and supplies by users and visitors. For example, sales that occur due to tourism like camping fees, restaurant sales, and cultural goods shopping centers increase the wellbeing of the local community (Otto et al., 2012). According to Othman and Jafari (2019), recreational parks help reduce stress and the anxieties of urban life and foster community relations, balancing the built and natural environment and therefore contribute to the overall well-being of the urban community. So, expanding and improving outdoor recreation opportunities is a no-lose proposition for residents as increased access to recreation opportunities enhances quality of life and health of the users (Otto et al., 2012).

Water resources play an important role as recreational destinations which contribute to the increase in tourism industry (Malan, 2010). These activities rely solely on the environmental quality of the lakes. That means the recreational uses of lakes are affected by changes in water quality. Water pollution caused by industrial effluents and municipality sewage may have severe consequences for the aquatic ecosystems as well as the tourism sectors, which rely on the water resources as a source of income and revenue generation. Yaping (1998) states that improvement of water quality increases demand for recreation in lakes with people willing to pay a higher price for better quality of environmental services.

The valuation task is complicated by the fact that the aesthetic value of lakes and rivers are nonmarket goods in that they are not provided by the interaction of buyers and sellers in a market (Corrigan et al., 2007). Since the services that the ecosystems provide and how they are affected by human actions are imperfect and difficult to quantify, the resources continue to be depleted and degraded at an unsustainable rate (National Research Council, 2004; Birol et al., 2006). Lack of available data in applying valuation methods in developing countries like time-series data on resource use productivity or socio-economic statistics on visitors to natural resource amenities can result in the valuation relying on rough approximations rather than accurate data and uncertainty as to whether the sample surveyed is representative of the population as a whole (UNEP, 1998). To implement the most efficient social and economic policies that prevent the excessive degradation and depletion of environmental resources, it is necessary to establish their full value, and to incorporate this into private and public decision-making processes.

Economic values are usually distinguished as use and non-use values. Use value is further classified into direct and indirect use values. Direct use values of water resources can be extracted, consumed or directly enjoyed. It is therefore known as extractive or consumptive use value (Hawkins, 2003). Direct use values of water resources include the consumption of fish for food, water for drinking, cooking and washing, irrigation, recreation and tourism. Indirect use of water resource services includes energy production and nutrient recycling. Non-use values are often intangible and include the value of leaving opportunities for future generations (bequest value) and the value from knowing that the resources exist, which is known as existence value. For water resource goods and services that are traded in the market place and whose prices are not distorted, market prices can be used as indicators for economic values. Often, however, most of goods and services do not have a market price and shadow pricing techniques can be applied to determine their economic values (Schuyt and Brander, 2004). Among several shadow valuation methods that economic theory distinguishes, a well-known method is contingent valuation, which directly obtains consumers' willingness to pay for a change in the level of environmental good, based on a hypothetical market.

Contingent Valuation Method (CVM) and its advantage over Travel Cost Method (TCM)

Contingent Valuation (CV) is the most widely accepted stated preference method used for estimating total economic value, including all types of non-use values (Hajkowicz and Okotai, 2006). The purpose of the contingent valuation method is to elicit individuals' preferences, in monetary terms, for changes in the quantity or quality of nonmarket environmental resources, which have the characteristics of non-excludability and non-divisibility (Perman et al., 2003; Birol et al., 2006). In conducting the contingent valuation surveys, acknowledgement of all stakeholders, careful survey design and administration, and post survey debriefings (particularly for examining the reasoning behind irrational responses) help improve the process of valuation of environmental resources (Duberstein and de Steiguer, 2004). To conduct a CV survey, special attention needs to be paid to the design and implementation of the survey. Focus groups, consultations with relevant experts, and pretesting of the survey are important pre-requisites. Decisions need to be taken regarding how to conduct the interviews; what the most appropriate payment bid vehicle is for example an increase in annual taxes, a single-one-off payment, a contribution to a conservation fund, among others as well as the WTP elicitation format. The survey may be conducted through face-to-face interviews, telephone or mail surveys. In developing countries, face-to-face interviews are considered the most appropriate because of high rates of illiteracy and defective telephone networks. Fortunately, personal interview is the best approach for reducing sampling bias (McClelland et al., 1993; Turner et al., 2004; Birol et al., 2006).

The contingent valuation estimates of Sauk river chain of Lakes watershed and Lake Margaret in central Minnesota yield mean WTP for Margaret of US$267 and for Sauk of US$17 (Welle and Hodgson, 2011). The findings reflect that the substantially higher WTP for Margaret respondents is driven by the higher level of recreation, the higher proportion of lakeshore ownership in the watershed, greater confidence in the effectiveness of the policy and higher average income. The analysis demonstrates that the watersheds are different in terms of how property owners in the watershed relate to the impaired lakes. The Margaret-Gull Chain has a high degree of surface water as percentage of watershed acreage compared to the Sauk, and consequently a high proportion of lakeshore owners relative to the population of property owners in the watershed. The Margaret-Gull Chain also has many highly-valued lake properties owned by people with high income and a large amount of recreational use by lake owners and visitors. The water quality improvement fee on water utility use of US$30, which was the focal point of the discussion, would mostly accepted by property owners. The findings imply that mean WTP would exceed the $30 amount for many households, so total benefits would be expected to exceed costs. While these revenues would be collected from all water utility customers, those closest to the improved surface waters would stand to benefit more than their costs (Welle and Hodgson, 2011).

The advantage of using Contingent valuation technique over Travel Cost Method (TCM) in valuation of water resources is its ability to capture both use and non-use values. Perman et al. (2003) explains the advantages of CVM over TCM as its answers go directly to the theoretically correct monetary measures of utility changes. This technique is enormously flexible in that it can be used to estimate the economic value of virtually anything. For example, using other valuation methods like hedonic pricing and travel cost method will underestimate the benefits people obtain from improved water resources as they measure only use values. In practice, getting more information close to reality through revealed preferences derived from observed behavior is a difficult task in non-market resources. The Travel cost approach assumes that various factors affecting visitors' travel costs, including both direct costs and opportunity costs of visitors' time, influence the length and frequency of visitation to a given destination. However, the travel cost approach has limitations particularly in applications to multiple destination trips and large number of local visitors with negligible travel cost to the site.

Using travel cost method, researchers may find income inversely related to demand and conclude that recreational park use is an inferior good. However, this conclusion contradicts the case where outdoor recreation is considered to be a luxury good. Such an inverse relationship may be a result of a large number of local visitors who use the recreational park frequently but whose demand for recreation in the park is somewhat irrelevant to income due to the short distance to the site. Contingent valuation, therefore, provides more meaningful results in such cases where travel cost method understate the value the residents place on the recreational park due to the negligible travel cost they incur when visiting the park. In the valuation of improved water quality for recreation in East Lake, Yaping (1998) applies both contingent valuation and travel cost methods. The multivariate analysis of travel cost method reveals income and education are insignificant factors affecting demand. Furthermore, travel cost method shows that income is inversely related to demand for East Lake, which implies that the lake is inferior good. However, the East Lake is still regarded as a luxury good (Yaping, 1998) whereas, the contingent valuation method of the same lake shows that education and income are significant at 1% level. The comparison of the values from TCM and CVM shows that the net addition of consumer surplus due to quality improvement with TCM is RMB¥18.09/m^2 at swimming level while the total WTP in the recreational area with CVM is RMB¥21.41/m^2 if water becomes clean enough for swimming (Yaping, 1998). This finding reflects that CVM value is higher than that from TCM.

Despite the strengths of this technique over others regarding its ability to estimate both values (use and non-use) and evaluate irreversible changes, contingent valuation method is criticized for its limitations in addressing full services and functions of the environmental resources. CVM is also criticized for its lack of validity and reliability (Mathews, 1999; Birol et al., 2006). As this technique is survey-based and all relevant stakeholders are not included in valuing resource for reaching effective resource management, outcomes of contingent valuation may, however, be less accurate (Duberstein and de Steiguer, 2004). In addition, since the contingent survey instrument is of a hypothetical market, the data is criticized for its bias, some of which are hypothetical bias and strategic bias (Birol et al., 2006; Krantzberg and de Boer, 2006).

Hypothetical bias is caused by the hypothetical market nature of the contingent valuation. Hypothetical bias is created when respondents are not capable of knowing the environmental resource values without participating in a market in the first place in spite of their well preparation to reveal their true values (Turner et al., 2004) whereas, strategic bias means that people purposively state a higher or a lower price than what they are willing to pay; in this way the resource will be either underestimated or overestimated and someone else will bear the over- or underestimated cost (Bulov and Lundgren, 2007). For instance, respondents may deliberately understate their WTP when they believe that the actual fees they will pay for provision of the environmental resources will be influenced by their response to the CV question. Conversely, realizing that payments expressed in a CV exercise are purely hypothetical, respondents may overstate their true WTP hoping that this may increase the likelihood of a policy being accepted (Birol et al., 2006). In the social sciences, bias in the estimated effects from any given study is very difficult to rule out, no matter how intuitively appealing the methodology. There is, unfortunately, no statistical silver bullet. Fortunately, sometimes the Heckman selection Model as an approach is applied to observational data for the purpose of estimating an unbiased causal effect (Briggs, 2004).

Heckman selection model for resource valuation

When the population of the study area is quite large with no boundaries, sampling can only define the scope that is selected by the researchers. It is possible to insert irrelevant variables or not to include associated variables in the sample, which may cause sample selection bias. Heckman's two-step model explicitly resolves potential sample selection bias (Zhang et al., 2014). The Heckman two-step model examines the two steps leading to respondents' decisions in a single model while distinguishing the influence of different factors between these two steps. That means it investigates the factors influencing willingness to pay along with payment level in a single model. It also prevents the disturbance of respondents whose WTP is zero.

In contingent valuation of Cheimaditida wetland, the mills inverse ratio, which is significantly different from zero, confirms the sample selection bias. The regression of the estimated inverse mills ratio against the parameters of the valuation equation produced an R^2 value of 0.10 which indicates an insignificant level of correlation. Thus the two-step model is appropriate for estimating the participation and valuation decisions for the proposed improvement of Cheimaditida wetland (Birol et al., 2006).

In Heckman two-step model, all explanatory variables must be contained in the first stage, while the second stage must contain fewer variables than the first stage (Baum, 2006). That means, Heckman model should include at least one variable in the first stage that is different from the variables included in the second stage. Based on this principle, Zhang et al. (2014) incorporate eight explanatory variables in the first stage and four explanatory variables in the second stage. The finding of CVM with Heckman's two-step model shows that farmers have positive WTP with their average annual WTP being US$64.39/household and income, residential location; arable land area and contracted water area are significantly related to payment levels for Poyang Lake Wetland (Zhang et al., 2014).

The Heckman model can help social work research by providing researchers with methods of detecting and correcting sample selection bias (Cuddeback et al., 2004). In other words, the application of Heckman's sample selection model shows efficiency and robustness of controlling for selection bias through a two-stage process (Gou, 2009). This model allows using information from non-supporting individuals to improve the estimates of the parameters in the regression model. Hence, the Heckman selection model provides consistent, asymptotically efficient estimates for all parameters in the model. Generally, the selection equation is estimated by maximum likelihood as an independent probit model to determine whether to participate and pay using information from the whole sample of supporters and non-supporters. A vector of inverse Mills ratios (estimated expected error) can be generated from the parameter estimates. The WTP amount, *y*, is observed only when the selection equation equals 1 (i.e. individuals support the program) and is then regressed on the explanatory variables, *x*, and the vector of inverse Mills ratios from the selection equation by ordinary least squares. Therefore, the second stage reruns the regression with the estimated expected error included as an extra explanatory variable, removing the part of the error term correlated with the explanatory variable and avoiding the bias.

In studying the relation between a dependent variable (WTP*)* and a set of explanatory variables, the Heckman model is explained as a proportion of the observations falls on WTP = *constant a*, and no observations are found below the known constant *a*. For instance, the WTP amount ranges from US$20 to US$100 and some respondents prefer to remain neutral, which literally WTP = 0. Therefore, respondents whose WTP is below US$20 are not observed. Consequently, the estimation of the parameters is violated. One way to deal with the case of observations found below a known constant is just making an assumption that it has originated from censoring of some latent variables. The simplest way of expressing the relation between WTP and the latent variable is using the Tobit model (Tobin, 1958), which is an extension of the Probit model.

$$WTP^* = \begin{cases} WTP, \text{if WTP} > \text{a} \\ \text{a}, \text{if WTP} < \text{a} \end{cases} \quad (1)$$

This Tobit model was later generalized by Heckman who introduced further a latent variable to take account of selection effects (Jonsson, 2008). There is a separate latent variable doing the censoring in Heckman model that is different to the variable determining the outcome equation. This difference also requires taking account of the correlation between the disturbances in the selection and outcome equation.

METHODOLOGY

Description of the study area

The recreational park (Figure 1) is located in Hawassa city along

Figure 1. Hawassa Amora-Gedel recreational park.

the lake side of Hawassa in the southern Ethiopia with the geographical location of 6°33' – 7°33'N and 38°22' – 39°29'E. Hawassa catchment has elevations ranging from 1692 to 1742 meter above sea level. The surface area of Lake Hawassa on average is 93.5 km^2 with maximum depth of 32.2 m and the average depth of 13.6 m. The seasonal variation of the lake water level ranges from 0.09 to 1.57 m with an average of 0.66 m (Halcrow, 2009). Unlike other closed lakes with alkaline characteristics, Lake Hawassa is one of the few fresh closed lakes with its electrical conductivity of 802 μS/cm, and pH=8.6 (Tenalem et al., 2007). The freshness of the lake water could be justified as water from Lake Hawassa catchment can flow to lakes of lower altitude of the Ethiopian rift valley, for example Lake Ziway, Langano, Abyata, Shala, Abaya and Chamo through the subsurface when the hydrological condition permits (Yemane, 2004).

Survey design and development

A contingent valuation survey instrument was designed as the scenario informs the change in the recreational park under valuation. It explains clearly how that change would come about; how it would be paid for; and the larger context that is relevant for considering the change. The question was phrased using the payment vehicle of entrance fee for quality improved recreational park. The design was to ensure the values expressed by the respondents would be those held for the recreational park management. Based on random sampling technique, 390 respondents were selected from the recreational park users using the formula: $n > 104+m$ (Green, 1997), where n = sample size, and m = the parameters that are expected to affect the willingness to pay for the park quality improvement. In addition, for regression equations using six or more predictors, an absolute minimum of 10 participants per predictor variable is appropriate. However, if the circumstances allow, a researcher would have better power to detect a small effect size with approximately 30 participants per variable (Van Voorhis and Morgan, 2007). To make the sample representative of the whole population, the sample size obtained using the above formula was critically examined in line with the proportionality of the sample to total population. The questionnaire was designed to consist three sections. The first section was about the respondents' knowledge, attitudes, and perception about the resource and its environmental problems, which provide an explanation of the environmental issue of interest together with information on the change in quality. The second section was about the contingent valuation scenario created for the resource improvement program and the respondents' willingness to pay in support of the proposed improvement. The third section was about the respondents' socio-economic characteristics like information on the respondents' educational level, income, and other socio-economic and demographic characteristics, which enable analysis and verification of the validity of responses on willingness to pay given by respondents.

Empirical model specification

When the population of the study area is quite large with no boundaries, sampling can only define the scope that is selected by the researchers. It is possible to insert irrelevant variables or not to include associated variables in the sample, which may cause sample selection bias. Heckman's two-step model explicitly resolves potential sample selection bias (Zhang et al., 2014). The model examines the two steps leading to respondents' decisions in a single model while distinguishing the influence of different factors between these two steps. That means it investigates the factors influencing willingness to pay along with payment level in a single model. It also prevents the disturbance of respondents whose WTP is zero. It is a two equation model: the regression model and the selection model.

Selection equation:

$$\text{Participation} = Z_i\gamma + u_i \tag{2}$$

Regression or observation equation

$$WTP = \beta X_i + \varepsilon_i \tag{3}$$

From the first stage (Participation), Mill's inverse ratio was constructed and then regressed by Ordinary Least Squares (OLS) as:

$$WTP = \beta X + \rho_{\varepsilon u}\sigma_\varepsilon \lambda_i(-Z_i\gamma) \tag{4}$$

Since the correlation between two disturbance terms was different from zero ($\rho_{\varepsilon u} \neq 0$), the OLS estimates were biased as it did not account for estimation of γ, which is an additional term that depends on the inverse Mill's ratio evaluated at $Z\gamma$. This omitted variable, $\lambda(\boldsymbol{z}\gamma)$, was correlated with X (Wooldridge, 1999).

Under the assumption that the error terms were jointly normal, we had:

$$WTP = \beta X + \rho_{\varepsilon u}\sigma_\varepsilon \lambda_i(-Z_i\gamma)$$

Where, $\rho_{\varepsilon u}$ is the correlation between unobserved determinants of propensity to support (u) and unobserved determinants of WTP (ε), σ_ε is the standard deviation of ε, and λ is the inverse Mill's ratio evaluated at $-Z_i\gamma$.

The WTP equation was estimated by replacing γ with probit estimates from the first stage, constructing the λ term, and including it as an additional explanatory variable in linear regression estimation of the WTP equation.

The Inverse Mill's ratio [$\lambda_i(-Z_i\gamma)$] was calculated using the formula:

$$\lambda_i(-Z_i\boldsymbol{\gamma}) = \frac{\varphi(-Z_i\gamma)}{1-\phi(-Z_i\gamma)} \tag{5}$$

Where, φ denotes the standard normal density function, and ϕ denotes the standard normal cumulative distribution function.

The Heckman model can help social work research by providing researchers with methods of detecting and correcting sample selection bias (Cuddeback et al., 2004). In other words, the application of Heckman's sample selection model shows efficiency and robustness of controlling for selection bias through a two-stage process (Gou, 2009). This model allows using information from non-supporting individuals to improve the estimates of the parameters in the regression model. Hence, the Heckman selection model provides consistent, asymptotically efficient estimates for all parameters in the model.

Generally, the selection equation is estimated by maximum likelihood as an independent probit model to determine whether to participate and pay using information from the whole sample of supporters and non-supporters. A vector of inverse Mill's ratios (estimated expected error) can be generated from the parameter estimates. The WTP amount, y, is observed only when the selection equation equals 1 (*i.e*. individuals support the quality improvement program) and is then regressed on the explanatory variables, x, and the vector of inverse Mill's ratios from the selection equation by ordinary least squares. Therefore, the second stage reruns the regression with the estimated expected error included as an extra explanatory variable, removing the part of the error term correlated with the explanatory variable and avoiding the bias.

To estimate the economic value of the recreational park and the factors that determine the willingness to pay for the park, the frequency of visit, satisfaction, gender, age, marital status, education, employment status, ownership of permanent asset (agricultural land) in the watershed, duration of the households in the watershed area, household's annual income, residential location were considered. Taking into account the factors that significantly affect the households' willingness to pay for the quality improved fish product, the equation for parametric mean WTP was derived as:

$$WTP = \beta_0 + \beta_1\text{frequency of visit} + \beta_2\text{satisfaction} + \beta_3\text{gender} + \beta_4\text{age} + \beta_5\text{marital status} + \beta_6\text{education} + \beta_7\text{employment} + \beta_8\text{agricultural land} + \beta_9\text{duration} + \beta_{10}\text{income} + \beta_{11}\text{location} + \beta_{12}\text{mill's inverse} \tag{6}$$

RESULTS AND DISCUSSION

Socio-economic characteristics of the recreational park visitors

From the total respondents, 78.2% were males while 21.8 were females (Table 1). The employment status reflects that the respondents participate in various economic activities like employment in governmental or non-

Table 1. The respondents' socio-economic characteristics

Variables		Absolute figure	Percentage
Gender	Male	305	78.2
	Female	85	21.8
Age	18 – 35	216	55.4
	36 – 50	156	40
	51 and above	18	4.6
Marital status	Married	304	77.9
	Not married	86	22.1
Family size	1 – 5	278	71.3
	6 – 12	112	28.7
Education	No formal education	7	1.8
	Primary school	125	32.1
	Secondary school	145	37.1
	Tertiary level	113	29
Employment status	Employee (Gov/NGO)	115	29.5
	Self-employed	121	31.1
	Agriculture	154	39.4
Income (Birr)	25,000 – 40,000	27	6.9
	40,001 – 60,000	156	40
	60,001 – 80,000	155	39.7
	> 80,000	52	13.4
Residential location	Urban	241	61.8
	Rural	149	38.2

[2]Gov = Governmental Organization; NGO = Non-Governmental Organization.
Source: computed from own data.

governmental organization, self-employment, and agricultural activities. The majority of the respondents were married and the family size of the respondents ranges from 1–12 with the average size of 4.4. The educational background reveals two-third of the respondents attained secondary or tertiary levels. About 55% of the respondents were in the youth age category while only 4.6% were in the age range between 51 and 87 years. The residential location of the respondents reveals that 61.8% were from urban areas while 38.2% from rural areas.

Responses of the visitors to the contingent valuation of the recreational park

The majority of the respondents expressed their willingness to participate in the recreational park improvement in order to provide the services at the maximum potential. About 80% stated their monetary contribution for the park improvement in terms of entrance fee ranging from Birr 5 to Birr 50, with the average value of Birr 24. From the respondents who expressed their willingness to participate in the park quality improvement, 70% stated the entrance fee ranging from Birr 20 to Birr 30, with the modal value of Birr 30 (Figure 2). The visitors who stated higher entrance fee were found to be of higher educational level and higher annual income earners with relatively small family size. The respondents who were not satisfied with the current status of the recreational park reflected their willingness to participate in the park improvement stating relatively higher entrance fee. The majority of the respondents who expressed their willingness to participate in the quality improvement were in the age range of 20 to 35 years. The mean willingness to pay for this age range was Birr 23.59 while for the age group higher than 35 years the average value of the entrance fee was Birr 24.64 though the variation of the average entrance fees of the two age groups is not statistically significant.

However, about 20% of the respondents preferred to remain neutral in the park quality improvement program. The reasons for not to participate in the quality improvement program was that these respondents were not able to afford any contribution at the time of the survey instrument. These respondents were found to earn low annual income and administer large family size. About 63% of them were also found to reside at distance more than 20 km from the recreational park. These

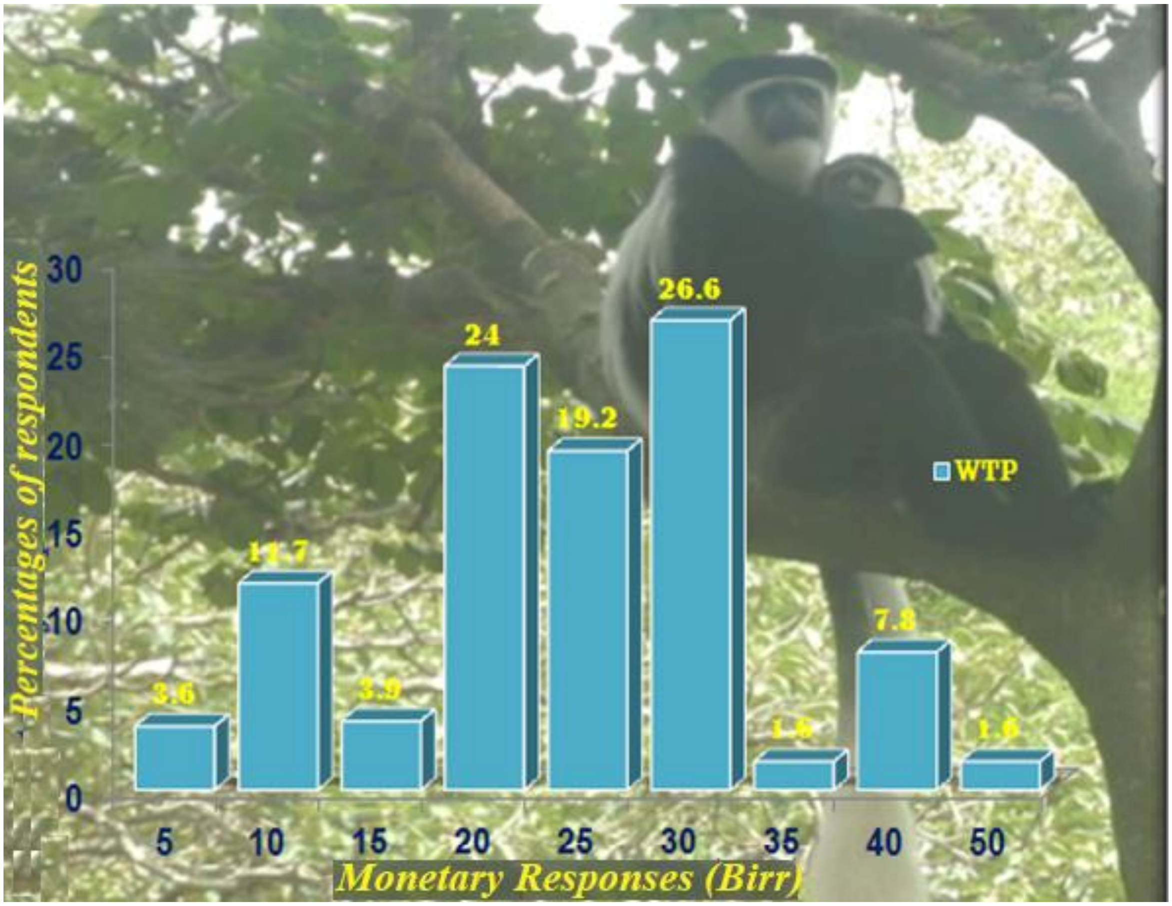

Figure 2. Distribution of monetary responses for the recreational park.
Source: Summary of own data.

respondents might have less access to the resource due to the travel costs to the recreational park.

Econometric analysis of contingent valuation for recreational park

The Heckman selection method was implemented in determining the factors affect the visitors' participation in the park quality improvement and the valuation of the improved recreational park with the payment vehicle of entrance fee. The contingent valuation results show that education, agricultural land owners, visitors who stayed longer in the watershed, income, multiple users of the park and urban residents positively influence the participation in the park quality improvement while those who were satisfied with the status quo, older visitors and those who administer large family size are less likely to participate in the resource quality improvement.

The valuation of the recreational park reveals households with a number of visits per year, male households, married visitors, educated households, employees with reference to farmers, agricultural land owners with reference to no asset owners in the watershed, visitors who stayed longer in the watershed, households with higher annual income and urban residents are willing to pay higher amount for the improved recreational park while the households who are satisfied with the current services and older households attach lower monetary value to the recreational park. The significant Mill's inverse ratio that was generated from the model as additional explanatory variable indicates that there was selection bias. The Heckman selection model was therefore applied to correct such selection bias.

The measure of the overall significance of the model with the null hypothesis that all coefficients were zero was rejected at 1% of significance level in favor of the hypothesis that at least one of the coefficients was different from zero. The pseudo R^2 was 0.5166 (Table 2), which reflected that 51.66% of the variation in the participation was explained by the variables included in the model. The adjusted R^2 (0.4911) reveals the variation in the valuation was explained by the explanatory variables by 49.11%. The overall significance level of Heckman selection (probit) at 1% implies that the model was acceptable to explain the variation in participation for

Table 2. Heckman two-step estimates of participation and valuation for recreational park.

Parameters	Participation model [coefficient (S.E)]	Valuation model [coefficient (S.E)
	Heckman's two-step (Probit)	Heckman's two-step (OLS)
Freqvisit	0.0911(0.2172)	0.1377(0.0442) ***
Satisfaction	-0.6349(0.2359) ***	-0.3106(0.0803) ***
Gender	0.2689(0.2592)	0.2289(0.0642) ***
Age	-0.0520(0.0138) ***	-0.0294(0.0061) ***
Marstat	0.3878(0.2800)	0.2371(0.0760) ***
Famlsize	-0.2187(0.0693) ***	-0.0383(0.0275)
Head	0.7425(0.3022)	–
Education	0.0983(0.0447) **	0.0323(0.0138) **
Govngo	-0.5609(0.3556)	0.3371(0.0853) ***
Selfemp	-0.3573(0.3418)	0.4431(0.0687) ***
Agricland	0.7264(0.3838) *	0.3455(0.1184) ***
Duration	0.3711(0.1893) **	0.1520(0.0781) ***
Income	0.4751 (0.1466) ***	0.2217(0.0560) ***
Distance	0.2388(0.2754)	0.0019(0.0781)
Usetype	0.8244(0.2965) ***	0.0189(0.1429)
Location	0.8421(0.3416) **	0.4927(0.1104) ***
Millsinv	–	-2.3898(0.9221) ***
Constant	-1.3468(1.0034)	2.3358(0.2402) ***
Sample size	390	308
Log likelihood	-96.9682	–
R^2	0.5166	0.5193
Adjusted-R^2	–	0.4911

***1% significance level; **5% significance level; *10% significance level with two-tailed test.
Source: Heckman model results of own data.

the park quality improvement by the explanatory variables.

Freqvisit

Freqvisit stands for the frequency of visit. The households with a number of visits per year are found to be positive and significant at 1% level. It can be explained as the households who expressed their motivation to participate in the resource improvement are likely to pay higher value for the improved recreational park. Tameko et al. (2011) also found frequency to be significantly correlated with willingness to pay. It implies that those who visit the urban park regularly are more willing to pay for the implementation of the management plan.

Satisfaction

It is negative and significant at 1% level in the participation and valuation of the recreational park. The households who were satisfied with the current services of the recreational park are less likely to participate in the quality improvement and also found to attach lower amount for the improved recreational park. This implies that those who have identified the poor services of the recreational park are willing to pay for the improvement. Yaping (1998) observed the positive and significant impact of visitors' judgment-on-quality on willingness to pay for the quality improvement.

Gender

It is positive and significant at 1% level. It implies that males are willing to pay higher monetary amount for the improved recreational park as compared to females. This can be explained as males have more access to outdoor activities and make decisions on finance to manage resources as compared to females. Tameko et al. (2011) explained the positive and significant coefficient of gender as more males are more willing to pay for the urban park improvement than females.

Age

It is negative and significant at 1% level, which implies that youths are more likely to participate in resource quality improvement and attach higher amount for the improved recreational site as compared to older people. The negative sign for age is consistent with the finding of Khan (2006) who explained as age appears to be an important determinant of demand for park visitation and inversely related. That is, as age increases, participation in the proposed improvement and valuation of the park decrease. Corrigan et al. (2007) explained the negative and significant effect of age in the study of aesthetic values as the youngest visitors have more free time and are more likely to visit attractive resources. Tameko et al. (2011) explained the negative and significant effect of age on willingness to pay as the older the respondents are the less they are likely to pay for the improved recreational park. McKean et al. (2005) also reflected age to negatively and significantly affect the water-skiing activity. However, Adili and Robert (2016) find positive and significant influence of age on the number of days a visitor stays in the park, and justifies as older visitors spent more days for recreation at Kilimanjaro National Park compared to middle aged and younger visitors.

Marstat

Marstat stands for the marital status. It is significant at 1% significance level on the valuation of the recreational park. The positive and significant effect of marital status on the valuation reflects that married individuals can help each other in covering other costs and then make decision on water resource improvement program as compared to unmarried individuals. Married couples may consider the bequest value of the resource and attach higher amount for the improved recreational park as compared to singles.

Famlsize

Famlsize refers to family size. It is negative and significant at 1 percent of significance level for the participation. Households with large family size are less likely to participate in the park improvement program as compared to households who administer small family members. Herath (1999) also found family size to be negative and significantly influence the WTP for the recreational values of Lake Mokoan in Victoria. This finding is again consistent with that of Moges (1999) in the analysis of willingness to pay for Lake Tana recreational site.

Education

The positive sign and significant effect of education on participation and valuation of the recreational park reveal educated people have better understanding on both use and non-use values of natural resources and ensure their motivation to participate in the improvement program. Educated people can easily realize the poor quality of non-marketable goods and the consequences of inadequate waste management and hazardous chemicals released from the industries and domestic wastes. People with higher educational level give much attention to recreational sites understanding that the scenic beauty has uncountable benefits to refresh mind stressed with various activities. Therefore, education positively and significantly influences the participation in the quality improvement and valuation for the improved recreational park. Corrigan et al. (2007) stated that willingness to pay increases with educational attainment in the study of aesthetic values of lakes and rivers.

Employment status (Gov/NGO employee or self-employed)

Employees are more likely to pay higher amount for the recreational park with reference to farmers. Most of the time farmers value natural resources in terms of the major uses they benefit like irrigation. The employees give more attention to the recreational value of the resource in addition to irrigation and hence reflect their willingness to pay high amount for the improved recreational park.

Agricland

Agricland stands for agricultural land. It is significant at 10 percent level for participation and 1% significance level for the valuation of the improved recreational park. Households who owned permanent asset like agricultural land are positively and significantly influence the participation on the resource quality improvement and valuation of the improved recreational park with reference to households who have no land in the watershed.

Duration

It is positive and significant on both participation and valuation of the recreational park. Households who stayed longer period in Hawassa watershed are more likely to participate in the quality improvement and attach higher value for the improved recreational park. This can be due to the fact that these people have realized the difference between the current and previous quality level of the park, and hence are motivated to improve the quality of the recreational park.

Income

The coefficient associated with income is positive and significant at 1% level on participation in the park improvement and the valuation of the improved recreational site. The income effect reflects the visitors' ability to pay higher monetary value for the resource improvement. Corrigan et al. (2007) find positive and significant effect of income on the determination of aesthetic quality of water resources. In the analysis of economic valuation of recreational use value of Kilimanjaro National park, Adili and Robert (2016) find positive and significant influence of income on the number of days a visitor stays in the park. According to Khan (2006), and Tameko et al. (2011), the positive and statistically significant impact of income on the willingness of visitors to pay is in conformity with the theory that the more the income of the users of the park increases, the more they are willing to pay for an improvement of the park.

Usetype

Usetype stands for uses of the park. It is positive and significant at 1% level in the participation of the resource improvement. Households who benefit in multiple uses of the resources like leisurely walk, academic excursion, reading in the park, fish consumption, boating, and beauty scenery are likely to participate in the improvement program. Tameko et al. (2011) indicate the different activities that the visitors undertake at the recreational park like marriage, snapping pictures, and friendly discussion have positive and significant impact on the willingness to pay. It means that the more the respondents undertake various activities in the park the more they are willing to pay for the improvement program.

Location

It has positive sign for participation and valuation of the improved park with the significance level of 5% and 1% levels for participation and valuation, respectively. It implies that urban residents are more likely to participate in the park management program expressing their willingness to pay high amount for the improved recreational site as compared to the rural residents. This finding is consistent with that of Radam et al. (2009) in the analysis of willingness to pay for the conservation of ecotourism resources at Gunung Gede Pangrango national park.

Parametric WTP estimates for the recreational park

To estimate WTP, researchers use parametric and non-parametric approaches depending on their objectives. In non-parametric approach, mean WTP can be calculated using the average value that the respondents state in support of the proposed project. However, this approach provides less economic information to extrapolate the estimated value to the whole population. Whereas, the parametric approach considers the socio-economic characteristics of respondents in the calculation of mean WTP. These socio-economic characteristics are common to the whole society of the study area. Hence, the mean WTP estimated using the parametric approach is more reliable than the non-parametric approach. Considering the significant variables, the regression equation for parametric mean WTP can be written as:

$$\text{WTP} = \beta_o + \beta_1\text{frequency of visit} + \beta_2\text{satisfaction} + \beta_3\text{gender} + \beta_4\text{age} + \beta_5\text{marital status} + \beta_6\text{education} + \beta_7\text{employment} + \beta_8\text{agricultural land} + \beta_9\text{duration} + \beta_{10}\text{income} + \beta_{11}\text{location} + \beta_{12}\text{mill's inverse} \quad (7)$$

Incorporating the coefficients and their respective mean values into the WTP equation, the parametric mean value for single entrance is calculated to be Birr 25.77 per person. The comparison between the parametric and non-parametric approach (Birr 24) shows that the parametric mean value is higher than the non-parametric value. Tameko et al. (2011) also found higher parametric mean WTP as compared to non-parametric approach in the valuation of improved urban park in Cameroon. This finding is also consistent with that of Hite et al. (2002) in willingness to pay for water quality improvements in the case of precision application technology. Therefore, the entrance fee to Amora-Gedel recreational park is preferably the value of parametric approach, which is Birr 25.77 per person.

Potential revenue for the quality improvement of the recreational park

The result of the survey instrument reflects the family size is 4.3 per household. UN estimates that the urban population of Ethiopia is growing at an average rate of 3.5% per year (Angel et al., 2013). The population of Hawassa watershed, which had been 502,096 in 2007 (CSA, 2007), was estimated to be 684,305 in 2016. Taking the average family size of the survey instrument, the households of the study area was estimated to be 159,140.

The revenue at various WTP level is calculated using the total households who can pay at least that amount. For instance, household who is able to pay Birr 20 can pay at least the amount less than Birr 20. To carry out such estimation, cumulative frequency of households is computed and then multiplied with respective average willingness to pay and frequency of households visit the recreational park in a year (Table 3). The revenue expected to be collected from the quality improved recreational park varies from Birr 598,433.92 to Birr 43,908,366.77 (Table 3) based on the entrance fee and the number of visitors who are able to pay the fixed entrance fee. The highest revenue can be collected at the

Table 3. Expected revenue for the improved recreational park.

Class interval for WTP (1)	Average WTP of the interval (class mark) (2)	Sample households WTP at least that amount (3)		Total households WTP at least that amount (4)	Visit frequency per year (5)	Total revenue (6) (2) * (4) * (5)
Birr	Birr	Nº	%	Nº	Nº	Birr
0	0	390	100	153,760	16	0
5 – 9.5	7.25	308	79	121,470	4	3,522,641.60
9.6 – 14.1	11.85	296	75.9	116,704	26	35,956,453.10
14.2 – 18.7	16.45	259	66.4	102,097	14	23,512,856.19
18.8 – 23.3	21.05	252	64.6	99,329	21	43,908,366.77
23.4 – 27.9	25.65	191	49	75,342	22	42,515,716.32
28 – 32.5	30.25	128	32.8	50,433	17	25,935,314.24
32.6 – 37.1	34.85	34	8.7	13,377	19	8,857,660.01
37.2 – 41.7	39.45	29	7.4	11,378	20	8,977,431.36
41.8 – 46.3	44.05	5	1.3	1,999	12	1,056,607.97
46.4 – 50.9	48.65	4	1	1,538	8	598,433.92

Source: own survey result.

entrance fee of Birr 21.05. However, only 64.6% of the total households are willing to pay the entrance fee of Birr 21.05.

As it can be seen (Table 3), the expected revenue increases irregularly as the entrance fee increases to Birr 21.05, where the possible revenue reaches maximum (Birr 43,908,366.77) and then decreases when the entrance fee increases further to Birr 48.65 (Figure 3). This implies that the maximum revenue is expected from the quality improved recreation park when the entrance fee is fixed at Birr 21.05, which gives the possible revenue of Birr 43,908,366.77. The implication of the rise of revenue when the entrance fee increases up to Birr 21.05 is that in inelastic range of demand curve total revenue increases with the rise of entrance fee. Conversely, in elastic range of demand, which is from Birr 21.05 to Birr 48.65, total revenue increases with decreasing of the entrance fee.

Elasticity refers to the responses of households to the change of entrance fee. In inelastic demand curve (from point A to point B in Figure 4), the number of households changes by a smaller percentage than does the entrance fee; whereas, in elastic demand curve (from point B to point C in Figure 4), the number of households changes by a larger percentage than does the entrance fee. The demand curve (Figure 4) has a negative slope like most of economic goods. For normal goods the demand curve is negatively sloped indicating that price increase affects the households' ability to pay within their limited income, keeping other factors constant.

Comparison of demand and revenue curves on the change of an entrance fee (WTP) reflects the relationship between elasticity and expected revenue from the recreational park. Table 4 summarizes the characteristics of the average WTP (entrance fee) elasticity of demand and the impact on total revenue.

The consumer surplus (CS) is the difference between the price consumers are willing to pay and the actual price they do pay. If the monetary value for the improved recreational park is set to respective average WTP, the consumer's surplus is calculated by summing up each of the areas (A_1 to A_{10}) (Figure 5). The sum of all the areas under the demand curve is Birr 69,088,644.90 (Table 5). The total consumer surplus is determined using the difference between the maximum amount the households are willing to pay (Birr 69,088,644.90) and the product of the mean WTP (Birr 25.77), the number of households who are able to pay that amount (75,342) and the average number of visits of those households per year (22 times). Therefore, the value of the consumers' surplus becomes Birr 26,572,928.58.

Conclusion

The majority of the households vote in support of the recreational park improvement program with the mean value of Birr 25.77 per person for single entrance. The educated households, those who have agricultural land with reference to residential land, the households who stayed relatively longer period in Hawassa watershed, individuals with higher annual income, households who benefit in multiple uses of the lake, and urban residents are more likely to participate in the park improvement program while the households who are satisfied with the current services of the recreational park, older people, and households who administer large family size are less likely to vote in support of the recreational park improvement program.

The valuation of the recreational park reflects that

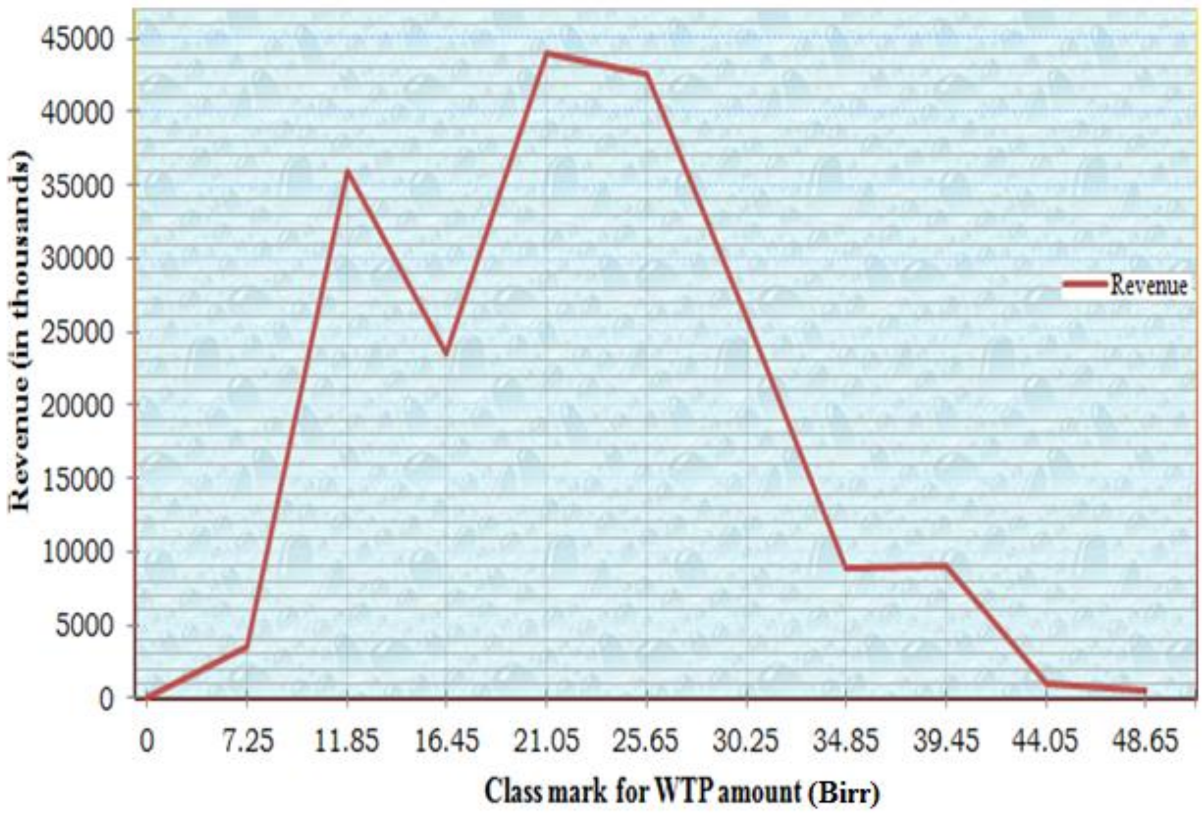

Figure 3. Estimated curve for revenue from the improved recreational park.
Source: computed from own survey result.

Figure 4. Estimated demand curve for recreational park.
Source: analysis of own survey result.

Table 4. A summary of WTP elasticity of household-demand in recreational park.

Absolute value of elasticity coefficient	Demand is:	Description	Impact on total revenue when:	
			Average bid Amount increase	Average bid amount decrease
Greater than one (ε_d>1)	Elastic or relatively elastic	Household-demand changes by a larger percentage than does average WTP	Total revenue decreases	Total revenue increases
Equal to one (ε_d =1)	Unit or unitary elastic	Household-demand changes by the same percentage as does average WTP	Total revenue is unchanged	Total revenue is unchanged
Less than one (ε_d <1)	Inelastic or relatively inelastic	Household-demand changes by a smaller percentage than does average WTP	Total revenue increases	Total revenue decreases

Source: own survey result.

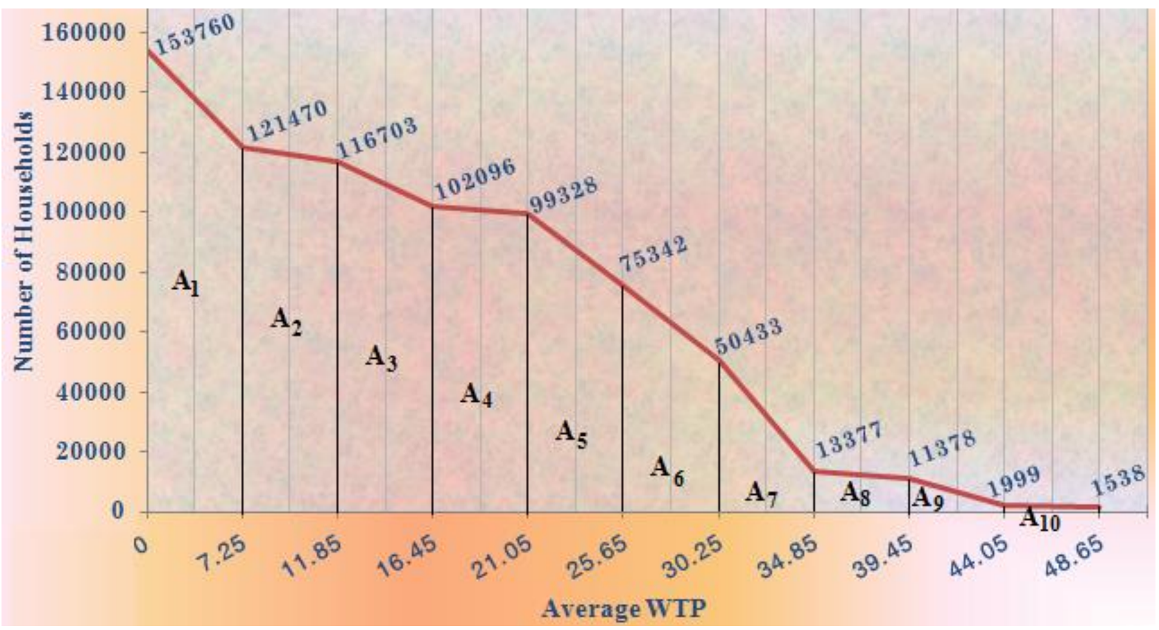

Figure 5. Consumers' surplus.
Source: Computed from own data.

households with a number of visits, males, married individuals, people with more years of education, employment status with reference to farmers, households who have agricultural land with reference to no land ownership in the water shade, those who stayed more than ten years in the watershed, households with high annual income and urban residents are willing to pay high value for the recreational park improvement. Whereas, those who are satisfied with the current status of the lake and services provided in the recreational park, and older people are less likely to pay for the quality improvement of the recreational park.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

Table 5. Calculation for consumers' surplus.

Average WTP	Area	Consumer's surplus value
7.25	$A_1 = \frac{1}{2}$ (153760 + 121470) x7.25 x 20	19,954,175.00
11.85	$A_2 = \frac{1}{2}$ (121470 + 116703) x 4.6 x 26	14,242,745.40
16.45	$A_3 = \frac{1}{2}$ (116703 + 102096) x 4.6 x 14	7,045,327.80
21.05	$A_4 = \frac{1}{2}$ (102096 + 99328) x 4.6 x 21	9,728,779.20
25.65	$A_5 = \frac{1}{2}$ (99328 + 75342) x 4.6 x 22	8,838,302.00
30.25	$A_6 = \frac{1}{2}$ (75342 + 50433) x 4.6 x 17	4,917,802.50
34.85	$A_7 = \frac{1}{2}$ (50433 + 13377) x 4.6 x 19	2,788,497.00
39.45	$A_8 = \frac{1}{2}$ (13377 + 11378) x 4.6 x 20	1,138,730.00
44.05	$A_9 = \frac{1}{2}$ (11378 + 1999) x 4.6 x 12	369,205.20
48.65	$A_{10} = \frac{1}{2}$ (1999 + 1538) x 4.6 x 8	65,080.80
Total		69,088,644.90

Source: analysis of own survey result.

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