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Population Density of *Cordia africana* Lam. across Land Use Gradients in Jimma Highlands, Southwest Ethiopia

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Abstract

This study was conducted to assess the population density of *Cordia africana* across land use gradients in the Jimma Highlands of southwest Ethiopia. A transect with a length of 23 km with 1km buffer was established across different land use types. The transect was stratified into different land use types (cropland, semi-forest coffee, natural forest, woodland, pasture, plantation). The study plots were randomly distributed in different land use types along the transect. The population density, diameter at breast height and height of each *Cordia africana* tree were taken from the one hectare plot. The biomass of the tree was calculated by using non-destructive allometric equation ($AGB = 0.0673(\rho D^2 H)^{0.976}$) and aboveground live carbon storage in the tree was estimated at 50% of the AGB. The highest population density was recorded from SFC system followed by cropland. *Cordia africana* was not recorded from pastureland and plantation forests. The highest aboveground live carbon storage in the biomass of the tree was also found in SFC system followed by woodlands. There was significant population density difference between the two levels of protections ($t = 5.34$, $P = 0.003$). There was also significant difference between the two levels of protections in aboveground carbon storage ($t = 3.219$, $P = 0.023$) in *C. africana*. The traditional coffee management system in Ethiopia has contributed to the conservation of *C. africana* species which is highly threatened in the wild. Strengthening the sustainability of SFC management system in the study area is important for the conservation of *C. africana* and other related species which are threatened in the natural forests.

Keywords: *Cordia africana; land use gradients; population density; biomass; carbon storage; Jimma Highlands.*

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1. Introduction

Cordia africana Lam is a tree species belonging to the family Boraginaceae, sub family Cordiodeae and genus *Cordia*. The tree is small to medium-size, reaching 10-18 m or more in forests, with a thick spreading crown and rarely a shrub [1]. The species is distributed in a wide range of geographic areas and a diverse climate showing that there are differences within the species. Its distribution ranges from 550-2600 m asl. The species commonly occurs in afromontane rainforests and undifferentiated afromontane forests of Ethiopia, usually along margins in clearings. The tree prefers areas with a fairly high amount of rainfall (range of annual rainfall, 700-2000 mm), sufficiently worm climate with fertile and drained soil [2]. The species is one of those early colonizers in forest regrowth. It has been reported to be indigenous in East and southern African countries and in Saudi Arabia and Yemen. *Cordia africana* is one of the most popular and fast growing indigenous tree species in Ethiopia. When it grows in crowded population, it grows faster and the stem becomes straight [3]. The plant uses this strategy to compete for light and later starts to produce side branches. Germination of the seed is epigeal, regeneration is through stump sprouting and adaptation to drought is by shading the leaves [4]. *C. africana* is economically an important indigenous tree species in Ethiopia. The tree is used as a source of food in most parts of Ethiopia [5]. According to [6], in Tigray (one of the Ethiopian Regions in the north), the fruit of *C. africana* in the wild is eaten by shepherds, while its fruits from backyards are collected and sold in the local market, and hence supplement the income of the local people. It is useful in agroforestry, timber production and maintaining ecological balance. The tree helps in nutrient recycling improving soil fertility [7] and water conservation improvements. The leaves make good mulch for the soil during the dry seasons. The fruits are edible [8], leaves serve as fodder for livestock [9], provide shade for coffee [10; 11] and used as medicine for human ailments [5; 12; 13; 14; 15] and for treatment of Livestock ailments [16]. Its flower is a good source of nectar and is one of the bee forage trees [17]. The timber is used for making high quality furniture [18;19] doors, windows, cabinet and drums. It is also good source of firewood [20]. *Cordia africana* is among the trees found scattered in farm lands. As it has been reported by many authors, on farm trees contribute to soil fertility due to their organic inputs during the nutrient cycling [21; 22; 23]. *Cordia africana*'s contribution in soil fertility had been reported by [7] in western Ethiopia. Due to land clearing for agriculture and settlement, fuel wood and commercial logging, the species has been depleted from the wild [24] in Ethiopia. Particularly, in northern Ethiopia, where deforestation and land degradation is severe, the species has been pushed out of its wild habitat and remained in some protected areas such as grave yards and monasteries [25], and also scattered in the farm lands. People's preference for household furniture made of *C. africana*, highly affected its population density in the wild, and now days are confined to the private farms and home gardens in southwest Ethiopia [26]. The species is also one of the threatened tree species in Ethiopia. So far, there has not been any work on the population density of *Cordia africana* across land use gradients in the Jimma Highlands of Ethiopia. Therefore, this research was designed to assess the population density of the species across land use gradients and propose some conservation strategies.

2. Study area and methods

2.1. Study area

The study area includes three districts (Setema and Goma from Jimma Zone; Didessa district from Illubabor Zone), southwest Ethiopia (Figure. 1). The area belongs to Eastern Afromontane Biodiversity Hotspot [27]. The transect is characterized by a mosaic of different land use types such as semi-forest coffee, natural forests, woodland, pasture and cropland. The natural forest and woodland are used as common pools from which the surrounding community gets timber, firewood poles and vines for construction of houses. The natural forest is characterized mainly by tree species like *Apodytes dmidiata*, *Millettia ferruginea*, *Fucus sur*, etc. The dominant canopy trees in the transect are *Albizia gummifera*, *Croton macrostachyus*, *Acacia abyssinica*, *Millettia ferruginea* and *Cordia africana*. Southwest Ethiopia is the wettest region of the country with the mean annual rainfall of 1900 mm. The study transect typically receives eight consecutive wet months from March-October. The heaviest rains fall from May to September. The dominant tree species in the woodland are *Accacia abyssinica*, *Combretum spp*., *Entada abyssinica* and *Terminalia schimperiana* [10]. Agriculture is the backbone of the economy of the people in all the three districts. Coffee is the dominant cash crop in the area while people also cultivate cereals (like maize, sorghum, barley) and pulses (peas and beans).

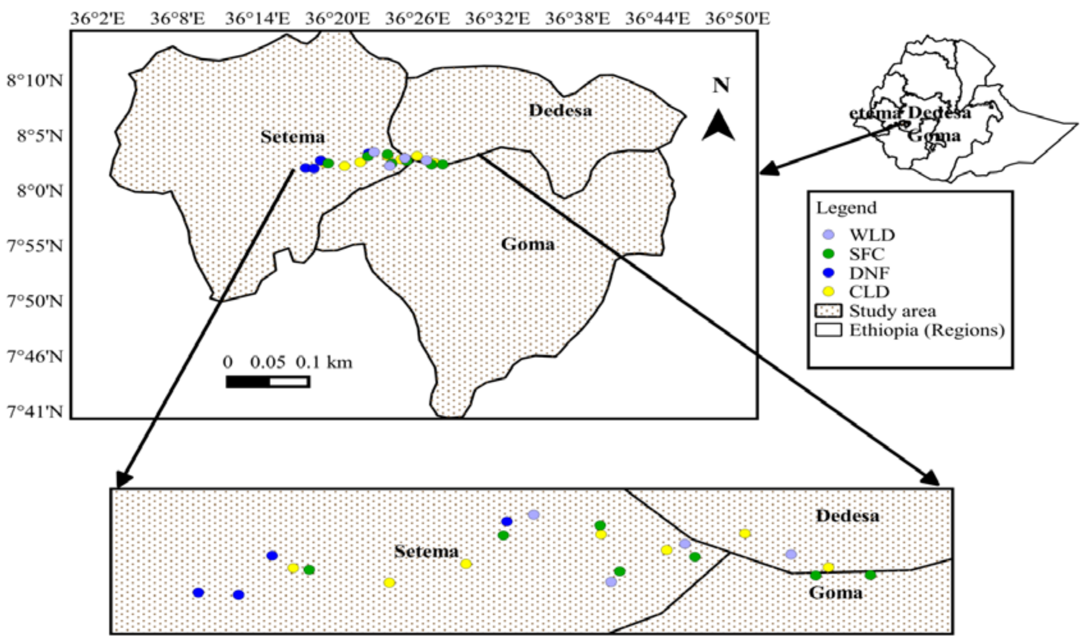

Figure 1: Study area showing Ethiopia and the distribution of the study plots across three Districts in southwest Ethiopia

2.2. Mothods

A transect was established across different landuse types starting from 1500-2300 m asl. The trasect was stratified into different land use types (semi-forest coffee, cropland, woodland and natural forest) during the reconaisence survey. Representative sample plots were randomly distributed in each land use types (the number of study plots in each land use type was based on the total size of the land use type). Stem count was taken from each one hectare plot. The circumference of each stem with diameter at breast height (DBH) ≥ 10 cm was recorded. For the stem abnormalities, we followed Rainfor protocols [28].

2.3. Data analysis

We used descriptive statistics to show the population density, aboveground live biomass, carbon storage, tree height and DBH. The impact of level of protection on the population density of *C. africana* in SFC system was analyzed using idependent samples t-test. Basal area (BA) for each tree of *C. africana* was calculated from equation 1.

$$BA = C/\pi \quad \text{---}(1)$$

Where, C = circumference of the tree at breast height.

Aboveground live biomass of each *C. africana* tree was estimated by using the revised, non-destructive allometric equation (equation 2) [29].

$$AGB = 0.0673(\rho D^2 H)^{0.976} \quad \text{---} (2)$$

Where ρ = wood specific gravity, D = diameter at breast heigh of each tree, H = the height of each tree). The amount of carbon stored in each cordia tree was estimated at 50% of the aboveground live biomass (AGB). The amount of CO_2 sequested by the tree was calculated by multiplying the amount of carbon in the biomass by 3.67 (which is the ration of the atomic mass of CO_2 (44.01) to the atomic mass of carbon (12)).

3. Result and Discusion

3.1. Cordia africana in different land use types

Cordia african was distributed across all semi-forest coffee plots, in most of the croplands and woodland plots. The species was recorded only from one plot of natural forest and was totally absent from pasture land and plantation forests. In line with [30], the natural forest of the study area was open for common use by the local community that contributed to the decline of the species from the natural forest. In those land use types where the species was recorded, there were differences in population densities of *C. africana*. The highest tree density ha^{-1} was recorded from semi-coffee forest and the least was from cropland. Compared to natural forest, the population density of *C. africana* was found to be high in semi-coffee forest. In private coffee forests, the species was protected by the owners for two purposes. As it has been indicated by [10; 11;30], *C. africana* is among the canopy trees which are protected for shade provision for the coffee shrubs following the trees in the fabaceae family (e.g. *Albizia spp*., *Accacia abyssinica etc*). The tree is also important source of quality timber for making household and office furnitures, and as a result, the owners of coffee plots provide maximum protection for *C. africana* tree in their coffee farm. In the natural forest and woodland which are used as common pool for resource provision for the community around, there is less or no protection and as a result, the density of *C. africana* declined. Farmers also mainatin *C. africana* in the farm lands covered by annual crops. *C. africana* was not recorded from pasture land and plantation forests. The tree is deciduous and it does not assist in shade provision for the heard of cattle during the dry season. Such trees are rarely maintained on the pasture land. *Cordia africana* was not recorded from plantation forests. According to the local people living around the plantation forest, the indigeneous trees had been cleared before planting the introduced species (*Cupressus* *lusitanica*, *Pinus patula*, *Grevillea robusta* and *Eucalyptus camaldulensis*). According to the local people, there had been continous follow up to remove any regenerating indigenous species including *C. africana* from the plantation forests. Allelopathic effect may also be a possible reason for the absence of *C. africana* from the plantation forests. The highest average height was recorded from the natural forest (H = 17.5±2.5 m, range 15-20 m), while the least was recorded from cropland (H = 10.41±2.81 m; range 6-19 m) (Figure 2D). When grown in forests where the competition for light is tough for the species, it grows straight up to capture enough light. Under such conditions, the growth of side branches of *C. african* is inhibited. This agrees with [3]. *Cordia africana* growing in forests reach a considerable height because of the strategy it developed to compete with other canopy trees for light. *C. africana* trees growing scattered in croplands are shorter in height compared to those growing in the forest and woodland. They produce several side branches forming flat crowns. Light is not a problem for the tree growing in the farm land and that was why those in the cropland were short and stardy compared to those in the forest.

3.2. Carbon storage and sequestration

The Largest biomass of *C. africana* (AGB = 8929.13 ha^{-1}) was recorded from SFC system, while the least was recorded from the natural forest (AGB = 716.89 ha^{-1}) (Figure 2E). The largest biomass of *C. africana* in SFC was contributed by both tree density (number of stems) and the trunk diameter. The cropland with least stem density has got larger biomass following the SFC system, mainly due to the tree DBH. This is an indication that old trees with larger DBH classes are found in the croplands. Almost all the *C. africana* trees in cropland are matured trees with larger diameter that contributed to the biomass of the trees in the cropland. The relatively largest amount of aboveground live carbon (AGC = 4.46, ton) in the biomass of *C. africana* was found in SFC, while the least (AGC = 0.36, ton) was obtained from the natural forest. The amount of CO_2 sequestered for one ton of carbon stored in the biomass is equivalent to 3.67 ton. For 4.46 ton of carbon stored in the biomass of *C. africana* in the SFC system, 16.38 ton of CO_2 was squestered. Relatively, the largest amount of CO_2 was converted by SFC systems compared to all other land use types in the transect.

3.3. Level of protection for SFC

Level of protection for the SFC in the study area varies from person to person who owns the coffee plot. Four SFC patches were highly protected from human influence, while the remaining three patches were poorly protected (Table 1). Differences in tree density were observed between highly protected and poorly protected coffee forests. Independent samples t-test showed that there was significant statistical difference ($t = 5.34$, $p = 0.003$) in the density of *C. africana* population among the plots of semi-forest coffee across levels of protection provided. The population density of *C.africana* was relatively high in SFC plots (Figure 3A) where the level of protection was high; while the density was lower in the plots where level of protection was poor. This shows that the coffee growers selectively nerture the seedlings and saplings of *C. africana* tree in their coffee plots. This was partly due to its quality as timber tree and shade provision for coffee shrubs. This agrees with [10;11]. Significant statistical differences ($t = 3.219$, $p = 0.023$) were also observed in aboveground live carbon storage among the plots of SFC across levels of protection.

Table 1: The impact of management intensities and level of protection provided on the tree density, biomass and carbon storage in *C. africana* tree for different patches of SFC system in the Jimma Highlands (SFC = semi-forest coffee)

land use	Density	Aboveground live biomass	Carbon (t/ha)	CO_2 Sequestered (t/ha)	Level of protection
SFC 1	24	17830.48	8.92	32.74	High
SFC 2	24	10891.18	5.45	20.00	High
SFC 3	21	7645.91	3.82	14.02	High
SFC 4	23	15392.34	7.70	28.26	High
SFC 5	3	1996.01	1.00	3.67	Low
SFC 6	6	2570.23	1.29	4.73	Low
SFC 7	14	6177.73	3.09	11.34	Low

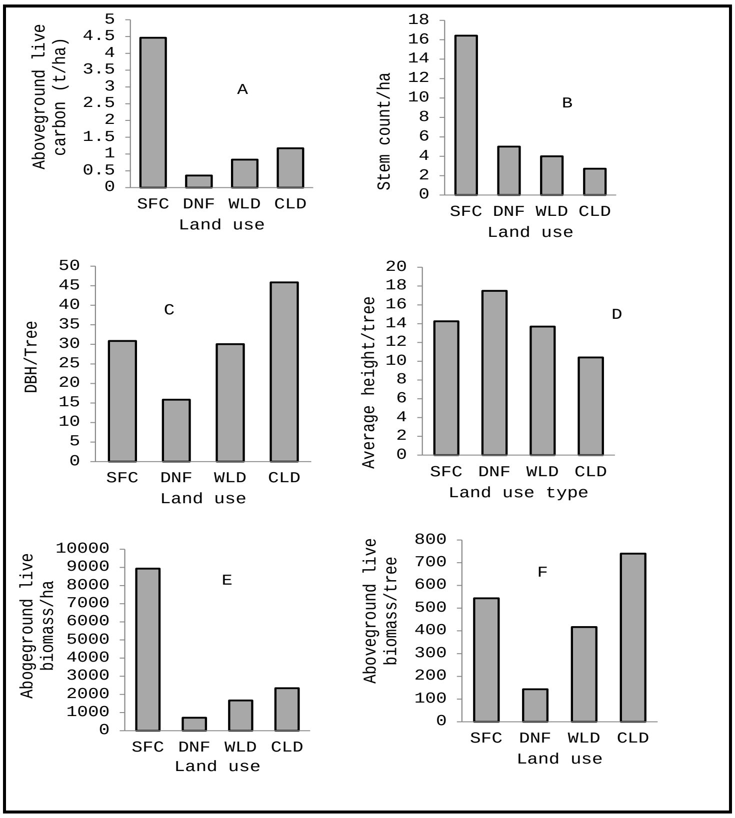

Figure 2: Carbon storage, population density, DBH, tree height and biomass of *Cordia africana* tree in different land use types across a study transect in the Jimma Highlands (SFC = semi-forest coffee, DNF = degraded natural forest, WLD = woodland, CLD = cropland, DBH = diameter at breast height)

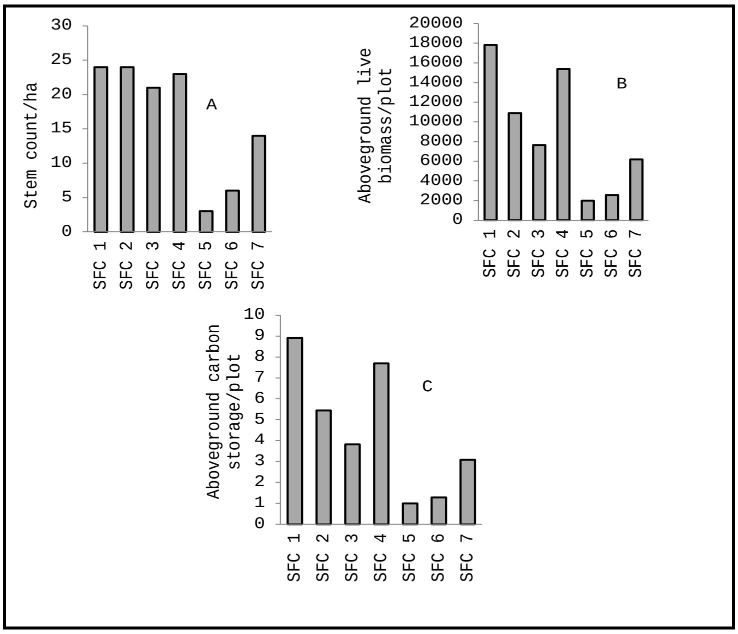

Figure 3: Population density, aboveground biomass and carbon storage in *Cordia african* tree across Semi-forest coffee system in the Jimma Highlands (SFC = semi-forest coffee).

4. Conclusion and recommendation

Semi-forest coffee management system has contributed to the *in-situ* conservation of *C. africana* species in southwest Ethiopia. The population density of *C. africana* has been depleted from the natural forest, while it is found in good number in traditionally managed coffee forests and croplands. Variation in SFC management intensities among the coffee growers has contributed to the variation in the population density of *C. africana* and its aboveground live carbon storage. The sustainability of semi-forest coffee management helps the sustainability of canopy trees which are otherwise depleting from the natural habitats. The conservation of canopy trees in the SFC system also assists the long term carbon storage in the tree biomass. For the continuity of the SFC system as a strategy for the conservation of the shade trees, mechanisms by which the farmers could maximize their coffee yield without compromising the canopy trees should be designed.

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