Journal of Ecology and The Natural Environment

Volume 7 Number 1, November 2015
ISSN 2006-9847

Academic Journals

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Pelczar JR, Harley JP, Klein DA (1993). Microbiology: Concepts and Applications. McGraw-Hill Inc., New York, pp. 591-603.

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Journal of Ecology and the Natural Environment

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academicJournals

Vol. 7(1), pp. 1-6, January, 2015
DOI: 10.5897/JENE2014.0491
Article Number: 8C38C9F49700
ISSN 2006-9847

http://www.academicjournals.org/JENE

Journal of Ecology and the Natural Environment

Full Length Research Paper

Abundance and diversity of major cultivable fungal flora of River Jhelum in Kashmir Himalaya

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Received 2 December, 2014; Accepted 19 December, 2014

The present work was carried out in the in river Jhelum of Kashmir Himalaya to assess the density and diversity of fungal flora, to isolate and identify the fungi from the water along with some physical parameters like pH and temperature which was carried out between June-November, 2011 at four sites differing from each other markedly in terms of biotic and abiotic factors. During the study, a variety of fungal strains were isolated and identified from the water of river at the four sites. The highest viable count of fungi was observed at site III with a cfu/ml of 3.6 x 10^2 in the month of July and the lowest viable count at site IV with a cfu/ml of 2.7×10^2 in the month of November. Among most dominant of the isolate identified 20% were *Aspergillus* spp. followed by 4% *Pencillium* spp. and 4% *Candida* spp. Comparative analysis of different types of colonies found at the four sites during the study indicates that the fungal density was dominant in the month of July.

Key words: River Jhelum, fungi, *Aspergillus* spp., *Pencillium* spp., and *Candida* spp.

INTRODUCTION

The valley of Kashmir is a lacustrine basin with an average altitude of 1585 m a.s.l. Both the valley and its surrounding mountains are home to a large number of aquatic habitats like lakes, ponds, streams, rivers and wetlands. It is estimated that 6% of the land area of Jammu and Kashmir is under aquatic habitats (Zutshi and Gopal, 2000). Water is essential to sustain life, and without it life becomes impossible, it is an indispensable commodity, which should be easily accessible, adequate in quantity, free of contamination, safe, affordable and available throughout the year in order to sustain life (Al Khatib and Salah, 2003). Fungi are among the most diverse groups of living organisms on earth, though inadequately studied worldwide (Grover et al., 2007). Aquatic fungi play a crucial role in the freshwater ecosystem in nutrient cycling by breaking down leaves and woody substrates and also as symbionts (Barlocher and Kendrick, 1981). Physical chemical factors of ecosystem play important role on the growth, multiplication, distribution and seasonal periodicity of aquatic fungi (Park, 1972). Fungi belong to the kingdom Eumycota. This kingdom comprises five phyla namely Ascomycota, Basidiomycota, Zygomycota, Chytridiomycota, and Glomeromycota (Kirk et al., 2001;

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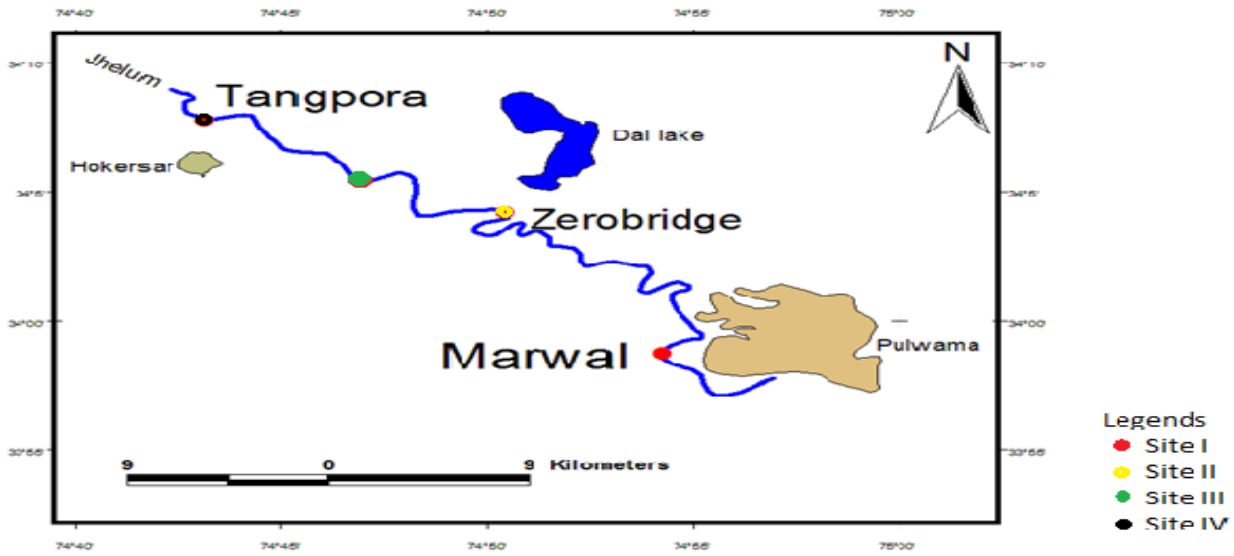

Figure 1. Geographical map of study areashowing the location of study area and sampling site.

Schußler et al., 2001). *Penicillium* species have been frequently recovered from water in the various studies performed. Several of the species in genus *Penicillium* and *Aspergillus* are known to produce mycotoxins in other substrates, such as food and beverages (Moreau, 1979; Pitt and Hocking, 1999) and detection of aflatoxins produced by *A. flavus* in water from a cold water storage tank was demonstrated by Paterson et al. (1997). Predominant fungal genera and species in treated and untreated water are: *Aspergillus, Cladosporium, Epicoccum, Penicillium, Trichoderma, Arthrinium phaeospermum, A. flavus, C. cladosporioides, Fusarium culmorum, Mucor hiemalis and Trichoderma harzianum* (Kinsey et al., 1999). Many other fungal genera isolated from Danube river water in Europe include*: Mortierella, Absidia, Rhizopus, Acremonium, Beauveria, Doratomyces, Monilia, Rhizopus arrhizus, Acremonium strictum, Fusarium oxysporum and Stemphyllium botryosum* (Tothova, 1999). What governs the distribution of freshwater fungi is difficult to determine, although some species appear to be more common either in temperate or tropical regions (Shearer et al., 2007; Raja et al., 2009).

Since no substantial work has been carried out regarding the current understanding and distribution of fungal flora in the Jhelum River. Therefore the objective of this study was to focus on the isolation and identification of the fungal flora from this important river

MATERIALS AND METHODS

Study area and study sites

Jhelum, the major waterway of Kashmir, originates from the spring Verinag located in the foot of a spur of the Pir Panjal Mountains in the district Anantnag from where a number of tributaries join the Jhelum and make it navigable from Khannabal to Wular Lake. The river runs a course of 203 km through the valley and the hydrology of River Jhelum is largely controlled by snowmelt in spring season and heavy rains from June to September. A total of four study sites (Figure 1) markedly different in respect of geographical and demographical features were selected for the sampling. These sites were characterized by having the moderate human population on both the banks along with the agricultural fields:

Site I: It was near Marval, Pampore lying between geographical coordinates 33˚ 58’ 45.4” N and 74˚ 54’ 16.5” E with an elevation of 1601 m. a.s.l. This site was located about 32 km from the main city centre (Lal chowk). On both sides of the bank the land was used for agricultural purposes and was bordered with residential hamlets around. The average depth of river at this site was about 1.6 m.

Site II: It was located (about 1.2 km from the city centre) at Zero bridge in Srinagar city lying between the geographical coordinates of 34˚ 4’ 9.2” N and 74˚ 50’ 20.88” E and having an elevation of 1582 m. a.s.l. At this stretch of the River, Jhelum congested human population and commercial activities takes place along the both sides of the banks. All along its course from Marval to Srinagar the river receives significant quantities of domestic wastes from human settlements and army cantonment areas. The average depth at this site was about 2 m.

Site III: This site was located about 10 km from main city centre at Qamarwari in Srinagar city lying between the geographical coordinates of 34˚ 05’ 35.9” N and 74˚ 46’ 45.4” E and having an elevation of 1579 m. a.s.l. At this site both commercial and residential activities take place along both sides of river, which directly release the sewage and other solid wastes directly into the river. The average depth at this site was about 1.2 m.

Site IV: This site was located at Tengpora about 26 km from the main city centre lying between the geographical coordinates of 74˚ 43’ 11” E and 34˚ 7’47.1” N and having an elevation of 1577 m. a.s.l. This stretch of River Jhelum was characterized by moderate human population on both the banks along with the vegetable cultivation. Human interference like emission of domestic sewage,

washing of clothes and other activities usually takes place at this particular site.

Laboratory analysis

Surface water samples were collected aseptically in pre-sterilized bottle on the monthly basis from June to November, 2011. During the present study Rose Bengal Agar media was used for isolation of Water fungi. At the end of the incubation period, the percentage frequency and percentage contribution of the fungal flora was calculated (Hogg and Hudson, 1966).

Dilution plate method

The water samples were mixed with sterile distilled water and a series of dilutions were made. From the dilutions, 0.1 ml inoculums was poured onto Rose Bengal agar and incubated at 28±2°C for 1 week to assess the growth of colonies (Waksman, 1922; Warcup, 1950; Bandh et al., 2011; Dar et al., 2013). The number of colonies counted was expressed as (colony forming units) cfu/ml and were calculated by using the formula:

Cfu/ml=n×d

Where, n= number of colonies; d = dilution factor = 1/dilution.

Identification of the fungal isolates was done upto genera level using standard fungal identification key of Barnett and Hunter (1999), Khulbe (2001).

RESULTS AND DISCUSSION

The study was carried out between in four months June-November, 2011 and a total of 40 isolates were obtained during the study. The results of isolation and enumeration are indicated in Table 1. The isolates were identified on the basis of difference in some morphological features like colony appearance, elevation, margin, condia colour and reverse colour of the colonies. The colony appearance ranged from circular, irregular and filamentous. The margin varied from entire filamentous, undulate and lobate. There was also considerable difference in the colour of colonies (dark green, sea green, yellowish white, cream white etc.). The individual colony count of different fungal isolates reveals that isolate type F23 was having the highest number of colonies (n=48) at site I followed by F6, F33, F30 and others. The colony count of isolate F23 was highest (n=24) in the month of July at site 2, isolate F33 had the highest number of colonies (n=38) followed by F30, F23 and others. The colony count of isolate F33 was highest (n=21) in the month of July at site 3, isolate F23 had the highest number of colonies (n=40) followed by F33, F4, F3 and others, and the colony count of isolate F23 and F33 was highest (n=22) in the month of July. At site 4, isolate F23 was had the highest number of colonies (n=40) followed by F33, F8, F5 and others. The colony count of isolate F23 was highest (n=22) in the month of July. The total colony count given indicates that isolate F23 had the highest total colony count (n=156) for all months followed by isolate F33 (n=119). The total monthly fungal population (Cfu/ml) was also recorded for all four months as indicated in Table 2 and the data recorded reveals that the maximum population during July was 3.6×10^2 for site 3 and least for site 1 (1.1×10^2) in November as shown in Table 3. The diameter of the identified species was recorded and ranged from 1.5 to 1.63 cm; the elevation of these species included flat, raised, convex and filamentous. The margin included filamentous entire convex undulate and entire. The colour of the colonies on both upper and reverse sides varied from cream, white, yellow, pink etc. Aspergillus sp. contributed 20% followed by Pencillium sp. (4%) and *Candida* (5%) as shown in Figure 2.

The results obtained regarding the Aspergillus and Penicillium species during the study are in agreement with the study of Kellerman and McBeth (1912) who mentioned that the species of genus *Aspergillus* and *Pencillium* are found in polluted lake waters and act as cellulose decomposer. These genera have also been reported frequently from the drain waters with maximum densities during high pollution (Khulbe and Durgapal, 1994). *Candida* spp. obtained during the study was found to be pathogenic to humans which are a concern but these species can thus act as good indicators of water pollution (Cooke, 1954). The data recorded for water indicates higher temperature during July and lower during November (Table 3). The fungal load also shows decreasing trend from June to November. The higher temperature in July may be the reason for better growth of fungal population. Similar results were suggested by Bock (1956) and Dar et al. (2013), who reported optimum temperature for growth fungi bacteria has to be between 15˚C and 31˚C thus confirming the results obtained during the study. The maximum fungal population in July may possibly be due to more feasible temperature and increase in organic matter (Khulbe and Durgapal, 1992). Increase of fungi indicates increasing organic loading in water (APHA, 1998). During our study in the month of November, fungal population was minimum which may be attributed to the low temperature. These results are in agreement with the study of Khulbe and Durgapal (1992) who in his studies on Naintal Lake, has reported that fungal population was maximum in August during high temperature while it was lowest in the month of January when temperature was relatively low.

Conclusions

From the study, it may be concluded that *Aspergillus* sp. and *Pencillium* sp. were present at all four sites during the study while as *Candida sp.* was found at site I in October and November. However, the Site III, on the River Jhelum showed the highest density of cultivable fungal population.

Table 1. Comparative analysis of different types of colonies found at the four sites in 2011.

Isolate	Site 1				Site 2				Site 3				Site 4			
	Jun.	Jul.	Oct.	Nov.	Jun.	Jul.	Oct.	Nov.	Jun.	Jul.	Oct.	Nov.	Jun.	Jul.	Oct.	Nov.
F_1	+	+	-	-	+	+	-	-	-	-	-	-	+	+	-	-
F_2	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
F_3	-	-	+	-	-	-	+	-	+	+	+	-	-	-	+	-
F_4	-	-	-	-	-	-	-	-	+	+	+	-	-	-	-	-
F_5	+	+	-	+	+	+	-	+	-	-	+	-	-	-	+	-
F_6	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-
F_7	+	+	+	-	+	+	+	-	-	-	+	-	-	-	-	-
F_8	-	-	+	-	-	-	+	-	-	+	-	-	+	+	-	-
F_9	-	-	+	-	-	-	+	-	-	-	-	-	-	-	+	-
F_{10}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
F_{11}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
F_{12}	+	+	-	-	+	+	-	-	-	-	-	-	-	-	-	-
F_{13}	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
F_{14}	-	-	-	-	-	-	-	-	+	-	-	-	-	+	+	-
F_{15}	-	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-
F_{16}	-	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-
F_{17}	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
F_{18}	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
F_{19}	-	-	-	-	-	-	-	-	+	+	-	-	-	+	-	+
F_{20}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
F_{21}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
F_{22}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{23}	+	+	+	-	+	+	+	-	+	+	+	-	+	+	-	-
F_{24}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+
F_{25}	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+
F_{26}	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+
F_{27}	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-
F_{28}	-	-	-	-	-	-	-	-	+	+	+	-	-	-	-	-
F_{29}	-	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-
F_{30}	+	+	+	-	+	+	+	-	-	-	-	-	-	-	-	-
F_{31}	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
F_{32}	-	+	-	+	-	+	-	+	-	-	-	-	-	-	-	-
F_{33}	+	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-
F_{34}	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
F_{35}	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
F_{36}	-	-	+	+	-	-	+	+	-	-	-	-	-	-	+	-
F_{37}	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-	+
F_{38}	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-	-
F_{39}	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-	-
F_{40}	-	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-

Table 2. Colony count and cfu/ml at the four sites during the study.

Site	June		July		October		November	
	Colony count	Cfu/ml	Colony count	Cfu/ml	Colony count	Cfu/ml	Colony count	Cfu/ml
I	24	2.4×10^2	30	3.0×10^2	15	1.5×10^2	11	1.1×10^2
II	21	2.1×10^2	29	2.9×10^2	21	2.1×10^2	19	1.9×10^2
III	23	2.3×10^2	36	3.6×10^2	30	3.0×10^2	23	2.3×10^2
IV	22	2.2×10^2	28	2.8×10^2	27	2.7×10^2	18	1.8×10^2

Table 3. Water temperature (°C) and pH recorded at four sites during June and November 2010.

Site	June		July		October		November	
	Temp.	pH	Temp.	pH	Temp.	pH	Temp.	pH
I	17	7.6	20.1	7.1	11	7.6	6	7.0
II	19.1	7.8	19	7.1	11.9	7.7	6.6	7.1
III	21.7	7.7	19	7.0	12.3	7.7	6.2	7.1
IV	21	7.7	22	7.2	11.2	7.8	5.8	7.1

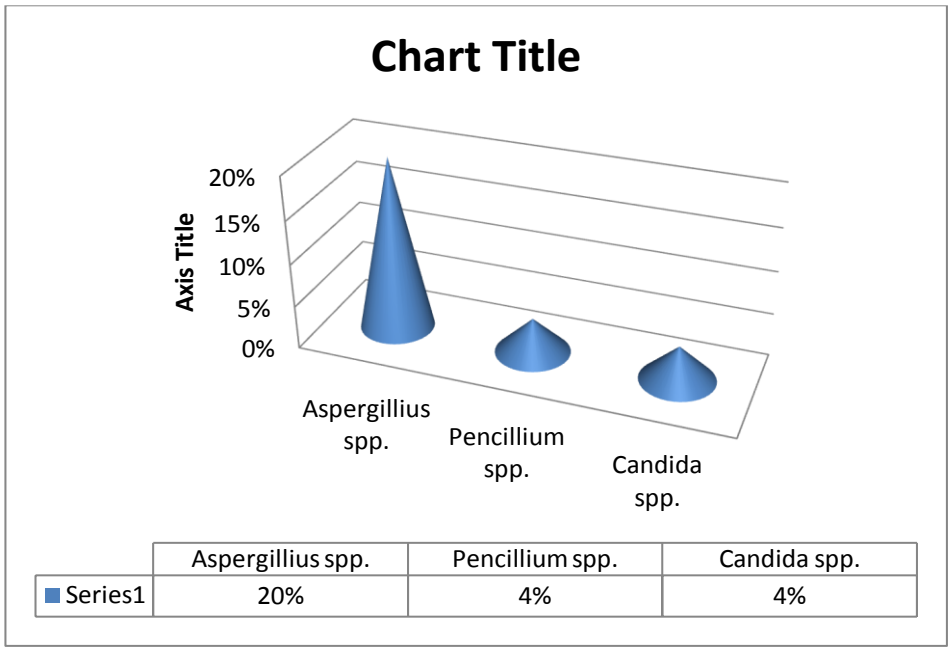

Figure 2. Percentages of identified species of fungi.

Conflict of Interests

The author(s) declare there is no conflict of interests.

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academicJournals

Vol. 7(1), pp. 7-13, January, 2015
DOI: 10.5897/JENE2014.0492
Article Number: E25C57049704
ISSN 2006-9847

http://www.academicjournals.org/JENE

Journal of Ecology and the Natural Environment

Full Length Research Paper

Population structure of rodents in Alage, Southern Ethiopia

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Received 3 December, 2014; Accepted 18 December, 2014

An ecological study on population structure of rodents was conducted in Alage, Southern Ethiopia. Sherman live traps were used to capture rodents in four habitats and trapping sessions. A total of 684 rodents that represented 11 species were captured. Regarding population size and density, *Mastomys natalensis* was the dominant species followed by *Arvicanthis dembeensis* while the least was observed in *Graphiurus murinus* in the study period. The highest biomass was recorded in *A. dembeensis* (6771.43 g/ha) followed by *M. natalensis* (6246.63 g/ha) and *M. erythroleucus* (3257.14 g/ha) while the least was recorded for *G. murinus* (10.2 g/ha) followed by *Mus musculus* (35.36 g/ha).The largest and lowest biomasses per habitat type were recorded for *M. natalensis* and *M. musculus*, respectively from bushland. There was variation in the population size, density and biomass among trapping sessions and habitats with the highest estimate in the second trapping session and bushland habitat type. All age groups were represented in the population with seasonal and age group variation. In conclusion, there was variation in population size, density and biomass of rodents among habitats and seasons. These population fluctuations might be mostly due to variation in rainfall, habitat heterogeneity, vegetation cover, reproductive patterns, quality and quantity of food and water.

Key words: Age, biomass, density, population, rodents

INTRODUCTION

Rodents, from mammals, constitute the largest order with more than 2,700 species and account for over 42% of all mammal species (Alpine et al., 2003; Singleton et al., 2003). Out of 2,700 species of rodents, 84 species have been recorded in Ethiopia, and of these 21% are endemic (Bekele, 1996a, b; Yalden et al., 1996). With their prolific nature of breeding, they represent a significant amount of biomass in different ecosystems. The abundance and distribution of small mammals could be affected by the nature and density of vegetation coverage (Bekele and Leirs, 1997; Datiko and Bekele, 2014). Thus, seasonal variation is an important factor regulating populations of rodents. Temperature, energy and nutrition are most important factors in determining reproduction potential, which influences population density of rodents (Magige and Senzota, 2006). Studies indicated that there could be seasonal, inter-annual and multi-annual fluctuations of rodent population structure (Leirs et al., 1996; Meserve et al., 1996).

Habitat structure, habitat selection, climatic condition,

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quality and quantity of food, fire and predation are the important factors that influence population fluctuations (Shurchfiesd, 1997; Shanker, 2001; Chekol et al., 2012). These fluctuations could be associated with the basic demographic processes such as reproduction, survival, mortality, emigration and immigration (Lima et al., 2001). Habitat heterogeneity as well as suitable vegetation coverage increases species richness, number and diversity by providing more niches, shelter and continuous supply of food that has been exploited by several species of rodents (Makundi et al., 2009; Addisu and Bekele, 2013).The quantity and quality of vegetation have been considered as prime factors that determined population size (Makundi et al., 2009).

Rodents naturally have high reproduction potential and ability to invade all habitats. This makes them to have great ecological and social values in this world. In spite of having high biodiversity of small mammals (Yalden and Largen, 1992; Bekele et al., *2003*), Ethiopia is among the least studied in terms of faunal diversity and documentation, their population ecology and population structure. Studies have indicated that population structure of the rodent community in many regions of Ethiopia are still poorly known. The same is true of rodents in Alage and its environs. Country wide studies on population structure of rodents in different habitats would be important to understand relationships between species and between rodents and the environment. Therefore, this study was proposed to carry out extended ecological surveys in this area to determine population structure of the rodents with the following specific objectives: 1) to evaluate the population density of rodents in different habitats; 2) to estimate the biomass of rodents in the study area; 3) to determine age as well as sex distribution of rodents in the area.

MATERIALS AND METHODS

Study area

An ecological survey of small mammals was carried out in Alage and its environs, Southern Ethiopia. It is located 215 km South of Addis Ababa along a Rift Valley bordering the two Rift Valley lakes, Abijata (10 km east) and Lake Shalla (8 km north). The area is located at 38°27' East longitudes and 7°36' North latitudes, with a range of altitude 1,580-1,650 m above sea level. It covers 4,200 hectare of land with an average altitude of 1,600 m above sea level. It receives bimodal rainfalls with mean annual rainfall of 860 mm. Temperature of the study area is known to fluctuate significantly; however, it mostly ranges between 16 and 29°C with mean daily temperature of 21°C.

Methods

Permanent 70 x 70 (4,900 m^2) live trapping grids were established in different habitat types. Grid 1 and 2 were randomly selected from natural habitats (acacia woodland and bushland), whereas grid 3 and 4 were selected from agricultural area (maize and wheat). Trapping was made in four sessions covering different seasons. The first session data gathering was carried out from end of August to the middle of September, and the second from end of September to October. The third session data assortment was conducted in December and the fourth from February to March. The first and second trapping sessions were conducted during and at late wet season whereas third and fourth sessions were during and at early dry season of the year.

In each trapping grid and session, 49 (7 x 7) Sherman live traps were set at 10 m intervals for three consecutive days. Traps were baited with peanut butter and crushed white onions and set between 05:00 and 6:30pm in the evening. Traps were covered with grasses and plant leaves to protect trapped animals against the strong heat and cold. A Capture-Mark-Recapture (CMR) method was employed by marking toe clipping and released at the point of capture.

Traps were checked twice a day: early morning and late afternoon. Trapped animals were removed from the trap, identified and recorded on grid and trap-station number. Then after, animals were weighed, toe-clipped for coding, sexed and aged (juvenile or young, sub-adult, adult), observed for sexual condition and released at the point of capture (Bekele, 1996a; Linzey and Kesner, 1997; Alpine et al., 2003). All the external attributes such as fur colour and texture, back colour of fore and hind foot, whisker and other physical features (size and shape) were also recorded. Sampled specimens were identified to the species level. For the specimen identification, museum specimens and taxonomic characters in Yalden and Largen (1992), Bekele (1996a) and Alpine et al. (2003) were used.

Data analysis

The raw data were stored and managed in excel spreadsheet. SPSS (version 15.0) statistical software was used to analyze the data. Population density was calculated for each habitat and trapping session by number of individuals of each species per hectare. Biomass is the mass of rodents in a specific area. Biomass was estimated using mean weight of each species multiplied by their density in each habitat and trapping sessions. Chi-square test was employed to evaluate the significant differences of different parameters.

RESULTS

A total of 684 individuals belonging to 11 species of rodents were captured by live-traps in a total of 2352 trap nights with 29.08% trap success from four trapping sessions. Trapped rodent species and their population size and weight range are indicated in Table 1. Regarding population size, *M. natalensis* comprised more than 32% of the total captures followed by *A. dembeensis* (23%), and *M. erythroleucus* (19%). The least population size was observed in *G. murinus* (0.2%) followed by *Rattus rattus* (0.9%) and *Mus musculus* (1.0%) in the study period. Body weights of the trapped rodent species were in the range of 5-155 g. The mean body weight of each trapped rodents' species is also indicated on Table 1. Population estimates of rodents in each trapping session are given in Figure 1. The variation in the population size was highly significant (χ^2=56.4, df=3, P<0.001) among trapping sessions. The second trapping session had the highest estimate followed by the third sessions while the first and fourth sessions showed the least population estimate.

Table 1. Population size, density and biomass of live-trapped rodent species in the study area.

Species followed by mean body weight	Population Size (%)	Weight range (g)	Density (no./ha)	Biomass (g/ha)
Mastomys natalensis (55.4 g)	221 (32.3)	15-108	112.75	6246.63
Arvicanthis dembeensis (84 g)	158 (23.1)	20-150	80.61	6771.43
Mastomys erythroleucus (48 g)	133 (19.4)	15-95	67.86	3257.14
Tatera robusta (96.3 g)	57 (8.3)	25-130	29.08	2800.56
Mus mahomet (10.6 g)	33 (4.8)	5-18	16.84	178.47
Pelomys harrin gtoni (87.8 g)	25 (3.7)	37-129	12.76	1119.9
Lophuromys flavopunctatus (60.7 g)	24 (3.5)	12-99	12.24	743.26
Stenocephalemys albipes (62.6 g)	19 (2.8)	30-87	9.96	606.84
Mus musculus (9.9 g)	7 (1.0)	7-13	3.57	35.36
Rattus rattus (104.8 g)	6 (0.9)	38-155	3.06	320.82
Graphiurus murinus (20 g)	1 (0.2)	20	0.51	10.2
Total (63.28 g)	684 (100%)	5-155	348.98	22083.4

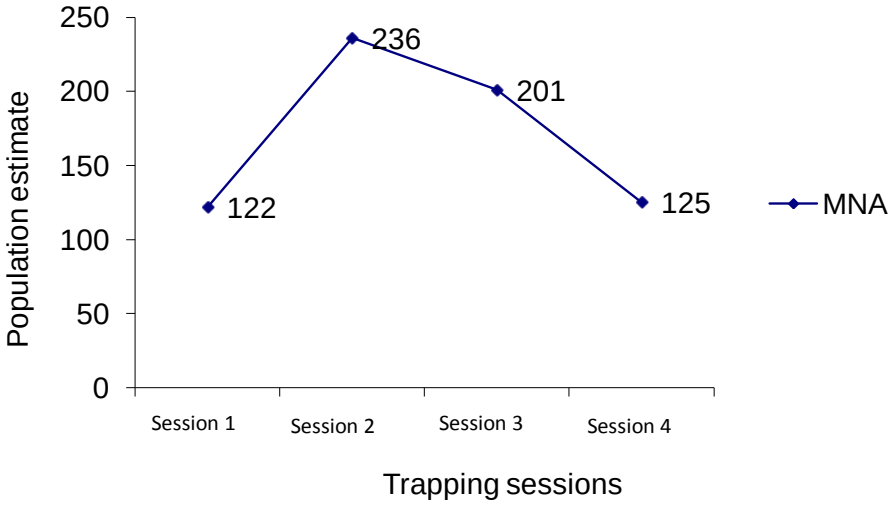

Figure 1. Population estimation of rodents in four trapping sessions.

Population density

The total density of trapped rodents in the study area was estimated to be 348.98 individuals/ha (Table 1). The highest overall population density was recorded in *M. natalensis* (112.75/ha) followed by *A. dembeensis* (80.61/ha) and *M. erythroleucus* (67.86/ha) while *G. murinus* (0.51/ha) followed by *R. rattus* (3.06/ha) and *M. musculus* (3.57/ha) were comprised the lowest population density (Table 1).

The population densities of rodents in different habitats during different seasons are given in Table 2. The density of rodents was more in bushland followed by acacia woodland during both seasons whereas the lowest density was recorded for wheat and maize farm during dry season. The highest population densities of *M. natalensis*, *A. dembeensis, M. erythroleucus* and *T. robusta* were recorded in bushland whereas the lowest was in wheat farm during dry season. There was no record for *T. robusta* in maize farm. The lowest and the highest density of *M. mahomet* was recorded in bushland during wet and dry season, respectively, but not recorded in acacia woodland. *Pelomys harringtoni* had more density in bushland and the least in wheat farm during dry and wet season, respectively; but not recorded in acacia woodland and wheat farm in the dry period. *Lophuromys flavopunctatus* was recorded only in bushland with more density in wet season. Highest population density of *S. albipes*, *M. musculus* and *R. rattus* was observed in bushland, wheat farm and maize farm, respectively during wet season. Among the trapped rodent species in the present survey, the population

Table 2. Number of individuals and population density (individuals per hectare) of rodents in different habitats during different seasons (density in parenthesis).

Species followed by mean body weight	Bushland		*Acacia* woodland		Maize farm		Wheat farm	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
M. natalensis (55.4 g)	56 (114.3)	78 (159.2)	29 (59.2)	19 (38.8)	13 (26.5)	3 (6.1)	20 (40.8)	2 (4.1)
A. dembeensis (84 g)	21 (42.8)	36 (73.5)	24 (49)	33 (67.3)	17 (34.7)	8 (16.3)	17 (34.7)	3 (6.1)
M. erythroleucus (48 g)	21 (42.8)	37 (75.5)	28 (57.1)	23 (46.9)	7 (14.3)	2 (4.1)	14 (28.6)	1 (2.0)
T. robusta (96.3 g)	10 (20.4)	19 (38.8)	8 (16.3)	10 (20.4)	0	0	8 (16.3)	2 (4.1)
M. mahomet (10.6 g)	1 (2.0)	15 (30.6)	0	0	5 (10.2)	3 (6.1)	7 (14.3)	2 (4.1)
P. harrin gtoni (87.8 g)	5 (10.2)	8 (16.3)	4 (8.2)	0	5 (10.2)	2 (4.1)	1 (2.0)	0
L. flavopunctatus (60.7 g)	14 (28.6)	10 (20.4)	0	0	0	0	0	0
S. albipes (62.6 g)	9 (18.4)	5 (10.2)	0	0	4 (8.2)	1 (2.0)	0	0
M. musculus (9.9 g)	0	1 (2.0)	0	0	2 (4.1)	0	4 (8.2)	0
R. rattus (104.8 g)	0	2 (4.1)	0	0	4 (8.2)	0	0	0
G. murinus (20 g)	0	0	0	1 (2.0)	0	0	0	0
Subtotal	137 (279.6)	211 (430.6)	93 (189.8)	86 (175.5)	57 (116.3)	19 (38.8)	71 (144.9)	10 (20.4)
Overall	SBL=348 (710.2)		AWL=179 (365.3)		MF=76 (155.1)		WF=81 (165.3)	

BL= bushland; AWL= acacia woodland; MF= maize farm; WF= wheat farm.

Table 1. Biomass (g/ ha) of rodents in different habitat types (figures in parenthesis are mean weight of species in each habitat).

Species	Habitats			
	Bushland	Acacia woodland	Maize farm	Wheat farm
M. natalensis	15302.33 (55.95 g)	4794.16 (48.94 g)	2043.56 (62.59 g)	2831.42 (60.32 g)
A. dembeensis	9856.96 (84.74 g)	9289.32 (79.86 g)	4141.29 (81.17 g)	3782.99 (97.55 g)
M. erythroleucus	5619.02 (47.47 g)	4819.94 (46.31 g)	838.96 (45.67 g)	1742.63 (56.93 g)
T. robusta	5538.66 (93.59 g)	3446.37 (93.83 g)	0 (0)	2218.57 (108.7 g)
M. mohamet	369.27 (11.31 g)	0 (0)	167.38 (10.25 g)	175.62 (9.56 g)
P. harringtoni	2114.17 (79.69 g)	773.16 (94.75 g)	1431 (100.14 g)	163.2 (80 g)
L. flavopunctatus	2974.79 (60.71 g)	0 (0)	0 (0)	0 (0)
S. albipes	1893.91 (66.29 g)	0 (0)	534.48 (52.4 g)	0 (0)
M. musculus	20.4 (10 g)	0 (0)	40.8 (10 g)	79.56 (9.75 g)
R. rattus	418.2 (102.5 g)	0 (0)	864.96 (106 g)	0 (0)
G. murinus	0 (0)	40.98 (20 g)	0 (0)	0 (0)
Total biomass	44075.3 (62.06 g)	23164.1 (63.4g)	10024.2 (64.6g)	11068.9 (67g)

density of *G. murinus* was the least when compared to other species in the study period.

Biomass estimation

The total mean biomass of rodents in the study area was 22083.4 g/ha. The highest biomass was recorded in *A. dembeensis* (6771.43g/ha) followed by *M. natalensis* (6246.63 g/ha) and *M. erythroleucus* (3257.14 g/ha) while *G. murinus* (10.2 g/ha) followed by *M. musculus* (35.36 g/ha) comprised the lowest biomass in the present study (Table 1).

Population biomass of rodents was highest in bushland and lowest in maize farm (Table 3). The largest and lowest biomasses per habitat type were recorded for *M. natalensis* (15302.33 g/ha) and *M. musculus* (20.4 g/ha), respectively from bushland. Biomass of rodents was highest in trapping session 2 and lowest in trapping session 4.The highest and the least biomass per trapping session were recorded for *A. dembeensis* and *M. musculus*, respectively in all trapping sessions except in trapping session 1 where *M. natalensis* had the highest biomass (Table 4). The biomass of rodents during the wet season (12566.6 g/ha) was greater than during the dry season (9521.3 g/ha).

Age distribution and sex ratio

Composition of different age groups of trapped rodent communities between seasons is given in Table 5. All

Table 2. Biomass (g/ ha) of rodents in different trapping sessions (figures in parenthesis are mean weight of species in each trapping session).

Species	Trappin g Session			
	Session 1	Session 2	Session 3	Session 4
M. natalensis	1250.64 (57.29 g)	2380.32 (61.38 g)	1403.55 (43.67 g)	1232.36 (60.38 g)
A. dembeensis	1202.53 (90.62 g)	2472.81 (91.45 g)	1719.4 (66.08 g)	1474.41 (96.18 g)
M. erythroleucus	632.4 (62 g)	1214.28 (47.6 g)	666 (37.29 g)	742.51 (51.96 g)
T. robusta	659.43 (107.75 g)	752.77 (105.43 g)	898.11 (88.05 g)	489.58 (87.27 g)
M. mohamet	15.3 (10 g)	52.02 (10.2 g)	67.82 (10.23 g)	42.84 (12 g)
P. harringtoni	167.79 (82.25 g)	608.4 (108.45 g)	343.74 (67.4 g)	0 (0)
L. flavopunctatus	248.39 (60.88 g)	239.69 (78.33 g)	90.27 (44.25 g)	164.72 (53.83 g)
S. albipes	198.9 (78 g)	241.74 (59.25 g)	68.85 (45 g)	97.42 (63.67 g)
M. musculus	3.57 (7 g)	26.52 (10.4 g)	5.1 (10 g)	0 (0)
R. rattus	59.16 (116 g)	157.08 (102.67 g)	0 (0)	104.55 (102.5 g)
G. murinus	0 (0)	0 (0)	10.2 (20 g)	0 (0)
Total Biomass	4415 (70.93 g)	8151.6 (67.7 g)	5273.2 (51.42 g)	4248.1 (66.6 g)

Table 3. Age distribution and sex ratio of live-trapped rodents (numbers in parenthesis are percentage).

Age groups	Sex		Season		Total
	Male	Female	Wet	Dry	
Young	56	63	40 (33.6)	79 (66.4)	119 (17.4)
Sub-adult	51	52	47 (45.6)	56 (54.4)	103 (15.1)
Adult	220	242	271 (58.7)	191 (41.3)	462 (67.5)
Total	327	357	358 (52.3)	326 (47.7)	684 (100)

age groups were represented in the population of trapped rodents during both dry and wet seasons. From the total 684 individuals captured, adults comprised 67.5%, sub adult 15.1% and young 17.4%. Age distribution was significantly varied (χ^2=26.0, df =2, P < 0.001) among seasons. More young individuals were captured during the dry seasons compared to wet season (χ^2=12.8, df =1, P <0.001). The number of adult individuals was higher than young and sub adult individuals in both seasons. Adults distribution among seasons in the present study was significantly different (χ^2=13.9, df =1, P< 0.001). From the total rodents captured, males comprised 327 (47.8%) and females 357 (52.2%). The sex ratio between seasons (46.4: 53.6% for the wet and 49.4:50.6% for the dry season) was not significantly different (χ^2=0.6, df =1, P>0.05).

DISCUSSION

In the present survey, *M. natalensis* was recorded as the most dominant species and its population size and density was very high. Similarly, different reports affirmed that *M. natalensis* was the dominant species in different parts of Ethiopia (Yalden et al., 1976; Datiko et al., 2007; Tadesse and Bekele, 2008; Chekol et al., 2012; Datiko and Bekele, 2014). Moreover, Mulungu et al. (2013) also showed that *M. natalensis* is the most dominant rodent in Tanzania. This might be due to high reproductive success and large litter size.

A. dembeensis was the second most dominant species with its population size and density with variable status in different habitats. This finding is in agreement with other reports elsewhere and in different parts of Ethiopia (Bekele and Leirs, 1997; Capula et al., 1997; Bekele et al., 2003; Gebresilassie et al., 2006; Chekol et al., 2012). This may be due to vegetation cover and grass loving nature of the rodent. Since this species is active during the day time, it requires more vegetation cover to protect itself from predators.

Mastomys erythroleucus was the third abundant rodent in the present study. It was comparatively common in *Acacia* woodland. This is in accordance with the findings of other researchers in different parts of Ethiopia (Bekele and Leirs, 1997; Bekele et al., 2003). *M. mahomet* and *M. musculus* were found in the three habitat types that include natural and farm habitats and exploited at altitudinal range between 1,590 and 1,635 m above sea level. This was not in line with the description of Bates (1988) that reported their occurrence exclusively in urban

and villages. However, this is consistent with other reports (Yalden, 1988a; Bekele and Leirs, 1997; Bekele et al., 2003; Gebresilassie et al., 2004). The least population size was observed in *G. murinus* only found in *acacia* woodland followed by *R. rattus* in the present study. *Lophuromys flavopunctatus* was recorded only in bushland with more density in wet season. This might be due to habitat specificity nature of these species (Makundi et al., 2009).

In the present study, there was variation in the population size, density and biomass among trapping sessions and habitats with the highest estimate in the second trapping session and bushland habitat type. These population fluctuations might be mostly attributed to variation in weather conditions, reproductive patterns, vegetation cover, food and water. This is supported by different researchers (Fernandez et al., 1996; Makundi et al., 2005; Gebresilassie et al., 2006; Makundi et al., 2009; Chekol et al., 2012; Mulungu et al., 2013; Datiko and Bekele, 2014). Although there was high rainfall that affects availability of food, water and vegetation covers, population numbers, density and biomass were low during the first trapping session. This might be due to increasing death rate associated with flooding storm and chilling effects and seasonality of reproduction in most species of rodent.

Habitat associated population size, density and biomass of rodents was lowered in farmlands. This could be due to the fact that farmlands had homogeneity and the crops were not at fruiting stage, which could influence continuous food supply unlike to heterogeneous habitat that supports different species of rodents. Moreover, farmlands had been cleared entirely as well as nearby habitats that determine shelter of rodents. In addition, maize farmland was waterlogged, which was unfavorable for rodents. This is in agreement with Mulungu et al. (2013) reports in Tanzania. In addition to farmlands, in *Acacia* woodland, the population size was decreased during the first and the last trapping session. This could be due to the fact that the grazing effect of wild mammals (mainly warthogs) and the topography of the habitat which would favor water logging during the wet season.

During the second trapping session, the population size, density and biomass was higher than the other sessions. This could be due to the fruiting time of wild plants and agricultural crops that supplied enough food for rodents. This is in accordance with Gebresilassie et al. (2006) report. Moreover, at fruiting time natural habitats as well as farmlands have better ground cover attracting more rodents that protect from predators. Further, the post breeding effect was revealed during late wet and early dry seasons; as a result of this the population number, density and biomass was increased.

During the last trapping session in our survey, the biomass of rodents was lower than the other trapping sessions, particularly in farmlands after harvest. This could be the fact that the trapping activities was made during the long dry period when food resource and vegetation coverage scarcity evidenced. This could influence the migration rate of rodents in searching for suitable habitats food and shelter. This finding is in line with that of Chekol et al. (2012) report. Population size, density and biomass of rodents was higher in bushland whereas was least in farmlands. This might be due to suitable vegetation cover, food source, and moderate temperature and moisture contents as well as habitat heterogeneity in bushland rather than homogeneous farmlands. This is agrees with other findings by Chekol et al. (2012) and Addisu and Bekele (2013).

The highest biomass was recorded in *A. dembeensis* followed by *M. natalensis* and *M. erythroleucus* while *G. murinus* followed by *M. musculus* comprised the lowest biomass in the study area. Even though the abundance of *M. natalensis* was greater than *A. dembeensis*, the highest biomass was estimated for *A. dembeensis* because of body weight variation. Although *M. mahomet* was captured more abundantly than *S. albipes* and *R. rattus*, its contribution to the overall biomass was limited due to their size. The six individuals of *R. rattus* contributed more to the overall biomass than 33 *M. mahomet*. The largest and lowest biomasses per habitat type were recorded for *M. natalensis* and *M. musculus*, respectively from bushland.

In our survey, all age groups were represented in the population of most rodent species and in all trapping sessions. However, there was significant difference in age distribution among seasons. In most of the study periods, adults dominated the population structure. The age distribution in a population of most species at different seasons was directly related to the seasonality in reproduction. More young individuals were captured during the dry seasons compared to wet season. The low frequency of captured of young or sub-adults followed the high number of pregnant female. This is in agreement with different reports (Taylor and Green, 1976; Happold and Happold, 1991; Bekele and Leirs, 1997).

In conclusion, there was variation in population size, density and biomass of rodents in different habitats and seasons. These population fluctuations might be mostly due to variation in rainfall, habitat heterogeneity, vegetation cover, reproductive patterns, quality and quantity of food and water. There was significant variation on different age groups associated with seasons; as a result of high number of pregnant females during the wet season. Moreover, seasonal breeding patterns appeared in most species. Therefore, from the result, this study attempted to indicate the population structure of rodents in Alage, southern Ethiopia. This would have value to contribute knowledge about the biodiversity of the ecosystem.

Conflict of Interests

The author(s) have not declared any conflict of interests

ACKNOWLEDGEMENTS

We acknowledge the Developmental Initiative Fund (DIF) and Addis Ababa University for their financial support.

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academicJournals

Vol.7(1),pp.14-22, January, 2015
DOI: 10.5897/JENE2014.0493
Article number: EF5F53349706
ISSN 2006-9847

http://www.academicjournals.org/JENE

Journal of Ecology and the Natural Environment

Full Length Research Paper

Carbon stock in Adaba-Dodola community forest of Danaba District, West-Arsi zone of Oromia Region, Ethiopia: An implication for climate change mitigation

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Received 7 December, 2014; Accepted 29 December, 2014

Forests can capture and retain enormous amount of carbon over long period of time. Their role in carbon emission balance is also well documented. However, especially in developing country, wide spread deforestation and forest degradation is continuing unknowingly and deliberately. This study was conducted to estimate carbon stock in dry Afromontane forest type of Danaba community forest (CF) of Oromia Regional State of Ethiopia. A systematic sampling method was used to identify each sampling point. Results revealed that the total mean carbon stock of the CF was 507.29 t·ha^{-1} whereas trees share 319.43 t·ha^{-1}, undergrowth shrubs 0.40 t·ha^{-1}, litter, herbs and grasses (LHGs) 1.06 t·ha^{-1} and soil organic carbon (SOC) 186.40 t·ha^{-1} (up to 30 cm depth). The ultimate result implies that Danaba CF is a reservoir of high carbon. To enhance sustainability of the forest potentiality, the carbon sequestration should be integrated with reduced emission from deforestation and degradation (REDD^{+}) and clean development mechanism (CDM) carbon trading system of the Kyoto Protocol to get monetary benefit of CO_2 mitigation.

Keywords: Carbon sequestration, climate change, community forest, mitigation.

INTRODUCTION

Forests are known to play an important role in regulating the global climate. International agreements on climate change recognized forests playing an important role in mitigating climate change by naturally taking carbon out of the atmosphere, thereby reducing the impact of CO_2 emissions (Perschel et al., 2007). The response of forests to the rising of atmospheric CO_2 concentrations is crucial for the global carbon cycle as they have huge potential in sequestering and storing more carbon than any terrestrial ecosystem (Jandl et al., 2006; Sundquist et al., 2008). Even though the role of forests in climate change mitigation is widely recognized, the recent assessment shows carbon stocks in forest biomass decreased by an estimated 0.5 gigatonne annually during the period 2005–2010 because of a reduction in the global forest area (FAO, 2010). Loss of forest biomass through deforestation and forest degradation makes up 12 to 20% of annual greenhouse gas emission, which is more than all forms of

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transportation combined (Saatchi et al., 2011). Especially, in Africa, forest degradation is very high which accounts for nearly 70% of the continent's total emissions (FAO, 2005). Hence, the endless rise of carbon emission is one of today's major concerns as it is the main causal factor for climate change.

Ethiopia is facing rapid deforestation and degradation of forest resources and experiencing the effects of climate change such as an increase in average temperature, and rainfall pattern variability, and is one of most vulnerable countries to climate change (World Bank, 2009). As Ethiopia is dependent on natural resources and agriculture, it is less able to cope with the shocks of climate change-induced droughts, floods, soil erosion and other natural disasters. People will find it hard to escape poverty if vulnerability to climate change persists. The government of the Federal Democratic Republic of Ethiopia has therefore implemented National $REDD^+$ working document in 2008 and Climate Resilience Green Economy (CRGE) Framework in 2011 by means of protecting and re-establishing forests for their economic, ecosystem services and carbon storage.

Even if the strategic frameworks focus on carbon emission management, Ethiopia does not have carbon accumulation records and databank to monitor and enhance carbon sequestration potential of different forests. Working in CFs would highly support the CRGE of Ethiopia by achieving carbon sequestration and conservation of biodiversity on the one hand, and empowering communities to take part and improve their living condition on the other hand since state owned forests are unsuccessful in their sustainability in the past decades. Although many Ethiopian people are living close to forests, the relationship of these people to forests has not been emphasized as an opportunity for spreading CFs to improve carbon sequestration.

An integrated forest management approach has been initiated in 2000 and named Forest Dwellers Association in Danaba CF. Danaba CF is a heavily exploited remnant coniferous forests found in West-Arsi Zone of Oromia Regional State of Ethiopia. Ongoing threats of observed human activities such as agricultural expansion, livestock grazing, illegal charcoal production and harvesting for firewood and construction which will likely diminish all carbon pools unless effective measures are enforced. Since large numbers of people are living close to the forest, incorporating the existing forest management strategy through Forest Dwellers Association with climate change mitigation potential of CDM carbon trading system of the Kyoto Protocol is important to overcome the problem.

Therefore, the study was designed to estimate the reserved carbon in all carbon pools of trees, shrubs, litter, herbs and grasses (LHGs) and soil of Danaba CF which would have high important as an information basis that can create the environment to attract climate change mitigation finances and so to expand and conserve CFs in Ethiopia.

MATERIALS AND METHODS

Study area

Danaba CF is a 5,437 ha forest that belongs to Adaba-Dodola CF priority areas under the administrative of Community Forest User Groups (CFUGs). The area is located in West Arsi Zone of Oromia National Regional State located 5-11 km South-East of Dodola town and 320 km South-East of Addis Ababa, Ethiopia (Figure 1). It lies between 06°54'20"N and 6°54'3"N latitude and between 39°8'19"E and 39°13'50"E longitude with an elevation ranging between 2490–3218 m a.s.l. According to Ethiopian National Meteorology agency weather data from 1995–2013, the mean minimum and maximum temperature of the study area is 3.6 and 24.3°C, respectively. The mean annual rainfall is 964 mm, of which 70-80% was received in main wet season of June to early September and 20-30% from remaining less pronounced wet periods. Vegetation of Danaba CF falls under dry-evergreen montane forest with strongly dominated by *Juniperus procera* and *Podocarpus falcatus* species. The parent soil material is made up of volcanic rocks of basalt and tuffs with rare rhyolites and the soils are brown or reddish brown of medium texture and freely draining. The soil is mostly of Luvisols type with Cherozem occurring in some place at lower altitudes (Digital soil and Terrain Data base of East Africa, 1997).

Sampling design and measurements

The field work for forest inventory was conducted from September 2013 to March 2014. A systematic sampling method was used for identification of sampling points distant 800 m from each other resulting in a total of 83 intersection points (Figure1- Sample plots). In each intersection, 20 × 20 m (400 m^2 equivalent to 0.04 ha) of plots were established for biomass inventory and identified using GPS and compass in the field.

In each biomass plot, all tree species were identified and had their diameter at breast height (DBH ≥ 2.5 cm) and height measured using diameter tape and Suunto Hypsometer, respectively. Following Bhishma et al. (2011) recommendations guideline for measuring carbon stocks in community managed forests, trees on the border were only included if more than 50% of their basal area falls within the plot. Trees overhanging into the plot were excluded, but trees with their trunks inside the sampling plot and branches outside were included.

Above-ground biomass calculation for trees used a two-way method: For tress ≥ 5 cm DBH, Chave et al. (2005) was used while trees having between ≥ 2.5 and < 5cm DBH, an allometric model of biomass and volume tables with species description for community forest management developed by Tamrakar (2000) was applied to calculate biomass.

Chave et al. (2005) model:

$$Y = \text{Exp.}\ \{-2.187 + 0.916 \ln (D^2 \times H \times S)\}$$

Where, Y: Above-ground biomass (kg), H: Height of tree (m), D: Diameter (cm) at breast height (1.3 m), and S: Wood density ($t.m^{-3}$) for specific species (Morales, 1987; Reyes et al., 1992; IPCC, 2003).

Tamrakar (2000):

$$\ln (AGSB) = a + b \ln (D)$$

Where, AGSB: Above-ground sapling biomass (kg), a and b: species specific constants (Sharma and Pukkala, 1990; Tamrakar, 2000), and: Diameter (cm) at breast height (1.3 m).

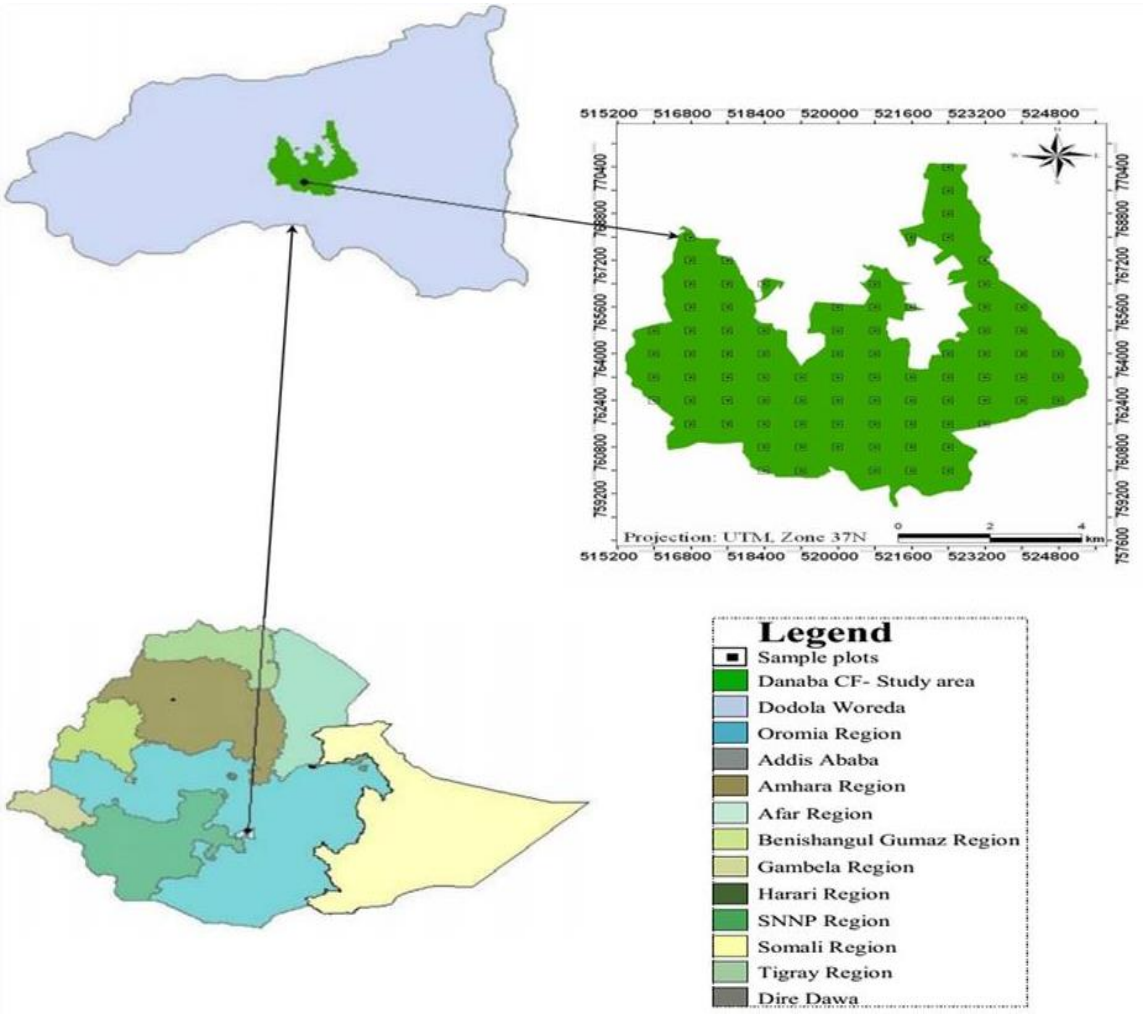

Figure 1. Map of Ethiopia showing Regional States, Danaba CF and location of acquired sample plots.

Below-ground biomass of tree species was calculated considering 15% of the aboveground biomass (Macdicken, 1997). The biomass of stock density was converted to carbon stock density by multiplying 0.47 fraction of the IPCC (2006) default value.

Additionally, at the center of each main plot a 5 × 5 m sub-plots were used for shrub species sampling. Numbers of individuals of each shrub species were counted and samples were uprooted.The species were divided into above- and below-ground by identifying the collar region and fresh weights recorded, and brought to the laboratory to determine dry biomass and percentage of carbon. A procedure adapted by Ullah and Al-Amin (2012) of the loss on ignition (LOI) method was used to estimate percentage of carbon in shrub species. In this method, initially taken fresh weight of samples was dried at 65°C in the oven for 48 h to take dry weight. Oven dried grind samples were taken (3.00 g) in pre-weighted crucibles, and then put in the furnace at 550°C for one hour to ignite. The crucibles were cooled slowly inside the furnace. After cooling, the crucibles with ash were weighed and percentage of organic carbon was calculated according to Allen et al. (1986).

$A_{sh} = (W_3 – W_1) / (W_2 – W_1) \times 100$

C (%) = (100 – % A_{sh}) × 0.58 (considering 58% carbon in ash-free litter material).

Where, C: Biomass carbon stock, W_1: Weight of crucible, W_2: Weight of the oven-dried grind sample and crucible and W_3: Weight of ash and crucible.

For sampling of LHGs (litter, herbs and grasses), a 1 m × 1 m sub-plots at all corner and middle positions of each main plot were used. LHGs within five 1 m^2 quadrats of each main plot were collected and weighed on the field, and 100 g of evenly mixed sub-samples were brought to the laboratory to determine dry biomass and percentage of carbon. To estimate the biomass carbon stock, the sub-samples taken in the field were used to determine an oven-dry-to-wet mass ratio that was used to convert the total wet mass to oven dry mass according to Pearson et al. (2005). The amount of biomass per unit area was calculated as:

$$LHGs = \frac{W_{field}}{A} * \frac{W_{sub-sample,dry}}{W_{sub-sample,wet}} * \frac{1}{10,000}$$

Where: LHGs: Biomass of leaf litter, herbs and grasses ($t.ha^{-1}$), W_{field}: Weight of the fresh field sample of leaf litter, herbs, and grasses- destructively sampled within an area of size A (g), A: Size of the area in which leaf litter, herbs, and grasses were collected (ha), $W_{sub\text{-}sample,\ dry}$: Weight of the oven-dry sub-sample of leaf litter,

Table 1. Biomass carbon stock of tree species (t.ha^{-1}).

Scientific name	Family	TAGB	TBGB	TB	TAGC	TBGC	TC
Juniperus procera Hochst. Ex Endl.	Cupressaceae	331.46	49.72	381.18	155.79	23.36	179.17
Podocarpus falcatus (Thunb.) R. B. ex Mirb.	Podocarpaceae	195.63	29.34	224.97	91.95	13.79	105.73
Cupressus lusitanica Miller	Cupressaceae	23.01	3.45	26.46	10.81	1.62	12.44
Maytenus arbutifolia (A. Rich.) Wilczek	Celasteraceae	18.16	2.72	20.88	8.54	1.28	9.82
Hagenia abyssinica (Bruce) J.F. Gmel.	Rosaceae	7.44	1.12	8.56	3.50	0.52	4.02
Eucalyptus globulus Labill.	Myrtaceae	5.63	0.84	6.47	2.65	0.40	3.04
Myrsine melanophloeos (L) R. Br.	Myrsinaceae	5.10	0.77	5.87	2.40	0.36	2.76
Ilex mitis (L) Radlk	Aquifoliaceae	1.72	0.26	1.98	0.81	0.12	0.93
Eucalyptus camaldulensis Dehnh.	Myrtaceae	0.95	0.14	1.09	0.45	0.07	0.51
Osyris quadripartita Salzm. ex Decne.	Santalceae	0.69	0.10	0.79	0.32	0.05	0.37
Oncoba spinosa Forssk.	Flacourtiaceae	0.39	0.06	0.45	0.18	0.03	0.21
Olea europaea L.	Olacaceae	0.36	0.05	0.41	0.17	0.03	0.19
Galiniera saxifraga (Hochst.) Bridson	Rubiaceae	0.21	0.03	0.24	0.10	0.01	0.11
Pittosporum viridiflorum Sims	Pittosporaceae	0.12	0.02	0.14	0.06	0.01	0.06
Hypericum revolutum Vahl	Hypericaceae	0.07	0.01	0.08	0.03	0.01	0.04
Myrsine africana L.	Myrsinaceae	0.06	0.01	0.07	0.03	0.00	0.03

TAGB, TBGB– total above- and below-ground biomass respectively; TB– total biomass; TAGC, TBGC– total above- and below-ground carbon respectively; TC– total carbon.

herbs, and grasses taken to the laboratory to determine moisture content (g), and $W_{sub\text{-}sample,\ wet}$: weight of the fresh sub-sample of leaf litter, herbs, and grasses taken to the laboratory to determine moisture content (g).

To determine percent of carbon in LHGs, the loss on ignition (LOI) method of Allen et al. (1986) was applied. The carbon density of LHGs was then calculated by multiplying biomass of LHGs per unit area with the percentage of carbon determined for each sample.

For SOC determination, soil samples were collected within five 1 m^2 quadrats in which LHGs samples were taken. Soil samples were collected up to 30 cm in depth (between 0–10, 10–20 and 20–30 cm depths) using a calibrated soil auger (IPCC, 2006). A composite sample was obtained by mixing soil from three layers taken from five sub-plots of each main plot in order to determine bulk density and organic carbon concentration. About 150 g of composite samples were collected from each main plot. To determine SOC, field's moist soil were dried in an oven at 105°C for 12 h in laboratory, and re-weighted to determine moisture content and dry bulk density. To estimate the percentage of organic carbon, samples were analysed by the wet oxidation method (Huq and Alam, 2005). The carbon stock density of soil organic carbon was calculated as recommended by Pearson et al. (2005) from the percentage of carbon and bulk density of soil at predetermined depth of the samples were taken.

$$SOC = \% C \times \rho \times d$$

Where. SOC: Soil organic carbon stock per unit area (t.ha^{-1}), %C: carbon concentration (%), d: soil depth (cm), and ρ: bulk density (g.cm^{-3}).

The carbon stock is then converted to tons of CO_2 equivalent by multiplying it by 44/12 or 3.67 of molecular weight ratio of CO_2 to O_2 (Pearson et al., 2007) in order to understand climate change mitigation potential of the study area.

Data analysis

Data for carbon density in trees, shrubs, litter, herbs and grasses and organic soil were processed using MS Excel spreadsheet and analysed using SPSS statistical software package.

RESULTS

Carbon store in tree species of Danaba CF

Out of the sixteen major tree species recorded in the study area, *Juniperus procera* and *Podocarpus falcatus* stored enormous density of carbon with 179.17 (56.1%) and 105.73 (33.1%)t·ha^{-1}, respectively; that amount accounts for approximately 90% of the Danaba CF carbon stock. *J. procera* had the highest total above- and below-ground biomass carbon with 155.79 and 23.36 t·ha^{-1}, respectively. The lowest carbon was recorded for *Myrsine africana* with 0.03 and 0.004 t·ha^{-1} of above- and below-ground carbon stock, respectively (Table 1).

Carbon stock share within DBH and height classes of tree species

Within eight category of DBH classes, 5–20 cm DBH class had the highest density of trees with 401 trees ha^{-1} (41.8%) while trees with DBH greater than 120 cm were the least dominant in the study area and consisting of 4 trees ha^{-1} (0.5%). Irrespective of the highest density of DBH class, the highest corresponding carbon reserves were found in DBH class of >80–100 (25.3%), >60–80 (20.1%) and >100–120 (15.8%) cm with 80.74, 64.20 and50.60t·ha^{-1} of corresponding carbon density, respectively. DBH class of 2.5–<5 cm was the reservoir of least carbon stock in the CF with 3.65 (0.5%) t·ha^{-1}

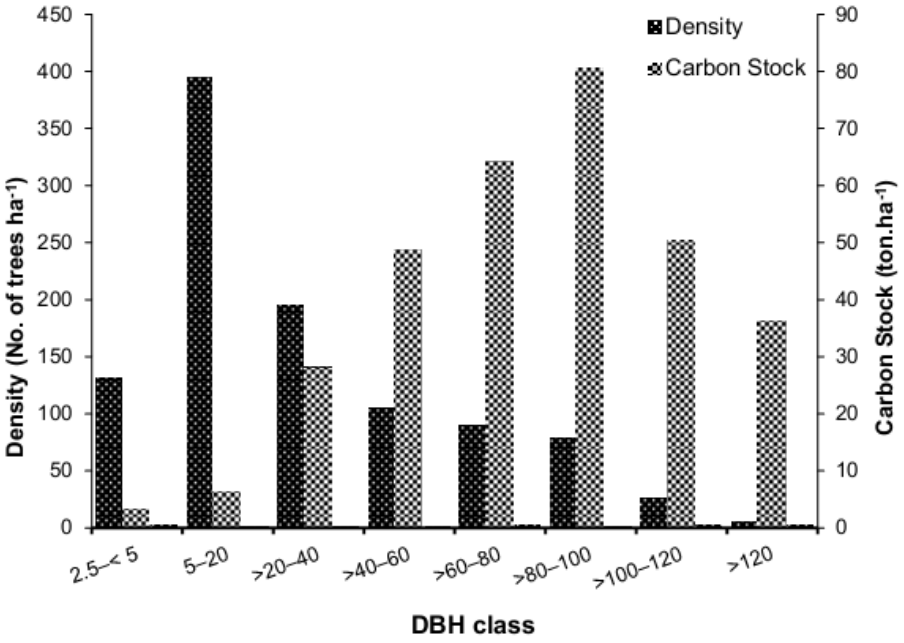

Figure 2. Carbon stock distribution within DBH classes.

of the total stock density (Figure 2).

The height of tree species were categorized into eight classes, of which height class of >10–15 m had the highest density of 355 trees ha^{-1} (34.5%) while least density of trees were found within the uppermost canopy of trees with >35 m of height class by accounting 3 trees ha^{-1} (0.3%). From the mean total mean carbon stock of the study area stored in above- and below-ground biomass of tree species of the study area, the highest carbon reserves were found in height class of >25–30 (25.4%), >20–25 (23.1%) and >15–20 (18.8%) m with corresponding stock density of 81.27, 73.79 and 59.97 $t{\cdot}ha^{-1}$, respectively(Figure 3).

Carbon store in shrub species of Danaba CF

Among six frequently occurring shrub species of the study area, mean carbon density of 0.40 ± 0.16 $t.ha^{-1}$ (1.47 CO_2 equivalents) was recorded. *Conyza hypoleuca* and *Carissa spinarum* were the highest and least store of carbon with 0.19 (46.3%) and 0.03 (7.3%) $t{\cdot}ha^{-1}$, respectively (Table 2).

Carbon store in LHGs and organic soil

In current inventory of Danaba CF, mean value of 1.06± 0.31 $t{\cdot}ha^{-1}$ carbon density with highest store seems to be in grasses. Hence, 3.89 $t{\cdot}ha^{-1}$ of CO_2 equivalents were stored in LHGs biomass.

The average bulk density of soil in the CF was estimated to be 0.937± 0.0535 $g.cm^{-3}$. The percentages of carbon content of the soil in the study area ranges from 2.27–15.85% with mean value of 6.38±2.6764%. Thus, the current average soil organic carbon investigated in the study area was found to be 186.40±76.5465 $t{\cdot}ha^{-1}$. Accordingly, the study area could possibly store 684.088 $t{\cdot}ha^{-1}$ of CO_2 equivalents within organic soil. The SOC share was varied at different soil depths. Table 3 and Figure 4 show variation of SOC among different soil profile. The average bulk density of the study area increased with depth increment. The mean values of bulk density from top, middle and deep soil profile were 0.82, 0.96 and 0.99 $g.cm^{-3}$, respectively; however, SOC decreased with depth increment (Table 3).

Thus, this study showed that the carbon density of trees, shrubs, LHGs and organic soil were found to be 319.43, 0.40, 1.06 and 186.40 $t{\cdot}ha^{-1}$, respectively. Hence, in the current study, the total carbon stock in Danaba CF was 507.29 $t{\cdot}ha^{-1}$ (Table 4). Accordingly, the maximum quantity of carbon stock was found in tree species with reservoir of 63% of the total carbon. The forest soil organic carbon ranked the second reservoir of carbon which has accumulated 36.7% of the total carbon in the study area. Shrubs and LHGs' biomass contributes small amount of carbon; stored only 0.1 and 0.2% of the total carbon, respectively (Figure 5).

DISCUSSION

The assessment of Brown (1997) and Achard et al. (2004) on biome-average tropical forest biomass carbon

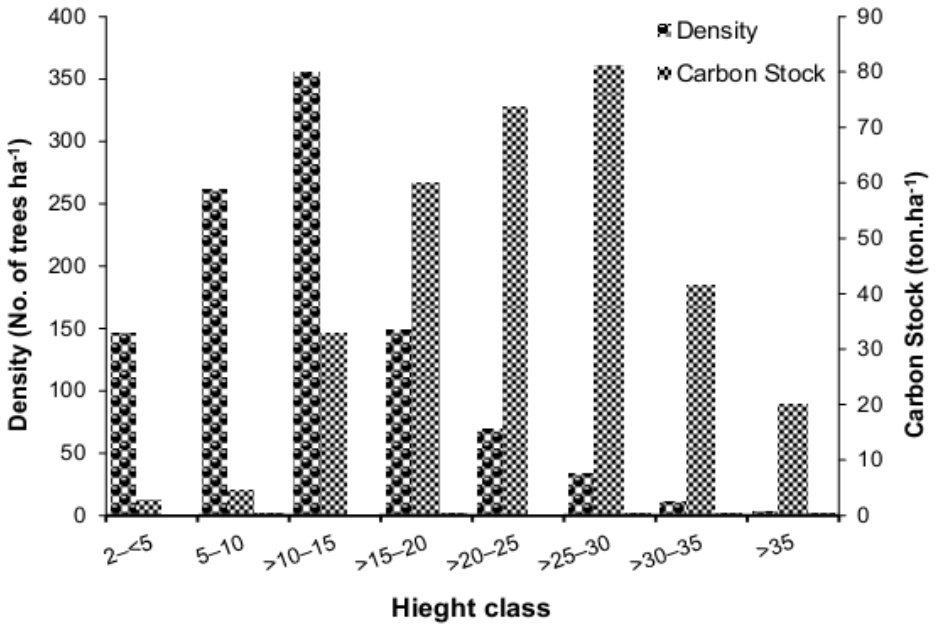

Figure 3. Carbon stock distribution within height classes.

Table 2. Biomass carbon stock of shrub species (t.ha^{-1}).

Scientific name	Family	TAGB	TBGB	TB	TAGC	TBGC	TC
Conyza hypoleuca A.Rich.	Asteraceae	0.30	0.15	0.45	0.14	0.05	0.19
Maytenus undata (Thunb.) Blakelock	Celastraceae	0.18	0.05	0.23	0.03	0.02	0.06
Rosa abyssinica Lindley	Rosaceae	0.09	0.02	0.11	0.04	0.01	0.05
Dovyalis abyssinica (A.Rich) Warb.	Flacourtiaceae	0.08	0.02	0.10	0.03	0.01	0.04
Erica arborea L.	Ericaceae	0.07	0.01	0.08	0.03	0.01	0.04
Carissa spinarum L.	Apocynaceae	0.08	0.03	0.11	0.02	0.01	0.03

TAGB, TBGB– total above- and below-ground biomass respectively; TB– total biomass; TAGC, TBGC– total above- and below-ground carbon respectively; TC– total carbon.

Table 3. Soil organic carbon stock at different soil depths

Depth of soil (cm)	Bulk density (g.cm^{-3})	Organic carbon (%)	SOC (t.ha^{-1}.depth^{-1})
0–10	0.82±0.101	11.70±3.243	95.01±15.550
10–20	0.96±0.162	6.35±3.182	59.34±12.441
20–30	0.99±0.151	5.42±2.549	52.11±13.893
F	6.61	19.05	11.87
P	0.0032**	0.0000**	0.0001**

** Values significant at α=0.05 (95%); SOC- soil organic carbon.

stock estimates and implications for global carbon cycle, the average carbon stock of Sub-Saharan Africa, Tropical Asia and Brazilian Amazon forests are 143, 151, 186 t.ha^{-1}, respectively. On the other hand, the mean biomass carbon stocks of trees in the Natural Forest of Bangladesh is 110.94 t·ha^{-1} (Ullah and Al-Amin, 2012), and Community Forest of Mid Hill Region of Nepal is 71.36 t·ha^{-1} (Anup et al., 2013). Hence, the present study was exceedingly higher than those continental and countries study as we found 507.29 t·ha^{-1}. Above- and below-ground trees carbon stock was comparable to the previous Ethiopian studies of tree biomass carbon of Egdu Forest (Adugna et al., 2013) and Tara Gedam Forest (Mohammed et al., 2014) while greater than

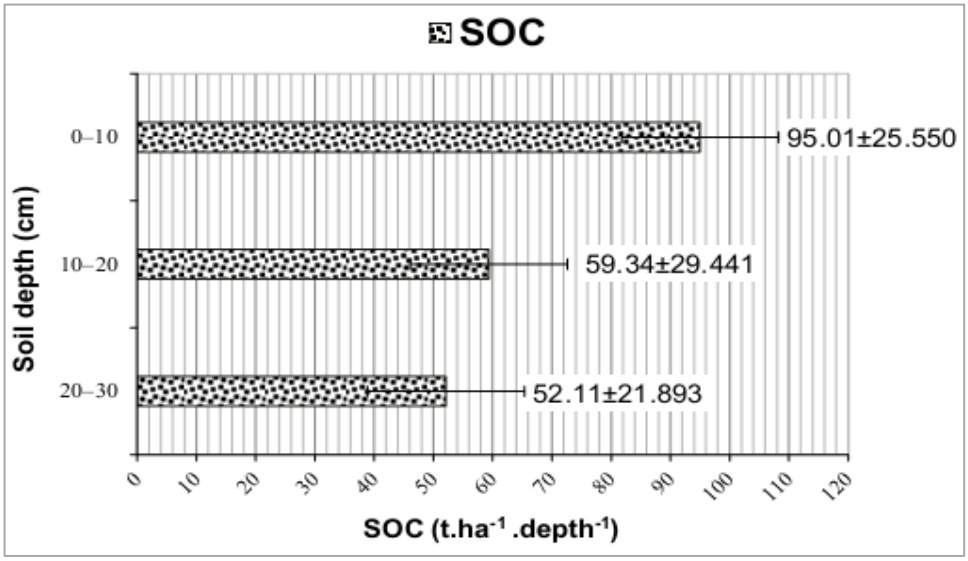

Figure 4. Soil organic carbon variation along different soil depth.

Table 4. Total carbon stock (t.ha^{-1}) in Danaba CF of Oromia Regional State, Ethiopia in 2014.

Carbon pools	TAGB	TBGB	TB	TAGC	TBGC	C(LHGs)	SOC	TC
Trees	591.00	88.65	679.65	277.78	41.65			
Shrubs	0.80	0.28	1.08	0.29	0.11			
LHGs						1.06		
Soil							186.4	
Total	591.80	88.93	680.73	278.03	41.76	1.06	186.4	507.29

TAGB, TBGB– total above- and below-ground biomass respectively; TB– total biomass; TAGC, TBGC– total above- and below-ground carbon respectively; C(LHGs) – Litter, herbs and grasses biomass carbon; SOC – soil organic carbon; TC– total carbon.

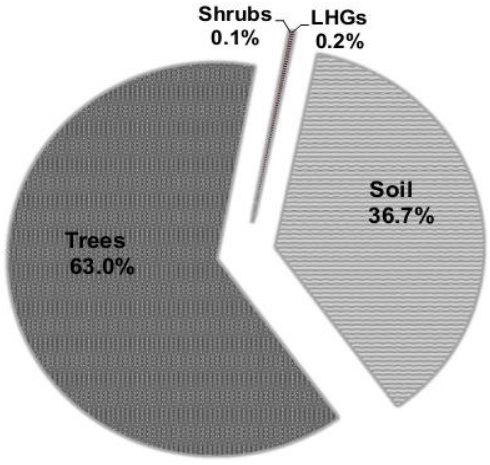

Figure 5. Carbon stock percentage in different forest strata.

Selected Church Forests (Tulu et al., 2013) and Woody Plants of Mount Zequalla Monastery (Abel et al., 2014). The variation might come from variation of age of the trees, existing species, and management of the forests. The use of an allometric model for biomass estimation might also help in explaining the difference in estimated value as explained that reliance on allometric equations could be one of the limitations resulting in large variations in such estimates (Lasco et al., 2000).

The mean carbon stock of shrub species of the CF was comparable to the carbon density found in Natural Forest of Bangladesh (Ullah and Al-Amin, 2012) while smaller than in Community Forests of Mid Hill Region of Nepal (Anup et al., 2013). Shrub species of Danaba CF contributed small biomass carbon by accounting only 0.1% of the total stock density. Huge canopies and observed seasonal plantation of tree species is unsuitable for shrub species regeneration.

LHGs biomass also shared small amount of carbon in the CF. The assessment on mean litter carbon of tropical forests varies between 2.6–3.8 t·ha^{-1} as reported by Brown and Lugo (1982) and 2–16 t.ha^{-1} by Brown (1997). The result was lower than those ranges. The mean stock density was also lower than most previous studies of

Ethiopian forest. The reason for the small carbon stock of LHGs is due to huge closed canopies of *J. procera* and *P. falcatus* up to the near ground making the growth of herbs and grasses unsuitable. The dominance of evergreen tree species of Danaba CF has also contributed to the existence of small litter falls. As the study area had mountainous manifestation, litter run off occurred and might cause for small carbon account in this pool. As the field data measurement was conducted in partial dry season, seasonal variation might also had significant contribution.

SOC of the study area was higher than the above mentioned Ethiopian forests of Menagasha Suba State Forest, Selected Church Forest, Woody Plants of Mount Zequalla Monastery and Woody Plants of Arba Minch Ground Water Forest. SOC estimates of Afromontane Rain Forests varies between 252 and 581 $t \cdot ha^{-1}$ (Munishi and Shear, 2004). The result of the present study was lower than this range. Besides, the value was also lower than that of Tara Gedam and Egdu Forests of Ethiopia. Rainfall and temperature variation of the studies might have contribution for this variation. Besides, mountainous manifestation of the study area might cause early run off litter, herbs and grasses which contributed to soil organic matter in decomposition. In the present study, SOC was found to be the highest inthe soil top layer, and this may be due to the accumulation and rapid decomposition of forest litter in the top soil (Figure 4). The pattern indicates that soil carbon decreased significantly with soil depth which revealed major trends in carbon accumulation which shows that it is found in the upper soil layers. Mendoza-Vega et al. (2003), Chowdhury et al. (2007) and Ullah and Al-Amin, (2012) found that more SOC was stocked at the soil depth of 0–14 cm. So, the result was in high conformity with those findings.

Conclusion

We observed that tree species stored the highest carbon stock of all carbon pools and *J. procera* reserved the highest biomass carbon stock. More than 50% of the trees were found in <20 cm DBH class. Hence, the study showed the forest is dominated by young trees after the implementation of community forest management through plantation and natural regenerations. The ultimate inference indicates that, there is high potential of increasing biomass carbon stock in the future if appropriate management of the forest is implemented. Existing timber harvesting should be done in a sustainable manner without disturbing the young trees to grow and increase their biomass. Communities should focus only on old and dead trees to fulfill the demand of firewood. Forest soil was also found to have a good reservoir of carbon stock in this forest. Different undergrowth shrubs and LHGs were also important pools that contributed to carbon sink in the CF though the carbon density were small as compared to many tropical forests. The CF was the reservoir of potentially high amount of carbon as compared to similar areas in the tropics particularly in tropical Africa, Asia and Latin America. Currently, the CF had the capacity to store 507.29 $t \cdot ha^{-1}$ carbon; helping in mitigating climate change by sequestering 1861.75 $t \cdot ha^{-1}$ of CO_2 equivalents which implies that remarkable carbon finance benefit has to be demanded. However, ongoing threats of observed human activities such as agricultural expansion, livestock grazing, harvesting for firewood and construction and illegal charcoal production will likely diminish all carbon pools unless effective measures have to be enforced. The carbon sequestration should be integrated with $REDD^{+}$ and CDM carbon trading system of the Kyoto Protocol to get monetary benefit of carbon dioxide mitigation which can be helpful for the sustainability of the forest.

Conflict of interests

The author(s) have not declared any conflict of interest.

ACKNOWLEDGEMENTS

The authors acknowledge Addis Ababa University, Oromia Forest and Wildlife Enterprise, Dilla University, Wondo Genet College of Forestry and Natural Resources and Ethiopian National Meteorology Agency, for the assistance during the research period. Fund was obtained from the Thematic Research of Addis Ababa University; “Floral and Fungal Diversity, Ethnobotany and Carbons Sequestration Potential of Western and Southwestern Forests of Ethiopia”.

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