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Pitout JDD, Church DL, Gregson DB, Chow BL, McCracken M, Mulvey M, Laupland KB (2007). Molecular epidemiology of CTXM-producing Escherichia coli in the Calgary Health Region: emergence of CTX-M-15-producing isolates. Antimicrob. Agents Chemother. 51: 1281-1286.

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Full Length Research Paper

Characterization and classification of soils along the toposequence at the Wadla Delanta Massif, North Central Highlands of Ethiopia

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The knowledge of soil properties and availability of reliable soil data play vital role in understanding the soil environment and its services. This study was conducted with the objective of characterizing and classifying soils of Wadla Delanta Massif, North Central Highlands of Ethiopia. Twelve representative soil pedons (profile pits) were opened on various landscape positions, described in the field and horizon-wise samples collected for morphological and physicochemical analysis. Variations in color (moist and dry) within a pedon and among pedons along the toposequence were observed with grayish, dark brownish or black colors dominating the surface layers, while stronger and brighter colors with shades of reddish brown and light brownish gray dominated the surface layers. The soils are heavy clays (35 to 80%), of low bulk density (1.02 to 1.35 g cm^{-3}), acceptable ranges of particle density for mineral soils (2.41-2.82 g cm^{-3}) relatively high total porosity (46.51-60.55%), and high available water holding capacity (129.9-287.9 mm m^{-1}).The soils were slightly acidic to moderately alkaline (6.25 to 8.29) in their reaction, salt free (EC < 0.5 dS m^{-1}), very low to medium in organic matter (0.12 to 4.82%) and total N (0.02 to 0.28%) contents, and available P (0.52 to 18.44 mg kg^{-1}), high to very high in CEC (31.98 to 65.48 cmolc kg^{-1}), exchangeable bases and base saturations (60.22 to 98.97%), with medium status of micronutrients occurring in order of Fe (0.82-10.40 $mgkg^{-1}$) >Mn (2.01-9.22 $mgkg^{-1}$) > Cu (0.80-6.03 $mgkg^{-1}$) > Zn (0.80-5.80 $mgkg^{-1}$), all of which were above the critical limit. Based on morphological, physical and chemical analysis, and the FAO-WRB Soil Classification System, the soils are classified as Mazi-Pellic Vertisols, Mazi-Calcic Vertisols, Haplic Cambisols and Mollic Leptosols. The soil potentials are hampered by their stickiness when wet and hard when dry, waterlogging and soil erosion due to inappropriate tilling and timing of cultivation. Therefore, integrated soil management is essential in the area.

Key words: Altitude, horizon, pedon, topography.

INTRODUCTION

Topography is one factor contributing to variation in soil morphological, physical and chemical characteristics (Amhakhian and Achimugu, 2011). Inadequate information on the influence of landscape on soil properties is a contributing factor limiting agricultural production in Ethiopia in general and in the study area in particular. Productivity of agriculture in the study area is severely constrained by the lack of adequate scientific information

on soil and land characteristics. Hitherto, there has not been any formal scientific study to characterize the soil resources of the area and map the soils using standard pedological classification systems. As a consequence, the potentials and limitations of the soils in the region are not adequately known. This has made the development of meaningful management scenarios all but impossible. As a result, the sustainable use of the soil resources for agriculture is facing future uncertainty.

Soil information gathered by systematic identification, grouping and delineation into different soil types is required if sound interpretations towards land use potential are to be made (Msanyaet al., 2003). A good inventory on soil properties and associated site characteristics is essential for advice on both current and potential land users on how to best use the resource. Soil fertility specialists need good soil information to identify the dominant soil types on which to conduct meaningful fertilizer trials and be confident that the findings are applicable to that soil type throughout region.

Although Ethiopia has long history of collecting basic information on soil characterization in the form of soil surveys (Eylachew, 1987, 1999;Mitiku, 1987; Mohammed, 2003;Abayneh, 2005), it is limited to a few selected high potential areas. Thus, much of the country information remains rather scanty relative to the large size of the country and the wide diversity of soils and landscapes. Furthermore, the few existing soil resource inventories that are available are characterized by their small scale nature with high level of generalization, generally based on few observations scattered over large areas. Moreover, these surveys have often used different methodologies and criteria. As a consequence, most existing studies cannot easily be correlated and all have limited utility, because of the coarse scale of the mapping. There is need for more efforts to be invested in a coordinated and systematic development of an inventory of the country's soil resources and other land information to facilitate sustainable land use planning activities. There is also a strong feeling that fertilizer trials should be done on well characterized soils to enhance transferability of information from one place to another.

Soil classification can also provide a basis for soil-related agro-technology transfer (Buol and Denton, 1984; Braimoh, 2002). Lawalet al. (2013) and Sharuet al. (2013) revealed that systematic soil classification links research results and their beneficial extension to field applications. Thus, soil classification is used to apply proper management practices, transfer technology and provide a ready-made map legend for soil surveyors. An example of the limited information on soil characterization and their classification can be found along the toposequence at the Wadla Delanta Massif in the North Central Highlands of Ethiopia. The present study was initiated to address the limited soils information in this region of the country. In the Wadla Delanta Massif of North Central Highlands of Ethiopia, the soils and land resources were systematically characterized, analyzed and mapped as part of a national effort to develop soil inventories for future planning and development.

MATERIALS AND METHODS

Description of the study area

This study was conducted at the Wadla Delanta Massif in Delanta District, north central highlands of Ethiopia (Figure 1). The study area lies between 11° 29' 29.82"and11° 41' 25.528" north latitudes and 39° 02' 19.186" to 39° 14' 05.038" east longitudes with elevation ranging from 2848 to 3486 meters above sea level (masl) and covering an area of 24,025 ha. It is located at about 499 km north of Addis Ababa and 98 km northwest of Dessie town.

The climate of the area is characterized by cold-dry and hot-dry seasons (from October to February and from March to June), respectively and wet season that extends from mid-June to September. The rainfall pattern is bimodal with peak periods from mid-July to early September. Fifteen years (1999-2013) mean annual rainfall is about 812 mm of which 60-70% is received in summer (*Kiremt)* and 30-40% in the spring (*Belg*) season (Figure 2).The mean annual minimum and maximum temperatures are 6.8 and 19.6°C, respectively (Figure 2).

Geology of the study area is characterized by the trap series of tertiary periods, similar to much of the central Ethiopian highlands (Mohr, 1971). Dereje et al. (2002) reported the area covered by Oligocene rhyolite and very thick ignimbrite units encompassing predominantly of alkaline basalt with numerous inter-bedded flow of trachyte. Granite, gneisses and basalt rock types exist in the area forming part of the basement complex and most of the soils are of basaltic parent material. Soils of the study area are greatly influenced by topography with high surface runoff during the main rainy season. There was no scientific studies in the area before this study except for FAO (1984) general soil survey (1:1 000 000 scale) made at the national level. The local people classified the soils into *Walka or Mererie Afer* (Vertisoils) in the plain area and *Nechatie or Gracha Af*er (Cambisoils) in steep slope or mountainous area.

The natural woodland and vegetation of the study area has disappeared due to overgrazing, increasing demand for fuelwood and charcoal, and conversion into cultivated lands. There are small patches of remnant natural forests on farm boundaries and around churches. Planted tree species like *Eucalyptus camaldulensis*, C*upressuslustanica, Acacia saligna*and A*cacia decurrens* are commonly found around homesteads and conserved lands. The *Eucalyptus camaldulensis* plantations are replacing the cultivated lands and expanding around backyards, stream banks and gully sides. Farming system is mixed livestock and crop production. The common rainfed crops grown in the area are bread wheat *(Triticumaestivum L.)*, food barley *(Hordenumvulgare* L.), faba bean (*Vicia faba L.*), lentil (*Lens culinaris L.*), grass pea (*Lathyrussativus* L.),

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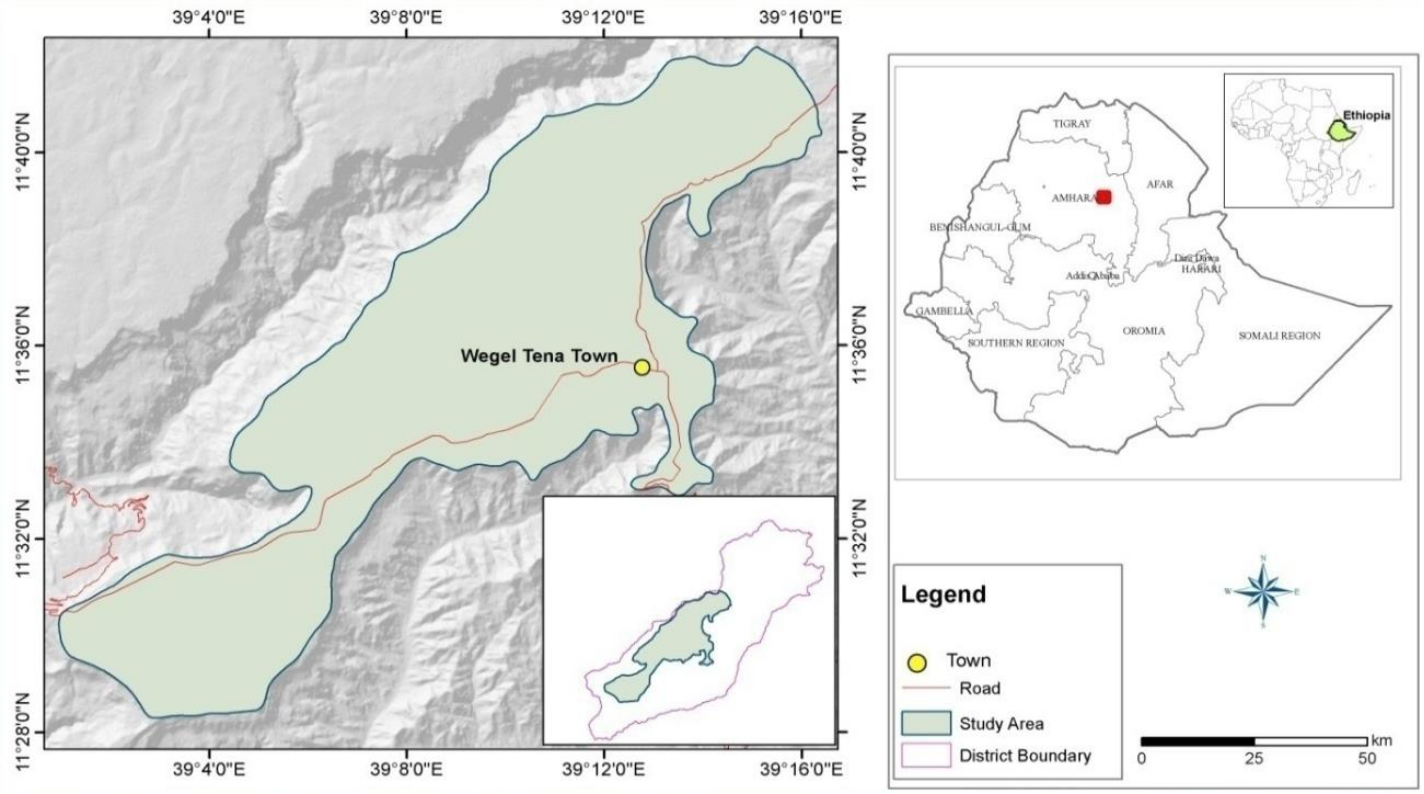

Figure 1. Location map of the study area.

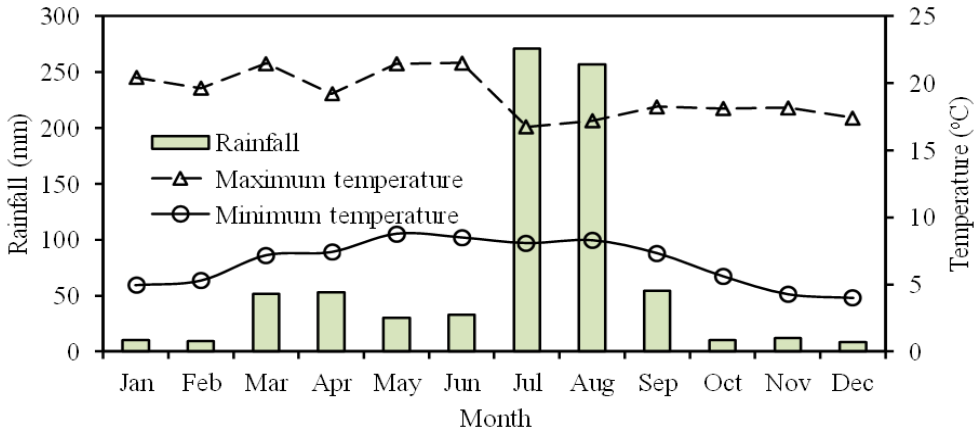

Figure 2. Mean (1999-2013) monthly rainfall, maximum and minimum temperatures of the study area.

chickpea (*Cicerarietinum L.*), teff (*Eragrostis tef L.*) and sorghum (*Sorghum bicolor L.*). All these crops are managed using traditional techniques and equipment (WAOR, 2013).

Site selection, field description and soil sampling

Before collecting soil samples, the existing land information were gathered from farmers and elders coupled with a visual observation in various parts of the district, obtaining base map (1:50,000 scale), preparing provisional map, extensive auguring to identify mapping units and sites for opening profile pits. The survey technique was a free survey following a stratified sampling technique and transect was drawn from the crest to the foot at the Wadla Delanta Massif, northcentral highlands of Ethiopia.Altitude along the toposequences ranged from 2600 to 3500 meter and was divided into three topographic categories: upper (> 3000 m), middle (2900-3000 m)

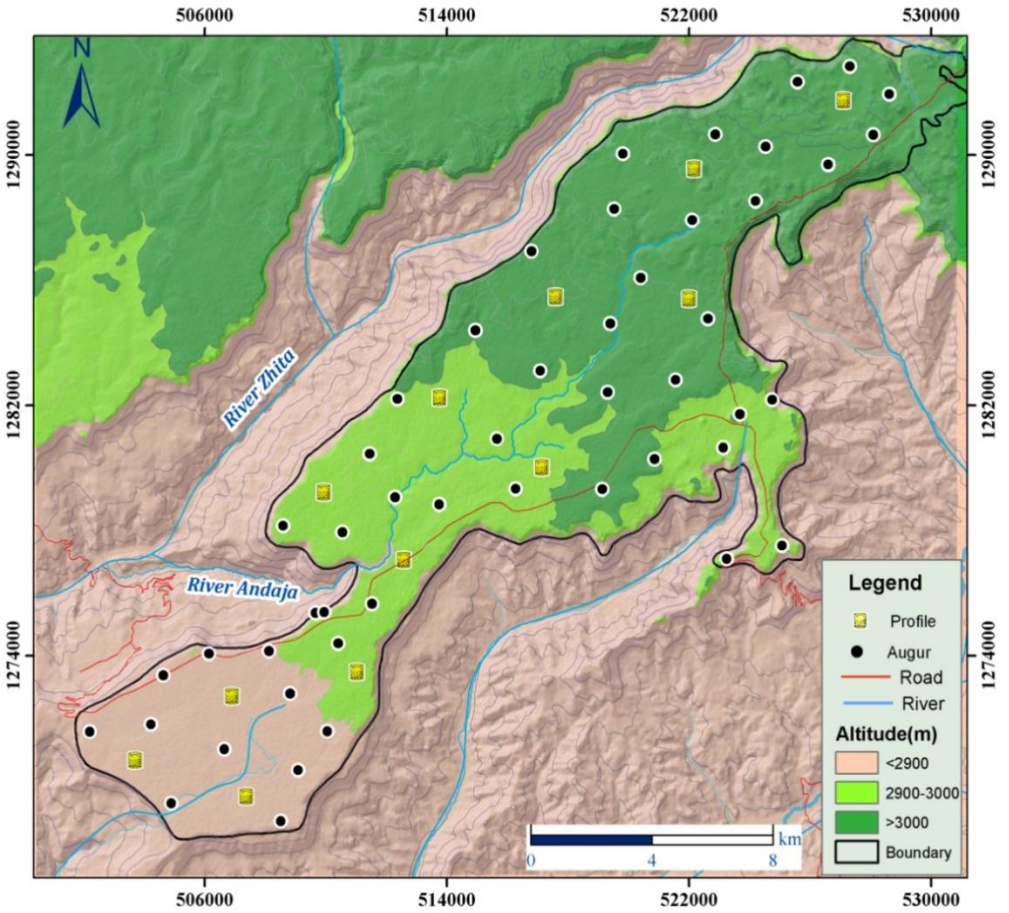

Figure 3. Elevation map of the study area.

and lower (< 2900 m). topographic positions. The study area was covered by an approximately 1:50,000 scale topographic map produced by Ethiopian Mapping Agency to determine different land units on the basis of topography and other external land characteristics. Topographic maps were also used for locating important land features to assist in soil mapping (Figure 3).

After having the preliminary site visit and verified interpretation of maps, pedons (profile pits) were opened on representative sites. Pedons were made to a depth of 2± m unless soil depth was limited due to stoniness or compactness. A total of twelve representative soil pedons (2 m wide x 2 m long x 2m deep) were excavated, described and sampled (Figure 3 and Table 1) following standard procedures to investigate morphological, physical and chemical properties of the soils. The horizons were designated *in situ* using FAO (2006a) guideline and soil color notation described using Munsell Soil Color Chart (1994). All sites were examined from February to April, 2012.

General site information and soil description were recorded; soil samples were collected from each generic horizons; properly labeled; air dried and crushed to pass through 2 mm sieve for analysis of most soil properties except for total N and soil OC in which case the samples were crushed further to pass through 0.5 mm sieve prior to laboratory analysis. Moreover, undisturbed (core) soil samples of known volume were collected, using core sampler, from each identified genetic horizons for bulk density determination and soil moisture retention characteristics. All pedons were geo-referenced using GPS, the elevation was recorded using an altimeter and the slope gradient was measured using clinometers. The soils of the study area were classified according to FAO-WRB (2006) Soil Classification Systems.

Laboratory analysis

Particle size distribution was determined by the modified sedimentation Bouyoucos hydrometer procedure (Bouyoucos, 1962). Bulk density (ρ_b) and particle density (ρ_s) were measured by core (Baruah and Barthakur, 1997) and pycnometer methods (Black and Hartge, 1986), respectively. Total porosity (*f*) was calculated from the measurements of bulk density (ρ_b) and particle density (ρ_p) as:

$$f = \left(1 - \frac{\rho_b}{\rho_s}\right) \times 100$$

Water retention at field capacity (FC) and permanent wilting point (PWP) were measured at -1/3 and -15 bars soil water potential, respectively, using pressure plate apparatus as described in Gupta (2004). Available water holding capacity (AWHC) was calculated as the difference between water contents at -1/3 and -15 bars of air-

Table 1. Site characteristics and land uses of the study area.

Pedon*	Latitude	Longitude	Altitude (masl)	Land use
MG01	11° 35' 11.940" N	39° 10' 46.980" E	2997	Grazing land
MC02	11° 33' 08.893" N	39° 06' 55.615" E	2931	Lentil crop already harvested
UC03	11° 39' 37.614" N	39° 12' 08.927" E	3143	Barley crop already harvested
UC04	11° 41' 25.528" N	39° 14' 05.038" E	3286	Barley crop already harvested
LG05	11° 31' 07.380" N	39° 04' 27.540" E	2880	Grazing land
LC06	11° 29' 29.820" N	39° 04' 59.940" E	2852	Wheat crop already harvested
LC07	11° 30' 19.226" N	39° 02' 19.186" E	2848	Wheat crop already harvested
MG08	11° 34' 18.597" N	39° 05' 28.309" E	2962	Grazing land
UC09	11° 37' 39.792" N	39° 12' 06.728" E	3050	Barley crop already harvested
UC10	11° 40' 25.158" N	39° 17' 31.078" E	3326	Barley crop already harvested
MC11	11° 36' 50.223" N	39° 09' 23.672" E	2910	Barley crop already harvested
UG12	11° 46' 5.395" N	39° 19' 53.728" E	3486	Grazing land

*The first number indicates the topography (1= upper, 2 = middle and 3 = lower), the 2nd and 3rd numbers indicate pedon (pit) number (01 = pedon 1, 02 = pedon 2, 03 = pedon 3…, 12 = pedon 12); C = cultivated, G = grass, L = lower, M = middle, U = upper topography and masl = meters above sea level.

dried soil sample, expressed in equivalent depth of water (mm/m) obtained by multiplying the gravimetric water content by the ratio of dry bulk density to density of water (taken as 1 g cm-3) and 1000 (conversion factor)

Soil pH was determined in H_2O (pH-H_2O) and 1M KCl (pH-KCl) using a glass electrode pH meter at the ratio of 1:2.5 soil to solution (Van Reeuwijk, 1993). Electrical conductivity (EC) was determined using a conductivity meter in a soil-water extract. Organic carbon (OC) was determined using the wet combustion method (Walkley and Black, 1934) and soil OM calculated by multiplying soil OC by 1.724. Total nitrogen was determined by the micro-Kjeldahl digestion, distillation and titration method (Bremner and Mulvaney, 1982). Available phosphorus (P) was analyzed using the sodium bicarbonate extraction solution (pH 8.5) method (Olsen et al., 1954) and amount measured by spectrophotometer.

Cation exchange capacity and exchangeable basic cations were extracted by 1M ammonium acetate (pH 7) method (Van Reeuwijk, 1993). From the leachate, exchangeable Ca and Mg were determined by atomic absorption spectrophotometer (AAS), while exchangeable K and Na were read by flame photometer. Percent base saturation was calculated as the ratio of the sum of exchangeable bases (Ca, Mg, Na and K) to the CEC of the soil multiplying by 100. Extractable micronutrients (Fe, Mn, Cu and Zn) were extracted by diethylenetriaminepenta-acetic acid (DTPA) method and the reading was quantified using AAS (Lindsay and Norvell, 1978). Calcium carbonate content was determined following acid neutralization method (Jackson, 1970). The analyses were undertaken at the Haramaya University Soil Chemistry Laboratory, Water Works Design and Supervision Enterprise Laboratory, and Sirinka Agricultural Laboratory Center.

RESULTS AND DISCUSSION

Soil morphological characteristics

The depth of the investigated soils ranged from slightly shallow to very deep with irregular A, B and C horizons (Table 2). Among the topographic positions, the upper pedons were relatively shallow in depth, moderate in stoniness and moderate to well drained soils. The lower topographic pedons were deeper, high in clay accumulation and gently sloping (2-4%). Generally, the thickness of the soils increased down topographic positions indicating the dominance of erosion over accumulation on the upper positions and otherwise in the lower topographic positions. The surface soils had higher concentration of plant roots and coarser texture, while the subsurface soils are finer in texture, denser and harder. At the surface horizons, the soil color matrix varied from dark gray (7.5YR 4/1, dry) to dark gray (2.5Y 4/1, dry) in the upper land pedons, very dark gray (7.5YR 3/1, dry) to brown (10YR 4/3, dry) in the middle land pedons, and dark gray (7.5YR 4/1, dry) to very dark gray (10YR 3/1, dry) in the lower land pedons. At the subsurface layers, it ranged from light reddish brown (2.5Y 6/4, dry) to light gray (2.5Y 7/1, dry) in upper topographic pedons, weak red (2.5YR 4/2, dry) to yellowish brown (10YR 5/6, dry) in middle topographic pedons and reddish gray (5YR 5/2, dry) to grayish brown (10YR 5/2, dry) in the lower topographic pedons.

The variations in soil color observed within and among the pedons might be reflections of differences in chemical and mineralogical composition, topographic positions, soil OM content, texture, parent materials and moisture regime. The dark color, in surface horizons, might be attributed to the effect of higher OM contents, while the reddish color, in the subsurface horizons, might be due to the presence of iron compounds in various states of oxidation and low OM content. Similar finding were reported by Dengizet al. (2012) who stated that variation in soil color could be related to OM, waterlogging, $CaCO_3$ accumulations and redox reaction in the soil.

Table 2. Selected morphological characteristics of soils at WadlaDelanta Massif, North Central Ethiopia.

Pedon	Horizon	Depth (cm)	Matrix color		Structure*1			Consistence*2			Boundary*3
			Moist	Dry	Grade	Size	Shape	Dry	Moist	Wet	
MG201	A	0-38	7.5YR 2.5/2	7.5YR 3/1	5	fn	cu	h	fr	ssk-pls	A-S
	Ass1	38-110	7.5YR 2.5/1	7.5YR 3/2	6	mid	prs	vh	fr	sk-pls	C-W
	Bss1	110-122	5YR 3/1	5YR 4/1	3	mid	prs	h	vfr	vsk-vpls	G-W
	Bss2	122-225+	5YR 3/2	5RY 3/3	1	mid	grn	Sh	vfr	sk-pls	A-S
MC202	Ap	0-20	10YR 2.5/1	10YR 3/1	5	mid	grn	vh	vfr	sk-pls	A-S
	Ass1	20-102	10YR 2.5/1	10YR 4/2	6	mid	abk	vh	fr	vsk-vpls	C-W
	Ass2	102-123	2.5Y 3/2	2.5YR 4/2	5	mid	prs	h	fr	sk-pls	A-S
	Bss	123-215+	5YR 3/2	5YR 3/3	3	mid	sbk	sh	fr	sk-pls	A-S
UC103	Ap	0-22	10YR 3/1	10YR 4/1	5	mid	grn	vh	vfr	vsk-vpls	A-S
	Bss1	22-33	10YR 2.5/1	10YR 4/2	6	mid	abk	vh	vfr	vsk-vpls	C-W
	Bss2	33-58	7.5YR 3/2	7.5Y 3/3	5	mid	prs	h	fr	sk-pls	A-S
	C	58-89+	5YR 3/2	5RY 3/3	3	mid	sbk	sh	fr	sk-pls	A-S
UC104	Ap	0-23	10YR 3/1	10YR 4/1	5	coarse	grn	vh	fr	sk-pls	A-S
	Ass1	23-58	10YR 5/2	10YR 6/2	6	coarse	prs	vh	fm	vsk-vpls	C-S
	C	58-95+	2.5Y 8/2	10Y8/2	1	mid	prs	sh	fr	nsk-npls	A-S
LG305	A	0-35	10YR 2/1	10YR 2/2	5	mid	cu	sh	fr	sk-pls	A-S
	Ass1	35-76	10YR 2.5/1	10YR 4/2	6	mid	prs	vh	fm	sk-pls	A-W
	Bss1	76-114	2.5Y 3/2	10YR 4/	5	mid	prs	vh	fm	vsk-vpls	C-W
	Bss2	114-205+	2.5Y 4/3	2.5Y 3/3	1	mid	prs	sh	vfr	ssk-spls	C-W
LC306	Ap	0-32	2.5Y 4/1	10YR 3/1	5	fn	grn	h	fr	sk-pls	A-S
	Ass1	32-76	10YR 2/2	10YR 3/2	6	mid	prs	h	fm	vsk-vpls	C-W
	Bss1	76-115	2.5Y 3/3	2.5Y 5/4	5	mid	prs	h	fm	vsk-vpls	C-W
	Bss2	115-216+	5YR 3/3	5YR 5/2	3	mid	prs	sh	fr	ssk-spls	A-W
LC307	Ap	0-28	7.5YR 3/3	7.5YR 4/1	5	fn	grn	vh	fm	vsk-vpls	A-S
	Ass1	28-110	10YR 3/1	5YR 4/1	6	mid	prs	vh	vfm	vsk-vpls	C-W
	Bss1	110-135	10YR 4/2	10YR 5/2	6	mid	prs	vh	fr	sk-pls	G-W
	Bss2	135-208+	10YR 3/4	10RY 4/4	1	mid	prs	sh	fr	sk-pls	A-S
MG208	A	0-37	10YR 2.5/1	10YR 4/2	2	fn	cu	sh	fm	sk-pls	A-S
	Ass1	37-140	10YR 2.5/2	10YR 4/1	6	mid	prs	vh	fm	vsk-vpls	C-W
	Bss1	140-189	7.5YR 3/3	7.5YR4/3	6	mid	abk	vh	vfm	vsk-vpls	C-W
	Bss2	189-198	10YR 4/4	10YR 5/6	6	mid	prs	h	vfm	sk-pls	C-S
	BC	198-245+	5YR 3/2	5YR 5/3	3	fn	grn	sh	fr	nSk-nspl	C-S
MC109	A	0-25	7.5YR 3/1	7.5YR 3/2	6	mid	grn	vh	fm	vsk-vpls	C-S
	B	25-48	7.5Y 2.5/2	7.5YR 3/2	6	coarse	abk	vh	fm	vsk-vpls	C-S
	C	48-75+	10YR 4/4	10YR 5/6	1	coarse	grn	sh	fr	nsk-npls	C-S
UC110	Ap	0-25	7.5YR 3/1	7.5YR 4/1	6	mid	grn	h	fr	sk-pls	A-S
	Ass1	25-62	10YR 2/2	10YR 3/3	6	coarse	prs	vh	fm	vsk-vpls	A-I
	Bss	62-78	2.5Y 4/2	2.5Y 5/2	4	mid	prs	h	vfr	sk-pls	A-S
	C	78-99+	2.5Y 6/2	2.5Y 7/1	1	mid	prs	sh	vfr	ssk-spls	A-S
MC211	Ap	0-25	10YR 3/3	10YR 4/3	5	coarse	grn	vh	fm	sk-pls	A-S
	Ass1	25-65	10YR 3/1	10YR 4/1	6	coarse	wdg	vh	fm	vsk-vpls	C-S
	Bss	65-95	5YR 4/4	5YR 3/4	5	mid	prs	vh	fm	vsk-vpls	C-W
	C	95-115+	5YR 3/4	5YR 5/6	1	mid	prs	sh	fr	nsk-npls	A-S
UG112	A	0-33	2.5Y 4/1	2.5Y 4/2	2	fn	cu	h	fm	sk-pls	S-C
	B	33-47	2.5YR 5/4	2.5YR 6/4	6	mid	prs	vh	fm	sk-pls	S-W
	C	47-65+	5YR 4/2	5YR 5/3	3	fn	prs	sh	vfr	nsk-npls	C-W

*1: 1 = Weak; 2 = Moderate; 3 = Slightly strong; 4 = Moderately strong; 5 = Strong; 6 = Very strong; vfn = Very fine; fn = Fine; mid = Medium; c = Coarse; vc = Very coarse; cu = Crumb; grn = Granular; prs = Prismatic; abk = Angular blocky; sbk = Subangular blocky. *2: sh = Slightly hard; mh = Moderately hard; h = Hard; vh = Very hard; fr = Friable; vfr = Very friable; fm = Firm; vfm = Very firm; pls = Plastic; vpls = Very plastic; sk = Sticky; vsk = Very sticky; spls = Slightly plastic; ssk = Slightly sticky; nsk = Non sticky; npls = Non plastic. *3: A = abrupt; C = clear; G = gradual; I = irregular; S = smooth; W = wavy.

There were considerable variation in the grade, size and shape of the soil structure among the pedons. Accordingly, the structure of the soils in the study area varied from weak to very strong, fine to coarse, granular to sub angular blocky structure. Most pedons had predominantly crumb and granular structure at the surface horizons to angular and sub angular blocky/prismatic structure in subsoil horizons. Similar results were reported by Buolet al. (2011) and Rai (2002) who found that the surface horizons had crumb (in grassland) and granular (in cultivated) soil structure, whereas the prismatic and angular soil structure were common in the subsurface horizons (Table 2).

Considering topographic locations, consistence of the studied pedons, on upper and middle topographic positions varied from slightly hard to hard (dry), friable/loose to firm (moist) and slightly sticky and plastic to very sticky and very plastic (wet), whereas the lower topographic pedons exhibited hard to very hard (dry), friable to firm (moist) and sticky and plastic to very sticky and very plastic (wet) consistence. Variation in soil consistence within pedons could be related to the particle size distribution, but mainly clay content and mineralogy of the clay particles. Similar findings were reported by Singh and Agarwal (2003) and Thangasamyet al.(2005). They revealed that soil consistence variation was affected by clay contents and types. Moradi (2013) also revealed the effect of soil texture on soil consistence.

Soil physical properties

The particle size distributions of the studied soils are predominantly of a clay texture, except for Pedons UC04, MC09 and UG12 which are clay loams. Moreover, none of the fractions showed consistent pattern with topographic positions, although the clay content irregularly increased with decreasing topographic positions and increasing soil depths (Table 3). Clay content ranged from 60 to 85% in subsurface horizons and lower topographic position. Similar findings were reported by Buolet al. (2011), Lambin and Esu (2011) and Prasad and Govardhan (2011) who found accumulation of clay in subsurface horizons and attributed this to the *in situ* formation of secondary clays, the weathering of primary minerals in B-horizon or the residual concentration of clays from the selective dissolution of more soluble minerals. The clay texture of the lower topography was heavy and could be associated with large accumulation due to the lateral movement of finer fractions from higher elevation as a result of erosion or clay translocation within the pedons. The silt to clay ratio, which decreased with soil depth, was < 1 in all the pedons. It was also evident in the progressive decrease in the silt: clay ratio with depth of pedons. The low silt to clay ratio in the subsoil layers indicate that the soils are at an advanced stage of development (Abayneh, 2005; Basavaet al., 2005), and confirm the existence of both clay migration and translocation in the pedons.

The bulk density was comparatively lower at the surface horizons than the subsurface horizons ranging from 1.02-1.27 g cm^{-3} in surface horizons, and 1.16-1.35 g cm^{-3} in subsurface horizons (Table 3). Therefore, the bulk density values of the studied soils were found to be within the acceptable range (1.0-1.5 g cm^{-3}) for agricultural use (Whiteet al., 1997). This implies that any compaction is not restricting root development (Nugaet al., 2008; Mulugeta and Sheleme, 2010). There were inverse relationships between soil OM and pore space with bulk density.

In all the topographic positions, particle density decreased consistently with increasing soil depths. The highest (2.82 g cm^{-3}) and lowest (2.41g cm^{-3}) values of particle density were recorded at the surface and subsurface horizons, respectively. Furthermore, it increased with increase in altitude (Table 3). Skopp (2002) revealed that typical particle density values for mineral soils ranged from 2.5-2.8 g cm^{-3}, with 2.65 g cm^{-3} being representative of most soils. Based on this range, particle density values recorded in soils of the study area fall within the normal range. Nevertheless, the relatively high particle density values recorded at the surface layers are contrary to established facts and could not be explained.

Total porosity (f) of the soils varied from 51.9 to 60.7% at surface horizons of the upper and lower elevations, while the subsurface horizons had relatively lower values that ranged from 46.2 to 57.1% (Table 3). Brady and Weil (2008)stated that optimum total pore space value for crop production is > 50%. Similarly, Michael (2008) revealed that total pore spaces in the clayey textured soils may vary between 40 and 60%. Therefore, the total porosity of the studied soils, considering these ranges, was in the acceptable range for crop production. Furthermore, the total porosity values observed in soils of the study area are generally high and this could be attributed to the high clay content and lower bulk density values of the soils.

The soil water content retained at field capacity (-1/3 bars) and permanent welting point (15 bars) varied from 355.8 to 581.0 and 240.3 to 480.8 mm/m, respectively. Although, the moisture retention varied inconsistently with soil depth, relatively higher values were recorded under the subsurface horizons, while the lowest values were observed in the surface horizons and at the extreme depth of the C-horizons (Table 3). It can clearly be seen that the water retention capacity of the soils at both suctions is relatively high indicating that the soils are slowly draining and waterlogging could be one major problem that requires attention in these soils. This high water retention capacity of the soils could be the result of the high clay content recorded in the study area.

Available water holding capacity (AWHC) showed an increasing trend with soil depth and decreased with topographic positions in most of the pedons. It ranged from

Table 3. Selected physical properties of soils at the WadlaDelanta Massif, North Central Ethiopia.

Pedon	Horizon	Depth (cm)	Particle size distribution (%)			Textural class	ρb (g cm^{-3})	ρs (g cm^{-3})	TP (%)	FC *(%v/v)*	PWP *(%v/v)*	AWHC (mm/m)
			Sand	Silt	Clay							
MG201	A	0-38	22	26	52	C	1.10	2.63	58.27	49.11	37.88	112.3
	Ass1	38-110	18	24	58	C	1.20	2.52	52.41	54.98	43.69	112.9
	Bss1	110-122	17	23	60	C	1.22	2.52	51.62	58.10	46.08	120.2
	Bss2	122-225+	18	20	62	C	1.23	2.43	49.41	47.72	39.49	82.4
MC202	Ap	0-20	22	26	52	C	1.08	2.58	58.05	48.24	36.53	117.1
	Ass1	20-102	19	22	59	C	1.16	2.59	55.31	55.25	41.32	139.4
	Ass2	102-123	18	20	62	C	1.18	2.44	51.89	54.88	42.04	128.4
	Bss	123-215+	17	17	62	C	1.19	2.44	51.17	52.81	41.53	112.8
UC103	Ap	0-22	21	26	53	C	1.08	2.62	58.67	48.07	28.70	193.7
	Bss1	22-33	18	22	60	C	1.19	2.47	51.87	53.29	29.44	238.5
	Bss2	33-58	12	16	72	HC	1.20	2.42	50.45	53.96	28.97	249.9
	C	58-89+	9	13	78	HC	1.23	2.41	49.05	55.25	28.13	271.3
UC104	Ap	0-23	29	36	35	CL	1.04	2.52	58.55	54.88	42.04	128.4
	Ass1	23-58	31	32	38	CL	1.27	2.51	49.38	55.25	43.32	119.4
	C	58-95+	37	28	35	CL	1.34	2.49	46.15	48.24	39.53	87.1
LG305	A	0-35	18	23	59	C	1.16	2.70	56.92	48.07	24.03	240.3
	Ass1	35-76	14	18	68	HC	1.18	2.65	55.53	53.29	25.65	276.5
	Bss1	76-114	13	15	72	HC	1.19	2.69	55.78	55.58	26.79	287.9
	Bss2	114-205+	10	12	78	HC	1.28	2.57	50.10	55.27	26.63	286.3
LC306	Ap	0-32	25	17	58	C	1.13	2.54	55.41	46.37	33.38	129.9
	Ass1	32-76	21	15	64	HC	1.22	2.52	51.58	52.74	32.42	203.2
	Bss1	76-115	14	10	76	HC	1.27	2.49	49.11	53.90	32.59	213.1
	Bss2	115-216+	12	8	80	HC	1.28	2.43	47.54	55.20	30.29	249.1
LC307	Ap	0-28	27	18	55	C	1.02	2.59	60.55	49.76	28.67	210.9
	Ass1	28-110	23	12	65	HC	1.21	2.46	50.74	53.85	32.26	215.9
	Bss1	110-135	13	14	73	HC	1.24	2.52	50.70	52.40	31.53	208.7
	Bss2	135-208+	14	11	75	HC	1.26	2.50	49.63	55.29	31.46	238.4
MG208	A	0-37	18	27	55	C	1.18	2.82	58.02	52.09	30.06	220.3
	Ass1	37-140	12	24	64	HC	1.23	2.81	56.27	55.09	32.18	229.1
	Bss1	140-189	18	14	68	HC	1.22	2.73	55.19	55.01	31.86	231.6
	Bss2	189-198	18	10	72	HC	1.28	2.60	50.57	59.76	33.52	262.5
	BC	198-245+	24	16	60	C	1.34	2.62	48.89	43.11	31.67	114.4
MC109	A	0-25	28	34	38	CL	1.22	2.72	54.94	53.42	38.31	151.1
	B	25-48	32	28	40	CL	1.29	2.73	52.75	55.05	39.33	157.2
	C	48-75+	38	26	36	CL	1.29	2.72	52.67	47.29	37.51	97.8
UC110	Ap	0-25	22	26	52	C	1.20	2.82	57.61	39.05	27.16	118.9
	Ass1	25-62	18	24	58	C	1.20	2.80	57.06	46.69	34.33	123.6
	Bss	62-78	22	18	62	C	1.23	2.65	53.42	43.72	30.26	134.5
	C	78-99+	38	22	40	CL	1.26	2.66	52.73	35.58	24.20	113.7
MC211	Ap	0-25	22	30	48	C	1.20	2.66	54.74	43.13	32.36	107.7
	Ass1	25-65	15	28	57	C	1.20	2.56	53.11	54.53	37.64	168.9
	Bss	65-95	25	20	55	C	1.22	2.61	53.31	48.16	37.51	106.6
	C	95-115+	34	28	38	CL	1.26	2.56	50.77	47.88	39.66	82.1
UG112	A	0-33	32	35	33	CL	1.27	2.63	51.79	49.48	36.86	126.2
	B	33-47	33	29	38	CL	1.35	2.64	48.96	50.35	35.03	153.2
	C	47-65+	36	29	35	CL	1.34	2.62	48.91	39.95	29.04	109.1

FC = Field capacity; PWP = permanent wilting points; AWHC = available water holding capacity; TP = total porosity; C = clay; HC= heavy clay; Ass/Bss = A/B-horizon and ss = slickenside.

82.1 to 287.9 mm/m (at subsurface). The values of AWHC were influenced by OM and clay contents within the horizons. According to McIntyre (1974) rating of AWHC, the AWHC of the soils varies from very low (<100 mm/m) to high (>200 mm/m).

The soils with higher clay content generally had better available water than those with lower clay content. Clay offers a higher resistance to movement of water because of its high proportion of micro-pores that store water in film or hygroscopically (Edoga, 2010). In line with this, Rawls et al. (2003) found out that for soils with high clay content greater than 19%, the average water retention grows as the clay content increases. Udomet al. (2011) also categorized soils with 70% and above clay content as very poorly drained. Therefore, the presence of appreciable amount of finer fractions in subsurface soils could increase the water holding capacity of the soils and facilitate a longer period of soil water retention for crop utilization. On the other hand, this high water retention could result in waterlogging conditions, thus requiring drainage.

Soil chemical properties

Soil pH, electrical conductivity and calcium carbonate

The results showed that the soil reaction was slightly acidic to moderately alkaline in all the topographic positions (Jones, 2003). The pH-H_2O values varied from 6.25 to 7.53 on the surface horizons and 6.80 to 8.29 in the subsurface soils. In general, the lower topographic positions had relatively higher pH values than the others. This may be due to more accumulation of bases removed from uplands/hill slopes and subsequent depositions at the lower slopes. The pH-H_2O showed an increasing pattern with increasing soil depth, which could be attributed to the downward translocation of basic cations as well as leaching.

The pH-KCl ranged from 5.03 to 6.52 on the surface and 5.16 to 6.80 in subsurface soils. In all the pedons $\triangle$pH (pH-H_2O – pH-KCl) values were positive, ranging from 0.64 to 2.09. This indicates the presence of net negative charge on colloidal particles of the exchange site (Papierniket al., 2007). According to Landon (1991), the soils of the study area had a preferable pH for most crops since most of the essential nutrients become available at pH above 5.5.

All pedons, irrespective of topographic positions, showed very low electrical conductivity which varied from 0.011 to 0.13 dS m^{-1}. Similar to soil pH, it showed an increasing trend with depth and topographic positions.

According to FAO (1988) ratings, the studied soils are categorized under non-saline soils. The lower values of EC in the study area might be due to the combined effect of pH and parent materials.

On the other hand, calcium carbonate ($CaCO_3$) content of the studied soils showed an increasing pattern with soil depth and it ranged from 0.11 to 24.07% (Table 4). The relatively high values (24.07 and 21.32%) recorded in the subsurface horizons of the upper topographic position might be due to the calcareous parent material. Similar findings were reported by Ozsoy and Aksoy(2007), in which case the $CaCO_3$ contents increased with depth. Field determination of carbonates also confirmed that there were clear and visible fizzes when tested with diluted (10%) HCl.

Organic matter, total nitrogen, C:N ratio and available phosphorus

Soil organic matter (OM) content varied from 0.21 to 3.19% in the upper altitude, 0.12 to 4.82% in the upper, middle, and lower topographic position pedons, respectively. The soil OM content was generally higher in the surface (1.51 to 4.82%) horizons than the subsurface (0.12 to 2.13%) horizons, decreasing with depth in all the pedons. This could be ascribed to biomass effects on surface horizons and fallowing practiced especially at the (upper) and (middle) topographic positions. According to Tekalign (1991) ratings, soil OM content of soils of the study area was in the range of very low to low in all the pedons, except for the pedons opened on grassland (UG12 and MG01) which was in the range of medium (Table 5).

Total nitrogen (N) varied from 0.02 to 0.18, 0.03 to 0.23 and 0.03 to 0.11% in the upper, middle, and lower topographic positions, respectively. Its variation with soil depth followed that of soil organic matter. According to Tekalign (1991) ratings, the total N content of the studied soils was categorized under very low to medium ranges. This indicates low N release from the OM sources since soil N is positively correlated with soil OM content. Similar results were reported by Allotey *et* al. (2008) in that over 90% of N found in soils is in organic form. Hartz (2007) revealed that soils with < 0.07% total N have limited N mineralization potential, whereas those having > 0.15% total N would be expected to mineralize sufficient amount of N during the succeeding crop cycle showing that most of the soils have good potential of N mineralization.

The carbon to nitrogen ratio (C:N) showed irregular distribution with soil depth and topographic positions.In some cases, the C:N ratio of the studied soils was relatively higher than the common range (8:1-15:1) for arable soils proposed by Brady and Weil (2008). Such high C:N ratio of the soils indicates that OM of the soils was not fully decomposed and N loss was apprehended. These differences among the pedons could be ascribed to the effect of variation in land uses along the toposequence. Intensive and continuous cultivation aggravates OM oxidation resulting in reduction of total N as compared to virgin, grass and fallow lands. Variations in available

Table 4. Soil pH, electrical conductivity and calcium carbonate at the WadlaDelanta Massif, North Central Ethiopia.

Pedon	Horizon	Depth (cm)	pH (1:2.5)			EC	$CaCO_3$
			H_2O	KCl	△pH	(dS m^{-1})	(%)
MG201	A	0-38	6.72	5.45	1.27	0.020	2.84
	Ass1	38-110	7.23	6.21	1.02	0.024	3.56
	Bss1	110-122	7.56	6.38	1.18	0.037	9.34
	Bss2	122-225+	7.73	6.00	1.73	0.034	3.56
MC202	Ap	0-20	6.98	5.65	1.33	0.012	2.63
	Ass1	20-102	7.05	5.97	1.08	0.013	3.54
	Ass2	102-123	7.21	6.14	1.07	0.013	4.76
	Bss	123-215+	7.92	6.50	1.42	0.130	4.81
UC103	Ap	0-22	6.99	5.69	1.30	0.020	3.93
	Bss1	22-33	7.66	5.75	1.91	0.022	5.17
	Bss2	33-58	7.99	6.45	1.54	0.029	9.54
	C	58-89+	8.12	6.47	1.65	0.033	12.72
UC104	Ap	0-23	6.57	5.17	1.40	0.013	3.24
	Ass1	23-58	7.78	6.24	1.54	0.016	5.11
	C	58-95+	8.02	6.63	1.39	0.017	24.07
LG305	A	0-35	7.16	6.52	0.64	0.046	5.37
	Ass1	35-76	7.78	6.59	1.19	0.047	8.52
	Bss1	76-114	7.88	6.63	1.25	0.048	17.36
	Bss2	114-205+	8.07	6.65	1.42	0.052	6.94
LC306	Ap	0-32	6.73	5.42	1.31	0.013	3.44
	Ass1	32-76	7.55	5.46	2.09	0.018	3.90
	Bss1	76-115	8.01	6.26	1.75	0.027	9.65
	Bss2	115-216+	8.11	6.18	1.93	0.028	9.59
LC307	Ap	0-28	6.83	5.12	1.71	0.012	2.97
	Ass1	28-110	7.39	5.67	1.72	0.011	3.09
	Bss1	110-135	8.09	6.46	1.63	0.023	12.02
	Bss2	135-208+	8.17	6.43	1.74	0.028	11.21
MG208	A	0-37	6.25	5.36	0.89	0.012	3.95
	Ass1	37-140	6.80	5.71	1.09	0.017	4.06
	Bss1	140-189	6.95	5.91	1.04	0.022	4.17
	Bss2	189-198	7.15	6.15	1.00	0.025	4.66
	BC	198-245+	7.60	6.40	1.20	0.027	2.09
MC109	Ap	0-25	7.00	5.21	1.79	0.015	0.11
	B	25-48	7.18	5.58	1.60	0.018	0.22
	C	48-75+	7.59	5.87	1.72	0.024	0.45
UC110	Ap	0-25	6.51	5.31	1.20	0.013	3.74
	Ass1	25-62	7.09	5.38	1.71	0.012	21.32
	Bss	62-78	8.11	6.60	1.51	0.024	15.21
	C	78-99+	8.19	6.80	1.39	0.025	15.12
MC211	Ap	0-25	6.90	5.33	1.57	0.023	2.75
	Ass1	25-65	7.26	6.01	1.25	0.024	3.74
	Bss	65-95	8.07	6.33	1.74	0.039	4.02
	C	95-115+	7.96	6.26	1.70	0.034	2.93
UG112	A	0-33	6.78	5.03	1.75	0.012	1.58
	B	33-47	6.84	5.16	1.68	0.013	2.54
	C	47-65+	7.60	6.60	1.00	0.021	1.24

△pH = pH (H_2O –KCl); EC = Electrical conductivity; $CaCO_3$ = Calcium carbonate.

Table 5. Soil organic matter, total nitrogen, C:N ratio and available phosphorous at the Wadla Delanta Massif, North Central Ethiopia.

Pedon	Horizon	Depth (cm)	Soil OM (%)	Total N (%)	C:N ratio	Av. P (mg kg^{-1})
MG201	A	0-38	4.82	0.23	12	18.39
	Ass1	38-110	2.14	0.12	10	10.88
	Bss1	110-122	1.09	0.04	16	3.48
	Bss2	122-225+	0.52	0.03	10	2.83
MC202	Ap	0-20	1.71	0.12	8	10.36
	Ass1	20-102	1.91	0.08	14	8.73
	Ass2	102-123	1.26	0.05	15	3.63
	Bss	123-215+	0.86	0.04	13	1.52
UC103	Ap	0-22	1.88	0.10	11	12.53
	Bss1	22-33	1.60	0.07	14	10.33
	Bss2	33-58	1.05	0.05	13	6.30
	C	58-89+	0.69	0.03	13	5.45
UC104	Ap	0-23	2.03	0.11	11	10.92
	Ass1	23-58	1.29	0.06	12	11.68
	C	58-95+	0.74	0.02	17	2.56
LG305	A	0-35	2.05	0.12	10	18.44
	Ass1	35-76	1.29	0.07	11	8.86
	Bss1	76-114	1.17	0.05	15	8.33
	Bss2	114-205+	0.67	0.03	13	2.61
LC306	Ap	0-32	2.14	0.11	12	14.01
	Ass1	32-76	2.03	0.11	11	14.73
	Bss1	76-115	1.41	0.06	14	4.75
	Bss2	115-216+	0.69	0.03	13	4.75
LC307	Ap	0-28	1.71	0.07	13	7.30
	Ass1	28-110	1.67	0.06	17	7.19
	Bss1	110-135	0.69	0.03	13	5.64
	Bss2	135-208+	0.55	0.03	10	5.83
MG208	A	0-37	1.97	0.14	8	14.53
	Ass1	37-140	1.91	0.11	10	2.10
	Bss1	140-189	1.62	0.08	12	2.04
	Bss2	189-198	1.55	0.05	20	1.98
	BC	198-245+	1.02	0.03	19	1.05
MC109	Ap	0-25	1.64	0.09	10	11.80
	B	25-48	1.57	0.11	8	4.53
	C	48-75+	0.12	0.03	2	3.36
UC110	Ap	0-25	2.76	0.12	13	9.84
	Ass1	25-62	1.84	0.09	12	1.92
	Bss	62-78	1.34	0.05	16	2.00
	C	78-99+	1.02	0.03	18	2.07
MC211	Ap	0-25	2.33	0.18	5	8.44
	Ass1	25-65	1.55	0.11	8	8.19
	Bss	65-95	0.67	0.03	13	2.33
	C	95-115+	0.53	0.03	11	3.11
UG112	A	0-33	3.19	0.18	10	10.46
	B	33-47	1.91	0.07	15	11.00
	C	47-65+	0.21	0.03	4	6.15

OM = Organic matter; N = Nitrogen; C:N = Carob to nitrogen ration; Av .P. = Available phosphorus.

phosphorus with soil depth and along the toposequence were also observed. Accordingly, it ranged from 1.92 to 11.68, 1.05 to 18.39 and 2.61 to 18.44 mg kg^{-1}, respectively, in pedons of the upper, middle and lower topographic positions. In general, available P showed an increasing trend down the topographic position and a decreasing trend with depth, which might be attributed to an increase in clay content and a decrease in soil OM content. The surface soils had relatively higher available P (7.30 to 18.44 mg kg^{-1}) than the subsurface soils (1.05 to 14.73 mg kg^{-1}). This might be due to better levels of soil OM content at the surface layers and application of P fertilizers. As per available P ratings suggested by Cottenie (1980), the available P content of soils of the study area falls under very low to low category in most of the pedons indicating that available P could be one of the most limiting nutrients for crop production in the study area.

Exchangeable bases, cation exchange capacity and percent base saturation

The extent of exchangeable bases followed unsystematic pattern of distribution along the toposequence. However, the trends showed an increase with soil depth for all the exchangeable bases except for exchangeable K resulting in high base accumulation in the subsurface horizons. This might be due to the existence of Ca and Mg bearing parent materials, the leaching process and the presence of K rich primary minerals. Therefore, exchangeable K is adequate for the production of most crops and K deficiency would not be expected in soils of the study area. Similar findings were reported by Ashenafiet al. (2010) who stated that the increment of exchangeable bases with depth was due to leaching process.The abundance of exchangeable bases on the exchange complex followed the order Ca> Mg > K > Na throughout the pedons. According to FAO (2006b) ratings, the exchangeable bases were high to very high for Caand Mg, medium to very high for K, and medium to high for Na for all the pedons.

The values of CEC at the surface and subsurface horizons were high for all pedons, which might be related to the soil OM and high clay contents, respectively. On the surface soils, it ranged from 31.98 to 48.06 cmolc kg^{-1}, while it varied from 32.16 to 65.48 cmolc kg^{-1} in the subsurface soils. In accordance with Landon (1991) ratings, it has high to very high ranges (Table 6). This relatively high CEC indicates good nutrient retention and buffering capacity of soils of the study area.

Following the high to very high exchangeable bases recorded in soils of the study area, the base saturation (BS) was also high. Landon (1991) rated soils having base saturation that is greater than 60% as fertile soils. In accordance with this rating, soils of the study area with their high BS can be categorized as fertile soils. Furthermore more, as per Hazelton and Murphy (2007) ratings, the BS of the studied soils varies between high to very high range.

Extractable micronutrients

The results obtained show that the extractable micro-nutrients in all the pedons decreased with increasing soil depth and values were in the order of Fe >Mn> Zn > Cu in all topographic positions. However, there were some cases where Mn> Fe, and Cu > Zn (Table 7). The extractable micronutrients of the surface soils were higher than the subsurface soils due probably to the relatively higher soil OM content in the surface soils. According to Jones (2003) ratings, the extractable micronutrients of the studied soils are categorized under low to high in Fe and Cu, medium in Mn, and medium to high in Zn (Table 7). In general, the extractable micronutrients content of most of the studied soils was above the critical levels of the respective micronutrients, implying that there is no urgent need for available micronutrients application for the time being.

Soil classification based on FAO-WRB system

Based on morphological, physical and chemical properties, the soils were classified according to FAO-WRB (2006) system (Table 8 and Figure 4). As the result shows most of the pedons have well developed structure (granular or fine sub angular blocky), dark colored sur-face horizons having a chroma of ≤ 3 and a value of ≤ 3 when moist, and ≤ 5 when dry. The surface layers of the pedons had more than 0.6% organic carbon; base satu-ration (by 1M NH_4OAc) of 50% or more throughout the horizon; pH-H_2O value of 6 or more; minimum thickness of 20 cm or more. All these satisfy the diagnostic criteria for Mollic horizon.

PedonMC09 and UG12 have limited soil depth, with continuous rock within 25 cm of the soil surface. Less than 20% (by volume) of fine textured materials was found in the upper 75 cm of the soil surface or extremely gravelly whichever is shallower; and no calcic, gypsic or spodic horizon. The pedon are located at high altitude (above 3000 m) and with strongly dissected topography. As a result, Pedons MC109 and UG12 qualify for reference soil group (RSG) Leptosols. The pedon were having a base saturation (by 1M NH_4OAc) of 50% or more throughout their profile and therefore qualifies for Mollic Leptosols (Eutric). Pedons UC03 and UC04, on the other hand have petro-calcic horizon to a contrasting layer between 50 and 100 cm, 30% or more clay,crack perio-dically, with intersecting slickensides and a thickness of 25 cm or more which qualify for reference soil group (RSG)Vertisols.They developed foam upon addition of 1 M HCl, indicating a calcium carbonate equivalent near or more than 15% which qualifies for calcic subsurface

Table 6. Exchangeable bases, cation exchange capacity and percent base saturation at the WadlaDelanta Massif, North Central Ethiopia.

Pedon	Horizon	Depth (cm)	Exchangeable cations and CEC (cmolc kg^{-1})					PBS (%)
			Ca	Mg	K	Na	CEC	
MG201	A	0-38	23.72	6.58	0.65	0.26	31.98	97.59
	Ass1	38-110	27.40	10.76	0.60	0.59	44.94	87.57
	Bss1	110-122	26.65	8.84	0.56	1.04	60.76	61.04
	Bss2	122-225+	25.28	7.12	0.54	1.11	41.76	81.52
MC202	Ap	0-20	22.12	7.62	0.63	0.37	33.34	92.20
	Ass1	20-102	27.72	10.08	0.62	0.58	43.74	89.16
	Ass2	102-123	27.85	8.48	0.38	0.74	39.74	94.24
	Bss	123-215+	21.61	7.88	0.28	0.96	37.40	82.17
UC103	Ap	0-22	19.37	7.24	0.82	0.58	41.33	67.77
	Bss1	22-33	29.56	7.45	0.85	0.82	47.67	81.14
	Bss2	33-58	29.83	8.25	0.78	1.00	44.33	89.92
	C	58-89+	24.41	8.42	0.72	1.03	39.67	87.17
UC104	Ap	0-23	22.36	8.86	0.69	0.29	40.22	80.06
	Ass1	23-58	26.32	13.94	0.62	0.52	51.74	80.02
	C	58-95+	29.43	6.55	0.42	0.54	44.06	83.85
LG305	A	0-35	20.78	7.70	2.01	0.59	32.18	96.59
	Ass1	35-76	30.22	7.35	1.51	0.63	62.17	64.04
	Bss1	76-114	31.88	8.58	1.39	0.73	47.03	90.52
	Bss2	114-205+	23.15	8.14	0.45	0.96	34.94	93.60
LC306	Ap	0-32	24.28	6.58	0.91	0.29	36.16	88.67
	Ass1	32-76	24.71	7.64	0.85	0.82	37.34	91.10
	Bss1	76-115	28.28	7.40	0.82	1.03	46.28	81.08
	Bss2	115-216+	25.44	7.32	0.83	1.22	40.34	86.28
LC307	Ap	0-28	18.22	8.08	0.98	0.33	44.14	62.55
	Ass1	28-110	23.81	9.60	0.85	0.59	38.16	91.32
	Bss1	110-135	33.48	5.80	0.80	1.03	58.34	70.47
	Bss2	135-208+	32.23	6.36	0.76	1.14	45.14	89.71
MG208	A	0-37	23.85	7.86	0.93	0.53	40.20	82.50
	Ass1	37-140	25.58	9.86	1.03	0.80	45.68	81.58
	Bss1	140-189	32.50	7.53	0.99	0.96	65.48	64.10
	Bss2	189-198	31.03	7.64	0.82	1.02	40.94	98.97
	BC	198-245+	25.65	5.83	0.33	1.14	49.89	66.04
MC109	Ap	0-25	26.02	6.22	1.05	0.33	47.62	70.59
	B	25-48	25.04	8.02	0.66	0.56	52.14	65.75
	C	48-75+	21.80	7.76	0.36	0.76	32.16	95.39
UC110	Ap	0-25	20.72	6.52	1.29	0.41	48.06	60.22
	Ass1	25-62	31.61	6.82	0.84	0.65	61.26	65.16
	Bss	62-78	32.06	7.82	0.79	0.94	60.74	68.51
	C	78-99+	31.49	5.68	0.44	1.14	56.58	68.49
MC211	Ap	0-25	20.58	6.56	0.98	0.57	35.68	80.42
	Ass1	25-65	25.47	8.36	0.88	0.77	58.72	60.41
	Bss	65-95	27.61	8.02	0.75	1.20	52.14	72.08
	C	95-115+	31.92	6.15	0.24	1.15	45.74	86.28
UG112	A	0-33	17.74	7.82	0.73	0.52	44.06	60.85
	B	33-47	18.34	7.94	0.66	0.66	42.26	65.31
	C	47-65+	26.56	8.50	0.22	0.85	55.96	64.55

CEC = Cataion exchangeable capacity; PBS = percent base saturation.

Table 7. Extractable micronutrient contents at the WadlaDelanta Massif, North Central Ethiopia.

Pedon	Horizon	Depth (cm)	Micronutrients (mg kg^{-1})			
			Mn	Fe	Cu	Zn
MG201	A	0-38	4.80	4.81	3.80	2.40
	Ass1	38-110	4.60	1.22	1.21	2.03
	Bss1	110-122	4.01	1.23	1.21	1.21
	Bss2	122-225+	2.01	0.82	0.82	0.82
MC202	Ap	0-20	5.60	6.01	2.01	3.61
	Ass1	20-102	6.02	6.03	1.20	3.80
	Ass2	102-123	5.81	3.01	0.82	3.60
	Bss	123-215+	2.22	1.21	0.82	0.82
UC103	Ap	0-22	5.87	6.02	3.22	3.00
	Bss1	22-33	7.07	7.27	3.67	3.87
	Bss2	33-58	5.13	5.15	2.27	2.80
	C	58-89+	4.07	3.88	2.40	1.20
UC104	Ap	0-23	7.60	8.80	4.81	3.61
	Ass1	23-58	6.05	6.01	0.83	3.60
	C	58-95+	5.61	4.01	0.80	2.80
LG305	A	0-35	4.62	6.22	2.07	3.05
	Ass1	35-76	7.62	9.20	2.80	5.80
	Bss1	76-114	4.73	5.60	2.21	2.40
	Bss2	114-205+	2.03	3.81	1.21	1.08
LC306	Ap	0-32	5.20	5.22	4.40	2.50
	Ass1	32-76	5.60	5.80	4.01	3.94
	Bss1	76-115	4.03	4.04	2.02	1.23
	Bss2	115-216+	4.80	4.22	3.60	1.60
LC307	Ap	0-28	6.81	6.82	3.22	2.85
	Ass1	28-110	8.02	8.18	5.82	3.80
	Bss1	110-135	5.61	7.41	4.01	3.60
	Bss2	135-208+	5.21	6.81	2.81	1.20
MG208	A	0-37	9.20	10.40	6.03	4.26
	Ass1	37-140	6.81	6.82	4.01	5.20
	Bss1	140-189	6.50	5.88	3.81	2.85
	Bss2	189-198	6.02	5.69	3.75	1.20
	BC	198-245+	4.02	4.60	1.20	0.80
MC109	Ap	0-25	6.01	6.02	2.41	3.61
	B	25-48	5.60	6.00	2.41	2.80
	C	48-75+	5.60	5.81	1.21	1.20
UC110	Ap	0-25	8.40	10.00	6.00	4.41
	Ass1	25-62	7.02	7.60	5.22	5.01
	Bss	62-78	6.88	7.22	5.20	3.60
	C	78-99+	5.22	3.20	0.82	3.20
MC211	Ap	0-25	9.22	9.22	3.20	4.01
	Ass1	25-65	6.61	7.81	2.81	4.00
	Bss	65-95	6.40	6.54	1.20	2.80
	C	95-115+	3.20	4.81	0.82	1.30
UG112	A	0-33	7.20	7.80	3.20	3.60
	B	33-47	7.21	6.81	1.21	2.80
	C	47-65+	6.02	5.41	1.21	1.20

diagnostic horizon and having hard to very hard structure, finer than very coarse granular in the upper 20 cm of the soils that fulfill the criteria of Mazic prefix qualifier. Therefore, the Pedons are classified as Mazi-Calcic Vertisols (Eutric).

Among the upper pedons, Pedon UC10 showed color alteration and had higher chroma and value (moist), redder hue, higher clay content in its subsurface horizon than the overlying and underlying layers, less carbonate than an underlying horizon and loamy very fine sand. The layer was an altered horizon more than 15 cm in thickness with a clay loam texture and moderately developed structure, genetically young subsurface horizon. The pedon had been identified as having cambic subsurface horizon. This pedon qualifies for RSG Cambisols. The pedon were also having a base saturation (by 1M NH_4OAc) of 50% or more throughout the profile fulfilling the requirements for eutric suffix, but not visible prefix qualifier. Thus, the pedons were classified as Haplic Cambisols (Eutric).

The subsurface horizons of the middle and lower topographic pedons (Pedens 01, 02, 08 and 05, 06, 07, respectively) qualify for a vertic horizon starting within 100 cm of the soil surface; the upper 20 cm have been mixed; containing 30% or more clay throughout the profile; formation of slickensides and wedge-shaped structural aggregates in the subsurface soil; alternate swelling and shrinking of clays resulting in deep wide cracks that open and close periodically and gilgai micro-relief. These criteria meet the requirements for vertic subsurface diagnostic horizon. The soils therefore qualify for RSG Vertisols. The pedons were having hard to very hard structure, finer than very coarse granular structure in the upper 20 cm of the soils that fulfill the criteria of Mazic prefix qualifier and therefore are classified as Mazi Vertisols (Eutric) which had base saturation (by 1M NH_4OAc) of 50% or more throughout the horizon, having in the upper 30 cm of the soil, a Munsell value of 3.5 or less and a chroma of 1.5 or less when moist. They fulfill the criteria of Pellic prefix and hypereutric suffix qualifiers, thus classified as Mazi-Pellic Vertisols (Hypereutric) (Table 8).

Conclusions

The studied soils are formed from Oligocene rhyolite and very thick ignimbrite units mainly from alkaline basalt parent materials and highly influenced by topography. The measured morphological, physical, and chemical properties exhibited spatial variations of different degrees with soil depth in a pedon and along the toposequence. This indicates the existence of different degrees of limitations, potentials and management requirements, the consideration of which is fundamental for sustainable use of soil resources in the study area. Based on morpholo-

Table 8. Diagnostic horizons, properties, quantifiers and soil types of the study area according to FAO-WRB soil classification system

Pedon	Diagnostic horizon		Diagnostic properties	Soil types
	Surface	Subsurface		
MG201	Mollic	Vertic	Vertic	MaziPellicVertisols (Hypereutric)
MC202	Mollic	Vertic	Vertic	MaziPellicVertisols (Hypereutric)
UC103	Mollic	Calcic	Vertic	Mazi Calcic Vertisols (Eutric)
UC104	Mollic	Calcic	Vertic	Mazi Calcic Vertisols (Eutric)
LG305	Mollic	Vertic	Vertic	MaziPellicVertisols (Hypereutric)
LC306	Mollic	Vertic	Vertic	MaziPellicVertisols (Hypereutric)
LC307	Mollic	Vertic	Vertic	MaziPellicVertisols (Hypereutric)
MG208	Mollic	Vertic	Vertic	MaziPellicVertisols (Hypereutric)
MC109	Mollic	-	-	MollicLeptosols (Eutric)
UC110	-	Cambic	Vertic	HaplicCambisols (Eutric)
MC211	Mollic	Vertic	Vertic	MaziPellicVertisols (Eutric)
UG112	Mollic	-	-	MollicLeptosols (Eutric)

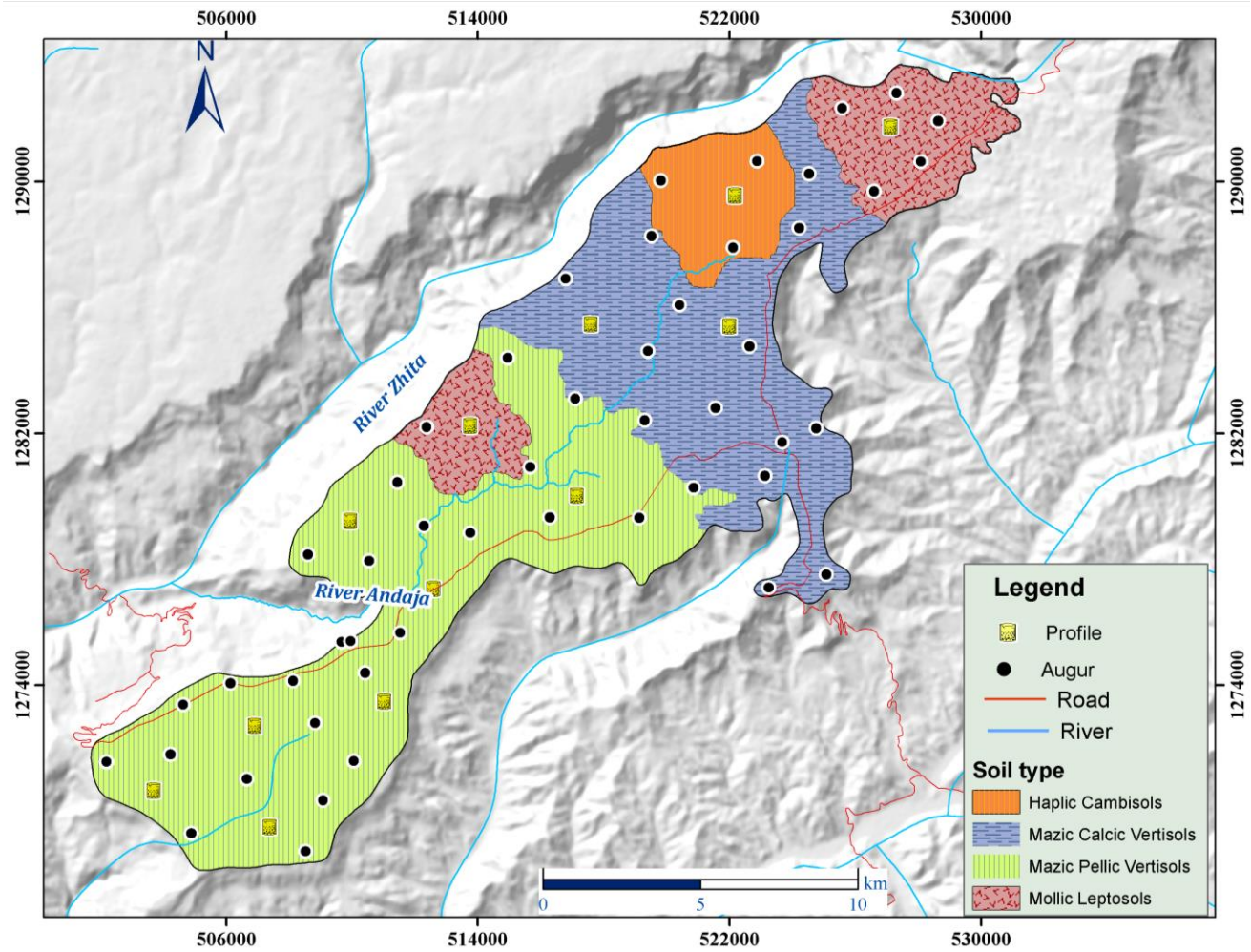

Figure 4. Soil map of the study area.

gica, physical, and chemical properties, and following the FAO-WRB classification and correlation system, the soils are classified as Mollic Leptososl, Haplic Cambisols, Mazi-Calcic Vertisols, and Mazi-Pellic Vertisols. The soils were low bulk density, high total porosity, the overall pH-H_2O slightly acidic to neutral, high in CEC and base saturation, low of soil OM, total N and available P, poorly drained, heavy textured clayey soils.

There was considerable variation in morphological and physicochemical properties along the topo-sequence. The upper elevations are shallow to moderately deep, somewhat well drained, clay loam in texture and grayish brown to light brownish gray in color, while the lowland and midland topography positions are deep to very deep, moderately well drained to poorly drained, clayey in texture and dark grayish brown to black and very dark gray in color. The soils are more pronounced in a vertic characteristics manifested by deep wide-opened cracks due to desiccation, the formation of slickensides at the middle part of the pedons, linear and normal gilgaimicro-relief, cyclic horizons and poor differentiation of their horizons, fine to medium, granular to angular/sub angular blocky with strong wedge-shaped structure,hard to very hard consistence when dry and very plastic and sticky when wet, shrink and swell with changes in soil moisture that creates a big problem of workability. Therefore, the workability of the soil is often limited to a very narrow period of time between drought stress and excess moisture.

The agricultural potential of the soils are hampered by their stickiness when wet and hardness when dry, waterlogging and a serious problem of soil erosions greatly affect crops production in the area. Inappropriate soil tilling and timing of cultivation practices are critical factors that impacts negatively on the efficient use of the soils. Therefore, integrated sustainable soil management practices have been designed to overcome the physical problems and special emphasis has been given to surface drainage, moisture conservation during the dry season and to drain excess moisture during the wet season, applies to Vertisol management like cambered beds, ridges, furrow and broad banks.

Conflict of Interests

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

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Floral hosts and pollen calendar of Asian giant honeybee, *Apisdorsata* Fabricius at Southern Karnataka, India

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Observations were made during 2011 and 2012 to record the floral hosts of Asian giant honeybee, *Apisdorsata* (Hymenoptera: Apidae) by following standard methods at arid, semi-arid and malnad regions of southern Karnataka, India. These regions are enriched with 252 foraging plant species which belong to 74 families with trees (49.3%), herbs (23.5%), shrubs (21.7%) and climbers (5.5%), supplying both pollen and nectar (63%), nectar (17.7%) and pollen (18.9%) source to *A. dorsata* population during different seasons. The Shanon-Wiener diversity index (H') showed high species diversity, that is, 3.256 to 3.864, indicating the constant nectar flow with little variations in to *A. dorsata* population. Since, *A. dorsata*is a voracious forager, it prefers to survive in the wild and contributes significantly to the pollination of various plants in this region leading to improvement in local vegetation. *A. dorsata* produces useful hive products to mankind. Knowledge on the floral hosts helps prepare pollen calendar that would reveal plant diversity and their interactions with insect pollinators in an ecosystem. Thus, it is important to conserve both plants and insect pollinators (for example, *A. dorsata*) to sustain our livelihoods and protect the local biodiversity.

Key words: Floral hosts, pollen calendar, *Apisdorsata,* southern Karnataka.

INTRODUCTION

Asian giant honeybee, *Apisdorsata* Fabricius (Hymenoptera: Apidae) is one of the largest bees in the genus *Apis* (Oldroyd et al., 2000). Being a voracious forager, *A. dorsata* shows high nectar and pollen gathering potential from various plants, which bear different size and shape inflorescence, secreting good amount of nectar and pollen. It migrates from place to place (for example, plains to hilly area and vice-versa) in response to varying floral resource (Dyer and Seely, 1994). During migration, *A. dorsata* interact with diversified flora for pollen and nectar. While doing so, it pollinates and propagates various flowering plants (Shubharani and Venkataramegowda, 2012) and help in local biodiversity conservation (Buchmann and Nabhan, 1996; Zayed, 2009).

In India, Karnataka State is housed with more than 4758 plant species from 1408 genera and 178 families and accounts for about 27% of Indian floral diversity

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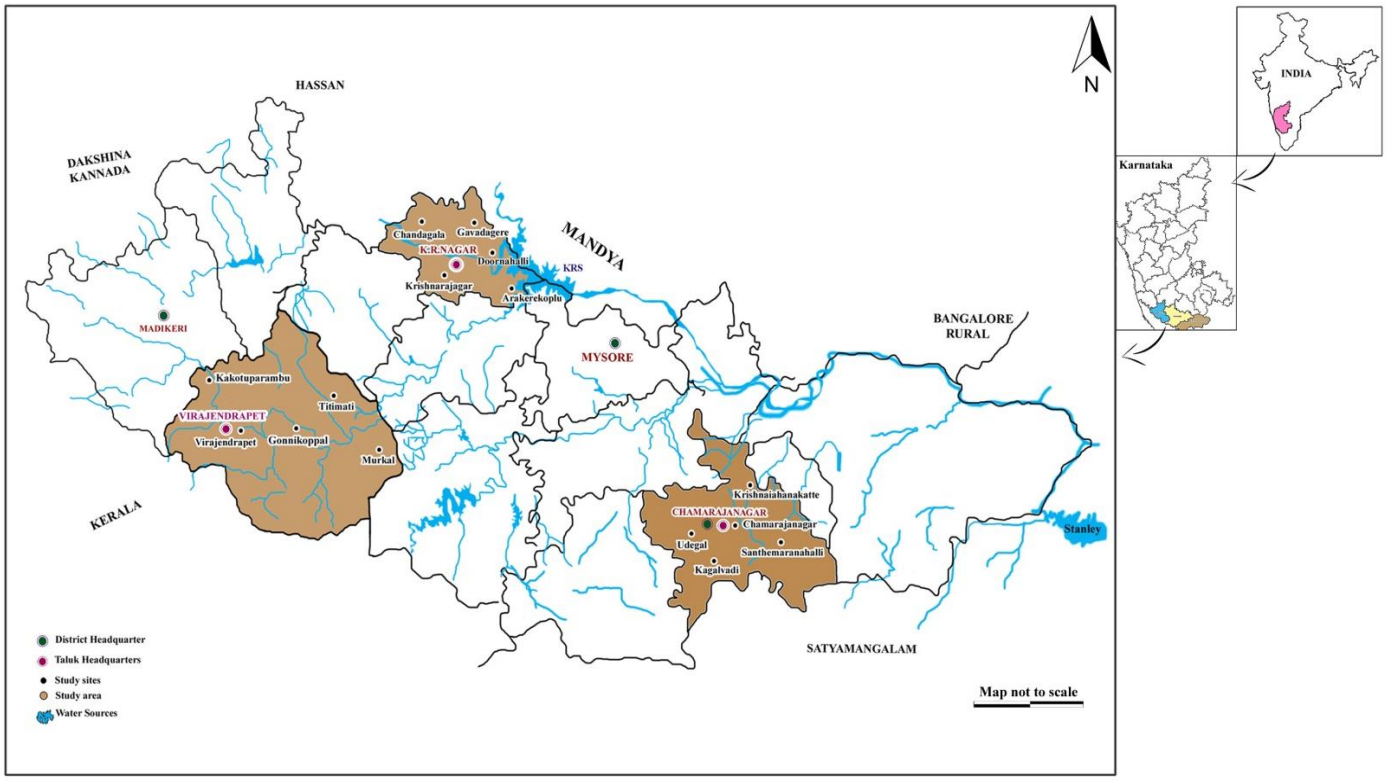

Figure 1. Map showing the study sites in southern Karnataka**.**

(Ganeshaiah et al., 2002). Of all, only few tree species appears to be used for nesting by *A. dorsata*. Moreover, several hundred flowering plant species are used for floral source by *A. dorsata*in the wild (Basavarajappa, 1998; Rao, 1998; Reddy and Reddy, 1989). Interestingly, domesticated honeybees namely *Apiscerana* and *Apismellifera* floral hosts were extensively studied at different regions of Karnataka by various authors. However, such type of studies exclusively on *A. dorsata* is meager and little is known about its flora at different parts of Karnataka and hence the foraging preference of *A. dorsata* is little known. Further, *A. dorsata*great role as pollinators of several plant speciesat its area of distribution is not reported in many countries (Neupane et al., 2006). Very few reports are available on the floral hosts of *A. dorsata* in India (Basavarajappa, 2012). Basavarajappa (1998 and 2004), Rao (1998) and Reddy and Reddy (1989) have reported the flowering plant species used as floral source by *A. dorsata*in the wild. However, reports on floral hosts to *A. dorsata*at arid, semi-arid and malnad regions of southern Karnataka are scanty. Moreover, there is a fairly even distribution of information on plant species (trees, shrubs, herbs and climbers), their nectar and pollen source for *A. dorsata* population and to predict pollen calendar in this part of Karnataka State.

Further, in recent past, *A. dorsata* population is declining gradually due to various man-made activities in southern Karnataka (Basavarajappa, 2012). It would affect the reproductive success of several plant species in the wild as well as at man-made ecosystems. Since, pollination is an essential ecosystem service that results in gene flow among flora both at man-made and natural ecosystems (Partap et al., 2000). Therefore, there is a dire need to identify the foraging plants (trees, shrubs, herbs and climbers) diversity and*A. Dorsata* interaction with these plant species. Being one of the most reliable natural pollinators,information on *A. dorsata* foraging plants is a pre-requisite to frame a pollen calendar to harness its hive products at different agro-ecological regions (Neupane et al., 2006). Hence, the present investigation was undertaken.

MATERIALS AND METHODS

Field observations were conducted in 2011 and 2012 to record the flowering plants namely trees, shrubs, herbs and climbers located on road sides, residential areas and in agri-horticultural ecosystems at the vicinity of *A. dorsata* colonies at arid, semi-arid and malnad regions of southern Karnataka, India (Figure 1). In arid (region with sparse rainfall, less humidity and dry conditions), semi-arid (region with moderate rainfall, humidity with congenial climate and malnad

(region with heavy rainfall, high humidity with wet climate) regions,minimum of three to maximum four study sites (100^2 meter sized areas) were earmarked randomly and altogether 12 study sites were selected. Each study site was visited nine times separately during rainy (June to September) winter (October to January) and summer (February to May) seasons. *A. dorsata* foraging plants were recorded by employing direct visual count (DVC) and an all out search (AOS) methods. Foraging plants were record by spending 10 to 15 min at every flowering plant after observing the movement of *A. dorsata* forager bees. *A. dorsata* forager bees visited flowering plants were recorded and classified into different types namely trees, shrubs, herbs and climbers as per Rao (1998) so as to determine their species richness and evenness as per Magurran (2004). Moreover, information on foraging plants was also collected from farmers, residents and people who knew about *A. dorsata* (locally called 'Hejjenu') by personal interact-tion. Foraging plants were photographed with the help of Canon-Power Shot S21S, 8.0 Mega Pixels Digital Camera with 12X Optical Zoom. The leaves and twigs of such flowering plants were collected and brought to the laboratory for identification with the help of herbarium, plant taxonomists and taxonomic keys as well as information given by Gamble (1967). The identified foraging plants were grouped into trees, shrubs, herbs, climbers and they were further grouped into medicinal plants (MPs) (various parts *viz*., leaf, stem, bark, root, flowers etc, of these plants are used for treating certain diseases), ornamental plants (OPs) (plants used extensively for their flowers), economically important plants (EIPs) (wood of these plants are used for timber production), fruit yielding plants (FYPs) (fruit producing plants) and vegetable plants (VPs) (leaves, tuber, flower, stem etc, of these plants are used as vegetables) to reveal their percent occurrence as per Rao (1973) and Basavarajappa (1998). Since, classifying flora into various groups is routinely practiced in beekeeping areas to understand the nectar and pollen production potential, it help to estimate the nectar flow in unifloral or multifloral honey production potential of the region (Rao, 1998; Basavarajappa, 2012).The percentage of trees, shrubs, herbs and climbers MPs, OPs, EIPs, FYPs and VPs were calculated by following the standard formula. The percent occur-rence of specific type of foraging plant =*A. dorsata* foraging bees observed on specific type of plant/Total number of flowering plants on which *A. dorsata* forger bees recorded x 100. To prepare the pollen calendar, all the flowering plants were further grouped into pollen, nectar and both pollen and nectar producing plants as per Rao (1973) so as to understand their apicultural values. Analysis of variance (ANOVA) was done to know the variation in distribution of flowering plants at different regions of southern Karnataka. Moreover, Shannon-Wiener diversity index (H') was used to calculate the diversity of flowering plants at arid, semi-arid and malnad regions by following the equation as per Magurran (2004).

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

H'= Shannon-Wiener Index; P_i = The proportion of individual flowering plant species found in the I^{th} species.

RESULTS

The distribution of foraging plant families of *A. dorsata* at arid, semi-arid and malnad regions of southern Karnataka is given in Table 1. Altogether 252 flowering plants belong to 74 families were interacted by *A. dorsata* for its floral source at southern Karnataka (Table 1). Amongst regions, malnad has highest (117) foraging plant species, which supported the *A. dorsata* population by extending nectar and pollen source. However, the foraging plants at semi-arid and arid regions were 73 and 62 species, respectively (Table 1). Analysis of variance of the data indicated that there was a significant variation (F=5.6848; P>0.001) existed between the regions with respect to the distribution of foraging plants (Table 1).

Further, distribution of flora type (trees, shrubs, herbs and climbers) and their importance to mankind as MPs, EIPs, OPs, FYPs and VPs, their percent contribution and the apicultural value of these plant species in terms of nectar and pollen supply to *A. dorsata* population at arid, semi-arid and malnad regions of southern Karnataka is depicted in Table 2. Among them, trees contributed highest (49.3%) floral source, it was followed by herbs and shrubs respectively 23.5 and 21.7%. The climbers extended 5.5% floral source to *A. dorsata* population (Table 2). Amongst foraging plants, medicinal plants (for example, *Centellaasiatica*, *Tinosporacordifolia*, *Hibiscus rosasinensis* etc.), fruit yielding plants (for example, *Mangiferaindica, Anonareticulata, Anonasquamosa, Tamarindusindica* etc.), economically important plants (for example, *Santalum album, Terminalia* sp. etc.), ornamental plants (for example, *Abutilon rosea, Impatiens balsaminia* etc.) and vegetable plants (for example, *Lagenarialecuantha, Momordicacharantia, Cucurbita maxima* etc.) were contributed floral source respectively 38.6, 15.6, 21.4, 15.7and 8.7% to *A. dorsata* population at southern Karnataka (Table 2). Total, both pollen and nectar yielding plants provided more (63.4%) floral source to *A. dorsata* compared to nectar yielding plants (17.7%) and pollen yielding plants (18.9%) (Table 2). Altogether, 63.4% foraging plants have provided both pollen and nectar to *A. dorsata* population. However, 18.9 and 17.7% foraging plants have provided respectively pollen and nectar separately to *A. dorsata* (Table 2). In arid region, both pollen and nectar yielding plants yielded highest (54%) floral source for *A. dorsata*. It was followed by pollen yielding and nectar yielding plants respectively, 25.4 and 20.6% for*A. dorsata* (Table 2). In semi-arid region, both pollen and nectar yielding plants yielded highest (72.7%) floral source for *A. dorsata*. But, the nectar yielding and pollen yielding plants have provided only 15.6 and 11.7% floral source, respectively, for *A. dorsata* (Table 2). In malnad region, both pollen and nectar yielding plants provided more (63.6%) floral source for *A. Dorsata* as compared to nectar yielding and pollen yielding plants (Table 2).

Further, interaction of *A. dorsata* population with the blooming period of foraging plants at arid, semi-arid and malnad regions of southern Karnataka are depicted in Table 3. The Shannon-Wiener diversity index (H^1) of foraging plants indicated no much variation between the regions. However, the H^1 was in between 3.256 and 3.864 and it haslarger value of H' (< 2) index. However, foraging plants were more (117 species) at malnad

Table 1. Distribution of foraging plant families of *Apisdorsata* at different regions of southern Karnataka.

S/N	Families	No. of species extended floral sources at			Total
		Arid	Semi-arid	Malnad	
1	Acanthaceae	1	2	2	5
2	Alangiaceae	-	-	1	1
3	Amaranthaceae	1	-	2	3
4	Anacardiaceae	1	3	3	7
5	Annonaceae	-	2	-	2
6	Apiaceae	-	-	1	1
7	Apocynaceae	-	1	1	2
8	Araceae	2	-	1	3
9	Asclepidaceae	1	1	-	2
10	Asteraceae	4	2	4	10
11	Balsaminaceae	1	1	1	3
12	Basellaceae	-	1	-	1
13	Bignoniaceae	-	1	3	4
14	Bombaceae	-	-	2	2
15	Brassicaceae	-	1	1	2
16	Burseraceae	-	-	1	1
17	Cactaceae	-	-	1	1
18	Caprifoliaceae	-	-	1	1
19	Caricaceae	1	-	-	1
20	Casuarinaceae	-	1	-	1
21	Celastraceae	-	-	2	2
22	Clusiaceae	2	-	6	8
23	Combretaceae	2	-	3	5
24	Convolvulaceae	-	-	3	3
25	Cucurbitaceae	5	5	-	10
26	Datiscaceae	-	-	1	1
27	Dilleniaceae	-	-	1	1
28	Dipterocapaceae	-	-	2	2
29	Droseraceae	-	1	-	1
30	Ebenaceae	1	-	1	2
31	Elaeocarpaceae	-	-	3	3
32	Elatinaceae	-	-	1	1
33	Euphorbiaceae	2	2	3	7
34	Fabaceae	15	12	14	41
35	Flacourtiaceae	1	-	2	3
36	Hydrocotylaceae	-	1	-	1
37	Icacinaceae	-	-	1	1
38	Lamiaceae	2	2	3	7
39	Lauraceae	-	-	1	1
40	Lecythidaceae	-	1	-	1
41	Lophopetalum	-	-	1	1
42	Lythraceae	-	-	2	2
43	Magnoliaceae	1	-	-	1
44	Malvaceae	3	4	3	10
45	Melastomataceae	-	-	1	1
46	Meliaceae	-	2	4	6
47	Menispermaceae	-	1	1	2

Table 1. Contd

48	Molluginaceae	-	1	-	1
49	Moraceae	1	2	1	4
50	Moringaceae	1	-	-	1
51	Musaceae	1	-	-	1
52	Myrtaceae	3	4	3	10
53	Nyctanthaceae	-	1	-	1
54	Nycteginaceae	-	2	-	2
55	Oxallidaceae	-	-	1	1
56	Palmae	1	-	1	2
57	Periplocaceae	-	1	1	2
58	Piperaceae	-	-	1	1
59	Poaceae	-	1	-	1
60	Portulaceae	1	-	1	2
61	Rubiaceae	-	-	4	4
62	Rutaceae	3	4	5	12
63	Santalaceae	-	-	1	1
64	Sapinadaceae	1	-	2	3
65	Sapotaceae	-	2	-	2
66	Scrophulariaceae	-	-	1	1
67	Smilaceae	-	-	1	1
68	Solanaceae	-	5	1	6
69	Sterculaceae	-	1	2	3
70	Ulmaceae	-	-	1	1
71	Verbenaceae	3	1	3	7
72	Violaceae	-	-	2	2
73	Vitaceae	-	1	1	2
74	Zingiberaceae	1	-	-	1
Total		62	73	117	252
'F' Value			5.6848* ; P > 0.001		

Note:* significant.

Table 2. Type of foraging plant and their apicultural value to *Apisdorsata*at different regions of southern Karnataka

S/N	Region	Type of Flora				Type of Flowering plant					Apicultural value		
		C	H	S	T	MP	EP	OP	FP	VP	Pollen	Nectar	Both
1.	Arid	7.9	23.8	23.8	44.5	30.2	17.5	17.5	19.0	15.8	25.4	20.6	54.0
2.	Semi-arid	5.2	24.7	23.4	46.7	41.6	19.5	14.3	16.9	7.7	11.7	15.6	72.7
3.	Malnad	3.4	22.0	17.8	56.8	44.1	27.1	15.3	11.0	2.5	19.5	16.9	63.6
Mean for southern Karnataka		5.5	23.5	21.7	49.3	38.6	21.4	15.7	15.6	8.7	18.9	17.7	63.4

C = Climber; H = Herb; S = Shrub; T = Tree; MPs = Medicinal plants; EIPs = Economically Important Plants; OPs = Ornamental Plants; FYPs = Fruit Yielding Plants; VPs = Vegetable Plants.

region and showed high (3.864) Shannon-Wiener diversity index as compared to arid and semi-arid regions, where the foraging plant species were respectively 62 and 73 and the H^1 was 3.256 and 3.405 (Table 3).

Foraging plant families and their floral hosts for *A. dorsata* at southern Karnataka is given in Table 4. Amongst 74 families, Fabaceae family contributed more (15.9%) foraging source (40 flowering plant species), followed by Rutaceae (12 flowering plant species) family supplying 5.3% floral source to *A. dorsata* (Table 4).

Table 3. Interaction of *Apis dorsata* population with blooming period of foraging plants at different regions of southern Karnataka.

S/N	Blooming period	Regions		
		Arid	Semi-arid	Malnad
1.	April – Aug.	1	1	-
2.	April – Feb.	-	-	1
3.	April – July	1	-	1
4.	April - June	1	3	5
5.	April - May	2	3	1
6.	April – Nov.	-	-	2
7.	April – Oct.	-	-	2
8.	April – Sept.	2	-	-
9.	All seasons	9	-	1
10.	Aug. – Dec.	1	1	3
11.	Aug. – Feb.	-	2	-
12.	Aug. – March	-	-	1
13.	Aug. – May	-	-	1
14.	Aug. – Nov.	1	1	2
15.	Aug. – Oct.	-	2	-
16.	Aug. – Sept.	2	1	1
17.	Dec. – April	-	-	1
18.	Dec. – Aug.	-	-	1
19.	Dec. – Feb.	1	-	1
20.	Dec. – March	-	-	2
21.	Dec. – May	-	-	1
22.	Feb. – June	-	1	2
23.	Feb. – April	3	2	3
24.	Feb. – Aug.	-	-	2
25.	Feb. – Dec.	-	-	2
26.	Feb. - July	-	-	3
27.	Feb. – March	2	-	2
28.	Feb. - May	2	1	2
29.	Feb. – Oct.	-	-	1
30.	Feb. – Sep.	-	1	2
31.	Jan – Feb.	2	-	-
32.	Jan. – June	-	-	1
33.	Jan. – April	-	2	1
34.	Jan. – Dec.	-	-	13
35.	Jan. – Feb.	2	1	1
36.	Jan. – March	1	1	4
37.	Jan. - May	-	-	3
38.	Jan. – Nov.	-	-	1
39.	Jan. – Oct.	-	-	2
40.	July – Aug.	1	2	1
41.	July – Dec.	-	1	-
42.	July – Feb.	-	-	1
43.	July – March	-	-	1
44.	July – Nov.	-	1	-
45.	July – Oct.	2	1	-
46.	July – Sept.	1	7	-
47.	June – Aug.	2	1	2
48.	June – Dec.	1	2	-
49.	June – Feb.	-	-	1
50.	June – July	1	-	1
51.	June – Nov.	1	-	1
52.	June – Oct.	1	1	-
53.	June – Sept.	1	4	2
54.	March – June	-	-	2
55.	March - May	-	-	1
56.	March – April	3	6	-
57.	March – Aug.	1	1	-
58.	March – July	-	1	2
59.	March – June	-	-	2
60.	March - May	4	5	1
61.	March – Nov.	-	-	1
62.	March – Oct.	-	-	1
63.	March – Sept.	-	1	1
64.	March. – Aug.	-	-	-
65.	May – June	-	-	1
66.	May – Aug.	2	2	1
67.	May – Dec.	-	2	1
68.	May – July	-	-	1
69.	May – Nov.	-	-	3
70.	May – Sept.	1	-	-
71.	Nov. – April	-	-	1
72.	Nov. – Dec.	1	-	4
73.	Nov. – Feb.	-	-	1
74.	Nov. – Jan.	1	-	2
75.	Nov. – March	1	2	1
76.	Nov. - May	-	-	1
77.	Oct. – Dec.	-	1	1
78.	Oct. – Feb.	1	1	-
79.	Oct. – Jan.	-	1	1
80.	Oct. – March	-	-	2
81.	Oct. – May	-	1	-
82.	Oct. – Nov.	-	-	1
83.	Sept. – March.	2	-	-
84.	Sept. – April	-	1	-
85.	Sept. – Dec.	-	2	2
86.	Sept. – Feb.	-	1	-
87.	Sept. – Jan.	-	1	-
88.	Sept. – March	-	-	-
89.	Sept. – Oct.	1	1	-
Total		62	73	117
H^1 Index		3.256	3.405	3.864

Table 3. Contd

The Asteracea, Cucurbitaceae, Malvaceae and Myrtaceae families contributed 4.4% each floral source (from 10 flowering plant species each). Similarly, the Clusiaceae family has contributed 3.5% floral source to

Table 4. Foraging plant families and their floral hosts to *Apisdorsata*at southern Karnataka.

S/N	Family	Species	Per cent	Total families	Per cent
1.	Alangiaceae, Apiaceae, Basellaceae, Burseraceae, Cactaceae, Caprifoliaceae, Caricaceae, Casuarinaceae, Datiscaceae, Dilleniaceae, Droseraceae, Elatinaceae, Hydrocotylaceae, Icacinaceae, Lauraceae, Lecythidaceae, Lophopetalum, Magnoliaceae, Melastomataceae, Molluginaceae, Moringaceae, Musaceae, Nyctanthaceae, Oxallidaceae, Piperaceae, Poaceae, Santalaceae, Scrophulariaceae, Smilaceae, Ulmaceae and Zingiberaceae	1 each	0.4	31	41.9
2.	Annonaceae, Apocynaceae, Asclepidaceae, Bombaceae, Brassicaceae, Celasteraceae, Dipterocapaceae, Ebenaceae, Lythraceae, Menispermaceae, Nycteginaceae, Periplocaceae, Portulaceae, Sapotaceae, Violaceae and Vitaceae	2 each	0.9	17	23.0
3.	Amaranthaceae, Araceae, Balsaminaceae, Convolvulaceae, Elaeocarpaceae, Flacourtiaceae, Sapindaceae and Sterculiaceae	3 each	1.3	8	10.8
4.	Bignoniaceae, Moraceae and Rubiaceae	4 each	1.8	3	4.0
5.	Acanthaceae and Combretaceae	5 each	2.2	2	2.7
6.	Meliaceae and Solanaceae	6 each	2.6	2	4.0
7.	Anacardiaceae, Euphorbiaceae, Lamiaceae and Verbenaceae	7 each	3.1	4	5.4
8.	Clusiaceae	8 each	3.5	1	1.4
9.	Asteraceae, Cucurbitaceae, Malvaceae and Myrtaceae	10 each	4.4	4	4.0
10.	Rutaceae	12	5.3	1	1.4
11.	Fabaceae	40	15.9	1	1.4
Total		252	41.4	74	100.0

Data is based on Table 1.

A. dorsata from its eight flowering plant species (Table 4). Moreover,from Anacardiaceae, Euphorbiaceae, Lamiaceae and Verbenaceae families, seven flowering plant species supplied 3.1% each floral source to *A. dorsata* population. Further, from Meliaceae and Solanaceae families, six flowering plant species have contributed 2.6% floral source each to *A. dorsata* population. Furthermore, Acanthaceae and Combretaceae families supplied floral source from their five flowering plant species each and contributed 2.2% floral source to *A. dorsata*. However, from Bignoniaceae, Moraceae and Rubiaceae families, four flowering plant species each have supplied 1.8% floral source each to *A. dorsata* population. Similarly, other foraging plant families percent contribution is depicted in Table 4.

Figure 2 shows the floral calendar for *A. dorsata* at arid, semi-arid and malnad regions of southern Karnataka. Since the foraging activity of *A. dorsata* coincide with the blooming of flowering plants, data from the Figure 2 clearly demonstrated that there was a considerable fluctuation with respect to the blooming period of foraging plants which occurred at different regions of southern Karnataka. Moreover, only few flowering plants (4%) showed blooming during most parts of the year and the remaining flowering plants bloomed during different months (Table 3). In general, the flowering plants blooming was good during January, February, March and April as compared to other months, where it was less than 10%, accordingly, the *A. dorsata* population interacted with these plants for nectar and pollen. In general, the floral source was almost normal and it was consistently available to *A. dorsata* during the years 2011 to 2012 at southern Karnataka (Figure 2).

DISCUSSION

Apisdorsata foraged on ornamental plants, medicinal plants, fruits yielding plants, vegetable plants, economically important plants which belong

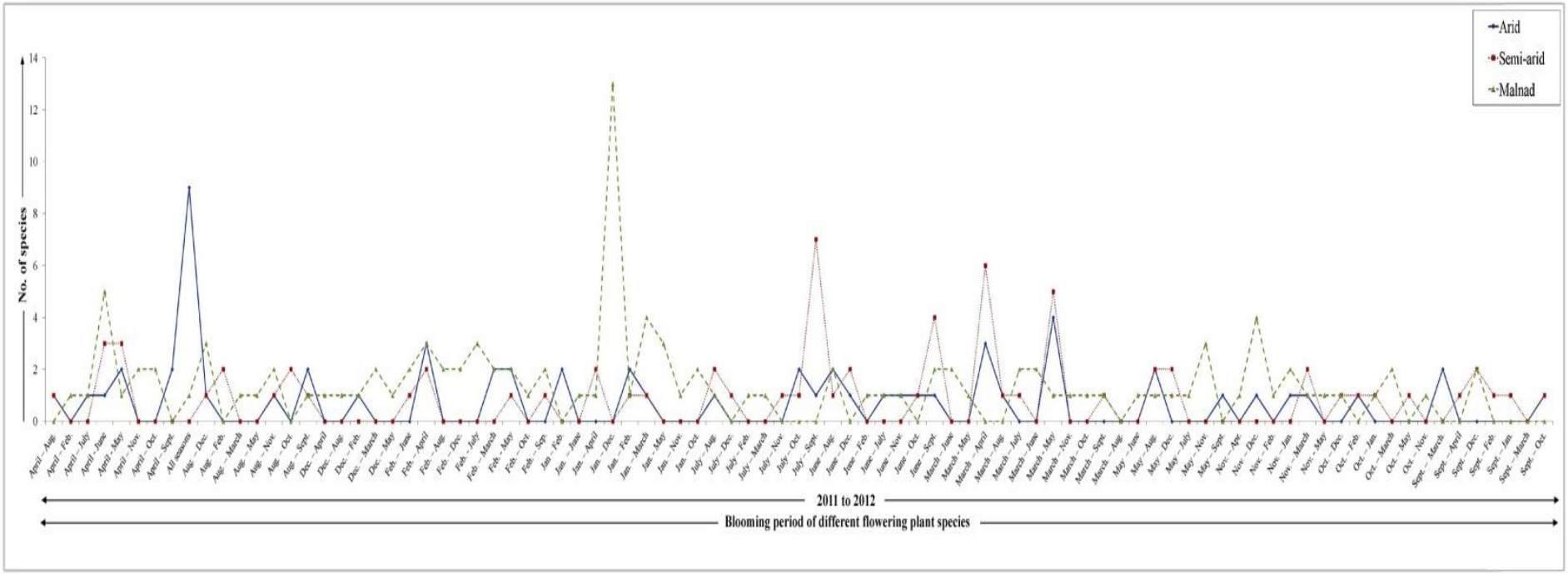

Figure 2. Floral calendar for *Apis dorsata* at arid, semi-arid and malnad regions of southern Karnataka.

to trees, shrubs, herbs and climbers at different regions of southern Karnataka.About 252 foraging plant species, which belongs to 74 different families were interacted by *A. dorsata* foragers during their nectar and pollen collection and proved themselves as voracious forager (Oldroyd et al., 2000). Classifying available flowering plants into various types is a common practice in apiculture, to understand the nectar and pollen potential of a region that could help predict pollen calendar and honey flow (Basavarajappa, 2012). Moreover, by visiting different species of trees, shrubs, herbs and climbers, which bear different size and shaped flowers and inflorescence secreting good amount of nectar and pollen, *A. dorsata* proved itself as one of the most reliable natural pollinator (Neupane et al., 2006).Thus, all the foraging plants are vital to *A. dorsata*for normal survival and its interaction could help assist certain plant species pollination and propagation in this part of the state. Hence, our observations agree with the earlier reports of Neupane et al. (2006), Shubharani and Venkataramegowda (2012).

Since interaction with each plant species is vitalto*A. Dorsata* with respect to their specific apicultural values,that is, pollen, nectar and both pollen and nectar source. Therefore, classifying plant species, which produce both nectar and pollen for honeybees, are called ‘honeybee plants’, plants which produce nectar, but little or no pollen are typically termed as ‘honey plants’ and plants yield pollen, but little or no nectar are termed as ‘pollen plants’ from the conservation point of view. Pollen plants are important especially at the time of colony build-up, when the honeybees need large amount of protein for their brood rearing. However, nectar plants are also important for developing colonies. In the present investigation

interaction with pollen, nectar and both pollen and nectar producing plants by *A. dorsata* was recorded during their blooming period at different regions of southern Karnataka. Diversified flowering plant species bloom during different months of the year and few species bloom throughout the year and showed good Shannon-Wiener diversity index (H^1)of more than two.This show good species richness and eveness (Magurran, 2004) and regarded as medium to high diverse in terms of species occurrence (Barbour et al., 1999) at southern Karnataka. However, high number of species richness in malnad region is attributed to the occurrence of heavy rainfall that contributes to the growth of many plant species. Further, the climatic, edaphic variability and anthropogenic activities are other factors associated with the difference in species richness at arid, semi-arid and malnad regions of southern Karnataka (Raghunandan and Basavarajappa, 2014).

Good floral source is one of the key factors that determine the *A. dorsata* colony distribution, accordingly, good colony density was recorded in this part of the state (Basavarajappa, 2012). Constructing pollen calendar for *A. dorsata* requires in depth study. However, attempts were made to provide baseline information on foraging plants of *A. dorsata* in this part of the state.As the pollen calendar differs from place to place and region to region preparing a pollen calendar for *A. dorsata*which would help predict the seasonal honey flow inturnidea of locally available bee flora prepared to know local biodiversity. In view of these reasons, pollen calendar of arid, semi-arid and malnad regions are prepared. Since different regions of southern Karnatakaare located in the tropics, weather is always pleasant with moderate climate throughout the year (Kamath, 2001). Perhaps, prevailed climate might have help grow diversified flowering plants, which bloom during different seasons and provided good amount of nectar and pollen for *A. dorsata*. Thus, nectar flow was continuous with little variations at different regions of southern Karnataka. Basavarajappa (1998, 2004 and 2012) reported that, certain plant species acted as both floral source and nest hosting trees for *A. dorsata* at maidan areas of Karnataka. Manjunath (2008) reported the plant species, which provide both floral source and nesting sites for *A. dorsata* in Mysore. Reddy and Reddy (1989) and Rao (1998) reported hundreds of flowering plant species utilized by *A. dorsata* for its floral source. However, during the present study, 62, 73 and 113 flowering plants supported *A. dorsata* population respectively at arid, semi-arid and malnad regions of southern Karnataka. Similar type of observations were made by Basavarajappa (1998), Joshi et al. (1998 a & b), Lakshmi and Suryanarayana (1998), Rao (1998), Singh et al. (1998), Singh(2002), Solomonraju (2002), Basavarajappa (2004), Bhattacharyaet al. (2005), Kumaret al. (2005), Singh et al. (2006), Tiwariet al. (2010), Basavarajappa (2010 and 2012), Shubharani and Venkataramegowda (2012) at different parts of India.

Since, honeybees (for example, *A. dorsata*) are indispensable components of terrestrial ecosystems, their presence are essential for the reproductive success of several plant species in the wildas well as at man-made ecosystems. Therefore, identification of foraging plants into trees, shrubs, herbs, climbers and then into economically important plants, fruit yielding plants, medicinal plants, ornamental plants and vegetable plants would help reveal their percent occurrence, apicultural value (Rao, 1973; Basavarajappa, 1998 and 2010)) and inturn understand local plant diversity. Thus, results presented in this paper agreed with the reports of earlier workers.

Furthermore, *A. dorsata*is a seasonal migrant, migrates from place to place in response to varying floral resource (Dyer and Seely, 1994). It travels more than three kilometers in search of forage and it would cover about 10 sq km in a day. During its migration and emigration, they visits various places in search of suitable floral hosts for pollen and nectar. The variability among flowering plants (trees, shrubs, herbs and climbers) showed species richness (number of species) and evenness (species distribution) from different regions of southern Karnataka that revealed good diversity for insect pollinators like *A. dorsata*.

Thus, presence of *A. dorsata* would indicate the status of flora of that region. Since, collecting data on foraging plants their usefulness to honeybee pollinators are prerequisite to frame a plan for effective crop pollination and production of bee hive products at different agro-ecological regions (Neupane et al., 2006), such types of studies exclusively on *A. dorsata* are presented for the first time in this part of the State. As *A. dorsata*is one of the major pollinators of angiosperms, its presence is important at all types of ecosystem for local biodiversity conservation (Buchmann and Nabhan, 1996; Zayed, 2009) and human survival. Its great role as pollinators of several plants at its area of distribution is well understood at various countries (Neupane et al., 2006). Moreover, reproductive success of several plant species in the wild as well as at man-made ecosystems is depended on *A. dorsata*.

The knowledge of flowering plants diversity is useful for establishing the apicultural activities and the state of honey production and shows the importance of insect-plant interaction in the environment. Thus, bee plants of the region would provide a greater insight into the pollination biology; in turn reveal the importance of conservation of both plants and insect pollinators. The services provided by plants and honeybees play a crucial role in sustaining our livelihoods and protect our health (Sobuj and Rahman, 2011).

Conflict of Interests

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

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Full Length Research Paper

Density and distribution of bongos (*Tragelaphuseurycerus*) in a high forest zone in Ghana

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This research was undertaken at Kakum Conservation Area (KCA) in the Central Region of Ghana, from October 2011 to September 2012. The aim was to determine the population density and factors affecting distribution of bongos *(Tragelaphuseurycerus)* for management planning and conservation of the bongo as well as tourism promotion. The methodology involved a field study of sampled plots that represented three habitat types, namely closed forest, open forest and thickets and habitat classification based on canopy coverage and locations of these habitats, whether marginal or deep inside the forest within each of the nine ranges. It was observed that encounters with bongos in KCA were more likely to be during early hours of the day, from 05.00 to 07.00 h GMT and later in the day, from 17.30 to 18.00 h GMT. The usual location was in their preferred thickets at four out of the nine ranges of KCA, and their distribution was not affected by seasonality or habitat utilization. About 5.3 bongos/km^2 currently occupy the KCA, which can be said to be currently under severe pressure as evidenced by the presence of hunting tools and human activities all over. The results of Pearson's correlation coefficient regarding bongo densities and water availability suggested that sources of water affected the distribution of the bongos in the KCA since more bongos were encountered closer to water sources. This underscores the importance of sources of water in the KCA for the conservation of the bongos, and the need to ensure adequate protection of the rivers and rivulets in KCA and off-reserve areas. These results have implications for the formulation of adaptive management plans that would protect the secretive, charismatic and largest antelopes in the KCA, thereby promoting tourism.

Key words: Population density, distribution, bongos, secretive, forest margins, Kakum Conservation Area, hunting pressure, water availability, tourism.

INTRODUCTION

The bongo (*Tragelaphuseurycerus* Ogilby, 1837) is the largest social forest-dwelling antelope in Africa, with geographical distribution within three discontinuous parts: East, Central and West (Bosley, 2003) (Figure 1). The species has been classified as Low Risk or Near Threatened with extirpations occurring in some African countries such as Benin, Togo and Uganda (IUCN, 2002). The species inhabits tropical jungles with dense undergrowth up to altitude of4000 m in Ghana, with exacerbated loss of habitat for mammalsdue to agriculture and

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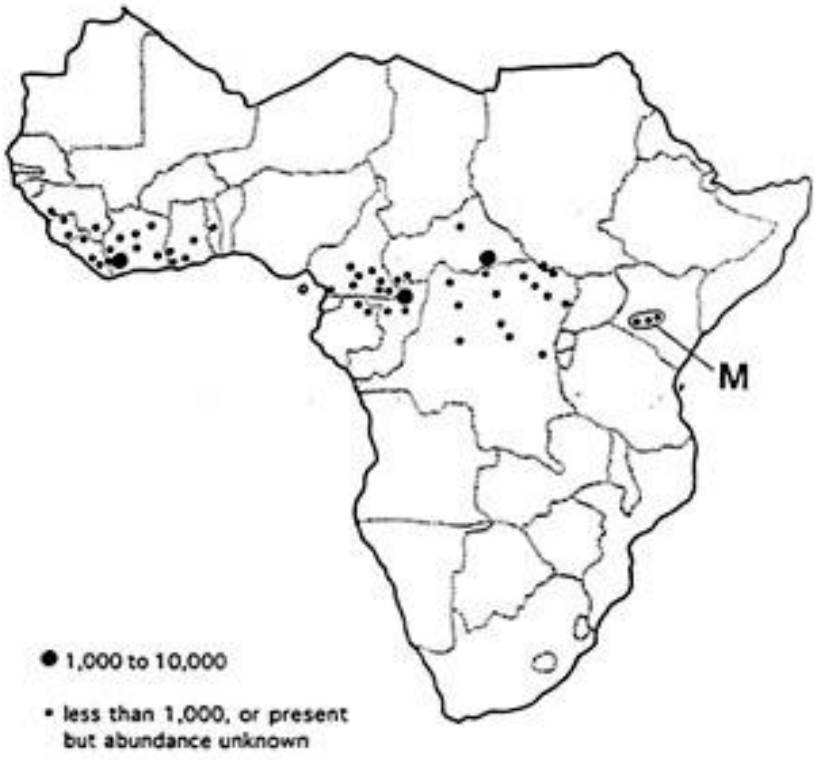

Figure 1. Distribution of bongos in Africa (Bosley, 2003).

deforestation. As expanding human populations compete with mammals for habitat, few forests including Kakum Conservation Area (KCA) remain for the bongo and; the future of bongos depends entirely on protected areas. Proper management of protected areas is thus very important and requires useful information from research studies as guide to the implementation of management schemes, specifically for the conservation of species, and more so for those endangered or near threatened such as the bongo. The bongo is a spectacular species with a relatively high touristic value. Yet, very few studies have been undertaken on wild bongos (Hillman, 1986; Hillman and Gwynne, 1987; Klaus-Hugiet al., 2000) with most information coming from captive populations in zoos. In the KCA, the bongo is second to the elephant in terms of size of the large mammal species, and its range in West Africa is limited as compared to elephants. Whilst the threatened status of elephants and some primates like the western chimpanzee *(Pan troglodytes)* and Miss Waldron's red colobus monkey *(Procolobus badius waldron)* has been given wide publicity (Oates et al., 1997), little is known about the bongos (East, 1990). Hiking expeditions for bongo sighting at the KCA have not been successful in many cases, even though this charismatic mammal would be interesting to view. In this study, the factors affecting the density and distribution of the bongo in KCA were assessed for management planning and action towards the conservation of the species, as well as tourism promotion. The study also investigates effects of water availability, habitat utilization and hunting pressure on the distribution of bongos in the study area.

Study area

KCA is located in a fragmented moist evergreen high forest zone in Southern Ghana (Figure 2), and consists of the Kakum National Park and its adjacent Assin Attandanso Resource Reserve, and occupies a 366-km^2 land area. Both areas were originally Forest Reserves but were legally gazetted in 1992 as wildlife conservation areas under the Wildlife Reserves Regulations (LI 1525). This transferred administrative jurisdiction to the then Wildlife Department, following recommendations based on an initial faunal survey (Hawthorne and Abu-Juam, 1993; Nchanji, 1994). The general climatic conditions of the country characterized by bimodal rainfall and two dry seasons (Durand and Skubich, 1982) prevail in the park. A heavy rainy season from April to July is followed by a light dry season from August to September. A light rainy season from October to early December is then followed by a heavy dry harmattan season from December to March (Kouadio et al., 2008). The fauna may concentrate in and around the few water spots available in the park during the dry harmattan from December to March.

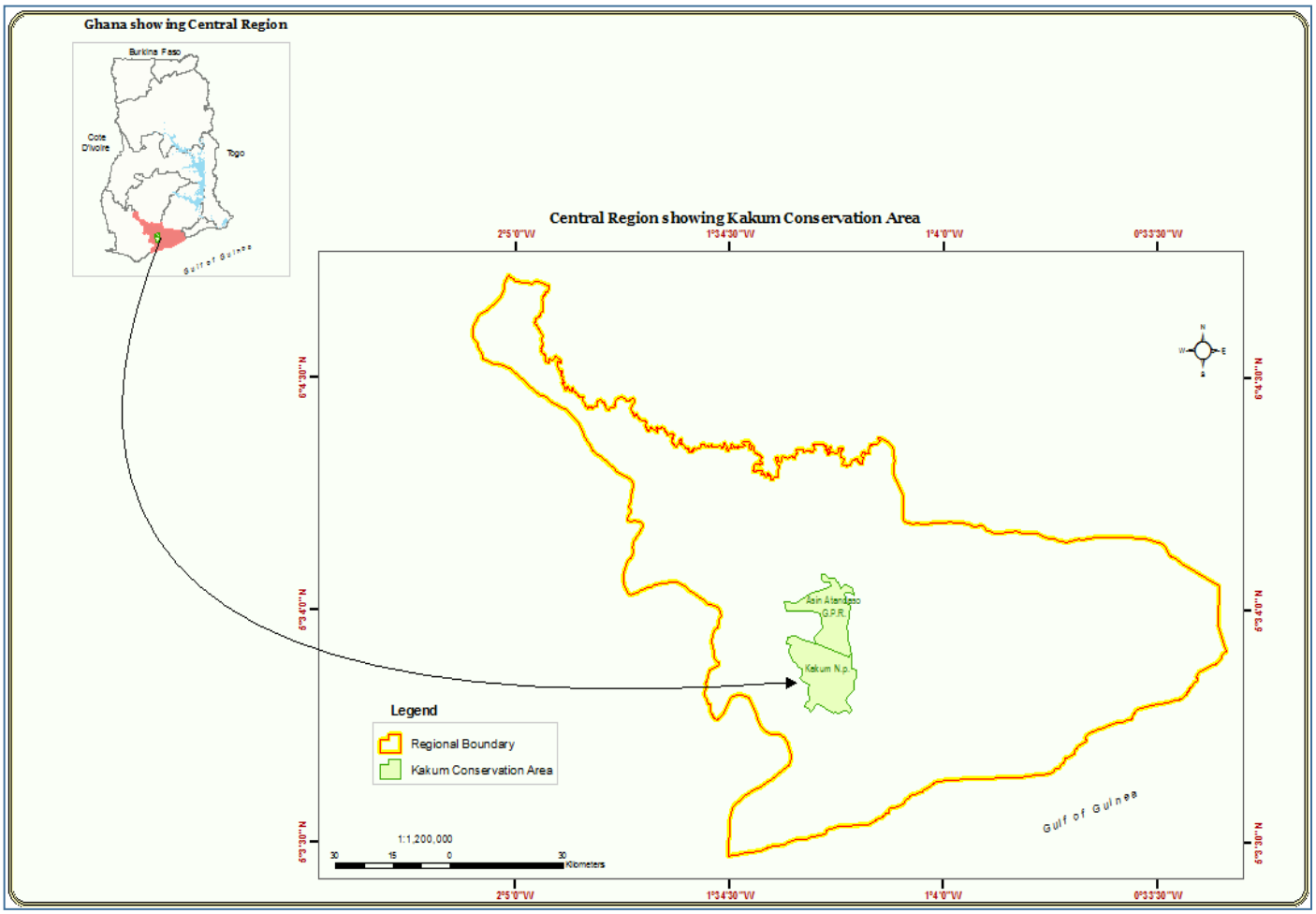

Figure 2. Location map of Kakum Conservation Area in the Central Region, Ghana.

The average annual rainfall is about 1600 mm (Forestry Commission, 2007). The average relative humidity is about 80% throughout the year while temperature ranges from 18.2 to 32.1°C. The terrain is flat to slightly undulating with an elevation of between 15 to 250 m above sea level (asl) (Forestry Commission, 2007). Most of the elevations occur in the south-western portion of the park. Light south westerly winds blow over the area almost throughout the year. The KCA is surrounded by about 52 local communities with a population of about 40,000 people who are mainly peasant farmers cultivating various food and cash crops, often close to the park boundaries (Monney et al., 2010).

About 105 species of vascular plants (Wildlife Department, 1996), 69 species of mammals (Yeboah, 1996) and about 266 species of birds (Dowsett-Lemaire and Dowsett, 2005) have so far been identified in KCA. Mammals include the potto (*Perodicticuspotto*), Demidoff'sgalago (*Galagoidesdemidoff*), bongo, African forest elephant (*Loxodontacyclotis*), and leopard (*Pantherapardus*). Many herpetofaunal species (Yeboah, 1996; Monneyetal., 2011) and a great number and diversity of butterflies (at least 405 species) (Larsen, 1994, 1995) have been recorded in the KCA, which, for effective patrol and monitoring is divided into nine ranges, namely Abrafo, Kruwa, Briscoe II, Adiembra, Homaho, Aboabo, Afiaso, Antwikwaa and Mfuom. Field staff are deployed from their camps adjacent to their ranges, and tourists led by tour guides use traditional routes in the park for hiking.

MATERIALS AND METHODS

Habitat classification

This study was undertaken from October 2011 to September 2012 using the nine ranges of KCA as study blocks, and camping at some vantage points from 04:00 to 08:00 h GMT and 16:00 to 18:30 h GMT. This became necessary because feasibility studies failed to sight the animal during the day to confirm reports by the staff. The study relied on a field study of sampled plots which were representative of three habitat types (closed forest, open forest and thickets) within each range. Habitat types were classified according

to canopy coverage (Wiafe et al., 2010). In the closed forest, light penetration to the forest floor was less than 25%, and tree canopy coverage was more than 75%. In the open forest, light penetration to forest floor was more than 25% with tree canopy coverage less than 75%. In the thickets, light penetration was less than 25% andthe canopy consisted of underbrush with coverage of more than 75%.

Sample plots, herd sizes and sighting times

To equalize sampling effort, two 200 m square plots were studied in different locations at each habitat type in each range, one at forest margin and another deep in the forest, and these locations were at least 1 km apart. In all 54 plots were surveyed over the period of study and each one was surveyed by eight people working in pairs and each pair taking charge of a portion of the plot to increase efforts. GPS coordinates at the centre of each plot were recorded. At each range plot surveys were conducted in each of eight months including both rainy and dry months and; from hideouts, including tree tops, hill tops and observation platforms, the number of bongos sighted, herd sizes and sighting times were recorded. Binoculars were used to facilitate viewing where necessary.

Mean bongo densities

Bongo densities were estimated by counting the number of individuals of bongo in each plot as follows: (1). The number of individuals of bongo in any plot divided by the plot area gave the bongos' plot density; (2). The number of individuals of bongo in the same habitat type were summed up and the result divided by the total area of all the plots in that habitat type to give the bongos' density for a specific habitat type; (3). The number of individuals of bongo in each habitat location were summed up and the result divided by the total area of all the plots in the same habitat location to give the bongos' density for a specific habitat location; (4). The number of individuals of bongo in each range were summed up and the result divided by the total area of all the plots in the same range to give the bongos' density for a specific range and; (5). The number of individuals of bongo in all plots in the study area were summed up and the result divided by the total area of all the plots to give a bongo density in the study area. As surveys were replicated eight times all densities were divided by eight to give mean densities.

Population densities and distribution of bongos

Distribution of bongos was measured in terms of the presence and absence of bongos, and their population densities in survey plots, in the different habitat types and their locations, and ranges of the Park during both rainy and dry seasons.

Habitat use

There was also daytime searching for signs of the presence of the bongos in each plot. The presence of bongo spoors (scats, footprints, etc.) was used as evidence of their presence. The degree of habitat use by the bongos was measured by signs of bongos' presence or absence, coded as follows: 0 = no sign of presence; 1 = signs of presence (footprints, dung), but no evidence of browsing; 2 = signs of presence and < 50% browsing; 3 = signs of presence and ≥ 50% browsing of the area.

The codes scored in each plot in the respective habitat types were ranked (1st for habitat that had the highest, 2nd for the next and 3rd for habitat that recorded the least number).

Water availability and hunting pressure

To find out whether water availability affected the distribution of bongos in KCA, the distance of each plot from the nearest source of available water was recorded using the nearest-features extension method in ArcView GIS (v 3.2), based on the GPS coordinates of the plots and geospatial data on the parks water bodies obtained from the Centre for Remote Sensing and Geographic Information System (CERSGIS), Accra. A correlation between distances of plots from water and the bongos' plot densities was then determined. Hunting pressure on bongos was measured by counting any sign of hunting activity in each plot, notably traps, spent cartridges, poachers' camping sites and footprints. Each tool or activity sighted was recorded as 1 and removed from the study area. Correlation between bongos' density and hunting pressure was determined.

Analysis of data

We used IBM's SPSS version 16.0 to calculate descriptive statistics including mean densities and their standard errors to analyze all data. To assess habitat use of bongos at KCA, Levene's test of homogeneity of variance (Zar, 2010) was used to test the null hypothesis that population variances were equal. A two-factor ANOVA was conducted twice to evaluate the: (i) seasonal differences in bongo densities with habitat type (closed forest at Park margins, closed forest deep inside the Park, open forest at margins, open forest deep inside, thickets at margins or thickets deep inside), and (ii) seasonal differences in bongo densities among the nine study ranges (Aboabo, Abrafo, Adiembra, Afiaso, Antwikwaa, Briscoe II, Homaho, Mfuom and Kruwa). The data was transformed using the log (base 10) function in order to convert it into a normally-distributed one. Where differences were statistically significant, a post-hoc analysis of the variances by either non-parametric Games-Howell multiple comparisons or parametric Tukey's HSD multiple pairwise comparisons test (Kleinbaum et al., 1988) was conducted. Descriptive statistics of ANOVA were used to evaluate the population densities as a function of the distribution of the bongos in the various habitat types and locations, and the ranges in the Park in both rainy and dry seasons. Descriptive statistics of ANOVA were used also to assess the differences in habitat use in the three habitat types and in the two different locations of habitat types and; Chi-square was used to test for the significance of the differences. In order to determine the association between bongo densities and water availability or hunting pressure, total bongo densities for habitats in all ranges for both rainy and dry seasons were log-transformed to obtain a linear relationship and also to meet the assumption of normality. A bivariate correlation between the density of bongos and distances from sources of water or hunting pressure was computed and Pearson's correlation coefficient (Cohen and Cohen, 1975) was calculated.

RESULTS

Sighting times and herd sizes

We observed bongos during early hours of the day, from 05:00 to 07:00 h GMT and in the evening between 16:00 and 18:30 h GMT (Figure 3) meaning that this species is likely crepuscular. There was no significant difference between morning and evening periods of encounter with the bongo (t=0.7806, p=0.4575). Of all the bongo herds encountered throughout the study, herd sizes ranged from one to eight individuals, with two as the modal size,

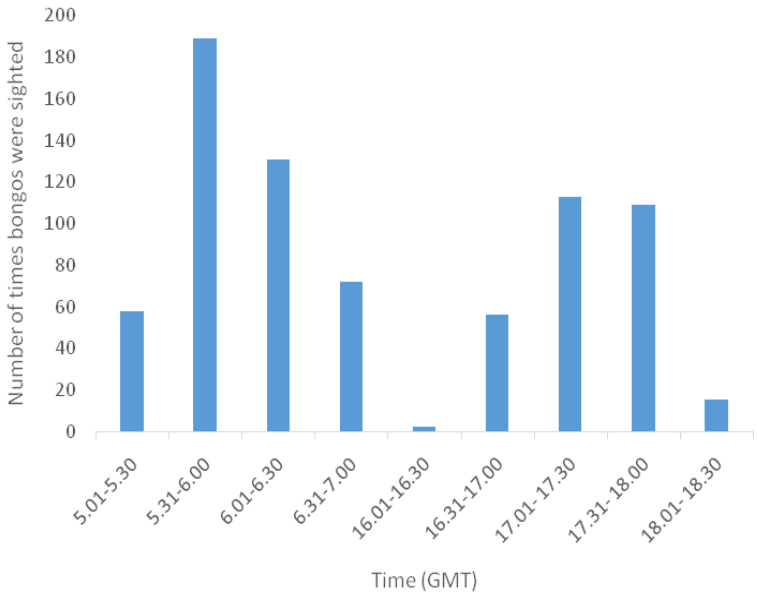

Figure 3. Time of encounter with bongos in the Kakum Conservation Area

though sizes as high as 15 individuals have been reported by field staff.

Mean bongo densities

ANOVA for the various combinations of the factors (season and habitat) and the dependent variable (bongo densities) indicated that in both the rainy and dry seasons, the highest bongo densities were recorded in thickets at the Park margins (Table 1). The mean was 0.9219 (σ=0.59056) per 100,000 m^2 in the rainy season and 1.0005 (σ=0.54398) per 100,000 m^2in the dry season. The next highest bongo density was also recorded in the thickets deep inside the Park. The mean values in the rainy and dry seasons were 0.6002 (σ = 0.59056) and 0.6213 (σ = 0.55254) respectively per 100,000 m^2. At the margin's closed forests, means of 0.4451 (σ = 0.1387) and 0.4370 (σ = 0.10544) were recorded for the rainy and dry seasons respectively per 100,000 m^2 estimates while deep inside closed forests were 0.3574 (σ = 0.22486) and 0.4863 (σ = 0.7325), respectively per 100,000 m^2. Also, mean bongo density for deep inside open forests was higher (μ/100,000 m^2 = 0.3548; σ = 0.44697) in the dry season than in the rainy season (μ/100,000 m^2 = 0.1995; σ = 0.41140). At margin's open forest, mean bongo density of 0.4478/100,000 m^2 (σ = 0.23199) was recorded during the rainy season, and 0.3028/100,000 m^2 (σ = 0.37707) during the dry season.

Overall, mean bongo population density per 100,000 m^2 was 0.5252 (σ = 0.45819) ranging from μ = 0.5495 (σ = 0.44841) in the dry season to μ = 0.5009 (σ = 0.46807) in the rainy season. The bongo population density per 100,000 m^2 was highest (μ = 0.9612; σ = 0.58670) in the thickets at the margins and lowest (μ = 0.2616; σ = 0.40872) in the open forests deep inside. The test for homogeneity of variance was highly significant (Levene'stest statistic = 3.820; $p < 0.05$). This indicates variances were not equal across groups, and therefore an assumption of ANOVA is violated. Games-Howell's post-hoc analysis which is free of assumptions of normality indicated a significant difference in bongo population densities between the open forests deep inside and the margins thickets in the Park. The estimated marginal mean for margins thickets was 0.961 ± 0.123, while that for open forests deep inside was 0.277 ± 0.138. It could therefore be concluded that margins thickets have the highest bongo density in the park.

Descriptive statistics of ANOVA for the independent variables (season and range) and the dependent variable (bongo densities) revealed interesting results. While the population densities were zero for three ranges, representing 33% of all the ranges or plots surveyed in the park in both rainy and dry seasons, others showed different results for the different seasons. At Abrafo, the population density of the bongo community during the rainy season was very low, with a mean of 0.02258 (σ = 0.15051), but shot up slightly to a mean of 0.0587 (σ = 0.10167) in the dry season. A similar trend was recorded at Kruwa, with mean 0.1910 (σ = 0.35236) in the rainy season and 0.894 (σ = 0.45189) in the dry season. Three of the four remaining sites recorded marginal increases in population density from the rainy to the dry season. At Adiembra, the mean population densities for the rainy and dry seasons were 0.6191 (σ = 0.38158) and 0.7131 (σ = 0.35374) respectively. Values for Afiaso were 0.7765 (σ = 0.36413) and 0.8112 (0.35088), while those for Antwikwaa were 0.6926 (σ = 0.37644) and 0.6919 (σ =0.35788). Mfuom recorded 0.7095 (σ = 0.38268) and

Table 1. Means, standard deviations, and the number of observations (N) of the factors affecting bongo densities (response).

Season	Habitat Type	Mean	Standard Deviation	N
Rainy	CF-M	0.4451	0.13872	5
	CF-D	0.3574	0.22486	5
	OF-M	0.4478	0.23199	6
	OF-D	0.1995	0.41140	6
	TH-M	0.9219	0.67651	6
	TH-D	0.6002	0.59056	6
	Total	0.5009	0.46807	34
Dry	CF-M	0.4370	0.10544	5
	CF-D	0.4863	0.07325	5
	OF-M	0.3028	0.37707	6
	OF-D	0.3548	0.44697	4
	TH-M	1.0005	0.54398	6
	TH-D	0.6213	0.55254	6
	Total	0.5495	0.44841	32
Total	CF-M	0.4410	0.11624	10
	CF-D	0.4218	0.17166	10
	OF-M	0.3753	0.30793	12
	OF-D	0.2616	0.40872	10
	TH-M	0.9612	0.58670	12
	TH-D	0.6108	0.54536	12
	Total	0.5244	0.45577	66

CF-M = closed forest margin; CF-D = closed forest deep; OF-M = open forest margin; OF-D open forest deep; TH-M = thickets margin and; TH-D = thickets deep.

0.7145 (σ = 0.34998). Overall, the highest bongo population density was recorded during the dry season at Afiaso (mean = 0.7938; σ = 0.34141) and the lowest at Aboabo, Briscoe II and Homaho (all recording zero in both seasons) followed by Abrafo during the rainy season (μ = 0.01039; σ = 0.19466). The means recorded at four stations, namely Adiembra, Afiaso, Antwikwaa and Mfuom were always much higher than at Abrafo and Kruwa, and there was not much difference in the mean bongo population densities between Abrafo and Kruwa. Again, it could be said that the population distributions of bongos in the various ranges were not uniform. They were absent from Aboabo, Briscoe II and Homaho, low in Abrafo and Kruwa and relatively high in Adiembra, Afiaso, Antwikwaa and Mfuom.

Population density and distribution of bongos

Bongos were present in six of the nine ranges and 36 of the 54 sample plots (representing 67% of all the ranges surveyed) in both seasons. They were absent from all the 18 plots in three ranges, namely Aboabo, Briscoe II and Homaho in both seasons. Bongos were present in both seasons in the same habitat type or absent in both seasons from the same habitat type, but never present in one habitat type during one season and absent during the other.

The 2*6 factorial ANOVA to determine the possible interaction between the distribution of the bongos in various habitats of the study area and the season of the year on the population densities of the bongos also revealed interesting results for all possible combinations of the analyses. There was no significant interaction between seasons and population distribution of bongos in the various habitats {F (5, 54) = 0.181, p>>0.05, Table 2}. From the partial ETA computed the interaction effect only accounted for 1.7% of the total variance in bongo densities between season and distribution of bongos in the habitats (Table 2). The profile plots of interaction (Figure 4) gives a pictorial representation of the interaction. It is observed that the lines are almost all parallel. The main factor (season) was not significant {F (1, 54) = 0.132, p>>0.05, Table 2}, only accounting for 0.2% of the variations in the population densities of the bongos. However, the habitat main effect was found to be significant {F (5, 54) = 0.005, p <0.05, Table 2}. This means that bongo population densities for the various habitats were different and Games-Howell's post-hoc analysis (Table 3) revealed the difference existed between open forests deep inside (with low population distribution) and margins thickets (with high population

Table 2. Test of subject effects for season and habitat type.

Source	df	Mean square	F	Significance	Partial Eta squared
Season	1	0.024	0.132	0.717	0.002
Habitat	5	0.681	3.750	0.005	0.258
Season x Habitat	5	0.033	0.181	0.968	0.017
Error	54				

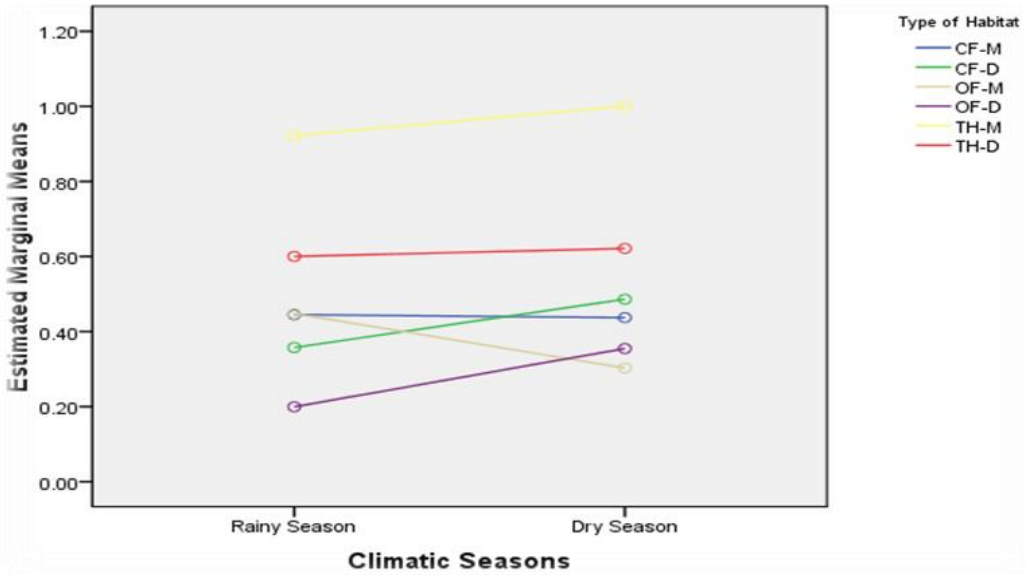

Figure 4. Comparing estimated marginal means of bongo densities in different types of habitats in the rainy and dry seasons during the study.

distribution). Bongos' population densities however did not differ between all other possible pairings of habitats (Table 3).

Also, there was no significant interaction between season and distribution of bongos in the various ranges of the park {F (5, 54) = 0.278, p>>0.05, Table 4}. Only 2.5% of the total variance in the bongos' densities was accounted for by the interaction between season and range of occurrence of the bongos in the park. The main effect by the season on the population distribution of the bongos in the ranges was also not significant {F (1, 54) = 0.562, p >>0.05, Table 4} and the season main effect accounted for less than 1% of the total variance in the bongos' densities. However, there was a highly significant {F (5, 54) = 9.591, p <<0.05, Table 4} main effect by the range factor. In other words, the bongos' population densities were statistically different across the different ranges of the bongos in the park. As the ratio of the highest to least recorded population densities was 7:1, variances across groups were expected to be small, which was confirmed by the test of homogeneity of variance {F (11, 54) = 1.090, p>>0.05}. However, Tukey's post-hoc analysis revealed significant differences (Table 5) in bongos' population densities between Abrafo and each of four ranges namely Adiembra, Afiaso, Antwikwaa, and Mfuom, but not Kruwa and; also between Kruwa and each of the four ranges. Between pairs of Adiembra, Afiaso, Antwikwaa and Mfuom, the differences were not significant (Table 5). This means that population densities varied across the ranges, but with Abrafo and Kruwa having similarly low densities and Adiembra, Afiaso, Antwikwaa and Mfuom similarly high densities. Bongos were absent from Homaho, Briscoe II and Aboabo.

In summary, the population densities of the bongos were not dependent on the time of climatic season (rainy or dry). On the other hand, the population densities of the bongos depended on the habitat in which they lived, particularly in four of the nine ranges of the park.

Habitat use

The results of cross-tabulation among degrees of habitat use are presented in Table 6. The figure in each cell indicates the number of times that degree of use was assigned in that habitat. For example, 24 in cell 1 implies

Table 3. Tukey's HSD post-hoc multiple comparisons of the various levels of the factor range.

Range(I)	Range(J)	Mean Difference (I-J)	Std. Error	Sig.
	Kruwa	-0.2441	0.17039	0.707
	Adiembra	-0.7657*	0.17322	0.001
Abrafo	Afiaso	-0.8977*	0.17039	0.000
	Antwikwaa	-0.7961*	0.17039	0.000
	Mfuom	-0.8158*	0.17039	0.000
	Abrafo	0.2441	0.17039	0.707
	Adiembra	-0.5216*	0.14955	0.012
Kruwa	Afiaso	-0.6536*	0.14626	0.001
	Antwikwaa	-0.5521*	0.14626	0.005
	Mfuom	-0.5718*	0.14626	0.003
	Abrafo	0.7657*	0.17322	0.001
	Kruwa	0.5216*	0.14955	0.012
Adiembra	Afiaso	-0.1320	0.14955	0.949
	Antwikwaa	-0.0305	0.14955	1.000
	Mfuom	-0.0502	0.14955	0.999
	Abrafo	0.8977*	0.17039	0.000
	Kruwa	0.6536*	0.14626	0.001
Afiaso	Adiembra	0.1320	0.14955	0.949
	Antwikwaa	0.1015	0.14626	0.982
	Mfuom	0.0818	0.14626	0.993
	Abrafo	0.7961*	0.17039	0.000
	Kruwa	0.5521*	0.14626	0.005
Antwikwaa	Adiembra	0.0305	0.14955	1.000
	Afiaso	-0.1015	0.14626	0.982
	Mfuom	-0.0197	0.14626	1.000
	Abrafo	0.8158*	0.17039	0.000
	Kruwa	0.5718*	0.14626	0.003
Mfuom	Adiembra	0.0502	0.14955	0.999
	Afiaso	-0.0818	0.14626	0.993
	Antwikwaa	0.0197	0.14626	1.000

*The mean difference is significant at the 0.05 level.

Table 4. Test of subject effects for season and ranges.

Source	df	F	Significance	Partial Eta squared
Season	1	0.340	0.562	0.006
Range	5	9.591	0.000	0.470
Season * Range	5	0.278	0.923	0.025
Error	54			

that in the closed forest, the degree of use of that habitat assigned a "no use" was coded 24 times. It appears that the degree of use coded 'no use', 'low use' or 'moderate use' was always least in the thickets while 'high use' was highest in the thickets (Table 6). In other words, it appears that the bongos used the thickets more than other habitat types. However, the trend was not clear between the closed and open forests and as Chi-square statistic at an alpha level of 0.05 was not significant (χ = 3.2121, df = 3, p = 0.36006), none of them could be said

Table 5. Mean differences of pair-wise comparisons of the types of habitats and their significance.

Habitats	CF-M	CF-D	OF-M	OF-D	TH-M	TH-D
CF-M						
CF-D	-0.01919					
OF-M	-0.06573	-0.04654				
OF-D	-0.17939	-0.16021	-0.11367			
TH-M	0.52016	0.53935	0.58589	0.69956**		
TH-D	0.16971	0.18890	0.23544	0.34911	-0.35045	

CF-M: closed forest margins; CF-D: deep inside closed forest; OF-M: open forest margin; OF-D: deep inside open forest; TH-M: thicket margins; TH-D: deep inside thicket. **Mean difference is significant at 0.05 by Games-Howell multiple comparisons test.

Table 6. Cross-tabulation between degree of habitat use and habitat type.

Degree of habitat use	Habitat type		
	Closed forest	Open forest	Thicket
No use	24	20	20
Low	5	6	3
Moderate	6	5	3
High	1	5	10

Table 7. Cross-tabulation between degree of habitat use and habitat location.

Degree of habitat use	Habitat location	
	Margin	Interior
No use	32	32
Low	4	10
Moderate	10	4
High	8	8

to be used more than the other. Also, in the case of habitat locations, scores for both forest margin and deep forest were the same for 'no use' and 'high use' and it appeared that margins were used more than deep forests judging from the results of low and moderate uses (Table 7). However, the difference in the degree of use between forest margins and deep forests was not significant (χ = 5.143, df = 3, p = 0.162).

Water availability and hunting pressure

Pearson's correlation coefficient for bongo densities and water availability was -0.468 and this was statistically significant (p = 0.005), suggesting a moderate and inverse correlation between bongo density and water availability. Thus bongo densities were lower when water was scarcer or farther away from bongo locations, and this affected bongo distribution in the KCA, with bongo standing to occur in areas closer to water sources.

A correlation coefficient of -0.267 suggested an inverse relationship between bongo densities and hunting pressure that could also suggest that higher hunting pressure reduced bongo densities and vice-versa; but as the correlation was found to be not significant at an alpha level of 0.05 (p = 0.127) hunting pressure could not therefore be said to have any effect on the distribution of bongos at KCA. Evidence of hunting activities included spent cartridges, traps of different types, poachers' camps, and matchboxes and reports from field staff confirmed that poaching was rampant with the use of dogs, guns and traps at all ranges and habitats.

DISCUSSION

Mammals of the tropical moist forest are not easy to see and count, as in the case of bongos, which are particularly secretive, making it difficult to encounter especially during daytime. Considering the total survey effort in this study, however, the results could be considered reliable. Spinage (1986) and Estes (1991) described bongos as nocturnal and Hillman (1986) observed most activity of the species from dusk to early morning; but Bosley (2003) described bongos as diurnal. This study found virtually no direct activity during the day, but there was no opportunity to obtain evidence of night activity since there were no surveys at night. It appearsthat the bongos in KCA are active in low light during theday.

Apart from direct encounter with the bongos, critical examination of footprints and feeding activities further support the hypothesis that intense activity occurred during the early and late hours of the day, rest by lying under dense cover during high light in the day and sleep at night. The explanation could be that poachers return home in the early and late hours after night and day duty respectively. Also leopards, the historical predators of calves of bongos (An Ultimate UngulateFact Sheet, 2004), are exclusively nocturnal and may find it difficult to locate the bongos when they are asleep at their hideouts under dense cover in the night. This may also account for the higher use of thickets by bongos in both forest margins and forests deep inside the park than other habitat types, as observed in this study. The thickets normally comprise slow and low-growing regenerating plants used as hideouts for the bongos as well as food sources, unlike the primeval or less-disturbed areas in the interior parts of the reserve where leaves and twigs of tall trees cannot be reached for consumption.

East (1990) reported crop-raids by bongos and though this study did not investigate field staff's reports on crop raids, it is suggested that location of bongos near forest margins, and therefore crop fields just after the boundary of the conservation area sometimes, is one possible benefit which may account for the use of thickets at forest margins by bongos. Dense thickets might offer good hiding places for bongos to raid nearby crop farms bordering the KCA. As there was a significant difference in densities among the ranges of occurrences of bongos, other factors than chance may account for the distribution of bongos in the ranges. For instance, the chance of encountering bongos at KCA is high at the margins of Afiaso, Adiembra, Antwikwaa and Mfuom ranges perhaps because of the abundance of thickets in these areas, which are re-growths of extensively logged forests.

There were very few bongo encounters at the Kruwa and Abrafo ranges and no encounters at Briscoe II, Homaho and Aboabo. These five ranges had evidence of severe human interference in the form of direct poaching and noise due to increased human populations or visitor influx. For example, Aboabo shares boundary with the Park; Kruwa and Briscoe II harbour the most notorious hunters, according to Park Management and; Abrafo experiences noise due to regular influx of visitors to the canopy walkway. For the purpose of bongo viewing, observation platforms would be more useful if they were erected at Afiaso, Antwikwaa, Mfuom and Adiembra near the forest margins as tourists have failed to view bongos from existing platforms at Briscoe II and Abrafo (Monney and Dakwa, 2014).

The results also indicated that water sources were necessary for the distribution of the bongos, since even thickets were avoided if they were farther away from water sources. This underscores the importance of conserving water bodies (rivers and rivulets) in the KCA and off-reserve.

Large herd sizes of up to 15 have been recorded in field reports and; elsewhere, Klaus-Hugi et al. (2000) encountered 10-20 bongo herd sizes in the Dzanga National Park, Central African Republic. This study did not however record herd sizes larger than eight. Even though large herds may split temporarily (Klaus-Hugi et al., 2000) or permanently, it is possible that threats to bongos in KCA in the form of poaching and predation may have reduced the herd sizes. There was no significant difference between bongo densities and hunting pressure in the various habitat types, habitat locations and ranges, suggesting that the mammals were equally exposed to hunting pressure, which could not therefore account for the distribution of the bongos. It is noteworthy that factors including illegal hunting and predation affect the abundance and distribution of bongos as they do to other mammals, notably elephants. However, Ottow et al. (1996) reported that bongo populations in a predominantly secondary forest in Bangassou in the Central African Republic were stable even though there was hunting pressure.

This study was not extensive enough to find evidence of reducing bongo populations in the KCA, yet patrol staff reported reducing bongo encounter rates. Estes (1991) reported a drastic decline of some isolated bongo populations in Africa and in Kenya, bongo populations are declining throughout their range as a result of overhunting, habitat loss and rising exploitation through safari hunting and have been nearly extirpated (Kingdon, 1997; East, 1999). The field staff reported active hunting with guns, traps and dogs, inside KCA, as evidenced by the spent cartridges and traps (wire snares and gin traps) found all over the reserve in this study. There was however no evidence of predation in this study, even though field staff reported that pythons *(Python sebae)* and leopards preyed on young bongos.

The elusive nature of bongos, coupled with difficulties in detecting over-exploitation of bongos, makes more reliable population estimates difficult, leading to 'sudden' drops in bongo numbers. This study estimated bongo populations at approximately 0.53 bongos per 100,000 m^2 (5.3/km^2) within an area of about 360 km^2 at the KCA. Estimated bongo density in the about 150 km^2 Dzanga National Park in the Central African Republic was 0.25/km^2 (Klaus-Hugi et al., 2000). This is an indication that bongo population densities in Africa's protected areas are low, and that there is need for institution of measures to ensure the adequate protection of bongos (East, 1990). The results of this study suggest that the bongo population at KCA is currently under severe pressure.

Protected area management requires information about species distribution, trends in species population densities and knowledge about the impact of potential threats on the population, such as hunting pressure (Carrillo et al., 2000) and logging (Frumhoff, 1995). Also,wildlife monitoring is essential for assessing the success of implemented management actions such as law enforcement

strategies and the establishment of research and tourist sites (Hockings et al., 2006). The results of this study have implications for the formulation of adaptive management plans to protect the secretive, charismatic and largest antelope in the Kakum Conservation Area.

Conflict of Interests

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

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