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Moran GJ, Amii RN, Abrahamian FM, Talan DA (2005). Methicillinresistant Staphylococcus aureus in community-acquired skin infections. Emerg. Infect. Dis. 11: 928-930.

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.

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

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Table of Contents: Volume 7 Number 2 February, 2015

ARTICLES

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Perspective Paper

A new locality record for an endangered tree species *Pittosporum eriocarpum* Royle (Pittosporaceae) in India

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***Pittosporum eriocarpum* Royle (Pittosporaceae) an endangered tree species is collected and reported for the first time from the Kangri, Dhamrol village of Bhoranj block which is quite near to Bhareri of Jahu road of district Hamirpur, Himachal Pradesh, North West Himalaya. This makes another locality record for an endangered tree species in the North West Himalaya. A detailed taxonomic description of the species along with colour photographs and specimens examined is presented in this paper to validate the new locality report and for easy identification of the species.**

Key words: *Pittosporum eriocarpum* Royle, locality record, endemic and endangered tree, Himachal Pradesh.

INTRODUCTION

Hamirpur (76º 18' to 76º 44' E and 31º 25' to 31º 52' N), is one of the smallest district of the Himachal Pradesh in terms of area but richest in terms of vegetation because it shares its boundary with district Kangra in the north, Bilaspur in the south, Mandi in the east and Una in the west. It is located in the south western part of Himachal Pradesh, North west Himalaya and the elevation varies from 400 to 1200 m amsl. The hilly tracts of district are totally covered by the famous Shivalik range and supports subtropical to temperate vegetations and offers congenial climatic conditions favourable for luxuriant growth of the vegetation including many rare, endangered species. While enumerating the floristics diversity of the district, an endemic, endangered tree species that is *Pittosporum eriocarpum* Royle has been collected from Kangri, Dhamrol village of Bhoranj block growing near the agricultural field which is quite near the Bhareri to Jahu road (Figure 1). Further, as per the previous reports, *P. eriocarpum* Royle is an endemic tree species restricted to Uttarakhand Himalaya (Osmaston, 1927; Kanjilal, 1928). Earlier records reported scarce population of *P. eriocarpum* in the lesser Himalayan range including Mussoorie hills and Doon Valley (Singh and Goel, 1999; Pundir et al., 2001; Padalia et al., 2010) in Uttarakhand state in and Chamba, Himachal Pradesh (Chowdhery and Wadhwa, 1984). Further based on the detailed literature and herbaria survey especially from Himachal Pradesh, it was reveals that *P.eriocarpum* Royle (family Pittosporaceae) was reported from only Chamba district, (Chowdhery and Wadhwa, 1984)

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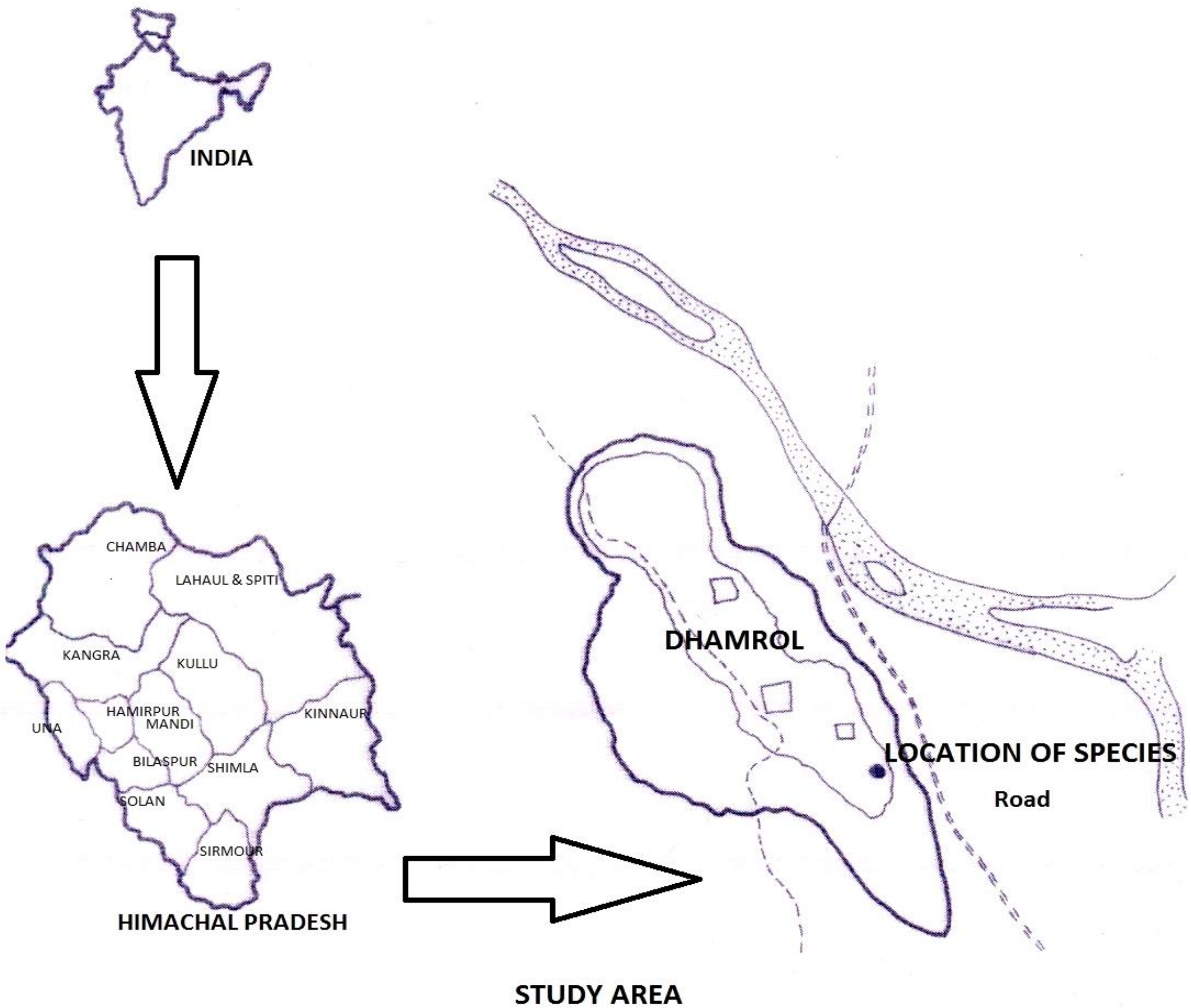

Figure 1. Location map of the study area.

and Rissa Khad Watershed near Riwalsar in Mandi district (Devi, 2013). The presence of this species in such area (locality) shows high conservation value of the Bharari village of Bhoranj block, and the presence of such species justify by the authors above said the localities is an interesting record. Further the species has been cited as Vulnerable in Red Data Book of Botanical Survey of India (Nayar and Shastri, 1987, 1988, and 1990) and as endangered by International Union for Conservation of Nature and Natural Resources (IUCN) World Conservation Monitoring Centre (WCMC, 1998)

In the present study, a brief introduction about taxon, morphological descriptions, specimens examined, ecology and distribution of taxon have been provided for easy identification. The voucher specimens were deposited in the Herbarium (SP-HP-007), Centre for Biodiversity Studies, Baba Ghulam Shah Badshah University, Rajouri.

Pittosporum is a genus of about 200 species of flowering plants in the family Pittosporaceae. The genus is probably Gondwanan in origin; its present range extends from Australia, eastern Asia and some parts of Africa of which 12 species occur wild in India (Little et al., 1989).

Pittosporum is a small evergreen tree, upto 12 m in height, bark thin, light greenish grey; leaves loosely crowded towards the ends of the branches; lanceolate to elliptic oblong; flowers yellow; fragrant, much in branched corymbose or umbelliform clusters; capsules orange, slightly compressed; seed orange red, coated with a resinous, viscid fluid (Figure 2a and b).

Habitat

Very rare (on the basis of distribution), growing singly

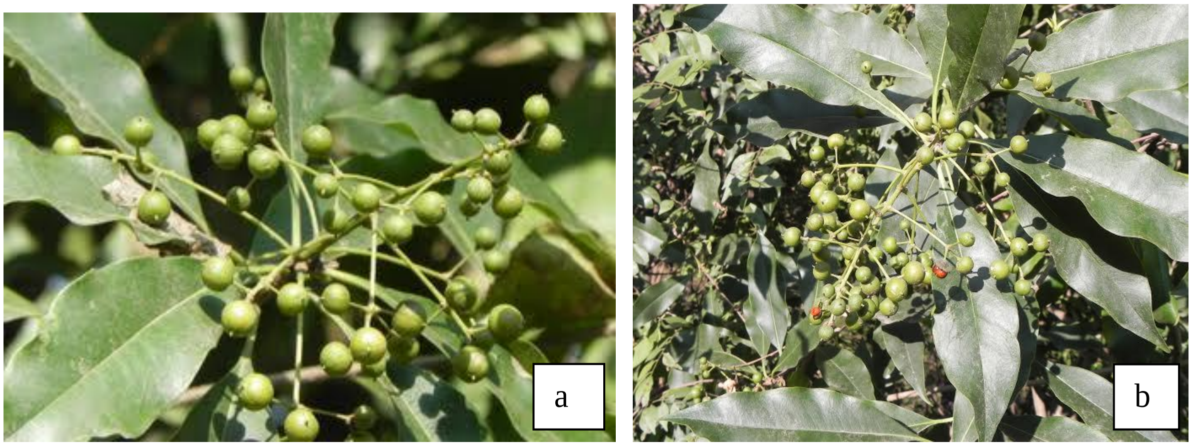

Figure 2. *Pittosporum eriocarpum* Royle with unripe (a) and ripe seeds (b) at Bhoranj Tehsil, District Hamirpur, Himachal Pradesh.

near the agricultural land along road side.

Specimens examined

Kangri, Dhamrol, 1145 m amsl, growing near the agricultural land along road side.

Distribution

North West Himalaya **(**Uttarakhand: Dehradun (around Kempty falls), Mussoorie hills and Jeullikot in Nainital district and Himachal: Chamba, Rissa Khad Watershed near Riwalsar, Mandi district).

Economic importance

It is classified as a multipurpose tree, and is lopped for fodder and fuel wood, and is a suitable species for soil conservation and reclamation of degraded sites.

Conflict of interests

The authors did not declare any conflict of interest.

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Review

Role of revegetation in restoring fertility of degraded mined soils in Ghana: A review

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The topsoil gets seriously damaged during mineral extraction. The consequences of physical disturbance to the topsoil during stripping, stockpiling and reinstatement results in soil degradation through loss of soil structure, accelerated soil erosion, excessive leaching, compaction, reduced soil pH, accumulation of heavy metals in soils, depletion of organic matter, decreased plant available nutrients, reduced cation exchange capacity, decreased microbial activity and consequent reduction in soil fertility. Management of topsoil is important for reclamation plan to reduce nutrient losses and eventually restore the fertility. Revegetation constitutes the most widely accepted and useful way to improve the fertility of degraded mined lands. A review was conducted to assess the contribution of revegetation to improvement of soil fertility of mined lands. The results obtained in this study indicate that revegetation through forest vegetation is one of the efficient means of restoring soil fertility through improvement in soil organic matter content, available nutrients, cation exchange capacity, increased biological activities as well as improvement in physical conditions of the soil. However, it will require longer periods to restore the fertility as closely as possible to the original level. The efforts to rehabilitate mined lands have focused on N-fixing species of legumes, grasses, herbs and trees. Some of the promising tree species that can be used for revegetation are Acacia, Leucaena and other legume trees that are acid-tolerant and can add substantial amount of organic matter to the soil. Long term revegetation using legume species of high metal accumulation and are acid tolerant should therefore be considered in mining areas.

Key words: Mining, soil physical properties, soil chemical properties, soil degradation, land rehabilitation, revegetation.

INTRODUCTION

Mineral extraction and processing are responsible for 10% of Ghana's industrial pollution resulting from emission of sulphur dioxide (SO_2), arsenic trioxide (As_2O_3), nitrous oxide (NOx) and particulate matter. For example, arsenic (As) emissions at Anglo Gold Ashanti, Obuasi are 1000 times higher than any world

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standards (Aubynn, 1997). Many research findings indicate that Ghana soils are impacted by mining activities especially that resulting from surface mining. This mining process uses heavy machinery and involves blasting during the extraction period. The blasting process alone kills soil beneficial organisms, disrupts the stable soil aggregates, and eventually deprives the soil of organic matter. These soils, or newly created substrates/ growth media are often inhospitable to vegetation due to combination of physical, chemical and microbiological factors.

Many areas disturbed by mining in Ghana are highly susceptible to erosion due to lack of existing vegetation, the presence of fine, dispersed particles and steep slopes, huge gullies and pits are created. Substrates, usually called the overburden or mine spoil, are often the characteristic of all gold mined lands in Ghana. Nearly all mine substrates have very low levels of macronutrients (especially nitrogen (N), phosphorus (P) and potassium (K)). Low pH is a particularly intransigent problem in wastes that contain iron pyrites, which, on weathering, will generate sulphuric acid and (if there is no acidic neutralizing capacity in the waste) induce pH values of <2.0. Toxicity, especially of aluminium, zinc and other metals in acidic wastes, can be a significant problem for plant growth. For instance, Assel (2006) reported pH level in soils of one mining area called Prestea/Bogoso in western region as low as 3.96. Low pH is a characteristic of all gold mined substrates of Ghana.

Some of these affected soils as a result of these gold mining activities are restored (Figure 2) according to Environmental Protection Agency's (EPA) directive; others are just left bare (especially those resulting from illegal small scale mining activities). Typical examples are the vast mining areas of the western region of Ghana, where many illegal mining activities abound (Figure 1).

Mining removes the vegetation and inevitably leads to the loss of some plant nutrients from the site (Amegbey, 2001). The process also scrapes the topsoil with bulldozers and other heavy machinery and the soil samples are taken to the laboratory for the purpose of extracting mineral. As topsoil is only about 20 cm deep, and have most of their plant available nutrients in the top soil, the scraping action of the bulldozers depletes the soils of the fertility and productivity exposing the unfavorable subsoil which are unsuitable for crop production (Bonsu and Quansah, 1992).

Furthermore, practices that remove the vegetative material prevent addition of organic matter into the soil. The loss of organic matter has been found to lead to reduction in soil fertility, deterioration of soil structure, water holding capacity and biological activities in the soil (Asiamah et al., 2001).

In Ghana, for instance, these developments coupled with other kinds such as manufacturing, construction, agriculture, and tourism strengthened the desire for formal legislative backing for environmental impact impacts assessment. Consequently, an act (Act 490) to legally establish the Environmental Protection Agency (EPA) was passed by Parliament in December 1994. Under the act, Ghana's EPC which became the EPA was given more powers to ensure environmentally sound development (Appiah-opoku and Mulamoottil, 1997). In accordance with Section 12 (1) of the Act, the EPA: ". . . may by notice in writing require any person responsible for any undertaking which in the opinion of the Agency has or is likely to have adverse effect on the environment to submit to the Agency in respect of the undertaking an environmental impact assessment containing such information within such period as shall be specified in the notice" (Environmental Protection Council, 1994 cited in Appiah-opoku and Mulamoottil, 1997).

Thus, the Act gives the EPA legal backing to request project proponents to conduct and submit environmental impact assessment studies for approval. Where it appears to the EPA that the activities of any undertaking pose a serious threat to the environment or to public health, the agency may serve enforcement notice on the person(s) responsible for the undertaking to take such steps as the agency thinks necessary to prevent or stop the activities (Appiah-opoku and Mulamoottil, 1997).

It is from this legal instrument that EPA requires all mining companies to "clean up and repair" lands degraded during their extraction process through various rehabilitation strategies. Part of the reclamation/ rehabilitation phase is revegetation of the mined sites. According to Said (2009), revegetation is believed to be an efficient phytoremediation strategy for removing contaminants/pollutants from soil or water, adding organic matter to the soil and thus improving fertility of degraded lands. This is so because, vegetation cover and consequently topsoil richness have been linked to both soil fertility and productivity as established by Young (1997). He established that trees have long been used to reclaim areas of degraded lands due to the capacity to grow under difficult climatic and soil conditions, coupled with their potential for soil conservation, and that decline in organic matter, which to a large extent is provided by the crown and roots of trees, almost invariably accompanies land degradation.

Organic matter not only supplies plant nutrients, but also plays a major role in the maintenance of the physical, chemical and the biological properties of the soil (Asiamah et al., 2001). In tropical soils, organic matter supplies most of the soil nitrogen, phosphorus and sulphur (Asiamah et al., 2001). Also, vegetation plays a major role in the process of erosion control on gullied areas, landslides, sand dunes, construction sites, road embankments, mine-spoils and pipe line corridors (Morgan, 2005).

It is against this background that this study, therefore sought to review literature on how revegetation

Figure 1. Degraded land left bare as a result of gold mining activity in Prestea, one of the small towns in Western Region of Ghana. Source: Mensah (2014).

Figure 2. Justice reclaimed refilled pit revegetated with *Senna siamea,* AngloGold Ashanti, Obuasi, Ghana. Age of plantation is 10 years. Source: Said (2009).

contributes to soil fertility improvement of the degraded mined soils. The study reviews data and published information concerning mining, their degradation processes on soil properties and the revegetation methods employed for rehabilitation.

LITERATURE REVIEW

Impacts of mining on soil physical, chemical properties and biological properties

The mining disrupts the aesthetics of the landscape and along with it disrupts soil components such as soil horizons and structure, soil microbial populations, and nutrient cycles of those are crucial for sustaining a healthy ecosystem and hence results in the destruction of existing vegetation and soil profile (Kundu and Ghose, 1997). The overburden dumps include adverse factors such as elevated bioavailability of metals; elevated sand content; lack of moisture; increased compaction; and relatively low organic matter content. Acidic dumps may release salt or contain sulphidic material, which can generate acid-mine drainage (Ghose, 2005). The effects of mine wastes can be multiple, such as soil erosion, air and water pollution, toxicity, geo-environmental disasters, loss of biodiversity, and ultimately loss of economic wealth (Wong, 2003; Sheoran et al., 2008).

Stripping operations at many open-cut coal mines in central Queensland, Australia resulted in spoil (waste rock) materials of tertiary origin being deposited on the surface (Grigg et al., 2006). Deeply weathered tertiary sediments can be highly sodic and moderately to extremely saline (Gunn, 1967), forming surface seals that limit infiltration and reduce plant available water. Following drying, they often form strong crusts that impede seedling emergence. These materials are also deficient in many nutrients, particularly nitrogen and phosphorus (Grigg et al., 2006).

Regardless of the overburden type used, plant available N and P tend to be low on mine soils, which may limit tree growth (Howard et al., 1988). Consequently, fertilization at some point during the rotation is usually needed to obtain rapid growth of trees planted on reclaimed mine sites (Koe et al., 1999). The top-soil is seriously damaged during mineral extraction. The consequences of physical disturbance to the topsoil during stripping, stockpiling and reinstatement, cause unusually large nitrogen transformations and movements with eventually substantial loss (Sheoran et al., 2010).

Loss of organic matter is characteristic for contaminated soils (Viventsova et al., 2005), as toxic levels of metals hinder soil biological activity, vegetation development and generation of OM. According to Stark (1977) and Dutta and Agrawal (2002), low level of organic carbon in mine spoil might be due to the disruption of ecosystem functioning, depletion of soil organic pool and also due to the loss of litter layer during mining which is an integral storage and exchange site for nutrients.

Impacts of mining on soil chemical properties

Soil pH

Soil pH is a measure of active soil acidity and is the most commonly used indicator of mine soil quality. The pH of a given mine soil can change rapidly as the rock fragments weather and oxidize. Pyritic minerals (FeS_2), when present, oxidized to sulfuric acid and drastically lower the pH, while carbonate ($Ca/MgCO_3$) bearing minerals and rocks tend to increase the pH as they weather and dissolve. Un-weathered (or un-oxidized) mine soils that contain a significant amount of pyritic-S in excess of their neutralizers (carbonates) will rapidly drop the pH to a range of 2.2-3.5 after exposure to water and oxygen. When the soil pH drops below 5.5, reduced legume and forage growth occur due to metal toxicities such as aluminum or manganese, phosphorus fixation, and reduced population of N-fixing bacteria. This growth hence inhibits plant root growth and many other metabolic processes. Vegetation achieves optimal growth in soils at neutral pH. A mine soil pH range in the range of 6.0 to 7.5 is ideal for forages and other agronomic or horticultural uses (Gitt and Dollhopf, 1991; Gould et al., 1996). Maiti and Ghose (2005) reported that the pH vary from 4.9 to 5.3 in a mining dump site situated in Central Coalfield Limited's (CCL), North Karanpura area, in the Ranchi district of Jharkhand State of India and thus indicated the acidic nature of the dumps. This acidic nature arose due to the geology of the rock presented in the area. It has been reported earlier that at pH less than 5, along with Fe, the bioavailability of toxic metal such as nickel, lead and cadmium also increases (Maiti, 2003).

Soil fertility

The three macronutrients with major importance for plants, namely nitrogen, phosphorus and potassium are generally found to be deficient in overburden dumps (Coppin and Bradshaw, 1982; Sheoran et al., 2008). All newly created mine soils, and many older ones, will require significant fertilizer element applications for the establishment and maintenance of any plant community. Organic matter is the major source of nutrients such as, available P and K in unfertilized soils (Donahue et al., 1990). A level of organic carbon greater than 0.75% indicates good fertility (Ghosh et al., 1983). The level of organic carbon in overburden was found to be 0.35 to 0.85%. Organic carbon is positively correlated with available N and K and negatively correlated with Fe, Mn, Cu and Zn (Maiti and Ghose, 2005).

Some of the important metallic micronutrients that are essential for plant growth are Fe, Mn, Cu and Zn. These micronutrients are available in the soil due to continuous weathering of minerals mixed with primary minerals. These metals are more soluble in acidic solution, and they dissolve to form toxic concentrations that may actually hinder plant growth (Donahue et al., 1990; Barcelo and Poshenrieder, 2003; Das and Maiti, 2006).

Impacts of mining on soil physical properties

Rock content

Soil particles, those smaller than 2 mm are responsible for majority of water and nutrient holding capacity in the mine soils. Particles larger than 2 mm are referred to as "coarse fragments". Soils constituting high coarse fragments have larger pores that cannot hold enough plant available water against leaching to sustain vigorous growth over the summer months. The coarse fragment contents in a typical mine spoil that vary (< 30- >70 %) due to differences in rock hardness, blasting techniques and spoil handling (Sheoran et al., 2010).

Particle size distribution of mine soils is directly inherited from their parent rocks or spoils. The rock content in the surface of a reclaimed bench or out slopes will decrease overtime due to weathering of rock fragments to soil sized particles. Top soil materials, when they can be salvaged, are typically present in much lower quantity in rock content than spoils and therefore have better water retention characteristics (Nicolau, 2002; Moreno-de las Heras et al., 2008). Hu et al. (1992) are of the opinion that soil with stone content greater than 50% should be rated as poor quality. Stone content of coal mine overburden dumps has been reported to be as high as 80-85% (Maiti and Saxena, 1998). Maiti and Ghose (2005) reported stone content in overburden dumps in range of 35-65%, with an average value of 55%.

Soil texture

Relative amount of sand (2.0 - 0.05 mm), silt (0.05- 0.002 mm), and clay (< 0.002 mm) sized particles determine the texture of soil (Sheoran et al., 2010). Mine soils with sandy textures cannot hold as much water or nutrients as finer textured soils like loams and silts. The silts are finer textured soils and have a tendency to form surface crusts, often contain high level of soluble salts, and have a poor "tilth" or consistence. The particle size distribution of the soils with loamy textures is generally ideal. Silt loam textures are common where spoils are dominated by siltstones (Ghose, 2005). Ghose (2005) reported the maximum sand content of 66% and clay only 8.6% in mined soil. Singh et al. (2004) and Singh (2006) also reported maximum content of sand (80 %) and least content of clay (11%) at the Singrauli Coal field in India. Low clay content means low cation exchange capacity of the soil. If the cation exchange capacity is high, then relatively larger doses of nutrients can be applied to the soil at one time and can retain sufficient moisture for plant growth than if the cation exchange capacity is low because applied nutrients will not be easily leached down in the former case in contrast with the latter case when the applied nutrients will easily be leached down (Kolay, 2000).

Soil aggregation

Soil aggregation controls soil hydrology, affects soil diffusion and the degree of nutrient availability into the soil (Lindemann et al., 1984; Heras, 2009), and may reduce erosion potential (Elkins et al., 1984), and constitutes a pathway of organic carbon stabilization and long term sequestration (Six et al., 2004). Aggregate structure breaks down as successive layers of soil are removed and stockpiled elsewhere on the site when mining begins. The resulting compaction reduces water holding capacity and aeration. Macro aggregate stability is largely responsible for macro porosity, which determines soil drainage rate and aeration; it changes seasonally and is often affected by cultivation and other landuse activities such as that of mineral mining. Micro-aggregate stability is more resilient than macro aggregate stability as the organic matters responsible for binding the soil particles together reside in pores too small for microorganisms to occupy (Gregorich et al., 1989). Micro-aggregates are less sensitive to cropping practices than macro-aggregates (Dexter, 1988) and are responsible for crumb porosity which controls the amount of available water for vegetation (Davies and Younger, 1994).

Moisture, bulk density, compaction and available rooting depth

Moisture content in a dump is a fluctuating parameter which is influenced by the time of sampling, height of dump, stone content, amount of organic carbon, and the texture and thickness of litter layers on the dump surface (Donahue et al., 1990). During the winter, the average moisture content of 5% was found to be sufficient for the plant growth. During high summer (May-June), moisture content in overburden dumps was reported to be as low as 2-3% (Maiti et al., 2002). Again, Maiti and Ghose (2005) reported average field moisture content of the entire dumps was 5% in a mining dump site situated in Central Coalfield Limited's (CCL), North Karanpura area, in the Ranchi district of Jharkhand State of India.

Bulk density of productive natural soils generally ranges from 1.1 to 1.5 gcm^{-3}. High bulk density limits rooting depth in mine soils. In seven year old overburden dumps, the bulk density was found to be as high as 1.91 Mgm^{-3} (Maiti and Ghose, 2005). Bulk density in the soil under a grass sward in the United Kingdom has been found to be as high as 1.8 Mgm^{-3} (Rimmer and Younger, 1997). Soil compaction directly limits plant growth, as most species are unable to extend roots effectively through high bulk-density mined soils (Sheoran et al., 2010).

Severely compacted (bulk density >1.7 g/cc) mine soils, particularly those with less than two feet of effective rooting depth, shallow intact bedrock and the presence of large boulders in the soil simply cannot hold enough plant-available water to sustain vigorous plant communities through protracted drought. Three to four feet of loose non-compacted soil material is required to hold enough water to sustain plants through prolonged droughts. Compacted zones may also perch water tables during wet weather conditions, causing saturation and anaerobic conditions within the rooting zone. Repeated traffic of wheeled mining machineries (loaders and haulers), and bulldozers to a lesser extent, form compacted zones in the mining dumps (Sheoran et al., 2010).

Slope, topography and stability

Rehabilitated mine soils with slopes greater than 15% are generally unsuitable for intensive land uses such as vegetable or crop production, but they may be suitable for grazing and reforestation. Broad flat benches and fills with slopes less than 2% often have seasonal wetness problems. Many benches with an overall gentle slope contain areas of extreme rockiness, pits, hummocks and ditches.

Average slope of most reclaimed modern mines is quite a bit steeper than the older benches, but the newer landforms are considerably smoother and more uniform in final grade. Bench areas directly above intact bedrock on older mined lands are usually fairly stable but maybe subject to slumping, especially when near the edge of the out slope.

Tension cracks running roughly parallel to the out slope indicate that the area is unstable and likely to slump (Sheoran et al., 2010). Decreased soil stability can lead to increase in bulk density because the matrix does not resist slaking, dispersion by water and the forces imparted by wheels, hooves and rainfall (Daniels, 1999). This, in turn, leads to decreased aeration and water infiltration rate and the development of anaerobic conditions. Nitrogen losses by denitrification may follow under such environment (Davies and Younger, 1994).

Mine spoil/soil color

Mining activities remove surface earth, piling it over unmined land and forming chains of external dumps (mine spoil/wasteland). Mine spoils possess very rigorous conditions for both plants and the microorganism culture. Biological functionality along with the nutrient cycle is disturbed leading to a non-functional soil system. This is mainly due to low organic matter contents and other unfavorable physico-chemical and microbiological characteristics (Singh and Singh, 1999, 2006; Jha and Singh, 1993). The color of a mine spoils or weathered mine soil can tell us much about its weathering history, chemical properties and physical make up. Bright red and brown colors in spoils and soils generally indicate that the material has been oxidized and leached to some degree. These materials tend to be lower in pH and free salts, less fertile, low in pyrites and more susceptible to physical weathering than darker colored materials. Gray colors in rocks, spoils and soils usually indicate a lack of oxidation and leaching and these materials tend to be higher in pH and fertility. Very dark gray and black rocks, spoils, and mine soils contain significant amounts of organic materials and are often quite acidic (Sheoran et al., 2010).

Dark colored spoils are difficult to revegetate during the summer months because they absorb a great deal of solar energy and become quite hot (Daniels, 1999). Evidence has indicated that the unassisted process of natural colonization of this spoil, like many others, can be very powerful and deliver fully developed and functional ecosystems within 100 years (Prach and Pysek, 2001; Bradshaw, 1997; Sheoran et al., 2010). The restoration of mine wasteland often therefore, requires active human intervention (what is called assisted regeneration) if the restoration goal is expected to achieve rehabilitation within a reasonable timeframe (Gathuru, 2011).

Top soil

The top soil has an important role, particularly in the establishment of native species (Amegbey, 2001). Top soil is used to cover poor substrate and to provide improved growth conditions for plants (Sheoran et al., 2010). Stockpiling of top soil in mounds during mineral extraction has been shown to affect the biological, chemical and physical properties of soil (Hunter and Currie, 1956; Barkworth and Bateson, 1964; Harris et al., 1989; Johnson et al., 1991; Davies et al., 1995). According to Amegbey (2001), stockpiling reduces the quality of the soil resources. Also, stockpiles become anaerobic, other plant propagules die and populations of beneficial soil micro-organisms are reduced significantly. For example, fresh soil contained about five to ten times as many seeds as soil stockpiled for three years at sand mine at Eneabba in western Australia (Amegbey, 2001). Top soil is a scarce commodity, and it is never stored in the majority of potential sources (Sheoran et al., 2010). Also, in a tropical climate where 90% of rainfall is precipitated within three months of the rainy season, storing of the top soil and preservation of soil quality remains problematic. Top soil is never stored for reuse; instead it is borrowed from nearby areas for the reclamation of the degraded mined-out areas (Sheoran et al., 2010). At a depth about 1 m in the stockpile, the number of anaerobic bacteria increases whereas those of aerobic bacteria decrease (Harris et al., 1989). This inhibits nitrification due to poor aeration within the stockpile leading to an accumulation of ammonia in the anaerobic zones. Once the soil is removed from the stockpile and reinstated, aerobic microbial population rapidly reestablishes, usually higher than the normal level (Williamson and Johnson, 1991) and nitrification restarts at higher than the normal rates(Sheoran et al., 2010). If high level of ammonia is present in a reinstated soil, the amount of nitrate generated is likely to be much greater than the normal. Consequently there is high potential for nitrogen loss to the environment via leaching and/or denitrification (Johnson and Williamson, 1994). Nitrate leached to water courses is not only a threat to aquatic environment and drinking water supplies (Addiscott et al., 1991) but if nitrogen is lost from soil in the form of gaseous nitrogen or nitrous oxides; this will contribute to the degradation of ozone layer (Isermann, 1994; Davies et al., 1995).

The period between the initial removal of top soil and the final laying of the same soil over the reclaimed area might have a long time elapsed. Hence, properties of stockpiled soil continually deteriorate and ultimately become biologically non-productive if it is not preserved properly (Ghose, 2005). Whenever possible, the topsoil should be replaced on an area where the landform reconstruction is complete (a phenomenon known as “direct return”) (Amegbey, 2001). Direct return has several advantages when compared with placing the topsoil in stockpiles and storing it then later used for rehabilitation. First, it avoids double handling. Second, the need to create stockpiles may mean that extra land must be cleared. Third, and most importantly, stockpiling reduces the quality of soil resources (Amegbey, 2001). Other researchers have shown that both the density and numbers of species of native plants are significantly decreased when an area is rehabilitated with stockpiled rather than direct-returned topsoil.

If the topsoil must be stockpiled then it should be for as short a time as possible and the stockpiles should be as low as possible with a large surface area 2 m high or less; the stockpiles should be revegetated to protect the soil from erosion, discourage weeds and maintain active populations of beneficial soil microbes; the stockpiles should be located where they will not be disturbed by future mining, as excessive handling will adversely affect soil structure (Amegbey, 2001).

Impacts of mining on soil biological properties

Soil microbe

Soil microbe populations must be addressed deliberately as another soil component. It plays a major role in aggregate stabilization, which is important for maintaining suitable structural conditions for cultivation and porosity for crop growth (Ghose, 2005). Their activity declines when soil layers are disrupted and is slow to resume independently. Soil microbes include several bacterial species active in decomposition of plant material as well as fungal species whose symbiotic relationship with many plants facilitates uptake of nitrogen and phosphorus in exchange of carbon. They produce polysaccharides that improve soil aggregation and positively affect plant growth (Williamson and Johnson, 1991). Sites with an active soil microbe community exhibit stable soil aggregation, whereas sites with decreased microbial activity have compacted soil and poor aggregation (Edgerton et al., 1995). Microbial activity decreases with depth and time as topsoil continues to be stored during mining operations (Harris et al., 1989). Microbial activity, measured in adenosine tri phosphatase (ATP) concentrations, plummets to very low levels within a few months. Response to glucose is slower by microbes at all depths, suggesting that metabolic rates decrease with time (Visser et al., 1984).

Bacteria

Bacteria play an important role in decomposition of organic materials, especially in the early stages of decomposition when moisture levels are high. In the later stages of decomposition, fungi tend to dominate. Rhizobia are single celled bacteria, belongs to family of bacteria *Rhizobiacea*, form a mutually beneficial association, or symbiosis with legume plants. These bacteria take nitrogen from air (which plant cannot use) and convert it into a form of nitrogen called ammonia ($NH4^+$) used by plants (Gil-Sotres et al., 2005).

Free living as well as symbiotic plant growth promoting rhizo-bacteria can enhance plant growth directly by providing bio-available P for plant uptake, fixing N for plant use, sequestering trace elements like iron for plants by siderophores, producing plant hormone like auxins, cytokinins and gibberilins, and lowering of plant ethylene levels (Glick et al., 1999; Khan, 2005).

When soil layers are removed and stockpiled, the bacteria inhabiting the original upper layers end up on the bottom of the pile under compacted soil. A flush of activity occurs in the new upper layer during the first year as bacteria are exposed to atmospheric oxygen. After two years of storage there is little change in the bacterial numbers at the surface, but less than one half the initial populations persist at depths below 50 cm (Williamson and Johnson, 1991).

Mycorrhizal fungi

Arbuscular mycorrhiza (AM) fungi are ubiquitous soil microbe occurring in almost all habitats and climates. The hyphae network established by mycorrhizal fungi breaks when soils are initially moved and stockpiled (Gould et al., 1996). It is well documented that mycorrhizal associations are essential for survival and growth of plants and plant uptake of nutrient such as phosphorus and nitrogen, especially phosphorus deficient derelict soils (Khan, 2005).

An important *Arbuscular mycorrhiza* genus is *Glomus*, which colonize a variety of host species, including sunflower (Marschner, 1995). Dual inoculation with *Trichoderma koningii* and AM fungi increased plant growth of *Eucalyptus globulus* under heavy metal contamination conditions (Arriagada et al., 2004, 2005).

There is a little decrease in viable mycorrhizal inoculum potential during the first two years of storage (Miller et al., 1985). Viability of mycorrhiza in stored soils decreases considerably and possibly to the levels 1/10 those of the undisturbed soil (Rives et al., 1980). Miller et al. (1985) indicate that soil water potential is a significant factor affecting mycorrhizal viability. When soil water potential is less than -2 MPa (drier soil), mycorrhizal propagules can survive for greater lengths of storage time; when soil water potential is greater than -2 MPa, length of storage time becomes more important. In drier climates, deep stockpiles may not threaten mycorrhizal propagule survival. In wetter climates, shallow stockpiles are more important to maximize surface-to-volume ratios with regard to moisture evaporation (Sheoran et al., 2010).

REHABILITATION OF MINED SITES/SOILS

Rehabilitation is the process by which the impacts of mining on the environment are repaired. It is an essential part of developing mineral resources in accordance with the principles of sustainable development (Amegbey, 2001).

Rehabilitation normally comprises two stages: land form design and the reconstruction of a stable land surface; and revegetation or development of an alternative land use on the reconstructed land form (Amegbey, 2001). This paper, however, concentrates on the revegetation stage of rehabilitation and its influence on the soil fertility status.

Revegetation of mined lands

The traditional way of restoring damaged soils is by long rotation forest fallowing (Blum, 1988). Soil provides the foundation for this process, so its composition and density directly affect the future stability of the restored plant community (Sheoran et al., 2010). Reclamation strategies must address soil structure, soil fertility, microbe populations, top soil management and nutrient cycling in order to return the land as closely as possible to its pristine condition and continue as a self-sustaining ecosystem (Sheoran et al., 2010). Reclamation and revegetation of abandoned mined lands are often limited by physical and chemical properties existing in the soil, including (but not limited to) low pH, high metal levels (including metal salts), low nutrient levels and poor or no soil structure (Said, 2009).

Soil structure and functions are degraded or lost during mining activities, which often result in soil toxicity, low nutrient availability and poor soil texture. Soil structure and function, although only a part of an entire ecosystem, are microcosm of the entire ecosystem. If these factors are not remediated, vegetation re-establishment and restoring ecosystem function will be difficult or impossible (Bradshaw, 1997).

Studies and analyses of biological and physiological characteristics of regenerated trees or newly planted trees and of the processes influencing productivity in such areas are necessary in order to improve the success of rehabilitation and reforestation activities (Kobayashi, 2004). Saline-sodic clay mine spoil materials excavated during open-cut coal mining in central Queensland, Australia, pose significant challenges for revegetation, particularly where suitable topsoil capping is not available (Grigg et al., 2006). While mulches lead to improved spoil moisture conditions in the laboratory, successful revegetation in the field also requires the removal of salts from the root zone (Grigg et al., 2006). High salinity constitutes a major limitation for plant establishment, reducing the level of seedling emergence by slowing germination (Bewley and Black, 1978) and thus increasing the time that the growth media must remain moist (Harwood, 1998). It also retards plant growth through osmotic stress, compounding the problem of a limited moisture supply from rainfall (Grigg et al., 2006).

Management of top soil is important for reclamation plan to reduce the N losses and to increase soil nutrients and microbes. Revegetation constitutes the most widely accepted and useful way to reduce erosion and protect soils against degradation during reclamation (Sheoran et al., 2010). Ecological restoration and mine reclamation have become important parts of the sustainable development strategy in many countries. Good planning and environmental management will minimize the impacts of mining on the environment and will help in preserving eco-diversity (Sheoran et al., 2010).

When attempting to restore a native ecosystem, the initial revegetation effort is unlikely to produce vegetation identical to the original. The initial revegetation effort must establish the building blocks for a self-sustaining system, so that successional processes lead to the desired vegetation complex (Amegbey, 2001; Sheoran et al., 2010).

The best time to establish vegetation is determined by the seasonal distribution and reliability of rainfall. All the preparatory works must be completed before the time when seeds are most likely to experience the conditions they need to germinate and survive (that is, reliable rainfall and suitable temperatures) (Amegbey, 2001; Sheoran et al., 2010).

According to Coppin et al. (2000), revegetation is defined as the process of vegetation establishment and aftercare undertaken as part of reclamation, rehabilitation or restoration. Surface mines, for instance, can be filled and the ground recontoured and planted to establish a suitable vegetative cover that protects the soil (Owen et al., 1998). Mine restoration efforts have focused on N-fixing species of legumes, grasses, herbs and trees. Metal tolerant plants can be effective for acidic and heavy metals bearing soils (Sheoran et al., 2010). Restoration of vegetation cover on overburden dumps can fulfill the objectives of stabilization, pollution control, visual improvement and removal of threats to human beings (Wong, 2003).

Recent studies suggest that phytoextraction (remediation using green plants) is a viable method of cleaning large areas of soil and that it may be an effective alternative to current soil cleanup methods (Blaylock et al., 1997; Huang et al., 1997; Watanabe, 1997; Ensley, 2000; Van der Lelie et al., 2001).

Vegetation has an important role in protecting the soil surface from erosion and allowing accumulation of fine particles (Tordoff et al., 2000; Conesa et al., 2007b). They can reverse degradation process by stabilizing soils through development of extensive root systems. Once they are established, plants increase soil organic matter, lower soil bulk density, and moderate soil pH and bring mineral nutrients to the surface and accumulate them in available form. Their root systems allow them to act as scavengers of nutrients not readily available. The plants accumulate these nutrients and redeposit them on the soil surface in organic matter from which nutrients are much more readily available by microbial breakdown (Li, 2006; Conesa et al., 2007a; Mendez and Maier, 2008a).

Methods used to revegetate mined lands

According to Williams and Bellitto (1998), revegetation work can generally be categorized into one of three basic approaches: agricultural; ameliorative; or adaptive approach. Most modern revegetation projects, and especially more difficult ones, utilize a combination of the ameliorative and adaptive approaches.

Agricultural approach

Williams and Bellitto (1998) explained that the agriculture approach, although somewhat outdated, has been used most often for revegetation in the past and is still the approach dictated by the Surface Mining Control and Reclamation Act of 1977 (SMCRA) regulations for coal mining projects. This approach utilizes the standard methods in the U.S.A of replacing the topsoil, fertilizing, and planting typical reclamation species to revegetate disturbed lands. Unfortunately, topsoil was not routinely salvaged during most historic mining activities and is not always available for use. Since the soils in the area surrounding most mine sites are naturally mineralized, importing suitable soils typically requires long, uneconomic haul distances. Therefore, the ameliorative and adaptive approaches, which directly revegetate mined lands without topsoil, are often desirable.

Although developed and used in Europe since the 1960s, it is believed that the first successful utilization of these approaches on the North America continent was at California Gulch Superfund site located near Leadville, Colorado in 1992. The approach used for the revegetation of this site was documented in the May/June 1996 issue of land and water magazine.

One of the cases of the practical application of the agricultural approach was the reclamation strategy employed by the AngloGold Ashanti Company limited at Obuasi in Ghana, to reclaim some of their mined lands (Appendix 1 and figure 4).

Ameliorative approach

Williams and Bellitto (1998) also indicated that the ameliorative approach involves chemically altering the soils to correct whatever problems are encountered. The approach can be used to raise the pH, and lower the solubility and availability of heavy metals to plants. In addition, the ameliorative approach can be used to stop further acid generation potential, and total and leachable metal concentrations. Standard agricultural analyses are also typically run on the soils. Based on this information, a site specific combination and rate of low cost waste materials and standard reclamation amendments, such as organic matter, lime and phosphate fertilizers, are specified to accomplish the required chemical reactions in the soil. Major nutrients identified as lacking in the soil can also be specified and included in the amelioration mixture.

Experience has shown that without some form of amendment, the spoils pose severe problems for vegetation establishment and growth (Bell et al., 1991; Philip, 1992; Harwood et al., 1999), even after 8 to 10 years of exposure at the surface (Banks, 1990; Grigg and Catchpoole, 1999). Grigg et al. (2006) examined the ability of sawdust or straw mulch amendments to ameliorate the adverse properties of these mine spoils and improve the success of revegetation efforts. In laboratory studies, mulch application improved infiltration, increased soil moisture retention and reduced surface crust strength. In the field, mulches incorporated to a depth of 0.15 m at application rates of at least 20 t/ha straw or 80 t/ha sawdust were needed to mitigate against capillary rise of salts during drying cycles and support satisfactory vegetation cover.

Application of salvaged topsoil to a depth of 0.3 m appears to offer a successful solution for revegetation of these materials (Grigg and Catchpoole, 1999). However, reserves of suitable topsoil material may not always be available, therefore alternative amendments are needed.

In the laboratory, gypsum addition can decrease dispersion, improve hydraulic conductivity, and reduce crust strength with drying (Bell et al., 1992), but improvements in vegetation establishment and growth with gypsum application in the field have not been demonstrated (Emmerton, 1984; Philp, 1992). Philp (1992) found that addition of gypsum increased the electrical conductivity of the treated material, thereby exacerbating the problems of high salinity for plant growth and survival.

In contrast, organic mulch amend-ments can improve revegetation success on saline-sodic bentonite spoils (Smith et al., 1985; Belden et al., 1990) and Philp (1992) reported encouraging preliminary plant establishment results using a straw mulch treatment. Organic mulches may therefore, provide a successful alternative amendment for the revegetation of saline-sodic spoils in central Queensland (Grigg et al., 2006).

A field trial was established on an out-of-pit dump at the Goonyella Riverside open cut coal mine in central Queensland, Australia by Grigg et al. (2006). They found out that typical physical and chemical characteristics of the spoil depict that clay content is relatively high, and the clay types are reactive in the presence of sodium, which, together with magnesium, dominates the soil exchange capacity, salinity is very high due to abundant chloride, organic matter content is low, as are the levels of major plant nutrients.

The spoil, therefore, presents an extremely hostile environment for plant establishment and survival. In the absence of amendment, natural plant colonization is sparse and dominated by salt-tolerant species (Carroll et al., 2000). Productivity of soil can be increased by adding various natural amendments such as saw dust, wood residues, sewage sludge, animal manures, as these amendments stimulate the microbial activity which provides the nutrients (N, P) and organic carbon to the soil (Sheoran et al., 2010).

Adaptive approach

Williams and Bellitto (1998) further explained that the adaptive approach involves identifying, specifying and establishing plants which are ecotypically differentiated, or adapted and tolerant of the site conditions. An *in vitro* plant tolerance testing method can be used to rapidly and cost-effectively screen a large number of plants for their tolerance to the specific conditions found at the site. This method involves utilizing tissue culture techniques and growth media adjusted chemically to emulate the specific site conditions. A plant's germination and initial root growth response are indicative of its response to actual site conditions. Varieties of some of these particular species were previously unknown to be tolerant of these typical site conditions.

In addition to low pH, high metal concentrations, and the often erodible nature of the soils, reclamation at historic mine sites is often further complicated by steep slopes and severe exposure problems related to mountainous area and high altitude. The combination of poor soil physical and chemical conditions and severe exposure difficulties can make natural recovery impossible and human rehabilitation very difficult in disturbed areas. Disturbed areas which have remained barren since their initial disturbance over 100 years ago are common. Previous attempts to revegetate these areas have often produced results which were less than acceptable to the concerned parties (Williams and Bellitto, 1998).

Other practical example of the use of adaptive approach to land revegetation could be made of the reclamation efforts at Haller Park at Bamburi Cement Mines in Mombasa, Kenya. Land reclamation started in 1971, by initially planting 26 tree species in open quarries. After six months, only three species survived. These were *Casuarina equisetifolia* sp., *Conocarpus lancifolius* sp. and coconut palm. *Casuarina* sp. was identified as a better pioneer because it could tolerate saline water despite being adapted to dry conditions; it can fix atmospheric nitrogen in the root system; it is an evergreen tree which constantly drops and renews foliage; and it grows fast, reaching 2 m in six months. The *Casuarina* tree or 'Whistling Pine', *C. equisetifolia* originated from Australia, but is now a common tree along the East African coast.

Casuarina trees have leaves with high tannin content. This makes their decomposition by micro-organisms difficult. In order to contain the problem, millipede (*Epibolus pulchripes*) was introduced, which was able to digest the Casuarina needle leaves and create the desired humus for the system. For more than 20 years, humus has been created partly in this way. As a result of the re-vegetation, insects and other life forms colonized the initial two square kilometers area which was under rehabilitation. By 1989, systematic introduction of indigenous coastal vegetation began.

By the year 2000, more than 300 indigenous plant species had been introduced, 30 species of mammals and 180 species of birds had found a home in the park. Some of the animals were introduced as 'orphans';

Figure 3. Revegetation of a residue from bauxite mining with nodulating and non-nodulating legume species, 3 months after transplanting the seedlings to the field, Amazon, Southeast Brazil. Franco et al. (1995).

others took refuge while some were deliberately introduced (Siachoono, 2010).

Species used in revegetation and their impacts

Revegetation of mine spoils requires designing a plant succession which will give adequate surface cover and increase the fertility of the soil (Morgan, 2005). Ideally, the succession should include rapid growing grasses to give ground cover as quickly as possible and stabilize the surface; legumes, to fix nitrogen; and other grasses and shrubs to provide a long term cover (Morgan 2005). Also, nodulating and non-nodulating legume species can be considered in the revegetation process (Figure 3).

Use of trees

Sometimes trees are considered in restoring degraded mined soils. Besides, trees have also been found to improve the soil fertility (Assel, 2006). Frequently, spoil bank areas are planted with trees in order to provide an income and also to remove the unsightly banks from view (Kohnke and Bertrand, 1959).

Dutta and Agrawal (2002) carried out a study on the effect of tree plantations on the soil characteristics and microbial activity of coalmine spoil land and realized that higher values of total N in comparison with fresh mine is due to the organic matter accumulation in soil by roots and leaching of N from the herbaceous vegetation of the plots. They also indicated that, during rainy season, the dead microbial population provides additional substrate, which further stimulates mineralization. Higher values of mineral N during rainy season may be due to easily decomposable substrate such as glucose, sucrose, amino acids and amides (Birch, 1958, Dutta and Agrawal, 2002). Decrease in N mineralization in winter and summer may be explained as increased microbial biomass which immobilizes the nutrients and build up their biomass in dry periods (Singh et al., 1989; Dutta and Agrawal, 2002).

Reclamation forestry, the afforestation of eroded or otherwise degraded land, has demonstrated the power of trees to build up soil fertility (Young, 1989). He also adds that the practice of shifting cultivation provides a demonstration of the capacity of forest to restore fertility lost during cultivation, for example.

Trees are very efficient biomass generators adding more organic matter to the soil, both above and below

Figure 4. Dokyiwa waste dump revegetated with mixed stand of *Acacia mangium* and *Senna Siamea*, AngloGold Ashanti mines, Obuasi, Ghana. Age of plantation is 10 years. Source: Said (2009).

ground, than other plants. Their deep roots involve a greater depth of the raw mine stones than grass and, with a little encouragement, penetrate to the less compacted spoil layers beneath the “cap” of trapped clays (Blum, 1988). Root depth is typically 50 cm for herbaceous species or 3 m for trees, although certain *phreatophytes* that tap into groundwater which have been reported to reach depths of 15 m or more, especially in arid climates (Negri, 2003).

Trees can potentially improve soils through numerous processes, including - maintenance or increase of soil organic matter, biological nitrogen fixation, uptake of nutrients from below and reach roots of under storey herbaceous vegetation, increase water infiltration and storage, reduce loss of nutrients by erosion and leaching, improve soil physical properties, reduce soil acidity and improve physical properties, reduce soil acidity and improve soil biological activity. Also, new self-sustaining top soils are created by trees. Plant litter and root exudates provide nutrient-cycling to soil (Pulford and Watson, 2003; Coates, 2005; Padmavathiamma and Li, 2007; Mertens *et al*., 2007).

Furthermore, rehabilitating mine spoils with trees may help reduce the tendency for compaction. If this new soils drain more easily, less water remain at the soil surface and possibility of soil erosion is reduced (Blume, 1988). Also, there is a plausible hypothesis that trees in general are more efficient than herbaceous plant in taking up nutrients released by weathering. Potassium, phosphorus, bases and micro nutrients are released by rock weathering particularly in the B/C and C soil horizons into which tree roots often penetrate (Young, 1989).

Grasses are considered as pioneer crops for an early vegetation purpose. Grasses have both positive and negative effects on mine lands. They are frequently needed to stabilize soils but they may compete with woody regeneration. Grasses, particularly C4 ones, can offer superior tolerance to drought, low soil nutrients and other climatic stresses. Roots of grasses are fibrous that can slow soil erosion and their soil forming tendencies eventually produce a layer of organic soil, stabilize soil, conserve soil moisture and may compete with weedy species. The initial cover must allow the development of diverse self-sustaining plant communities (Shu et al., 2002; Singh et al., 2002; Hao et al., 2004).

Mixed species

Generally, a mix of plant species is required because it is impossible to predict the success of any one species in marginal environments where the vegetation is going to receive little or no maintenance (Morgan, 2005). Monocultures are disadvantaged due to the vulnerability to pests and diseases, they do not satisfy fully the multiple use and conservation roles, do not provide a balanced ecosystem and also they fail in providing more balance stable system in the face of environmental variability and directional change than mixed cultures. Mixed forestry systems, on the other hand, might be more stable as they sequester carbon more securely in the long term. In short, mixed systems could offer more to mitigating climate change than monocultures.

The species mix should include grasses, forbs and woody species, both bushes and trees, except where specific requirements make such a mix undesirable, as with some types of gully reclamation or along pipe line corridors (Morgan, 2005). For instance, evidence and induction, according to Young (1989), therefore suggest that for erosion control, the direct effects of the tree canopy in providing cover and reducing soil loss are less than those of ground cover/cover crops. Thus, the direct prevention of soil erosion, for example, is most effectively achieved by a cover of surface litter, consisting of crop residues, tree pruning or both.

For example, Liao et al. (2000) had reported that through 10-year observation, the total litter production of mixed plantation of *Cunninghamia lanceolata* and *Michelia macclurei* in the proportion of 1:1 was 43% higher than that of pure *C. lanceolata* plantation. Parrotta (1999) also observed that litter production was generally higher in mixed plantations than in mono-specific *Eucalyptus* plantations in Puerto Rico. Zhang et al. (1993) had also found that the annual litter amount of 55-year old *Pinus massoniana* and *M. macclurei* mixed forest was 11.2% higher than that of a similar-aged *P. massoniana* stand. Species composition is important for litter production within the same climate range (Sundarapandian and Swamy, 1999; Yang et al., 2004). Kelty (2006) also reviewed the role of species mixtures in plantation productivity. However, the effects of broadleaved trees in mixed plantations on amount and pattern of litter fall are not clearly understood.

Nutrient return through litter plays an important role in maintaining soil fertility and primary productivity of forest ecosystems. Wang et al. (1997) found that the amount of nutrient return via leaf litter to forest floor in the mixed plantation of *C. lanceolata* and *M. macclurei* was two and three times as much as that in the pure *C. lanceolata* plantation.

The results of Forrester et al. (2005) also demonstrated that mixing *Acacia mearnsii* with *Eucalyptus globules* increased the quantity and rates of N and P cycled through aboveground litter fall when compared with *E. globules* monocultures. Other researchers have also found quantities of N and P cycled through litter fall were higher in mixtures of N-fixing trees and non-N-fixing trees than monocultures of the non-N-fixing species (Binkley, 1992; Binkley et al., 1992; Binkley and Ryan, 1998; Parrotta, 1999).

Indigenous/native/local species versus exotic/ introduced/foreign species

Role of exotic or native species in reclamation needs careful consideration as newly introduced exotic species may become pests in other situations. Therefore, candidate species for vegetation should be screened carefully to avoid becoming problematic weeds in relation to local to regional floristic. For artificial introduction, selection of species that are well adapted to the local environment should be emphasized. Indigenous species are preferable to exotics because they are most likely to fit into fully functional ecosystem and are climatically adapted (Li et al., 2003; Chaney et al., 2007).

Wherever possible, native species should be chosen. A study of the neighboring sites often gives a good indication of what species are most likely to survive and thrive (Morgan, 2005). Singh et al. (2002) also reported that native leguminous species show greater improvement in soil fertility parameters in comparison with native non-leguminous species. Also, native legumes are more efficient in bringing out differences in soil properties than exotic legumes in the short term (Sheoran et al., 2010).

The use of introduced or exotic species should not be ruled out, however, especially where the local environment has deteriorated beyond that of adjacent sites or where numbers of local species are limited. The revegetation plan should allow for plant succession to take place naturally. In many cases, the objective is to establish pioneer species to give immediate cover and improve the soil, permitting native species to come in and take over as the colonizing plants decline (Morgan, 2005).

On mine spoils, nitrogen is a major limiting nutrient and regular addition of fertilizer nitrogen may be required to maintain healthy growth and persistence of vegetation (Yang et al., 2003; Song et al., 2004). An alternative approach might be to introduce legumes and other nitrogen-fixing species. Nitrogen fixing species have a dramatic effect on soil fertility through production of readily decomposable nutrient rich litter and turnover of fine roots and nodules. Mineralization of N-rich litter from these species allow substantial transfer to companion species and subsequent cycling, thus enabling the development of a self-sustaining ecosystem (Zhang et al., 2001).

Factors to consider in selecting species for revegetation

According to Morgan (2005), species to be used for revegetation should be selected based on their following parameters; properties of rapid growth; toughness in respect of diseases and pests; ability to compete with less desirable species; adaptability to the local soil; and adaptability to the local climatic conditions.

When the species to be used in the revegetation programmes are trees, they should possess the following qualities, according to Young (1997), for it to be qualified for use in soil fertility improvement/restoration: Primarily have the capacity to grow on poor soils; High rate of nitrogen fixation; High and balanced nutrient content in foliage litter; Liter low in lignin and polypherols; Either rapid liter decay where nutrient release is desired or moderate rate of liter decay where soil cover is required; Absence of toxic substances in litter or root residues; Well-developed tap root system; High rate of leafy biomass production; and dense network of fine roots with a capacity for mycorrhizal association.

Species selection will depend on local soil and climatic conditions but should aim to provide a uniform rather than clumpy pattern of vegetation to avoid concentrations of runoffs and localized erosion. The ideal condition is difficult to achieve, however, where the soils have low water retention capacity or are toxic, or where cold, drought or exposure inhibits plant growth.

Choosing vegetation which has beneficial effect is important (Morgan, 2005). For instance, in order to reduce the cost of reclamation of mine spoil mounds from tin mining on the Jos Plateau, Nigeria, the Mine Lands Reclamation Unit chose *Eucalyptus* sp. which could be cropped as a source of fuel and pole timber but these have resulted in significant declines in the base status and pH of the soil (Alexander, 1990) to the detriment of other plant growth (Morgan, 2005).

The revegetation of eroded ecosystems must be carried out with plants selected on the basis of their ability to survive and regenerate or reproduce under severe conditions provided both by the nature of the dump material, the exposed situation on the dump surface and on their ability to stabilize the soil structure (Madejon et al., 2006). Normal practice for revegetation is to choose drought-resistant, fast growing crops or fodder which can grow in nutrient deficient soils. Selected plants should be easy to establish, grow quickly, and have dense canopies and root systems. In certain areas, the main factor in preventing vegetation is acidity (Sheoran et al., 2010). Plants must be tolerant of metal contaminants for such sites (Caravaca et al., 2002; Mendez and Maier, 2008b).

THE ROLE OF REVEGETATION IN IMPROVING AND RESTORING SOIL FERTILITY

Fertility regeneration and maintenance is especially critical in areas devoid of the tropical forest vegetation necessary for quicker natural restoration (Asafu-Agyei, 1995). Apart from the fact that, trees and their litter prevent direct impact of torrential raindrops on soils and impede the movement of run off as well as preventing further erosion (Bonsu et al., 1996) on de-surfaced soils; forest biomass also decomposes to yield organic matter which improves soil fertility, structure, and other hydro-physical properties (Anane-Sakyi, 1995; Bonsu et al., 1996; Ingram, 1990). Anane-Sakyi (1995) also adds that, herbs, shrubs and trees supply organic materials in the form of litter to the soil under fallow and hence hastens the rate at which natural fertility returns to the fallow land.

Agboola (1990) also observed that, in undisturbed fallow, the nutrients move from the soil to the mat layer to the vegetation, and back to the soil and mat layer through the litter fall. The mat layer mechanism also serves as a means for nutrient conservation because most of the nutrients are located in the mat of roots and humus that occur on or near the soil surface. According to Anane-Sakyi (1995), the more the litter produced under the fallow, the more the soil organic matter, and the more fertile the land.

According to Dutta (1999), litter fall acts as a critical regulating component to enrich the microbial biomass on mine spoil. Root biomass and above ground plant biomass are considered to be the main source of soil organic and the latter is highly correlated with microbial biomass (Schnurer et al., 1985; Dutta and Agrawal, 2002). Kimaro et al. (2007) carried out a study on nutrient use efficiency and biomass production of tree species; it was observed that after 5 years rotation, top soils under *Gliricidia sepium* (Jaqua), *Acacia polyacantha* Wild and *Acacia mangium* Wild were the most fertile with soil organic carbon and exchangeable cation status raised close to those in natural systems. Soil inorganic nitrogen and extractable phosphorus levels reached sufficiency levels for subsequent maize culture.

Several processes have been identified by which trees can enhance the chemical and physical properties of the soils (Ingram, 1990). Other researchers like Troeh et al. (1980), also point out that the establishment of the vegetation on soils disturbed by constructional activities, and the subsequent increase in soil organic matter on these soils, results in the improvement in soil hydro-physical and chemical properties. These improvements, according to Ingram (1990), Asafu- Agyei (1995) and Cooper *et al*. (1996) include the following:

1. Improved soil physical structure (better soil aggregation and stabilization; reduced bulk density; increased available water capacity; improved infiltration; improvement in the soil texture) resulting from the higher levels of organic matter, old tree root channels and increased macro faunal activities. Although these are influenced by texture and clay type; organic gums and fungal and bacterial mycelia can bring soil particles into aggregates resulting in structural stability and good pore-

size distribution, which in turn provides good water holding capacity, favorable permeability and aeration as well as a good rooting depth and resistance to surface erosion.

2. Improved activity of soil organisms (such as fungi, arthropods, termites and worms) through a cooler and moister microclimate; as well as improved substrate for microbes which can contribute to nutrient needs in addition to the production of growth promoting substances.

3. Increase in nutrient status. A more closed nutrient cycle through the capture of nutrients which will otherwise be leached from beyond the tree or crop routine zone.

4. Improvement in cation exchange capacity (CEC) to enhance nutrient retention as well as enabling efficiency of nutrient utilization.

5. Reduced aluminium toxicity and low pH through enhanced cycling bases and the production of metabolic substance which temporally complex aluminium as well as buffering of the soil against rapid changes in acidity, alkalinity and salinity.

Furthermore, Young (1989) points out that soils developing under natural woodland or forest; the classic brown earth of temperate regions or red earth of the tropics is fertile. The soil is well structured, has good moisture-holding capacity, is resistant to erosion and possess a store of fertility in a nutrients bound up in organic molecules.

Role of revegetation in improving the soil physical properties

Maintenance or improvement of soil physical conditions

The superior soil structure, porosity, moisture characteristics and erosion resistance under forest is well documented, as is their decline on forest clearance. Porosity is a key to many physical properties: pores of 5-50 µm in diameter determine available water holding capacity, while those of over 250 µm in diameter are necessary for root penetration (Young, 1989). Compaction occurred during degrading of overburden and topsoil, mining, and reclamation activities at the time of unfavourable moisture conditions, and because of insufficient time for the soil-forming processes to decrease bulk density (Yao and wilding, 1995; Bradshaw, 1997). Akala and Lal (2001) explained that abrupt increase in bulk density at the 30 cm depth is due to overburden and spoil material being extensively graded before topsoil application and the presence of large amounts of rock fragments at depths below 30 cm. Agodzo and Adama (2003) explained that water content of the soil is an important property that controls its behaviour. Moreso, bulk density is an indicator of problems of root penetration, soil aeration and also water infiltration.

Improvement of infiltration and soil moisture availability/content

Ground vegetation, such as grasses will protect the slope against erosion by rain drop impact and run off, and also trap moving sediments, while shrubs and trees will increase the strength of the soil through root reinforcement. Vegetation increases the infiltration of water into the soil (Morgan, 2005). However, this can cause problems where rainfall amounts and intensities are very high. Whilst the resulting reduction of in runoff will help control surface erosion, the increased moisture content of the soil may exacerbate the rate of mass soil failure (Morgan, 2005). Young (1997) reported that the reduction in runoff is, to a small degree, caused by canopy interception and direct transpiration, but the greater part of its results from higher soil infiltration capacity under trees. Hamilton and Pearce (1987) also report that the dense surface-root system, under both natural forest and plantations, serves both to improve infiltration and to hold the soil in place.

Breaking of compact or indurated layers by roots

The improvement in surface protection causes a reduction in crusting and effect in compaction leading to increased infiltration; less leaching and prevention of erosion (Ingram, 1990; Asafu- Agyei, 1995; and Cooper et al., 1996).

Modification of extremes of soil temperature

There is experimental evidence from studies of minimum tillage that a ground surface litter cover greatly reduces the extremely high ground temperatures sometimes over 50°C, that is expected on bare soils in the tropics (Young, 1989). Again, Kolay (2000) points out that bare soil absorbs heat and becomes very hot during summer very quickly and becomes very cold during the winter, but this will not happen if the surface of the land is kept covered with vegetation which serves to insulate the soil. In this case, the soil will neither become too hot or too cold.

Improvement of soil texture and soil structure

According to Dutta and Agrawal (2002), significant variations in silt and clay suggest that plantations are capable of changing the soil texture after their establishment and growth in due course. Jha and Singh (1991) indicated that the textures of mine spoils are drastically disturbed due to irregular pilling of overburden materials. The naturally revegetating mine spoil of five years ago showed percentages of sand, silt and clay as 61, 25 and 14. Particle size distribution is a major soil physical factor governing a successful revegetation on reclaimed land as it influences water holding capacity, bulk density, soil moisture availability and nutrient contents as well as availability.

Role of revegetation in improving the soil chemical properties

Reduction of soil acidity

Trees tend to motivate the effect of leaching through addition of bases to the soil surface (Young, 1989). However, whether tree litter can be a significant means of raising pH of acid soils is doubtful, owing to the orders of magnitude involved (Young, 1989). One of the reasons for the above is that the calcium which trees supply through litter fall is insufficient to reduce the acidity even by a one pH point (Young, 1989). According to Young (1989), there are even cases where, in the temperate zone, tress produce acid, mor-type humus, which can lead to appreciable increase in soil acidification. However, experiments have also proven that the bases released by litter decay can check acidification. The increase in pH due to plantations suggests that the organic matter input modifies the pH of the soil. Since most plant species used for revegetation are dicotyledonous, these may release more base cations like Ca^{2+} into the soil and thus increase the pH of the soil more than the fresh mine spoil (Dutta and Agrawal, 2002). Richart et al. (1987) and Dutta and Agrawal (2002) also observed that the change in pH of opencast spoil was directly related to the tree growth. For plant nutrient availability (Ghose, 2004) optimum pH is 6.5 to 7.5.

Reduction of salinity or sodicity

Afforestation has been successfully employed as a means of reclaiming saline and alkaline soils (Young, 1989). For example, under *Acacia nilotica* and *Eucalyptus tereticornis* in Karnal, India, lowering of top soil pH from 10.5 to 9.5 in five years and of electrical conductivity from 4 to 2 dSm^{-1} have been reported, but with trees establishment assisted by additions of gypsum and manure (Gill and Abrol, 1986; Grewal and Abrol, 1986).

Reduction of the rate of organic matter decomposition

It is known that the rate of loss of humified organic matter is lower in forest than agriculture. Shading by the canopy and litter cover of trees, given reduced temperature, is one of the reasons for this effect (Young, 1989).

Availability of nitrogen

Nitrogen is believed to be absorbed from the atmosphere and stored in the soil, which is then taken up in the form of nitrates by plants for use. The root nodules found on especially leguminous species help to achieve this. Leguminous cover crops such as *Pueraria, Centrosema* and *Calapogonium* are more effective. Tree species such as *Leucaena leucocephala* and other leguminous tree species are also equally effective. The nitrogen absorbed from the atmosphere in turn contributes to improving the soil fertility. The litter fall which improves the organic matter status of the soil eventually provides a favourable soil environment for N-fixation. Proteins present in this organic matter as well as the bodies of soil micro-organisms are decomposed to amino acids which are further oxidize to nitrates (Kolay, 2000), of which plants can make use of. Useful legume tree species may contribute around 12 tons of dry litter and 190 kg of N/ha/yr to renovate degraded soils (Franco and de Faria, 1996). Some legumes like *Leucaena* may provide above 500 kg of N ha^{-1} y^{-1} (Sanginga et al., 1986).

Availability of phosphorus (P)

Mineralized P is found to be higher in soils treated with organic matter. Mbagwu et al. (1994) found soils treated with increasing rates of organic matter to have a corresponding increasing content of P. However, the total P accumulation in stem and bark is far greater than in leaves alone. P in the surface litter only accounts for small percentage of the total accumulation in the forest (Ren and Yu, 2008). It has been suggested that P deficiency is the inhibitive factor resulting in slow growth of *Acacia mangium* (Ribet and Devron, 1996; Xu et al., 1998; Ren and Yu, 2008).

Exchangeable cations

Vanlauwe et al. (2005) carried out a study to evaluate the functioning of trees as a safety-net for capturing nutrients leached beyond the reach of crop roots by investigating changes in exchangeable cations (Ca, Mg and K) and pH in a wide range of medium to long term alley cropping trials in savanna of West Africa. They noticed that the topsoil Ca content, effective cation exchange capacity, and pH were substantially higher under *Senna siamea* than under *L. leucocephala, Gliricidia sepium*, or the no-tree control plots in sites with a Bt horizon rich in exchangeable Ca. They attributed this to the recovery of Ca from the subsoil under *Senna* sp. The increase of the

Table 1. Soil properties under vegetated fields.

Available nutrients at two soil levels (kg/ha)	**Under *Prosopis cineraria***	**Under *Prosopis juliflora***	**Open field**
N: 0- 15 cm	250	203	-
15- 30 cm	193	212	196
P: 0-15 cm	22	10	8
15- 30 cm	10	5	4
K: 0- 15 cm	633	409	370
15- 30 cm	325	258	235

Source: Aggarwal (1980), cited by Young (1989), page 94.

Ca content of the topsoil under *Senna* sp. relative to the no-tree control treatment was related to the total amount of dry matter applied since trial establishment. The lack of increase in Ca accumulation under the other species was related to potential recovery of Ca from the topsoil itself and/or substantial Ca leaching. The accumulation of Ca in the topsoil under *Senna* sp. had a marked effect on the topsoil pH, the latter increasing significantly compared with the *Leucaena, Gliricidia* and no-tree control treatments.

Table 1 shows the possible effects of vegetation establishment (revegetation) on soil rehabilitation and restoration. It shows soil properties under the canopy of individual trees and those in the surrounding areas without tree cover. It could be seen that soils under vegetation had accumulated higher N, P and K than those under open field. This is due to the increased supply of litter provided by the vegetation which contributes organic matter, which in turn decomposes to release nutrients and that are responsible for improvement in soil fertility on degraded mined lands. This conforms to the research by Ingram (1990) and Troeh et al. (1980) who reported that the increased supply of litter (above and below ground residue) under natural fallow is considered to be responsible for the maintenance of soil organic matter and improvement in soil productivity of degraded lands. For instance, for *Acacia albida,* cases of 50 to 100% increases in organic matter and nitrogen under the canopy are known, together with increased water-holding capacity (Felker, 1978). Young (1989) also comments that in semi-arid climates, it is common to find higher soil organic matter and nutrient content under tree canopies than in adjacent open land.

Role of revegetation in improving soil biological properties

Maintenance and increment in soil organic matter

Organic matter is defined as the portion of soil that includes animal and plant remains at various stages of decay. There are three components of soil organic matter: living biota (the roots, microbes and other organisms that occupy the soil); fragments of plants and animal remains in various stages of decay such as fallen leaves, dead organisms, animal excreta, or crop residues; and residues of active decay, organic compounds remaining on the soil which is called humus (Plaster, 2009).

Ingram (1990) and Troeh et al. (1980) point out that, the increased supply of litter (above and below ground residue) under natural fallow is considered to be responsible for the maintenance of soil organic matter and improvement in soil productivity on degraded lands. Of all the effects of trees, that of maintaining soil organic matter levels through the supply of litter and root residues is the major cause of soil fertility improvements. It is the prime mover of nutrients, from which stems many of the other soil improving processes (Young, 1997). According to Barber (1995), the chemical composition of soil organic matter is approximately 50% carbon, 5% nitrogen, 0.5% phosphorus, 39% oxygen and 3% hydrogen. However, he noted that these values fluctuate from soil to soil. The organic matter of a typically well-drained mineral soil is small, varying from 1 to 6% by weight in the topsoil and even less in the subsoil. The main effects of soil organic matter are on soil physical properties and nutrient supply (chemical effects) (Young, 1989).

Physically, organic matter improves conditions of all mineral soils for many reasons. Organic matter helps sandy soils by increasing their water-and nutrient-holding capacity. It also improves clay soils by loosening them and improving their tilth (Plaster, 2009).

The major chemical effect is with nutrient supply. The supply is balanced across the range of primary, secondary and micronutrients so long as it remains in the form of organic molecules, it is protected from leaching (other than in the case of podzols) and it is a slow release of nutrients in available forms through mineralization (Young, 1989).

Other merits of organic matter upon nutrient supply are the blocking of phosphorus-fixation sites, which improves the availability of phosphorus; and the complexing of improved availability of micronutrients. It has been suggested that a good organic matter status provides favourable soil environment for fixation. A further chemical effect is the remarkable enhancement of CEC by the clay-humus complex; this is particularly important where CEC of a clay mineral is low, as in soils dominated by kaolinitic clay minerals and free iron oxides such as feralsols and acrisols (Young, 1989). Raising the CEC improves nutrient retention both of naturally recycled elements and those added in fertilizer.

In a 2005 study, consistent applications of organic matter increased production nutritional status of crops on sandy soils, improved soil quality and reduced the need for fertilization (Plaster, 2009).

Russell (1973) also reported that the principal source of nitrogen which is a very essential nutrient for crops growing on land not receiving any nitrogenous fertilizer is that which is released by the soil population decomposing the organic matter. This organic matter, according to Young (1997), is supplied largely by tree residues. Soil organic matter is therefore, said to be central to soil management.

Production of a range of qualities of plant litter

This has the effect of distributing, over time, the release of nutrients mineralized by litter decay. Where the vegetation species are trees, they provide both woody and herbaceous residues, and thus a range in quality both of above – ground litter and root residues (Young, 1989).

Timing of nutrient release

Given the range in quality of tree residues, their different rate of decay will cause the release of nutrients to be spread over time. In managed systems this release can be partly controlled, through selection of tree species on the basis of rates of leaf decay and timing of pruning (Young, 1989).

Effects upon soil fauna

Trees greatly modify the kinds and amounts of soil fauna, generally in order to favor fertility (Young, 1989). A specific indirect effect has been suggested that shade trees in plantations, through reduction of weeds by shading, result in less need to use chemical herbicides which adversely affect soil fauna.

According to Dutta (1999), litter fall acts as a critical regulating component to enrich the microbial biomass on mine spoil. Root biomass and above ground plant biomass are considered to be the main source of soil organic matter and the latter is highly correlated with microbial biomass (Schnurer et al., 1985; Dutta and Agrawal, 2002).

Role of revegetation in checking soil erosion

Agronomic measures of erosion control use the protective effect of vegetation covers to reduce erosion. According to Kohnke and Bertrand (1959), the only effective method of erosion control and the logical way of bringing strip-mined lands back into usefulness is to revegetate them.

The main purpose of erosion control on land previously used for mining is to create a stable environment for vegetation establishment and growth, in order to promote reclamation of land for agriculture or recreation, and to minimize off-site drainage. Since mine spoil banks are generally areas where erosion starts very quickly and because of the infertile and toxic nature of the material, vegetation grows very slowly (Morgan, 2005).

Vegetation plays a major role in the process of erosion control on gullied areas, construction sites, road embankments, landslides, sandstones, mine – spoils, and pipe-line corridors (Morgan, 2005). Vegetation also acts as a protective layer or buffer between the atmosphere and the soil (Morgan, 2005).

The above ground components such as leaves and stems, absorb some of the energy of falling raindrops, running water and wind, so that less is directed at the soil, whist the below ground components, comprising the root system, contribute to mechanical strength of the soil (Morgan, 2005). This mechanical strength of the soil helps to reduce runoff and conserves the soil moisture and therefore, aid to increase the soil moisture availability content of the soil.

Also, crops and vegetation which give good ground cover and have an extensive root system help to reduce water erosion (Biswas and Mukherjee, 1994). Dense sods produced by grass and several leguminous plants are outstanding examples in this respect (Biswas and Mukherjee, 1994). As a method of increasing infiltration and reducing runoff, revegetation is carried out in gully erosion control where the area around the gullies is treated with grasses, legumes, shrubs, trees, or a combination of these aided in the early stages by mulching in some cases (Morgan, 2005).

Tree planting (in afforestation) is recognized as a suitable method of reducing run-off and erosion, especially if applied to head water catchment as a means of regulating floods (Morgan, 2005).

Experiments have shown that afforestation can reduce runoff in gullied areas by 65 to 80% and soil loss by 75 to 90% (Morgan, 2005). Again, Gong and Jiang (1977) reports that the use of grass in revegetating gullied areas can also reduce run off by 50 to 60 and soil loss by 60 to

80%.

SUMMARY AND CONCLUSION

This review was conducted to assess the contribution of revegetation to improvement of soil fertility of degraded mined lands. The following summary and conclusions were made:

Mining results in soil degradation through destruction of soil structure, accelerated soil erosion, excessive leaching, compaction, reduced soil pH, accumulation of heavy metals in soils, depletion of organic matter, decreased plant available nutrients, reduced cation exchange capacity and decreased microbial activity.

The results obtained in this study indicate that revegetation through forest vegetation is one of the efficient means of restoring lost soil fertility through improvement in soil organic matter content, available nutrients, cation exchange capacity, increased biological activities as well as improvement in physical conditions of the soil.

From the review, it can be concluded that revegetation can improve fertility of degraded mined lands but it will require longer period to restore the fertility close to the original level. Some of the promising tree species that can be used for revegetation are *Acacia, Leucaena* and other legume trees that are acid-tolerant and can add substantial amount of organic matter to the soil.

Conflict of interest

The author has not declared any conflict of interest.

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APPENDIX 1

Revegetation of degraded mined lands by AngloGold Ashanti Company Limited, Obuasi, Ghana (Said, 2009) (Figures 2 and 4)

In days past the top soil excavated prior to mining was kept for reclamation or re-vegetation. The mine spoil comprising the waste rock and tailings were used for the re-vegetation of the study area. Presently, the top soil will be heaped and kept where it can easily be accessed and used during reclamation or revegetation. Nitrogen-fixing plants such as *Acacia mangium, Senna siamea* and *Leucaena leucocephala* are used for the revegetation exercise. Analysis of the soil samples under a 10 year revegetation found the soil moisture content at 9.1, 8.2 and 14.1% and for areas under *A. mangium, S. siamea* and mixed plantation of *A. mangium* and *S. siamea respectively,* as compared to the area under natural forest (under *Tectona grandis*) with 14.5% moisture content. The moisture content of the “Dokyiwa” reclaimed site (area under the mixed plantation) was similar to that of the un-mined area under natural vegetation (*T. grandis*). Other soil physical and chemical parameters such as texture, bulk density, soil pH, total nitrogen, available phosphorus, soil total carbon and exchangeable cations also showed encouraging results. These show the improvement in the soil fertility as a result of revegetation.

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Incidences of fetal deaths in rescued female leopards (*Panthera-pardus*) of Shivalik Hills in Northern India

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Twelve adult female leopards trapped in snare traps were rescued from Shivalik Hills areas of Himachal Pradesh. Of the 12 female leopards, 33.33% (4) leopards were found pregnant while others 66.67% (8) female leopards were non pregnant. Of the eight dead female leopards, 62.5% of trapped female leopards died because of body gripper trap injuries while in 37.5% of female leopards the cause of mortality was feet trap injuries. The maximum of the trapping that is 50% (6) were in the winter season followed by rainy (33.33%) (4) and summer (25%) (3) Seasons. Out of 12 female adult rescued leopards, four female leopards could survived and others eight succumbed to trapping injuries. There was 100% mortality of all the fetuses in rescued free range female leopards. The fetuses were 1-3 in numbers in their uterus. Three leopards were in mid stage of the gestation while one leopard was in its early stage gestation.

Key words: Trapping, fetal deaths, Leopards (*Panthera pardus*), Shivalik Hills.

INTRODUCTION

The leopard (*Panthera pardus*) is a large carnivore species and listed as near threatened species by International Union for the Conservation of Nature (2002) due to its declining population (Henschel et al., 2008). The population of the common leopards In India, based on pugmark censuses has been reported to be 9,844 leopards in 2001 (Singh et al 2008). The common leopard density reported to be 1.0–25.5 per 100 km^2 in the Indian subcontinent (Ramesh, 2010). There are various factors thought to be responsible for this decline in population and is a great concern throughout the world. The direct conflict of leopards to human population is considered as major case of the declining in the population of the leopards in India (Mishra, 2001; Mishra et al., 2002). Depletion in population of the wild prey is also considered as one of the cause for decline in population of leopards (Karanth and Stith, 1999). Population of the various species of the free range wild animals decreases day by day. Trapping kills millions of targeted as well as non targeted species throughout the world): by using different types of the traps. Snare traps are wire trap used by some scientists to capture wild animals (Berchielli and Tullar, 1981; Englund, 1982; Skinner and Todd, 1990). These snare traps are used as neck, body gripper traps to capture canids also (Noonan, 2002; Goodrich et al., 2001; Logan et al., 1999; Onderka et al., 1990; McKinstry and Anderson, 1998) . These traps are considered as the cause of mortality of free range wild

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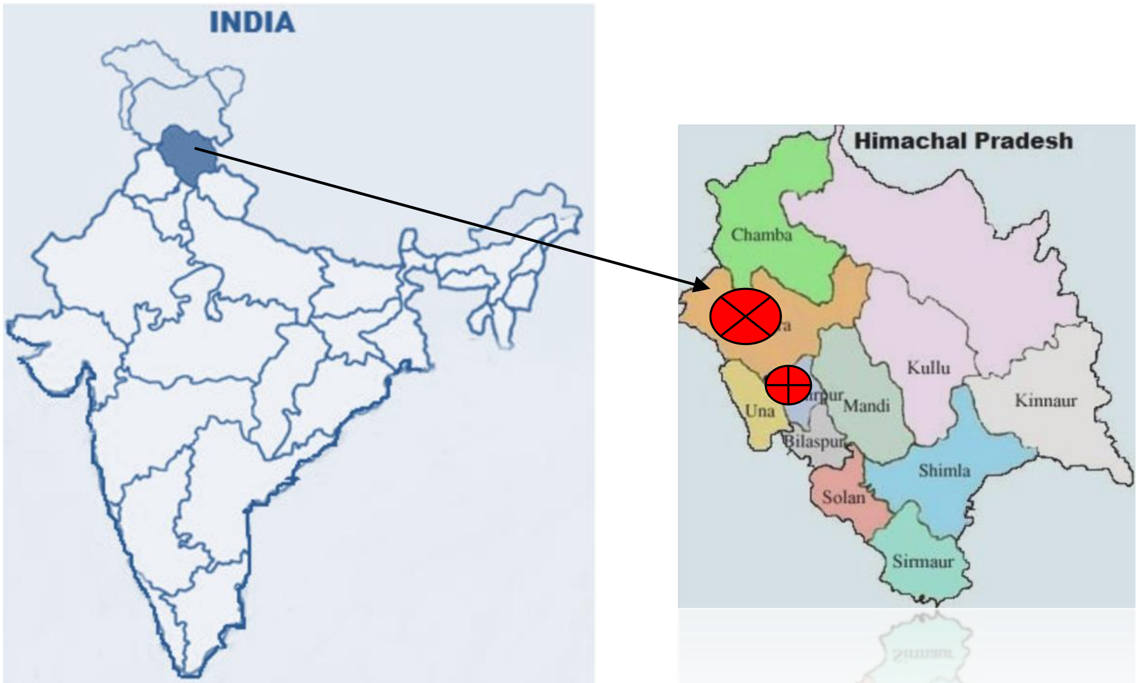

Figure 1. Red areas showing rescue of female leopards sites.

animals and mortality has also been reported to be 84.74% in herbivores, 79.06% in carnivores by Vijay et al. (2012) from these traps.

The productivity of the female leopards starts in their earlier stage of their life and they starts producing offsprings in the age of 2 years while they stop producing at the age of 8.5 years (Bailey, 1993; Friedman and Case, 2002; Macaskill, 2009). They produce average of 2-3 offsprings on an average and their average period of gestation is 97-102 days.

In the world there little is known about the fetal deaths of female leopards. This work reports an investigation on the fetal deaths and also others causes correlated with the fetal deaths in the rescued free range leopards of the Shivalik Hillas areas of Himachal Pradesh in India.

MATERIALS AND METHODS

Study site

The study was conducted in the Western region of Himachal Pradesh in Northern India and Shivalik hill areas includes outer Himalayas that is Hamirpur, Kangra and Una districts.The Shivalik hills area ranges from 350 to 1500 mand it's latitude varies from 30°22'40" North to 33°12'40" North and longitudes 75°45' 55" East to 79°04' 20" East. The annual rain in this area varies from 1500 to 1800 nm (Figure 1).

The present study was carried out on free range rescued female leopards who were trapped in the illegal trappings at various locations in Shivalik Hills and were rescued to Dhauladhar Nature Park Gopalpur in Himachal Pradesh in India. We included mainly adult female leopards of age ranging from 2-10 years were studied. The age of animals were calculated on the basis of the previous studies (Stander, 1997). The study was carried out over a period of 5 years: from March 2010 to September 2014 during the rescue and rehabilitation of the free range wild animals in Himachal Pradesh in India.

The animals were rescued after proper darting with projectile gun with a dart of 3-5 ml capacity. The main anaesthesia used was Xylazine hydrochloride (100 mg/ml) (Troy's Pty ltd Australia) at 1.5 mg/kgbwt and Ketamine hydrochloride (100 mg/ml) (Troy's Pty ltd Australia) at 5-8 mg/kgbwt (Karabi et al., 2012). The trapped leopards were rescued by the rescue team of Dhauladhar Nature Park Gopalpur and after rescue the injured leopards were brought to Dhauladhar Nature Park Gopalpur and were treated for their injuries using standard protocol of surgical management of wounds. The status of the fetuses was observed only at the time of the necropsies of the female leopards. The necropsies were performed as per standard protocol of necropsies in leopards (Kurade et al 2012).

RESULTS AND DISCUSSION

Twelve female adult leopards were rescued from various locations of the Shivalik Hills of Himachal Pradesh during the rescue operations of the trapped leopards. The leopards were trapped in snare traps and were trapped in different traps like body gripper traps, foot traps and neck traps. Out of 12 female adult rescued leopards, four female leopards could survived and others eight succumbed to trapping injuries. Of the 12 female leopards, 33.33% (4) leopards were found pregnant while

Table 1. : Showing trapping mortality of female leopards

Season	Trapping of female leopards	Pregnant female leopards	Mortality of Female leopards
Winter	6(50%)	4(100%)	5(62.5%)
Rainy	4(33.33%)	-----	2(25.0%)
Summer	3(25.0%)	-----	1(12.50%)

the others leopards were non pregnant [(66.67% (8)]. The mortality of 62.5% of trapped female leopards were because of body gripper trap injuries while in 37.5% of female leopards the cause of mortality was from fore-feet and hind feet traps injuries. There was 100% percent mortality of all the fetuses in rescued free range female leopards. Three leopards were in mid stage of the gestation while one leopard was in its early stage of gestation. The fetuses were 1-3 in numbers in their uterus. The maximum trapping [50% (6)] were in the winter season followed by rainy (33.33%) (4) and summer (3) (25 %) seasons (Table 1).

The present results provide the first record of the fetal deaths in the rescued free range leopards in Shivalik Hills in northern India. The leopards were rescued from the farm fields during the time of the their illegal trapping by the farmers or poachers. Out of 12 female adult rescued leopards, four female leopards could survived and others eight succumbed to trapping injuries as many of the trapped leopards were trapped in body gripped traps of the snares. The trapping injuries causes shock, dehyderation and poor physiological condition which are mainly considered as the etiology of the mortality of the trapped animals (Perrin, 1975; Gurnell, 1982). The study of the fetal deaths could be done the data from the rescued female leopard's post mortem examination only is gotten. Most leopards were in their mid pregnancy stage in winters only as their breeding seasons also lies from December to February in India (Balme et al., 2012). The maximum trapping that is 50% were winter season as compared to other seasons; the reason for this more trapping in winter season in the Shivalik Hills areas could be because of the snow falls in higher areas which leads to shifting of the preys like barking deers, rabbits, porqupine and other small sized preys to plain areas of the Shivalik Hills of the Kangra and Hamirpur districts in Himachal Pradesh in India. The litter size was 1-3 in the present study which agrees with the previous studies conducted on the breeding of the leopards in the various parts of the world by various workers (Seidensticker et al., 1990; Owen et al., 2010; Balmeet al., 2009).

The death of all the fetuses in the uterus may be because these animals were trapped in the body gripper traps and tried to get escape by continuously puling their bodies in forward and backward positions: body gripper traps leads to crushing of the fetus due to continuous pressure of the snares in the body gripper traps. The cause of the deaths of the leopards trapped in the feet may be because of septicemia. The survivals of the cubs in free range were very less as noticed by various workers (37%, Balmeet al., 2012; 50%, Bailey, 2005; 53%, Owen et al., 2010). There are little studies done on the fetal deaths and this is thought to be influenced by various factors but mainly maternal age, intuitively, motherhood of older female leopards are the factors considered for the survival of the cubs in the free range (Pettorelli and Durant, 2007).

In the present study the fetus deaths were correlated with other factors like body gripper traps which is also considered as major cause of deaths of wild animals. Leopard (*Panthera pardus*) is an endangered schedule – I wild animal under wildlife protection act 1972 and it's illegal trapping need to be stopped immediately so that declining population of this species can be conserved at an early stage in the region of the Shivalik Hills areas of the Himachal Pradesh in India.

Conflict of interest

Author did not declare any conflict of interest.

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Full Length Research Paper

Trade of the most popular Indigenous fruits and nuts, threats and opportunities for their sustainable management around the Ivindo National Park (INP), Gabon

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Sustainable management of forest resources in and around national parks continues to be a growing challenge in Gabon. Rural people living close by national parks continue to depend on those forest resources to meet their various livelihoods needs despite strict governmental restriction on access and use of forest resources, especially inside of national parks. Hence, most of these resources are mismanaged and overexploited while innovative mechanisms that would assist parks' managers in sustainably managing these protected forests are lacking. A semi-structure interview was administrated to 79 sellers that were found in the three local markets located near the Ivindo National Park (INP), in the province of Ogooué Ivindo (Gabon). This survey aimed at clarifying the trade values of most of the popular indigenous fruits and nuts species and the sellers' perceptions on resource decline for an improved management of resources inside and outside of the Ivindo National Park. From both inside and outside of the park, *Coula edulis, Irvingia gabonensis and Dacryodes buettneri* tend to be among the most sold wild fruits and nuts according to 82.3, 73.4 and 31.6% of the respondents respectively. *I. gabonensis* fetches the highest sale price in FCFA and represents the most important income provider to sellers followed by *C. edulis* and *D. buettneri.* Since social status of sellers such as marital status and ethnicity appear to be the driving factors to people's entry to this trade, therefore they need all to be considered as key variables in regulating usages of these traded wild fruits and nuts. Despite the importance of indigenous fruits and nuts as source of income, resource decline have been acknowledged by almost all the sellers. Hence, sellers should be considered as key partners in identifying species in needs of conservation. Among the drivers of resource decline include the impacts of logging companies, climate change (unpredictability of rainfall), and unsustainable harvesting practices of the valued indigenous resources. Sustainable management of these valued indigenous forest resources call for a careful implementation of an innovative mechanism that would regulate demand and assist park managers in managing forest resources in a sustainable manner. Most critically, further studies need to look at the practical approach of setting up quotas based harvesting of these valued indigenous forest resources.

Key word: Trade, indigenous fruits and nuts, threatened species, sustainable management, adaptive management, Ivindo National Park, Gabon.

INTRODUCTION

Gabon, located in Central Africa, is endowed with a rich biodiversity including dense forest covering 25,767 000 ha, more than 80% of the total national territory (Caballé, 1978). This dense tropical forest supports the development of the forestry sector and the livelihoods of many local populations (Kaimowitz, 2003; Beauchamp and Ingram, 2011; Jamnadass et al., 2011; Ingram et al., 2012; Lescuyer et al., 2012; Tieguhong et al., 2012) including Non Timber Forest Products (NTFPs). NTFPs provide livelihoods to local people which include trees bearing fruits such as indigenous fruits and nuts. These forest products are one of the most important traditional resources and represent major sources of foods and income generation for people in the country (Walker and Sillans, 1961; Bourobou-Bourobou, 1994;Bourobou-Bourobou and Posso, 1995; Pineau, 1995; Corblin, 2006; Viano, 2005).

The Gabonese government has made tremendous efforts towards protecting the country's rich biodiversity and promoting its sustainable management through establishing a network of 13 national parks (covering nearly 11% of total national land area) throughout the country since 2002 (AFDB, 2011). This conservation effort has started since colonial period with Lopé reserve and the Ipassa Makokou Biosphere Reserve's establishment in 1946 and 1979 respectively. The establishment of national parks' represents therefore one of the traditional approach adopted by the Gabonese government for strict protection and sustainable management of its natural resources. However, one of the often mentioned constraints of this approach is that it negatively affects the livelihoods of local people living nearby those protected forests in terms of access and use of forest resources that get to be used by them to meet their various basic needs (Okouyi Okouyi, 2006; Lescuyer, 2006; Sassen and Wan, 2006; Corblin, 2006, Viano, 2005).

In addition, mechanism that could help resources managers to regulate usages and market demands over valued forest resources such as indigenous fruit trees and nuts in all core areas of national parks are new in most developing countries. In case such mechanisms are available they do not often contribute to improve the livelihoods of forest dependent people in most cases (Laird et al., 2010a). In developing countries such as Nepal, the importance of non timber forest products for rural communities has been overlooked and available governmental legislations have contributed to poorly regulate resources extraction, use, trade and marketing of these forest products leading therefore to resources decline and negative impacts on the livelihoods of resource users generally (Pandit et al., 2004; Subedi, 2010; Uprety et al., 2011).

Scholars such as Laird et al. (2009) and Laird et al. (2010a) have pointed out factors that might contribute to undermine successful implementation of governmental forest policies including: (i) the contradicting nature of the forest policies with regards to forest tenure and property rights, (ii) the poor stakeholders' consultations regarding the implementation of projects that might affect their livelihoods, and (iii) the lack of depth analysis of the complexity of factors that might affect the sustainability and equity in resources access and use while designing forest resources management plans. Other driving factors stressed by Larsen et al. (2000), Chhetri (2009), Kunwar et al. (2009), Pokharel (2010), Uprety et al. (2011) and Patel et al. (2013) include: (i) the non recognition of legal traditional rights of collectors over harvest of the forest products, (ii) the lack of effective involvement of local people in forest resources management and policy elaboration process.

Since poor forest policy's implementation can indirectly lead to deforestation and unsustainable use of forest resources, therefore avoiding such issue and its negative impact on local people's livelihoods has led several scholars to suggest sustainable use of resources as a viable management's mechanism that would more likely reconcile biodiversity conservation (slowing deforestation) and enhancing local people's livelihoods (Arnold and Pérez, 2001; Ahenkan and Boon, 2010; Brussaard et al., 2010; Gondo et al., 2010;Laird et al., 2010a; Laird et al., 2010b; Powell et al., 2010; Rabbi et al., 2010; de la Torre et al., 2011), Laird et al., 2011; Mutenje et al., 2011).

In Gabon for example, policy and legislations regulating access and usages of forest resources are available for forests and national parks, as a part of natural resources management system of the country (Forest Code of 2001; the National Parks Law of 2007; decree on Customary Rights Law of 2004). Under such policy and legislations, access and use of forest resources is free in the transition area, regulated in the buffer zone, and strictly prohibited inside of all national parks of the country (Gabonese Republic, 2007). In addition, available studies country wide have poorly focused on assessing people's perceptions on access and use of wild traditional forest products including fruits and nuts that are gathered from indigenous trees on one hand and to determine their economic value on the other hand as an approach to regulate market demand and improve forest resources management in the country.

Moreover, the poor policy makers' knowledge on what are the most valued forest resources of the park also contributes to undermine the correct management of national parks, given that some of these forest resources

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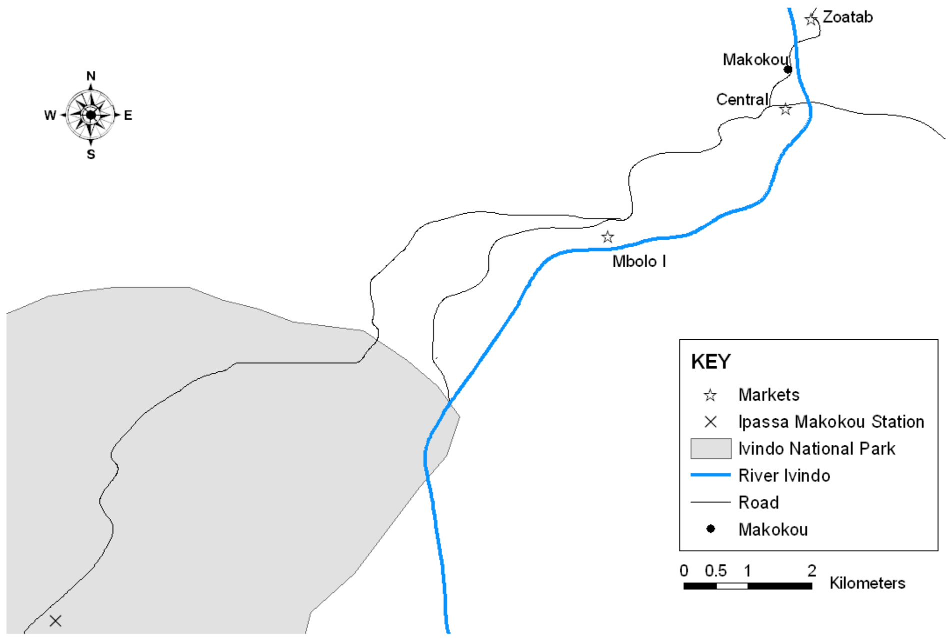

Figure 1. Surveyed marketplaces around the commune of Makokou in the province of Ogooué Ivindo, north east Gabon.

(indigenous fruit and nuts) are pivotal to the livelihoods of the rural communities living near national parks in Gabon (Walker and Sillans, 1961;Bourobou-Bourobou, 1994; Bourobou-Bourobou and Posso, 1995;Pineau, 1995; Corblin, 2006;Viano, 2005; Okouyi Okouyi, 2006;Lescuyer, 2006;Sassen and Wan, 2006) and throughout Africa (Leakey *et al*., 2005; Arnold *et al*., 2011;Jamnadass et al., 2011; Sunderland, 2011). Consequently, any attempt towards improving the management and conservation of forest resources of national parks including in the Ivindo National Park (INP), one of the newly established national parks, requires a clear understanding of the economic and social value of the most traded indigenous fruits and nuts products and the traders' perceptions on the current status of those traditional resources from the wild. Therefore, this study represents a most necessary starting point to inform policy makers' and raise their awareness on the decline of these forest resources, assisting park managers on pursuing a sustainable management of the parks' resources.

MATERIALS AND METHODS

Study area

The study was conducted in three local marketplaces around the commune of Makokou, provincial city of the province of Ogooué-Ivindo (north-eastern of Gabon) that is located close by the Ivindo National Park (INP) with geographical coordinates of (0 23'-0 33'N, 0 42'-12 49E) in Central African region (Figure 1). The region of Makokou is characterized by an equatorial climate, marked by high humidity, high rainfall of 1,700 mm and temperature averaging 24°C year round (IRET/CENAREST, 2003). The population of the region estimated at about 15,000 people includes many ethnic groups such as the Bantus and the Baka pygmies. The Bantus break up into small groups including Fang, Kwélé, and Kota with Fang and Kota being the dominant ethnic groups in the area (Betti, 2013).

The forest of the region of Makokou belongs to the Guineo-congolian phyto-geographical type (Amalfi et al., 2010; Yombiyeni et al., 2011; Sonke et al., 2012) with abundant fauna and floristic resources, including 1,200 floral species already inventoried. Among valuable timber and non-timber forest products commonly encountered around the study area include indigenous fruits and nuts trees. These forest products known as multiple uses trees species are considered by local people as major sources of timber (*Dacryodes buettneri*) and foods, income generation and healthcare (*Coula edulis* and *Irvingia gabonensis*) (Lescuyer, 2006; Sassen and Wan, 2006; Corblin, 2006; Viano, 2005).

The current Ivindo National Park (INP), one of the oldest protection areas in Gabon, is selected as a case study of typical national park of the country. The Ivindo National Park was formerly known as Ipassa Biosphere Reserve of 10,000 ha that was established in 1979 and composed of three main areas: a central core area of 10,000 hectare, a 2 km of wide band as buffer zone, and a 3.5 km of transition area (Gabonese Republic, 1971). The reserve area was extended to become the current Ivindo National Park covering an area of 300,000 ha today. Although, rules and regulations of the national parks exist under the Forest Code of 2001, the decree on Customary Rights Law of 2004 and the National Parks Law of 2007, however, access and use of resources are strictly prohibited, especially inside of all core areas of the national parks (Gabonese Republic, 2001, 2004, 2007). In addition, firewood is the only forest product allowed to be collected freely from the national parks to sustain the livelihoods of rural people while other forest products even non-timber forest products including nuts and fruits from indigenous trees are prohibited to be consumed in the core area, and their extraction is regulated in the buffer zone (Gabonese Republic, 2007).

The consumption, use and trade of indigenous fruit and nuts have been central component of the livelihoods of majority of rural communities throughout Africa (Akinnifesi et al., 2006; Leakey et al., 2005) including in Gabon, however, there is a scarcity of studies assessing the current economic value of the most popular indigenous fruits and nuts, and traders' perceptions on resource decline to regulate market demand and improve the management of national parks' resources. In addition, the observed mismanagement and the decline of the resources as to do with poor policy makers' knowledge on what are the valued forest resources gathered from the wild.

Species selection and data collection

C. edulis, *D. buettneri* and *I. gabonensis* represent the three indigenous fruits and nuts that were selected for this study as a result of their popularity, their higher market price and their consumptive values that were evidenced during the previous household survey (Mikolo and Ito, 2014). The data were obtained through different techniques including; key informant interview and a semi-structure questionnaire that was administered to seventy nine sellers throughout the three local markets that were identified within the commune of Makokou as followed: Central market (n=31), Mbolo market (n=17) and Zoatab market (n=31). Questionnaire administration was based on a one hundred percent sampling strategy while participation of sellers in the interview was voluntary.

This work was constructed around the following four aspects: (1) the socio-economic profile of sellers and forest products outsourced, (2) the trade values of the most popular indigenous fruits and nuts, (3) the relationship between trade values of the most popular indigenous fruits and nuts and the socio-economic profile of sellers, (4) the cross tabulation relationships between sellers' awareness on resources decline, drivers of resource decline and opportunities for improving sustainable management of forest resources around the Ivindo National Park.

Data analysis

Statistical analyses were conducted using SPSS, v17.0 to generate descriptive statistics such as means, frequency tables, and percentages and cross tabulations with regards to the above four aspects. Non-parametric statistics (Mann Whitney U tests and Kruskal Wallis tests) were performed to test differences between amounts of the resources sold, the economic value of the traded resources and the socio-economic profile of the sellers.

RESULTS AND DISCUSSION

Social status of sellers and forest products outsourced

In total, seventy nine sellers representing 77% of identified respondents have voluntary participated in the market survey. Table 1 shows the social status of sellers and forest products outsourced in the study. Since 95% of the respondents were female respondents therefore the trade of most popular indigenous fruits and nuts tend to be highly gendered segmented as is the case in many regions of Central Africa. In Cameroon for example, the study of Perez et al. (2002) found that the traded forest product is gendered related and that gender differences found depends on business size, product specialization, market strategies involved as well as profit margins generated. Other factors driving gender differences in the trade of forest products include the level of people's involvement in the segment of the value chain, availability or not of regulations measures on customary rules and legal regulatory norms guiding access and use of forest resources (Ingram et al., 2014). However, depending on the physical nature of the activity, female respondents tend to be less dominant in forest products related enterprises such as woodcrafts (Shackleton and Shackleton, 2003, 2004; Nkuna, 2004; Paumgarten, 2005; Mikolo Yobo, 2007; Christian et al., 2008). On the contrary, the higher involvement of female respondents in this trading activity has probably to do with their needs to supplement households' incomes.

The majority (96%) of people interviewed originated from Gabon compared to other nationalities probably because of their proximity to the resources added to the fact that they are probably more knowledgeable about where to find these valued forest products from the wild than foreign people. Almost sixty percent of the respondents are involved in the trade on a part time basis while the rest are full-time sellers. Thus, trading of forest resources on a part time basis may represent an important livelihood strategy sets in place by respondents since it allows them to carry multiple livelihoods activities for meeting other households' needs (Shackleton and Shackleton, 2003, 2004).

The collectors-sellers types of respondents tend to represent the majority (96%) of people encountered in the study compared to the sellers' type of respondents only (4%). It was found in the surveyed area that poorly educated people tended to dominate the trade of the most popular indigenous fruits and nuts since the majority (84%) of them have no education (8%) while 76% of respondents have reached primary education. Although, the net primary school enrolment's rate is relatively high (96%) in the country, however, this rate tends to drop while people reach secondary and university studies as a result of internal issues within the Gabonese education's system (World Bank, 2006). Thus, this poor education attainment may have driven sellers to enter such a trade as evidenced by Nkuna (2004) in the case of Hazyview area of the Mpumalanga Province (South Africa). He showed that people with no or poor education are more likely to get into the informal forest trading activities such as woodcrafts than in the formal trading sector. As a result, low education may have driven sellers' involvement into the trade of wild fruits and nuts given that people with poor education are less likely to get an employment in the formal sector in Gabon.

The trade of indigenous fruits and nuts is dominated by Kota ethnic group (58%), one of the major ethnic groups in the region, while others ethnic groups such as Mahongwé (19%), Fang (6%), Shamayé (6%), Kwélé (5%), Foreign (4%) and Sake (1%) have also managed to enter into this trade. In addition, the trade of the most popular indigenous fruits and nuts is dominated by non-married people

Table 1. Social status of sellers and forest products outsources (N=79).

Feature		Count	%	Mean	Min	Max
Gender	Female	75	94.9			
	Male	4	5.1			
Nationality	Gabonese	76	96.2			
	RD Congolese	1	1.3			
	Camerounese	1	1.3			
	Ghanean	1	1.3			
Sellers status	Collectors-sellers	76	96.2			
	Sellers only	3	3.8			
Sellers type	Part-time	47	59.5			
	Full-time	32	40.5			
Education level	None	6	7.6			
	Primary	60	75.9			
	Secondary	13	16.5			
Ethnicity	Kota	46	58.2			
	Mahongwe	15	19.0			
	Fang	5	6.3			
	Shamaye	5	6.3			
	Kwele	4	5.1			
	Sake	1	1.3			
	Foreign	3	3.8			
Marital status	Concubine	35	44.3			
	Married	16	20.3			
	Widow	15	19.0			
	Single	13	16.5			
Driving factors to the trade	Lack of employment	55	69.6			
	Additional income sources	22	27.8			
	Meeting consumers needs	2	2.5			
Working experience (Years)				11.41	0.2	25.0
Age (Years)				43.54	23.0	71.0
Household size				6.13	1.0	11.0
Forest products outsources	Inside of the park	0	0.0			
	Inside-Outside of the park	76	96.2			
	Outside of the park	3	3.8			

n, number of sellers who have exactly participate to the survey.

representing altogether almost (80%) of the respondents including concubine (44%), widow (19%), and single people (15%) while married people represent the rest.

Seventy percent of the respondents have mentioned entering the informal trade of indigenous fruits and nuts as a result of lack of employment while other respondents have stressed additional income sources (28%) and meeting consumers' needs (2%) as the driving factors to their entry to this trade. In the case of rural areas of South Africa for example, factors such as people's proximity to the location of the resources and the lack of additional costs (except labor related one) involved in resources extraction have been cited as drivers of people's entry to the trade of marula (*Sclerocarya birre*a) beer (Shackleton and Shackleton, 2003, 2004). In Gabon, the state seems to fail to absorb the rising numbers of new entrants into the formal economy given the relatively higher level of unemployment rate 30% among the youth population with age ranging from 16 to 25 years old and poverty level estimated at 33% in the country as a results of the high income inequality among the Gabonese people (GDS, 2008; Mc Kinsey report,

Table 2. Trade value by species (N=79).

Species	No. of users	%	Selling amount/ season*			Income/ season*			Price/ Kg		
			Mean (Kg)	Min	Max	Mean (FCFA)	Min	Max	Mean	Min	Max
All species	79	100.0	301.2	24	610	174,949.4	14,400	377,500	536.1	461	699
Coula edulis	65	82.3	133.2	24	240	67,741.5	14,400	154,000	506.2	400	700
Irvingia gabonensis	58	73.4	231.9	33	400	152,919.0	19,800	280,000	660.3	600	800
Dacriodes buettneri	25	31.6	67.6	50	160	21,940.0	15,000	48,000	326.0	300	350

season*=harvesting season; Currency: 1 euro=655.5 FCFA.

2014). Since a large proportion of the population remains poor (especially in rural areas) and that they find difficulty in finding proper employment therefore the informal trade of indigenous fruits and nuts may still continue to provide livelihood opportunities to these impoverished rural people and their families throughout the country.

The average number of years of experience of the sellers in this study is 9±7 with minimum=0; maximum=25 years. Given that average age of sellers was estimated at 43±11 with [minimum=23; maximum=71] years therefore these people are mostly adults who may represent a potential working force for the formal sector. Since average family size is estimated at 6±3 with [minimum=1; maximum=11] therefore it represents a non-negligible labor force at the disposal of the sellers and their families, especially in time of resources outsources. As a result, family members plays a potential role in helping the main sellers in resources collection from the wild and their sale at marketplaces (Fu et al., 2009; Shackleton et al., 2011; Katel and Schmidt-Vogt, 2011; Asfaw et al., 2013).

Regarding resources outsourced, the majority (96%) of respondents has acknowledged collecting indigenous fruits and nuts from different trees that were found either inside or outside the park. As the collection of indigenous fruits and nuts depend on resources availability therefore the future management of these wild forest products has to be directed to either inside or outside of the park and or to both inside-outside of the park.

Commercialization of the most popular indigenous fruits, nuts and sellers' livelihood dependence on valued resources

Table 2 shows variations in amounts of forest products sold, gross mean income generation and market price of the most popular indigenous fruits and nuts in the study. Although, all (100%) the respondents are involved in the sale of all the three most popular indigenous fruits and nuts, however variations exist with regards to mean amounts of resources sold, total gross mean income generated per season and total mean price per kg given range differences observed between minimum and maximum. The popularity of these forest products is also evidenced by the proportion of respondents engaged in their sale. Since 82 and 73% of the respondents are engaged in the sale of *C. edulis* and *I. gabonensis* respectively therefore they can be considered as the most popular indigenous fruits and nuts while *Dacryodes buettneri* represents the least popular species given that (32%) of the respondents are involved in their sale.

For the less popular indigenous fruits and nuts namely *Dacryodes buettneri*, average total amounts of resources sold per season and gross mean income generated were relatively lower than of the two most popular indigenous fruits and nuts (*Coula edulis* and *Irvingia gabonensis*) in terms of average total amounts of resources sold per season and gross mean income generated. Out of the three wild indigenous fruits and nuts, *Irvingia gabonensis* (600 FCFA per Kg) is fetching the highest mean market price followed by *Coula edulis* (400 FCFA per kg) and *Dacryodes buettneri* (300 FCFA per Kg). Consequently, wild fruits and nuts that are fetching the highest market price are also those ones that are being sold and generate most gross mean income per season, especially *Irvingia gabonensis* and *Coula edulis*. In other words, sellers tend to depend more on wild fruits and nuts of a higher market prices.

Resource users' dependence on forest resources of higher economic values is not without any negative ecological impacts on resources base and on local people's livelihoods (Peres et al., 2003;Ticktin, 2004; Belcher and Schreckenberg, 2007), especially absence of controlled resources management. However, its negative ecological impacts on resources tend to depend on trees parameters such as parts of the plants use, harvesting practices and intensity, inadequate management practices (Hall and Bawa, 1993; Ticktin, 2004; Uma Shaanker et al., 2004). In the case of this study, the trade of these valued wild fruits and nuts seems to have negative impacts on resources' availability since most of the sellers have acknowledged that these forest resources are declining from the wild. Thus, alleviating such negative ecological impacts on resources base has driven some scholars such as Syampungani et al. (2009), Hirsch et al. (2011), Lewis et al. (2011), and McShane et al. (2011) to suggest a win-win approach as a way to reduce biodiversity decline and enhance livelihoods of forest dependent people.

In the case of Gabon, such an initiative aiming at improving biodiversity conservation and securing the livelihood local people (at the same time) is relatively recent. Indeed, the Gabonese government has made tremendous efforts in linking biodiversity conservation and livelihood security of local people by banning logs harvesting and commercial trade of five multiple (timber and non-timber forest products) uses plant species including *Poga oleosa* (Afo), *I. gabonensis* (Andock), *Tieghemella Africana* (Douka), *Baillonella toxisperma* (Moabi) *and D. buettneri* (Ozigo) until 2033 (Gabonese Republic, 2009). Among the list of the prohibited species include two of the target tree species of this study, especially *Irvingia gabonensis* and *Dacryodes buettneri.* The former represents the most sold indigenous nuts while the latter is the least sold indigenous fruits as a result certainly of consumers' wealth and price that they can afford for them.

Some of the drivers of households' consumption of forest resources such as wildlife include wealth and price of the goods (Wilkie and Godoy, 2001;Wilkie et al., 2005; Shackleton and Shackleton, 2006; Eniang et al., 2008;Fa et al., 2009; Godoy et al., 2010;Brashares et al., 2011; Foerster et al., 2012). Indeed, the consumption of such forest resources augments with rising of households' wealth and that while price of these forest products goes up its consumption diminishes. Thus, controlling the combined effects of such drivers on resources' consumption and its potential impact forests resources has led Wilkie et al. (2005) to suggest proper taxation coupled with better law enforcement as a valuable solution to overcome the issue of resources decline. According to East et al. (2005), understanding the in-depth causes driving demands of such wild forest products represents one of the starting point to solve the related effects of household wealth on consumption of forest resources.

In the case of this study, the high selling price of *I. gabonensis* and *C. edulis* (comparatively to *Dacryodes buettneri*) that were observed has certainly to do with the lower availability of these forest resources from the wild. Indeed, a recent ecological study carried out by Christian and Ito (2014) has shown that *I. gabonensis* and *C.edulis,* two of the most popular indigenous fruits and nuts, are in lower availability inside and outside of the park as a result of past anthropogenic pressures. Consequently, the scarcity of *Irvingia gabonensis* and *Coula edulis* from the wild may have contributed to increase their selling price at market. One of the direct consequences of the uncontrolled trade of wild forest products (especially those in lower availability) is its negative ecological impacts on species population (Ticktin, 2004) and on people's livelihoods (Eniang et al., 2008). Overcoming such negative impacts on forests and local people's livelihoods has led scholars such as Bennett et al. (2007), Sims (2010), Mukul et al. (2010), Duchelle et al. (2012) to suggest sustainable use and promotion of the commercial extraction of forest products as a viable solution to reconcile biodiversity conservation and livelihoods security of rural peoples in some cases

Regarding this study, viable solutions to regulate the trade of most popular indigenous fruits and nuts are suggested at the end of this paper.

Relationship between mean amounts of wild fruits and nuts sold, their gross mean income generation and socio-economic profile of sellers

Tables 3 and 4 investigated the relationship between mean amounts of wild fruits and nuts sold and socio-economic profile of sellers on one hand and the relationship between gross mean income of these wild forest products and socio-economic profile of sellers on the other hand. The results of these analyses showed that no significant differences were found between each of the socio-economic profile of the respondents including gender, nationalities, sellers' types, job's type and education level and mean amounts of resources sold through Mann Whitney tests and Kruskal Wallis tests. In addition, no significant differences were also found between the previous socio-economic profile of the respondents and gross mean income generation. This may imply that gender, nationalities, sellers' types, job's type and education level of the respondents have no influence on the amounts of resources sold and income generated from their trade.

On the contrary, significant differences were found between ethnic groups and each of the following variables including mean amounts of resources sold (X^2 = 15.90, p= 0.01) and gross mean income generation (X^2 = 14.06, p= 0.02) through Kruskal Wallis tests (Tables 3 and 4). Indeed, Saké and Kwelé ethnic groups all together tend to sell significantly less mean amounts of wild fruits and nuts and generate also less gross mean income from not only all the three wild species but also for each of the wild forest products than other ethnic groups including Fang, Kota and Mahongwe. The above result stresses also that ethnicity in terms of social knowledge of the respondents represents a key driving factor to people involvement into the trade of wild fruits and nuts.

Since Kota, Mahongwe and Fang (the dominant ethnic groups) tend to be highly dependent on the wild forest products therefore resources management has to be based on ethnicity dominance in the area. Community organizations based on ethnic groups may represent a good example of informal institutions arrangement, especially with regards to their contribution to sustainable management of natural resources (Leach et al., 1999).

In such approach, successful resources management may require those informal bundles of rights in terms of property rights and resources ownership as well as the roles and responsibilities of resources users are clearly defined and that they are effectively devolved to local users groups by the state (Larson and Ribot, 2004; Hartter and Ryan, 2010; Lambini and Nguyen, 2014).

Table 3. Economic value and amounts of traded forest products by sellers social status in the study area.

Social status		Species	#	%	Mean amount/ season*		
					Kg	Min	Max
Gender	Male	All species	4	5.1	292.5	130.0	440.0
		Irvingia gabonensis	4	5.1	197.5	130.0	240.0
		Coula edulis	2	2.5	120.0	120.0	120.0
		Dacriodes buettneri	2	2.5	70.0	60.0	80.0
	Female	All species	75	94.9	301.7	24.0	610.0
		Irvingia gabonensis	54	68.4	234.4	33.0	400.0
		Coula edulis	63	79.7	133.6	24.0	240.0
		Dacriodes buettneri	23	29.1	67.3	50.0	160.0
Nationality	Gabonese	All species	76	96.2	302.7	24.0	610.0
		Irvingia gabonensis	55	69.6	234.8	33.0	400.0
		Coula edulis	64	81.0	132.5	24.0	240.0
		Dacriodes buettneri	24	30.4	67.1	50.0	160.0
	Others	All species	3	3.8	263.3	130.0	480.0
		Irvingia gabonensis	3	3.8	176.6	130.0	220.0
		Coula edulis	1	1.3	180.0	180.0	180.0
		Dacriodes buettneri	1	1.3	80.0	80.0	80.0
Sellers' type	Collectors-sellers	All species	76	96.2	302.7	24.0	610.0
		Irvingia gabonensis	55	69.6	234.8	33.0	400.0
		Coula edulis	64	81.0	132.5	24.0	240.0
		Dacriodes buettneri	24	30.4	67.1	50.0	160.0
	Sellers only	All species	3	3.8	263.3	130.0	480.0
		Irvingia gabonensis	3	3.8	176.6	130.0	220.0
		Coula edulis	1	1.3	180.0	180.0	180.0
		Dacriodes buettneri	1	1.3	80.0	80.0	80.0
Seller job's type	Full-time	All species	32	40.5	312.5	50.0	570.0
		Irvingia gabonensis	26	32.9	247.3	110.0	360.0
		Coula edulis	27	34.2	117.8	50.0	240.0
		Dacriodes buettneri	6	7.6	65.0	50.0	80.0
	Part-time	All species	47	59.5	293.5	24.0	610.0
		Irvingia gabonensis	32	40.5	219.3	33.0	400.0
		Coula edulis	38	48.1	144.1	24.0	240.0
		Dacriodes buettneri	19	24.1	68.4	50.0	160.0
Education levels	None	All species	6	7.6	243.3	80.0	520.0
		Irvingia gabonensis	3	3.8	216.6	150.0	260.0
		Coula edulis	4	5.1	142.5	80.0	200.0
		Dacriodes buettneri	2	2.5	120.0	80.0	160.0
	Primary	All species	60	75.9	316.1	24.0	610.0
		Irvingia gabonensis	46	58.2	236.1	33.0	400.0
		Coula edulis	50	63.3	135.2	24.0	240.0
		Dacriodes buettneri	21	26.6	63.8	50.0	80.0
	Secondary	All species	13	16.5	259.6	65.0	570.0
		Irvingia gabonensis	9	11.4	215.0	65.0	340.0
		Coula edulis	11	13.9	120.9	70.0	180.0
		Dacriodes buettneri	2	2.5	55.0	50.0	60.0
Ethnicity	Kota	All species	46	58.2	288.7	33.0	520.0
		Irvingia gabonensis	33	41.8	230.1	33.0	360.0
		Coula edulis	38	48.1	131.3	50.0	240.0
		Dacriodes buettneri	9	11.4	77.7	50.0	160.0
	Mahongwe	All species	15	19.0	425.6	60.0	610.0
		Irvingia gabonensis	14	17.7	250.3	65.0	400.0

Table 3. Contd.

		Coula edulis	14	17.7	153.5	60.0	220.0
		Dacriodes buettneri	12	15.2	60.8	50.0	80.0
	Fang	All species	5	6.3	310.0	160.0	440.0
		Irvingia gabonensis	3	3.8	260.0	240.0	300.0
		Coula edulis	5	6.3	138.0	80.0	240.0
		Dacriodes buettneri	1	1.3	80.0	80.0	80.0
	Shamaye	All species	5	6.3	219.6	24.0	570.0
		Irvingia gabonensis	3	3.8	216.6	110.0	340.0
		Coula edulis	3	3.8	116.0	24.0	180.0
		Dacriodes buettneri	2	2.5	50.0	50.0	50.0
	Kwele	All species	4	5.1	150.5	32.0	340.0
		Irvingia gabonensis	2	2.5	195.0	150.0	240.0
		Coula edulis	3	3.8	70.6	32.0	100.0
		Dacriodes buettneri	0	0	0	0	0
	Sake	All species	1	1.3	90.0	90.0	90.0
		Irvingia gabonensis	0	0	0	0	0
		Coula edulis	1	1.3	90.0	90.0	90.0
		Dacriodes buettneri	0	0	0	0	0
	Foreign	All species	3	3.8	263.3	130.0	480.0
		Irvingia gabonensis	3	3.8	176.6	130.0	220.0
		Coula edulis	1	1.3	180.0	180.0	180.0
		Dacriodes buettneri	1	1.3	80.0	80.0	80.0
Marital status	Concubine	All species	35	44.3	248.6	24.0	520.0
		Irvingia gabonensis	21	26.6	199.2	33.0	280.0
		Coula edulis	28	35.4	141.0	24.0	240.0
		Dacriodes buettneri	7	8.9	81.4	50.0	160.0
	Single	All species	13	16.5	305.7	65.0	570.0
		Irvingia gabonensis	12	15.2	208.8	65.0	340.0
		Coula edulis	10	12.7	120.0	70.0	180.0
		Dacriodes buettneri	4	5.1	67.5	50.0	80.0
	Married	All species	16	20.3	405.0	50.0	610.0
		Irvingia gabonensis	13	16.5	264.6	200.0	400.0
		Coula edulis	14	17.7	161.4	60.0	220.0
		Dacriodes buettneri	13	16.5	60.0	50.0	80.0
	Widow	All species	15	19.0	309.4	80.0	470.0
		Irvingia gabonensis	12	15.2	276.6	120.0	360.0
		Coula edulis	13	16.5	96.3	50.0	160.0
		Dacriodes buettneri	1	1.3	70.0	70.0	70.0
Reasons for entering the trade	Lack of employment	All species	55	69.6	289.6	24.0	570.0
		Irvingia gabonensis	42	53.2	230.5	33.0	360.0
		Coula edulis	45	57.0	122.4	24.0	240.0
		Dacriodes buettneri	11	13.9	67.2	50.0	80.0
	Additional income sources	All species	22	27.8	340.7	32.0	610.0
		Irvingia gabonensis	15	19.0	241.0	65.0	400.0
		Coula edulis	19	24.1	154.3	32.0	240.0
		Dacriodes buettneri	14	17.7	67.8	50.0	160.0
	Meeting consumers needs	All species	2	2.5	185.0	150.0	220.0
		Irvingia gabonensis	1	1.3	150.0	150.0	150.0
		Coula edulis	1	1.3	220.0	220.0	220.0
		Dacriodes buettneri	0	0	0	0	0
Total			79				

Table 3. Contd.

Statistical analysis		Mean income/season*			Statistical analysis	
Chi-Square	P-Value	FCFA	Min	Max	Chi-Square	P-Value
147.00	0.96	169,750.0	78,000.0	273,000.0	150.00	1.00
		130,500.0	78,000.0	192,000.0		
		54,000.0	48,000.0	60,000.0		
		24,500.0	21,000.0	28,000.0		
		175,226.7	14,400.0	377,500.0		
		154,579.6	19,800.0	280,000.0		
		68,177.8	14,400.0	154,000.0		
		21,717.4	15,000.0	48,000.0		
23.00	0.62	176,065.8	14,400.0	377,500.0	24.00	0.65
		155,078.1	19,800.0	280,000.0		
		67,675.0	14,400.0	154,000.0		
		21,687.5	15,000.0	48,000.0		
		146,666.6	78,000.0	254,000.0		
		113,333.3	78,000.0	154,000.0		
		72,000.0	72,000.0	72,000.0		
		28,000.0	28,000.0	28,000.0		
102.00	0.78	176,065.7	14,400.0	377,500.0	98.00	0.71
		155,078.1	19,800.0	280,000.0		
		67,675.0	14,400.0	154,000.0		
		21,687.5	15,000.0	48,000.0		
		146,666.6	78,000.0	254,000.0		
		113,333.3	78,000.0	154,000.0		
		72,000.0	72,000.0	72,000.0		
		28,000.0	28,000.0	28,000.0		
717.00	0.73	180,850.0	15,000.0	291,000.0	722.00	0.76
		158,692.3	66,000.0	238,000.0		
		56,933.3	25,000.0	120,000.0		
		20,666.6	15,000.0	28,000.0		
		170,931.9	14,400.0	377,500.0		
		148,228.1	19,800.0	280,000.0		
		75,421.0	14,400.0	154,000.0		
		22,342.1	17,500.0	48,000.0		
2.21	0.33	147,166.6	40,000.0	340,000.0		0.38
		154,666.6	90,000.0	192,000.0		
		85,750.0	40,000.0	120,000.0		
		38,000.0	28,000.0	48,000.0		
		183,295.0	14,400.0	377,500.0		
		154,821.7	19,800.0	280,000.0		
		68,788.0	14,400.0	154,000.0		
		20,785.7	15,000.0	28,000.0		

Table 3. Contd.

		149,253.8	40,000.0	291,000.0		
		142,611.1	45,500.0	204,000.0		
		56,436.3	28,000.0	90,000.0		
		18,000.0	15,000.0	21,000.0		
		171,467.4	19,800.0	347,500.0		
		154,266.6	19,800.0	238,000.0		
		67,742.1	25,000.0	154,000.0		
		24,722.2	17,500.0	48,000.0		
		240,633.3	30,000.0	377,500.0		
		163,678.5	45,500.0	280,000.0		
		77,000.0	28,000.0	140,000.0		
		20,000.0	17,500.0	28,000.0		
		172,200.0	96,000.0	225,000.0		
		156,000.0	144,000.0	180,000.0		
		73,000.0	32,000.0	144,000.0		
		28,000.0	28,000.0	28,000.0		
		119,000.0	14,400.0	291,000.0		
15.90	0.01**	140,333.3	77,000.0	204,000.0	14.06	0.02*
		48,000.0	14,400.0	72,000.0		
		15,000.0	15,000.0	15,000.0		
		93,500.0	16,000.0	228,000.0		
		129,000.0	90,000.0	168,000.0		
		38,666.6	16,000.0	60,000.0		
		0	0	0		
		54,000.0	54,000.0	54,000.0		
		0	0	0		
		54,000.0	54,000.0	54,000.0		
		0	0	0		
		146,666.6	78,000.0	254,000.0		
		113,333.3	78,000.0	154,000.0		
		72,000.0	72,000.0	72,000.0		
		28,000.0	28,000.0	28,000.0		
		146,208.5	14,400.0	347,500.0		
		133,323.8	19,800.0	196,000.0		
		76,178.5	14,400.0	154,000.0		
		26,357.1	17,500.0	48,000.0		
9.19	0.01**	179,115.3	40,000.0	291,000.0	7.58	0.02*
		141,458.3	45,500.0	208,000.0		
		54,300.0	28,000.0	84,000.0		
		22,000.0	15,000.0	28,000.0		
		225,937.5	15,000.0	377,500.0		
		170,769.2	120,000.0	280,000.0		

Table 3. Contd.

	81,428.5	30,000.0	140,000.0	
	19,615.3	15,000.0	28,000.0	
	184,013.3	40,000.0	267,000.0	
	179,333.3	84,000.0	238,000.0	
	45,169.2	25,000.0	64,000.0	
	21,000.0	21,000.0	21,000.0	
Test cannot be performed	170,245.4	14,400.0	347,500.0	Test cannot be performed
	152,638.1	19,800.0	238,000.0	
	60,293.3	14,400.0	154,000.0	
	21,772.7	15,000.0	28,000.0	
	193,522.7	16,000.0	377,500.0	
	157,900.0	45,500.0	280,000.0	
	83,157.8	16,000.0	144,000.0	
	22,071.4	17,500.0	48,000.0	
	100,000.0	90,000.0	110,000.0	
	90,000.0	90,000.0	90,000.0	
	110,000.0	110,000.0	110,000.0	
	0	0	0	

Season* corresponds to harvesting season. Mann Whitney U tests were performed for variables related to Gender, Nationality, trader types and job opportunities types. Kruskal Wallis tests were performed for variables related to educational levels, ethnicity, marital status and reasons for entering the trade.

Table 4. Sellers' awareness and rational for resources decline and suggested solutions for successful use and management of the resources.

Species	Awareness on resource decline			Rational of resource decline			Suggested solutions to overturn resource decline		
	Response	Count	%	Response	Key word count	%	Response	Key word count	%
Irvingia gabonensis				Climate change	21	37.5	Better climate	21	37.5
	Aware	56	96.6	Logging companies	19	33.9	Deforestation reduction	19	33.9
				Unsustainable use	16	28.6	Sustainable use	16	28.6
	Unaware	2	3.4						
Total		58	100.0		56	100.0		56	100.0
Coula edulis				Climate change	26	42.6	Better climate	26	42.6
	Aware	61	93.8	Logging companies	18	29.5	Deforestation reduction	18	29.5
				Unsustainable use	17	27.9	Sustainable use	17	27.9
	Unaware	4	6.2						
Total		65	100.0		61	100.0		61	100.0
Dacriodes buettneri				Climate change	9	39.1	Better climate	9	39.1
	Aware	23	92.0	Logging companies	7	30.4	Deforestation reduction	7	30.4
				Unsustainable use	7	30.4	Sustainable use	7	30.4
	Unaware	2	8.0						
Total		25	100.0		23	100.0		23	100.0

Table 5. Recommendations on potential regulation of commercial resources of the park.

Regulation by		Inside	Buffer zone	Outside
Quotas (Amounts)		P to P	R to A	A to A
Socio-economic status		P to P	R to A	A to A
Other options	Restocking and cultivation	P to A	R to A	A to A
	Alternative income source	P to P	P to R	A to A
	Reducing disturbances	A to A	A to A	A to A

P=Prohibit; R=regulate; A=allow.

Indeed, the effective devolution of policy tenure, power and responsibilities to local resource users has to contribute to yield collective action and equity in resources management and stakeholders' involvement in decision making over forest resources (Larson and Ribot, 2004). In Gabon, community participation in forest and national parks resources management has been acknowledged by both the Forest Code of 2001 and the National Parks of 2007; however, the transfer of rights to local groups of users appears not to be effective on the grounds. As a result, capacity building of institutions is needed to strengthen their roles in resources management.

Significant differences were also found between marital status and each of the following variables including mean amounts of wild fruits and nuts sold (X^2 =9.19, p= 0.01) and gross mean income generation (X^2 =7.58, p= 0.02) using Kruskal Wallis tests (Tables 3 and 4). This may imply that widow respondents tend to sell and generate significantly less income from wild fruits and nuts from *C. edulis* and *D. buettneri* than others marital statuses of respondents in the study. Since marital status is driving sellers' dependency on the trade of wild fruits and nuts therefore it needs to be taken into account in the future design of forest resources management in the area.

In the case of this study, limiting access to members of the same household alone or excluding other potential users may contribute to undermine the successful management of forest resources unless well-defined and clear rules directed to regulate resources use are set among community members (Ostrom et al., 1999; Poteete and Welch, 2004). Consequently, in that process, social costs and conflicts caused by such exclusionary approach have to be avoided (Lele *et al*., 2010). Avoiding such pitfalls while improving resources management has led scholars such as Ostrom (1999), Charnley and Poe (2007) and Lele et al. (2010) to take into account policy based on resources tenure and property rights changes.

In Gabon, the effective devolution of some responsibility and authority to the local community is less likely to happen given that the Gabonese government has retained the exclusive property rights and ownership over forests and land. Indeed, the ownership rights over forests have never been granted to the local communities by the Gabonese government in the country except a user fruits rights (Gabonese Republic, 2001, 2007). One of the often mentioned concerns with regards to the lack of ownership over forest resources is that local communities become more vulnerable and exposed to issues of state's land grabbing (Wily, 2011). Avoiding such issue has led Mudekwe (2007) to suggest the need for forest policy changes so that it reflects the current level of local people's dependence on forest resources upon which they depend on for years in Zimbabwe. In Gabon, the government has not yet embarked on such forest policy changes yet.

Awareness on resources decline, rational and suggested solutions to overturn such issue

Table 5 shows the relationships between sellers' awareness on resources decline, rational of their decline and suggested solutions to successful overturn such issue. Regarding respondents' awareness level, almost all sellers were aware of the decline of *I. gabonensis, C. edulis* and *D. buettneri* according to 97, 94 and 92% of the respondents respectively. Since sellers have a high level of awareness or ecological knowledge on the decline of these fruits and nuts species from the wild therefore they need to be considered as key partners in identifying species in need of conservation and their sustainable management (Gunatilake et al., 2012) at local level. At state level, the issue of resources decline is well known from the Gabonese forest's administration and the state given that a policy initiative aiming at sustainably managing forest resources has led to the ban of harvesting and commercial trade of the five multiple use species such as *Poga oleosa* (Afo), *Irvingia gabonensis* (Andock), *Tieghemella Africana* (Douka), *Baillonella toxisperma* (Moabi) *and Dacryodes buettneri* (Ozigo) (Gabonese government, 2009). Among those species include also two of the valued wild fruits and nuts of this study, especially *I. gabonensis* and *D. buettneri.*

In the case of this study, the drivers of resources decline are multiple. Among mentioned drivers include climate changes (seasonality changes, unpredicted rainfall) according to 38-43% of the respondents followed by logging companies' activities (selective and uncontrolled harvesting) according to 30-34% of the interviewees then unsustainable harvesting (no norms of harvesting) as acknowledged by 28-30% of the people interviewed (Table 5). Past and current anthropogenic pressures including land clearing for agricultural fields' establishment based on slush and burns and logging companies through selective logging operations and uncontrolled illegal logging have all certainly contributed to the decline of these multiple use timber and non timber forest products from the wild (Lescuyer, 2006, Sassen and Wan, 2006, Corblin, 2006, Viano, 2005). Indeed, locations of forests that are actually found inside and outside of the Ivindo National Park have been granted to logging operations by the forest department until 2004 and that local people get to use forest resources in those locations even before the park was gazette in 2002 (Lescuyer, 2006).

Around the Miombo woodlands in Mwekera area (Zambia), the study of et al. (2009) has contributed to highlight drivers of resources decline including the absence of rules or norms guiding harvesting of wild fruits species, deforestation caused by charcoal extraction and expansion of land for agriculture purposes. Consequently, the loss of certain species of trees from the forest may have serious livelihoods implications for rural people who depend on those forest resources. In other words, fewer trees may mean less forest products upon which local people would derive foods and income from for household livelihoods maintenance. The issue of loss of forest and its negative impacts on local people livelihoods is even more enhance in absence of domestication initiatives and alternatives livelihoods provision by the state to those people (Kalaba et al., 2009).

In this study, some of the solutions to overcome the issues of resources decline have been suggested by the respondents themselves and are among the following "Better climate", "Deforestation reduction" and "Sustainable use" according to 38-43, 30-34 and 28-30% of the respondents respectively (Table 5). Indeed, improving the management of forest resources inside and outside of the park through a "Better climate" driven by the unpredictability of rainfall might be a less plausible solution to achieve on the ground due to difficulty in predicting rainfall. According to Dale et al. (2001), climate change can have an impact on forests structure and composition on one hand while it influences also the severity and magnitude of forest disturbances through rainfall shift on the other hand.

Regarding the others two suggested solutions to overcome the issue of resource decline including, the "reduction of deforestation" through the ban of logging activities inside of the park might contribute certainly to lower the impact of past anthropogenic pressures on the population of species. However, this suggested solution could not contribute to stop people from accessing and using illegally these forest resources in the long term as a result of several issues including the lack of: (i) resources ownership granted to local people by the state, (ii) domestication initiatives to alleviate household dependence on resources base, and (iii) alternative livelihood provision to the households in the area.

Regarding the last suggested solution and knowing that one of the key concerns of local people and parks' managers is the increasing scarcity of valued forest resources including fruits and nuts species from the wild therefore "Sustainable use" may represent a viable solution to overcome the observed issue of resources decline. In Gabon for example, since the country has turned towards the diversification of its economy through the development of Non Timber Forest Products based enterprises it is therefore crucial for the Gabonese government to take into consideration such sustainable use mechanism as a part of the country innovative approach to regulate and overturn issue of resource decline for both livelihoods sustainability and biodiversity conservation.

Until such a mechanism is in place, several trials and errors experiments are still needed to be carried out before it being widely used throughout the country as a magic solution. Achieving that would more likely ensure future access of forest resources for local people while pursuing at the same time government conservation's efforts as suggested by Mudekwe (2007) in Zimbabwe. Others options falling within sustainable use management of these valuable wild fruits and nuts species may include setting up quotas over harvesting of valued forest resources, restocking of wild species coupled with the implementation of domestication initiatives (local planting) of these forest products in the fields (Maghembe et al., 1998; Leakey et al., 1994; Akinnifesi et al., 2006). Among others valuable solutions to lower local people's dependence and pressure on the wild forest products may also include provision of alternative income sources to local people through proper incentive (DeFries et al., 2007; Davidar et al., 2010). Above all, this study has come up with the following mechanism (author suggestions) as a way to regulate sustainably the trade of the three valued wild fruits and nuts species gathered from different locations of the Ivindo National Park as shown (Table 5).

Conclusion and recommendations

The contribution of wild indigenous fruits and nuts gathered from different locations of the Ivindo National Park in sustaining the livelihoods of sellers has been clearly shown in this study since these forest products represent an integral part of the livelihoods of rural sellers as source of income generation. *Coula edulis* and *Irvingia gabonensis* appear to be the most popular traded wild fruits and nuts with regards to the proportion of people involved in the trade, mean amounts of resources sold, gross mean income and their marketed price while *Dacryodes buettneri* is acknowledged as the least popular fruits species.

Since *I. gabonensis* fruits species is fetching a higher market price followed by *C. edulis* and *D. buettneri* therefore it can be stressed that traders depend most on forest resources of higher market value in the study. This study also contributes to show that traders' dependency on forest resources of higher market value is not without any consequence on outsourced resources from the wild. Furthermore, since marital status (social) and ethnicity (affinity with forest resources) of sellers seems to drive people's involvement into the trade of wild indigenous fruits and nuts for income generation therefore these key variables need to be considered in regulating such commercial trade of forest products in the study.

Despite the importance of wild indigenous fruits and nuts as source of income, resources decline have been acknowledged by almost all the sellers. Drivers of resources decline include the impacts of logging companies (selective logging), climate change (unpredictability of rainfall) and unsustainable harvesting practices of these wild indigenous fruits and nuts' species. In addition, achieving conservation and sustained livelihoods of rural sellers call for a careful implementation of the mechanism suggested to regulate market demands of these valued wild resources in the study area. Moreover, further studies should aim at looking on the practical approach of setting up quotas based harvesting of these wild indigenous fruits and nuts for resources management purposes.

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Conflict of interests

The authors did not declare any conflict of interest.

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Social organization in the mountain nyala (*Tragelaphus buxtoni*) population in the Bale Mountains National Park, Ethiopia

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This study was conducted in 2009 and 2011 in the Bale Mountains National Park in Ethiopia to assess social organization of endemic and endangered mountain nyala. The main objectives of this study were to identify social group types of the mountain nyala in the park, and to determine the frequency of occurrences, group sizes and number of age/sex categories in social group types. Based on age/sex composition, five social group types were distinguished: all-male, all-female, male-female, female-juvenile and male-female-juvenile group types. A total of 572 groups and 5187 individuals of mountain nyalas were recorded during the study period. Overall mean and typical group sizes for the species were 9.1 ± 0.5 (range: 1–107) and 24 animals, respectively. Male-female-juvenile social group type was the most frequently observed group type (31% of the total records), contained the highest proportion of animals recorded (64%) and had the largest mean group size (18.5 ± 0.8) and typical group size (31.9) than the other social group types. Lone animals constituted 16.3 and ~2% of the total groups and animals recorded, respectively, in which over two-thirds of them were adult males. Both mean number and proportion of individuals of each age/sex category across social group types significantly increased when they were associated with one or two other age/sex categories than when not associated. In general, data presented here represents the first detailed information available on the species' social organization behaviour and provides important base-line information.

Key words: Group size, mountain nyala, park, social group, social organization.

INTRODUCTION

The mountain nyala (*Tragelaphus buxtoni*) Lydekker (1911) is a spiral-horned antelope endemic to Ethiopia (Brown, 1969; Yalden et al., 1984). This species has been declining considerably both in number and distribution (Stephens et al., 2001; Befekadu and Afework, 2004; OARDB, 2007; Evangelista et al., 2008; Malcolm and Evangelista, 2011; Yosef et al., 2010). It inhabits three discrete mountain ranges in Ethiopia's south-eastern highlands (the Ahmar, Arsi and Bale Mountains); with the majority of the population (80% of the total) being persisting

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in the Bale Mountains, it has an estimated global total population of 3,500-4,000 animals (Evangelista et al., 2008; Manor and Saltz (2003); Malcolm and Evangelista, 2011; Yosef et al., 2012). These recent reports show the substantial population decline that mountain nyala has been experiencing as Yosef (2007) estimated the total population of mountain nyala ranging between 1720 and 2035 individuals; when compared with earlier report of 7000-8000 animals by Brown (1969). It is currently listed as an endangered species by IUCN which has been primarily attributed to uncontrolled hunting and habitat loss and degradation (IUCN, 2013). Thus, given its national and global conservation significances and the ever increasing threats facing it through direct and indirecthuman-inducedactivities(Malcolmand Evangelista, 2011; IUCN, 2013), having detailed information regarding the biological and ecological aspects of the species has been identified as one of the top management-oriented priority research topics by the Bale Mountains National Park (BMNP) management (OBARD, 2007).

Previous studies on mountain nyala have been primarily focusing on its distribution, activity patterns, population status and structure (Brown, 1969; Hillman, 1986; Woldegebriel, 1997; Stephens et al., 2001; Befekadu and Afework, 2002, 2004; Malcolm and Evangelista, 2011; Anagaw et al., 2011, 2013 Yosef and Afework 2013). Detailed information on aspects of their social grouping is lacking and as such, the aim of this study was directed at filling this gap and providing baseline information against which future works can be compared

Social organization in ungulates is considered to be the adaptive outcome of selective pressures arising from predation and intra- and/or inter-specific competitions (Leuthold and Leuthold, 1975; Gerard and Loisel, 1995; Desbiez et al., 2010). Several studies have suggested that such social organization is affected, separately or interactively, by a number of factors such as predation and human-induced disturbances (Leuthold and Leuthold, 1975; Hillman, 1986, 1987; Gerard and Loisel, 1995; Befekadu and Afework, 2004; Loe et al., 2006; Stankowich, 2008). For instance, a study of kob antelope (*Kobuskobkob*) population in Comoé National Park, Côte d'Ivoire, which was suffering from heavy over-hunting by both natural predators and humans, found that population decline resulted in changes to the social organization of the species (Fischer and Linsenmair, 2007).

This implies that data collected on patterns of ungulate social grouping is of paramount importance for conservationists as this information, if gathered on regular time intervals, could help detect changes in the patterns, which in turn aids to assess the underlying causes; and develop appropriate management actions required to abate the causes (Jarman, 1974; Fischer and Linsenmair, 2007; Bagchi et al., 2008). Although acquiring detailed information on wild ungulates' social behaviour is acknowledged for effective conservation management, such datais lacking for several of Ethiopian's endemic species, including the endangered mountain nyala (*T. buxtoni*). This study was, therefore, undertaken to: (1) identify the social group types of the mountain nyala population in the BMNP; (2) determine the frequencies, group sizes and group compositions (numbers of age/sex categories) of the social group types; and (3) investigate the effects of habitat type on these variables.

MATERIALS AND METHODS

Study area

BMNP was established in 1971. It is situated between 6° 29' and 7° 10'North, and 39° 28'- 39° 58' East. The current area of the Park is 2200 km^2 and covers a landscape that ranges in altitude from 1500 to 4377 m asl (Hillman, 1986; OBARD, 2007). The park encompasses five vegetation zones: the northern grasslands, northern woodlands, Ericaceous forest, the Afro alpine moorlands and grasslands, and southern Harenna forest (OARDB, 2007). Seventy-eight mammals and 278 bird species have been recorded from the BMNP; of which 20 mammals and six bird species are endemic to Ethiopia (Addisu, 2007, 2011). The area usually receives eight months (March to October) rainfall a year (Hillman, 1986).

The present study (Figure 1) was carried out in the northern section of BMNP, encompassing two (i.e. the northern grasslands and northern woodlands) of the five vegetation zones in the park. These habitats harbour over 75% of BMNP's mountain nyala population (Hillman, 1986; Befekadu and Afework, 2004; Malcolm and Evangelista, 2011). The landscape is characterized by mountainous ranges with a central broad flat valley and varies in elevation from 3000 to 3550m asl. The mountainous areas are covered by three isolated forest patches [namely: Adellay forest (location, 6°50' N and 39°33' E), Boditti (6°57' N and 39°33') and Dinsho hill (6°50' N and 39°36' E)], which is dominant by *Hagenia abyssinica* and *Juniperus procera* tree species (OARDB, 2007). The central flat valley (also known as Gaysay valley; 6°53' N and 39°33' E) is generally classified as a montane grassland ecosystem and is dominated by swamp grasses and sedges of *Cyperus* and *Scirpus* genera and low bushes of *Artemesia afra* and *Helichrysum splendidum* (Befekadu and Afework, 2004; Bezawork et al., 2009; OBARD, 2007; Yosef et al., 2012).

Data collection

The three forest patches and Gaysay valley were delineated as four separate blocks and data collection in these blocks was done during August to October both in 2009 and 2011. Observations in each block were made on different days, but under similar weather conditions and within similar time of the day (early in the morning from 07:30 to 10:30 h and late in the afternoon from 14:30 to 17:30 h), when the animals are more active (Befekadu and Afework, 2004). Each block was visited four times in each year by same two people and observations were aided by 8 × 40 Nikon Binoculars. Data recorded whenever a group of mountain nyala was observed were: block name, date, time, group size, group composition and habitat type. Operational definition of a 'group' used in this study was: any number of animals of the species found together at any point in space and time, within a distance of less than 50 m between them, and apparently in sensory contact with one another(Leuthold and Leuthold, 1975; Hillman, 1987).

Previous reports indicate that young males of mountain nyala leave nursery groups and associate with adult males when they become sub-adults and sub-adult females usually remain in the nursery groups until they give birth (Hillman, 1986; Befekadu and

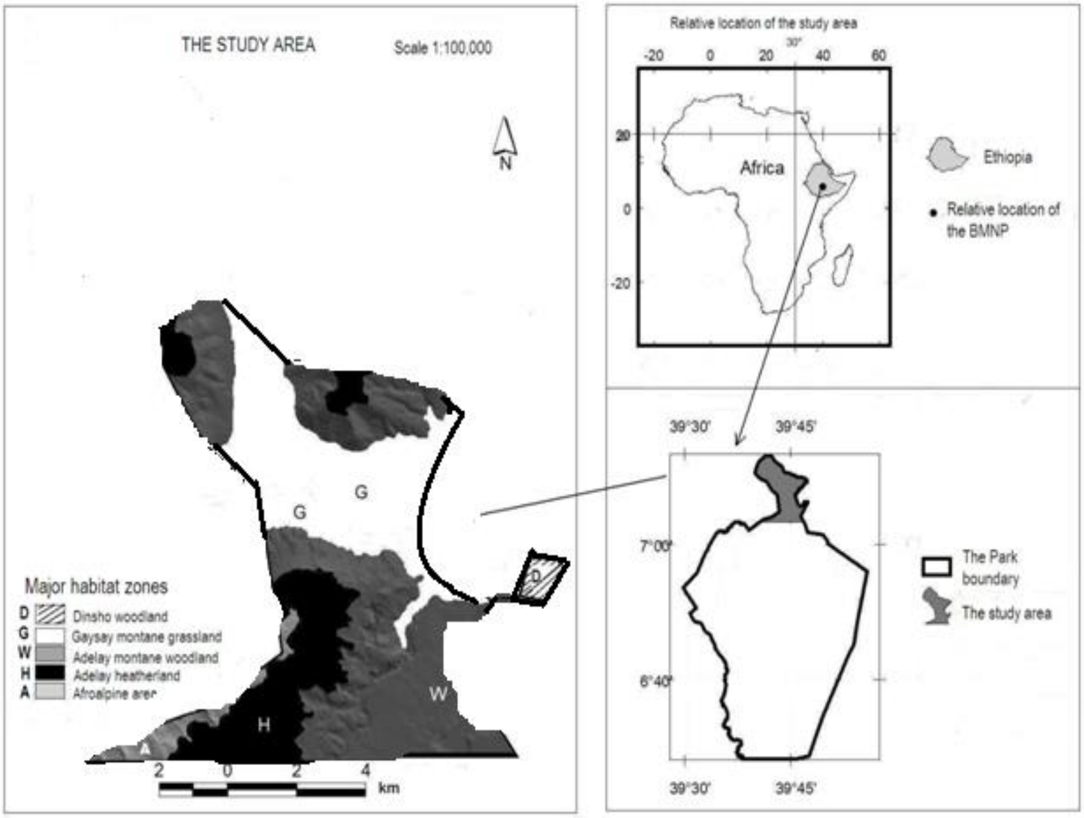

Figure 1. Map of the study area.

Afework, 2004). Thus, the composition of all mountain nyala groups seen over the study period was recorded using three age/sex categories: adult male (old and young/sub-adult males), adult female (old and young/sub-adult females) and juveniles of both sexes (immature and calves of both sexes). This distinction was made based on body size and other morphological features like presence/absence and size of horns. As (sub)adult of mountain nyala show sexual dimorphism (only males' bear horns) and juvenile males bear smaller horns and juvenile females are smaller in body size than (sub)adult females, it was possible to accurately assign individuals of the species to age/sex categories. For each group observation, habitat type within which it was observed was also recorded as either forest woodland or open grassland.

Data analysis

Data from the eight counting sessions over the two years were combined due to small sample sizes to analyze them separately. Social group types of the mountain nyala were identified based on each recorded group's composition of the three different age/sex categories; thus, records with similar composition were classified as one of the possible social group types.

Differences in relative frequencies of occurrences of the whole mountain nyala groups and occurrences of each social group type between habitat types and in frequencies of occurrences of each pair of the social group types within and across habitats were tested using Chi-square tests. Chi-squaretests were also used to test differences in the proportions of animals recorded across and between each pair of group types. Group size data was expressed in three ways: as mean group sizes, typical group sizes and group size frequency distributions. Mean values are more useful to compare different sets of data; whereas typical group size expresses the group size experienced by the majority of individual animals, and frequency distributions are better to illustrate the actual grouping patterns of a given species and/or group type of the species (Jarman, 1974; Hillman, 1987; Bagchi et al., 2008). Levene's test of equality of variances of the group sizes of mountain nyala across group types was significant ($F_{4, 567}$ = 24.430, P< 0.005) and log-transformation of the raw-data did not improve the fit of the data (Levene'stest:$F_{4, 567}$= 2.950, P< 0.005). Thus, non-parametric tests (Kruskal-Wallis and Mann-Whitney tests) which do not assume homogeneity of variance were used to compare mean group size differences across social group types, of each social group type between habitat types and between each pair of the social group types within and across habitats. 'Typical group size' of each group type was estimated from the sum of the squares of all individuals in all groups of that group type, divided by the total number of individuals recorded for that group type (Jarman, 1974, Hillman, 1987). To see how patterns of group size distributions differ across the social group types, all groups recorded for each group type were classified into five group size categories (Bagchi et al., 2008): solitary (single animal), family unit (2–3 animals), small groups (4–6 animals), medium groups (7–10 animals) and large groups (>10 animals), and percentage relative frequencies of the number of groups recorded in each group size category for each group type were graphically illustrated. Results of ANOVA analysis of the numbers of each age/sex category across the social group types showed heterogeneity of variance in all cases. Thus, the non-parametric tests of Kruskal-Wallis and Mann-Whitney were used to see differences in mean number of each age/sex category across and between pairs of the social group types, respectively. All these analyses were conducted in SPSS version 20.

RESULTS

Social group types

Based on the composition of the three different age/sex categories, five consistently seen social group types were identified: (1) all-male group type (groups containing only sub-adult males), (2) all-female group (groups containing only sub-adult females), (3) male-female group (groups containing only sub-adults of both sexes), (4) female-juvenile groups (groups containing sub-adult females and juveniles and calves), and (5) male-female-juvenile group (groups containing sub-adults of both sexes and juveniles and/or calves).

Group type frequency and proportion of animals seen in each

The relative frequency of occurrence of each social group type of mountain nyala and the proportions of animals recorded in each of them are presented (Table 1). A total of 572 groups consisting of 5187 animals of mountain nyala were recorded during the study period. Independent of group type, the relative frequencies of occurrences of mountain nyala groups recorded was significantly different between habitat types ($\chi2$ =139.028, df = 1, $P<$ 0.05 (Table 1a), being higher in the woodlands. However, when each group type was considered separately, no significant difference between habitats was found for any of them in this regard (in all cases, $\chi2$ = 0.000–0.006, df = 1, $P<$ 0.05 (Table 1a). Similarly, non-significant differences were found within each habitat type across the group types in their relative frequencies of occurrences (woodland: $\chi2$= 0.221, df = 4, $P<$ 0.05; Grassland: $\chi2$= 0.130, df = 4, $P<$ 0.05). Regardless of habitat type, the relative frequencies of occurrences of mountain nyala groups recorded was significantly different across group types ($\chi2$= 196.503, df = 4, $P<$ 0.05 (Table 1a). The male-female-juvenile group type was the most frequently observed (31% of the total group records), followed by female-juvenile group type (26%), all-male group (18%), all-female group (15%) and male-female group (11%). However, significant differences between each pair of group types in this aspect were found only between all-female vs. male-female-juvenile, male-female vs. female-juvenile and male-female vs. male-female-juvenile group types ($\chi2$ = 5.262–9.809, df = 1, $P<$ 0.05 in all cases (Table 1a).

Regardless of habitat type, the proportions of animals recorded in each group type were also significantly different across the social group types ($\chi2$ = 131.821, df = 4, $P<$ 0.001). Over two-third (64%) of the total animals recorded were in the male-female-juvenile group type, while female-juvenile group type contained the second highest proportion (21%), both of which were significantly different from each other, as well from the other group types ($\chi2$ = 7.026–55.736, df = 1, $P<$ 0.001 in all cases (Table 1b). However, no such significant difference was detected between pairs of all-male, all-female and male-female group types ($\chi2$ = 0.213–1.473, df = 1, $P>$0.05 in all cases (Table 1b).

Group size

Habitat type had no significant effects on the mean group sizes of mountain nyala either when the social groups were treated together (Mann-Whitney U = 29704.500, $P>$ 0.05) or separately (in all cases, U = 259.00 - 2787.500, $P>$ 0.05). However, the effects of habitat was revealed when mean group sizes of each possible pair of the five social group types were compared within each habitat type, of the twenty (ten in each of the two habitat types) comparisons made, a non-significant result in mean group size difference was found only between male-female and female-juvenile group type in the grassland habitat (Mann-Whitney *U:* 205.500, $P>$ 0.05; (Table 1). With the exception of a non-significant result just mentioned above, in both habitat types, the differences observed were in the direction of: male < female <male-female < female-juvenile < male-female-juvenile.

Combining data from the two habitat types, a significant difference in mean group sizes of mountain nyala groups was found across the social group types (Kruskal-Wallis test: $\chi2$ = 359.908, df = 4, $P<$ 0.05). Regardless of the different social group types, the overall mean (± S.E.) group size of mountain nyala was 9.1 ± 0.5 (Range = 1–107; Table 2), with typical group size of 24 animals. When group types were considered separately, male-female-juvenile group type had significantly larger mean and typical group sizes (mean ±S.E.= 18.5 ± 0.8; typical =31.9), while all-male group type had the smallest mean and typical group sizes (mean ± S.E.= 1.5 ± 1.0;typical = 2.2) as comparison to other group types (Table 2). In general, similar to the results found while treating data from the two habitat types together, mean group sizes of the group types also significantly differed from each other when data from the two habitat types were lumped (in all cases, Mann-Whitney U: 105.000-4942.500,$P>$ 0.05), the differences observed being in the direction similar to what was reported above for each habitat type.

Given the non-significant effects of habitat type on the mean group sizes of mountain nyala either when the social groups were treated together or separately, the relative frequencies of group size distributions of (% of total records) and percent proportion of animals recorded in each group size category for each social group type was illustrated independent of habitat type (Figure 2).

When all the group types were considered together, percentage of mountain nyala groups recorded across the group size categories were almost uniform, but the largest proportion of animals occurred in the large group size category (> 10 animals). In the all-male group type, solitary and groups of small number of animals were common, with the majority of animals occurring in solitary

Table 1. Frequency of social group types and proportion of animals seen in each.

Habitat type	Social group type					
	M	F	MF	FJ	MFJ	Total
(a) Frequency of social group types (% total; n = 572)						
Grassland	25(17.2)	17(11.7)	13(9.0)	45(31.0)	45(31.0)	145(25.3) [a]
Woodland	78(18.3)	70(16.4)	48(11.2)	99(23.2)	132(30.9)	427(74.7) [b]
Total	103(18.0)[a]	87(15.2)[ab]	61(10.7)[abc]	144(25.2)[abd]	177(30.9)[ad]	572(100.0)
(b) proportion of animals seen in each social group type (% total; n = 5187)						
	Social group type					
	M	**F**	**MF**	**FJ**	**MFJ**	
	3.0[a]	5.2[a]	6.8[a]	20.7[b]	64.2[c]	

Abbreviations for social group types: M = all-male; F = all-female; MF = male-female; FJ = female-juvenile; MFJ = male-female-juvenile.Values outside brackets are absolute frequencies, while those inside are relative frequencies expressed in percentages. Significant differences (at 0.05 significant level) are indicated by different superscript letters: the letters under the column 'total' shows between habitat differences, while those across the raw 'total' shows differences between each pair of social group types.

Table 2. Mean group size (M.g.s.) and 'typical' group size (T.g.s.)± S.E. of social group types.

Habitat type	Parameter	Social group type					
		M	F	MF	FJ	MFJ	Overall
Grassland	M.g.s. ± S.E.	1.3 ± 0.1	2.4 ± 0.4	5.0 ± 0.1[a]	6.7 ± 0.7[a]	18.0 ± 2.3	8.6 ± 0.9
	Range	1-2	1-7	2-13	2-20	3-69	1-69
	T.g.s.	1.4	3.4	7.8	10.1	30.6	22.8
Woodland	M.g.s. ± S.E.	1.6 ± 0.1	3.3 ± 0.3	6.0 ± 0.1	7.8 ± 0.6	19.0 ± 1.4	9.2 ± 0.6
	Range	1-7	1-11	2-28	2-36	3-107	1-107
	T.g.s.	2.4	4.8	10	12.8	32.4	24.3
Overall	M.g.s. ± S.E.	1.5 ± 1.0	3.0 ± 1.1	5.7 ± 1.3	7.4 ± 0.8	18.5 ± 0.8	9.1 ± 0.5
	Range	1-7	1-11	2-28	2-36	3-107	1-107
	T.g.s.	2.2	4.6	9.6	12.1	31.9	24

Unless indicated by the same superscript letters, mean values of the five group types presented in each habitat and overall (combined habitat) are significantly different from each other in the direction indicated: M <F < MF < FJ < MFJ; while mean values of each group type and all groups are significantly different between habitats.

groups; while family- and small-sized groups were the most common group sizes in all-female groups with the majority of animals occurring in the family group size. Female-juvenile and male-female-juvenile group types were characterized by small and large group sizes, respectively, with the largest proportion of animals occurring in the large group size category for both cases (Figure 2).

Number of age/sex categories in each group type

Kruskal-Wallis test showed that there were significant differences in mean number of animals of adult males, and of adult females, across the different group types (adult male, $\chi2 = 33.950$, df = 2; and, adult female, $\chi2 = 99.175$, df = 3, $P< 0.001$ in both cases). In general, mean number of individuals of each age/sex category significantly increased when they were associated with one other age/sex category than when not, and this increment was more pronounced when each of them were associated with the other two age/sex categories (in all cases, adult male, Mann-Whitney *U*: 2471.000–5570.500; adult female, *U*: 2118.500–7659.500; juveniles, *U*: 6616.500; $P < 0.05$) (Figure 3). Proportion of number of animals of each age/sex category across the social group types showed that 60–70% of animals of each of them were recorded in the male-female-juvenile group type (Figure 4).

Lone mountain nyalas

Ninety-three (16.3%) of the total groups recorded were

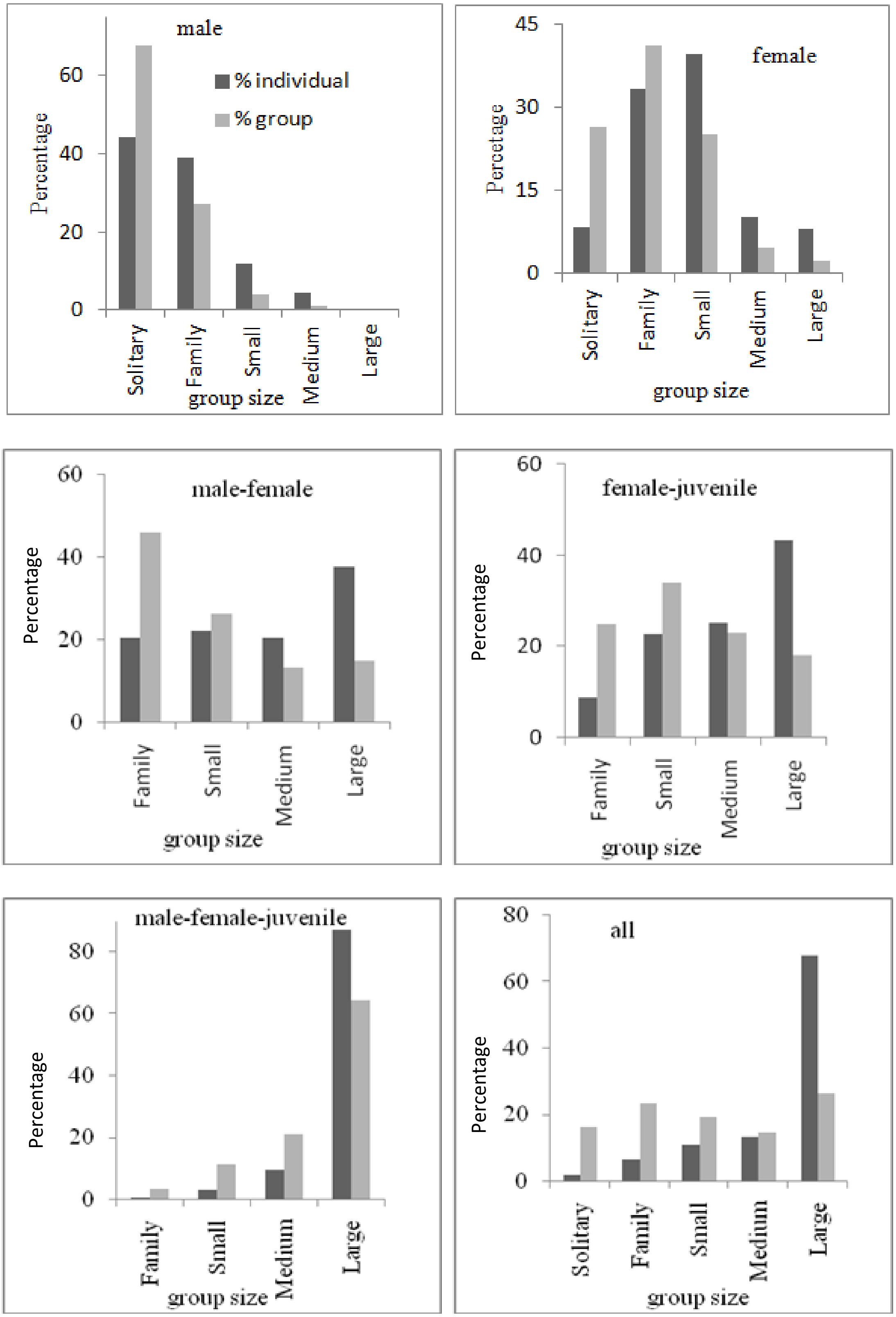

Figure 2. Group size frequencies (in % of all groups recorded for that group type) of each social group type of mountain nyala and number of animals seen (in % of all individuals recorded for that group type) in each group size category of each social group type. Group size categories were defined as: solitary = single animal; family unit = 2–3 animals; small groups = 4–6 animals; medium groups = 7–10 animals; and large groups >10 animals.

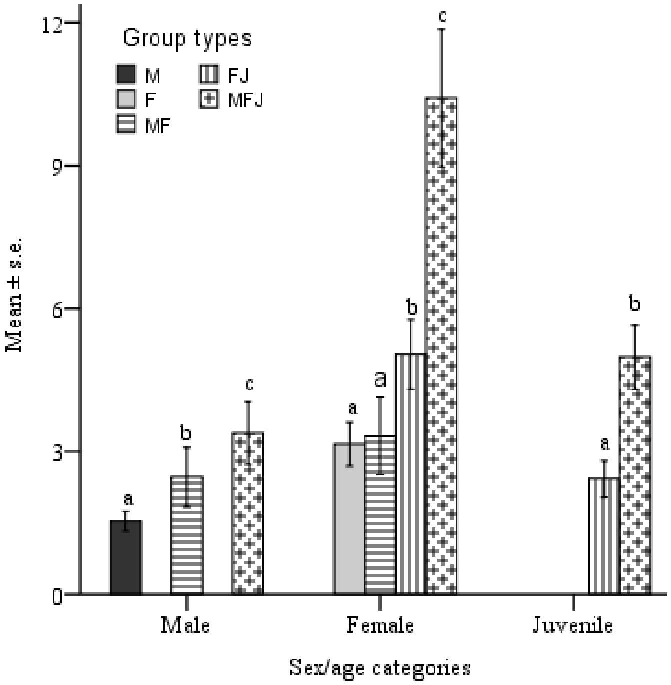

Figure 3. Mean (± S.E.) number of individuals of each age/sex categories in each social group type of mountain nyala. For each age/sex category means indicated by different letters are significantly different across the social group types at 0.05 significant level with Mann-Whitney test. Abbreviations for social group types are as defined in Table 1.

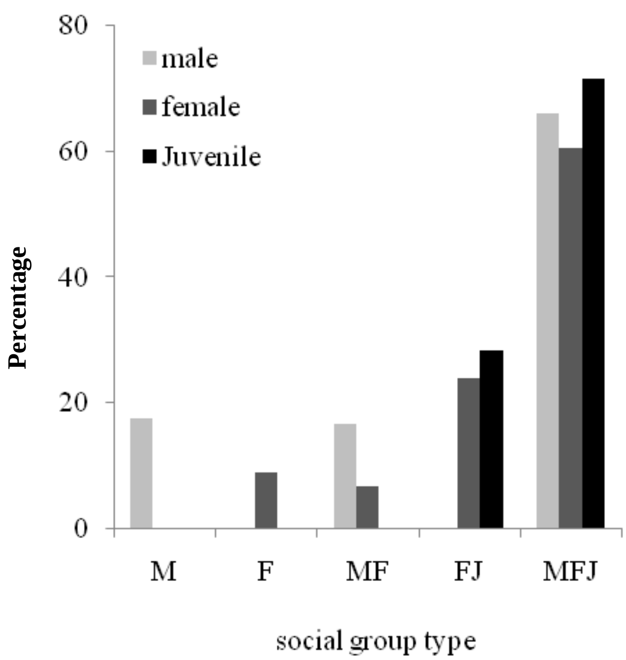

Figure 4. Proportion and percentage of each age/sex category recorded across social group types (Abbreviations for social group types are as defined in Table 1).

lone animals, representing 1.8% of the total animals observed for mountain nyala. Over two-third (70 records or 75.3%) of the loners were males and juveniles were not seen alone, implying that adult male nyala relatively shows higher tendency to exhibit solitary behavior. These figures represent 20.5 and 4.9% of all group records, and 7.7 and 0.8% of all individuals seen for male and female mountain nyalas, respectively.

DISCUSSION

This study relatively presented detailed data, as compared to others studies (Befekadu and Afework, 2004; Yosef et al., 2010, 2012), on the species concerning patterns of social organization mainly, focusing on frequencies of occurrences, group sizes and compositions of the different social group types, as well as the influence of habitat type on these attributes. Although habitat type had a significant effect on the frequency of occurrence of overall mountain nyala groups in the study area, this effect was non-significant when each social group type was separately considered. Furthermore, no significant effects of habitat type on mean group sizes of overall groups and each group type were revealed. These results, particularly, in the case of mean group sizes, contrast with the general presumption that ungulates form larger group sizes in open habitats than in dense habitats, which is mainly attributed to a defensive mechanism against higher predation pressure in open habitats (Leuthold and Leuthold, 1975; Hillman, 1987; Gerard and Loisel, 1995; Tadesse and Kotler 2014; Loe et al., 2006). Thus, this lack of differences between open grassland and woodland habitats in the present study may be due to the similarities existing between the two habitats in the stimuli (e.g. resource availability, competition, predation and/or disturbances) in response to which the formation of social organization of the species was necessitated.

Previous reports indicate that young (juveniles and calves) of both sexes of mountain nyala usually associate with adult females until they become sexually mature (Hillman, 1986; Befekadu and Afework, 2004). Similarly, juveniles were not encountered in the absence of females during the present study, indicating the presence of strong bond between mothers and juveniles/calves. Thus, as suggested by Hillman (1986), the basic social unit of mountain nyala consists of an adult female with her offspring from the past one or two births and these family units often aggregate, forming large groups. This is easily seen (Figure 2) where family (2–3 animals) and small (4–6 animals) group sizes of mountain nyalas were the most common of any group type where females were present, except when all age/sex categories were considered together which formed larger group sizes due to aggregations of different family units.

Overall group size, the low incidence of lone animals and preponderance of lone adult male of mountain nyala reported here are also consistent with the previous reports (Hillman, 1986; Befekadu and Afework, 2004). Coupled with the occurrences of several adult males together within a male-female and male-female-juvenile group types (as observed in the present study), such low incidence of lone animals (particularly, of adult males) in antelopes is an indication of the non-territorial behavior exhibited by adult males of such species (Leuthold and Leuthold, 1975; Hillman, 1987), which is in accordance with the suggestions of Hillman (1986) and Befekadu and Afework (2004) for mountain nyala. Although males of mountain nyala are presumed to be non-territorial, they usually leave groups and become solitary when they get older (Hillman, 1986; Befekadu and Afework, 2004). The tendency for adult males to become solitary when they get older has also been reported for other ungulate species, such as common eland (*Tragelaphus oryx*) and African buffalo (*Syncerus caffer*) (Hillman, 1987). However, it is noted that such solitary adult males of the common eland, a species known to exhibit a non-territorial behaviour, often return to nursery groups periodically and continue to contribute to reproduction, while those of the African buffalo, a territorial species, do not rejoin groups and not contribute to reproduction there after (Hillman, 1987). In the case of mountain nyala, whether these solitary males remain in a solitary state or rejoin the male-female and/or nursery groups and continue to contribute to reproduction is yet to be demonstrated and requires further study based on long-term observations of individually known animals and/or on the age effects of testes activity of such old males (Hillman, 1987).

Population fluctuations in ungulate species due to natural and/or unnatural factors results in changes in patterns of their social grouping (Fischer and Linsenmair, 2007; Bagchi et al., 2008), suggesting that monitoring of such behaviour could indicate the population status or the presence of some sort of threatening factors operating against them. For instance, a comparative study of Fischer and Linsenmair (2007) on the kob antelope in the Comoé National Park, Côte d'Ivoire, showed that groups with five and less animals made up 34.9% of all observed groups in 1993 when their population was at normal density, but their percentage increased to 70% in 1998 after heavy population decline. Therefore, frequency of group size distribution presented here for mountain nyala shows the pattern existing among the different group types at present and thus constitutes important base-line data for managers of the species. Future changes could be interpreted as a warning sign that necessitates investigation into the underlying causes in order to take appropriate mitigation measures.

The male-female-juvenile and the female-juvenile group types, respectively, were the first and second most frequently observed and with the highest mean group sizes than the other group types. This perhaps indicates that group types containing juveniles generally occur most frequently and with large aggregations of animals than group types without juveniles, which is consistent with the results reported for similar larger antelopes, such as the common eland (Hillman, 1987). The data also showed that all the three age/sex categories attained their first and second maximum mean numbers and proportions in these group types (Figures 3 and 4). Although the reason why such large congregations occurred in groups of mountain nyala containing juveniles is unclear, several factors such as the presence of tendencies for juveniles to associate with their peers, predation and/or human-induced disturbances could be among the major causes of such aggregations (Leuthold and Leuthold, 1975; Hillman, 1987; Loe et al., 2006; Stankowich, 2008). As observed in other ungulates (Hillman, 1987), if there is a tendency for juveniles of mountain nyala to associate with their peers, to which adult females are attracted, this would result in theformation of large groups in the female-juvenile group type. The occurrence of large number of females together in the female-juvenile group type, on the other hand, could increase the number of estrous females in the group, to which males are attracted, thus resulting in such disproportionately higher group size in the male-female-juvenile group type.

Predation is known to be another factor that shapes patterns in social groping in ungulates (Leuthold and Leuthold, 1975; Hillman, 1987; Loe et al., 2006). Although several wild and domestic carnivores have been reported to predate upon mountain nyala (Hillman, 1986), the main diurnal predators [of juvenile mountain nyala, in particular] are semi-feral/domestic dogs (*Canis familiaris*) Addisu, (2008). Post-mortem data collected during 2002–2007 showed that 89% of mortality cases reported for juvenile mountain nyala were due to hunting by semi-feral/domestic dogs (Addisu, 2008). Thus, the higher aggregation in the nursery groups was perhaps in response to such predation, since large group benefits from the group's dilution effect and improved predator detection probability (Hillman, 1987; Fischer and Linsenmair, 2007). This might hold true as there has not been reports on adult mountain nyalas being hunted by dogs (Hillman 1986; Addisu, 2008) and are therefore not often forming such large groups unlike the nursery groups that usually suffer from such dog predation. In addition to dog predation, anthropogenic disturbances due to unrestricted human and livestock movement in the area (Befekadu and Afework, 2004; OARDB, 2007; Bezawork et al., 2009; Yosef et al., 2012) could also play an important role in shaping the grouping pattern reported here (Stankowich, 2008).

In conclusion, the cumulative results obtained from the frequency of occurrences of the different social group types, as well from their group sizes and compositions, can provide important information for managers of a number of endangered wildlife species, including the mountain nyala, as changes in these patterns over time would make these managers to investigate the underlying causes and take appropriate conservation measures. However, it has been noted that social organization in ungulates is often in state of flux lasting from a few hours to several days in response to different environmental factors (Hillman, 1987; Loe et al., 2006; Fischer and Linsenmair, 2007; Bagchi et al., 2008). Therefore, long-term observations on individually known animals of mountain nyala are required to elucidate the durability /stability of the social associations reported here.

Conflict of interests

The authors did not declare any conflict of interest.

Abbreviations: ANOVA, Analysis of variance; **BMNP,** Bale Mountains National Park; **IUCN,** International Union for Conservation of Nature and Natural Resources.

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Full Length Research Paper

The diversity, abundance and habitat association of medium and large-sized mammals of Dati Wolel National Park, Western Ethiopia

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Knowledge of the faunal diversity, abundance and habitat preference are basics for the status determination and proposing appropriate conservation measures. A survey was conducted to assess the diversity, relative abundance and habitat association of medium and large-sized mammals of the Dati Wolel National Park, Western Ethiopia from September 2012 to April 2013. It was hypothesized that the area is rich in mammalian species that prefer to live in grassland and woodland close to water source. Four habitat types were assessed during the study (wetland, woodland, riverine forest and grassland). Line transect survey method was used to collect data in the four sampled habitats. A total of 28 mammalian species were recorded. Woodland was the habitat with the most diversity of mammals (H' =2.643) followed by riverine forest (H' = 1.60677), and the wetland was considered the habitat with the least diversity of species (H'= 1.04086). *Hippopotamus amphibius* (hippopotamus; 43.92%) and *Syncerus caffer* (African buffalo; 33.3%) were the most abundant species, while *Mellivora capensis* (honey badger) and Ichneumia *albicauda* (black backed jackal) were the least observed (0.099%, each). The greatest species similarity was recorded between woodland and grassland (SI=0.76) and the lowest was between woodland and wetland (SI= 0.4). Thorough inventory for faunal diversity, involving multiple seasons and all vertebrates, strengthening the now loose park management by involving the local people will ensure the sustainability of the ecosystem in supporting the riche biodiversity components.

Key words: Diversity indices, evenness, habitat preference, mammals, species richness, transect lines.

INTRODUCTION

The mammalian fauna of Ethiopia is under study (Bekele and Yalden, 2014). Yet, with about 320 species currently recorded, the country is one of Africa's most diverse nations for mammals (Vreugdenhil et al., 2012). Among these, 36 species are endemic, about a quarter of which are large mammals (Tefera, 2011). Endemism even occurs at the level of genera with six endemic genera of mammals recorded so far of which four are monotypic (Mega-dendromus, Muriculus, Nilopegamys, and Theropithecus) and the other endemic genera are

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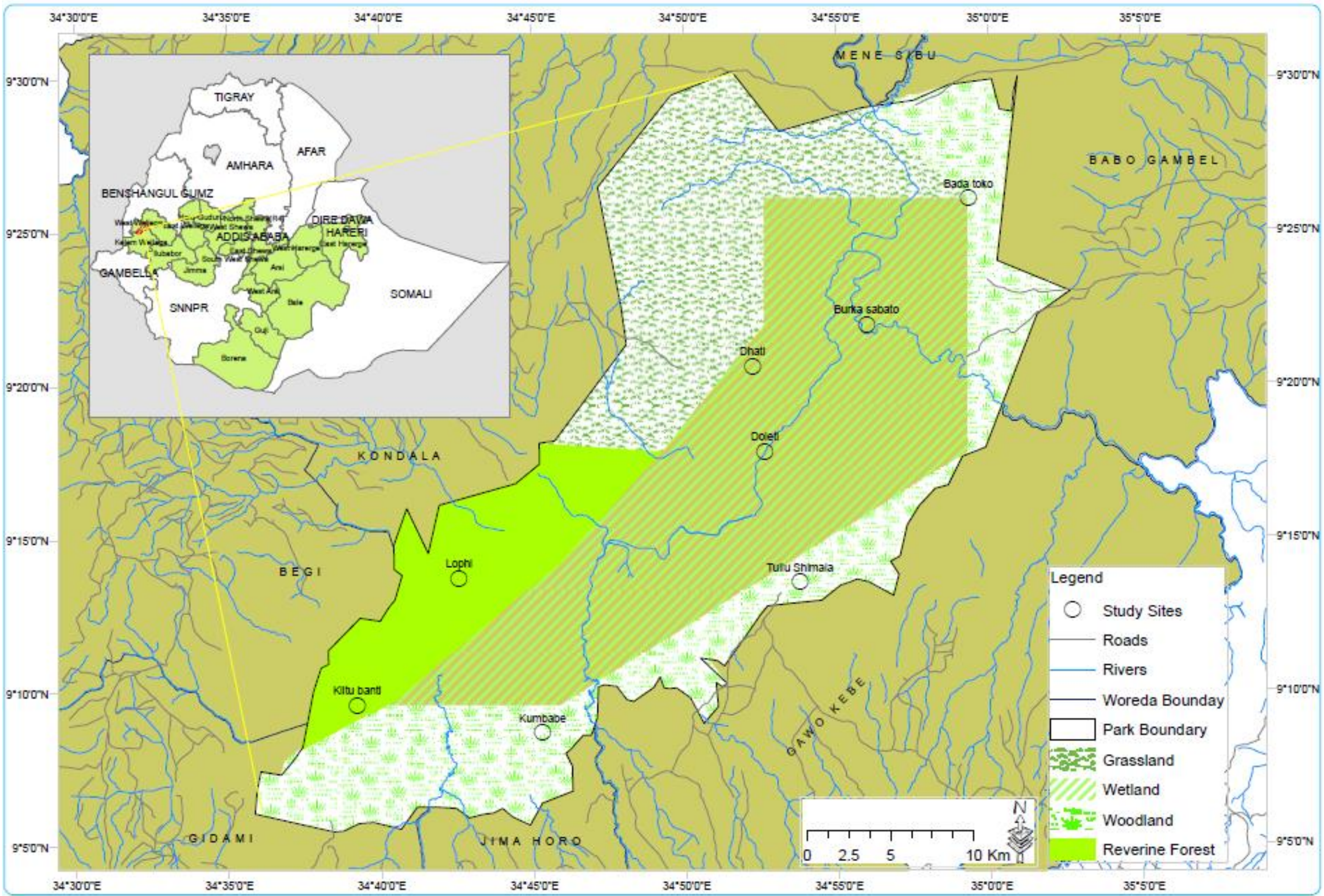

Figure 1. Map of the study area.

Desmomys and Stenocephalemys (Vreugdenhil et al., 2012).

The under estimated faunal records of the country are only from the protected areas, where they are relatively well preserved (Young, 2012), but the records and conservation status are still poorly known outside these areas (Bekele and Yalden, 2014). In addition, ranges of natural ecosystems of the country are continually collapsing mainly for the anthropogenic reasons (Yosef et al., 2010). Hence, more than ever, the survival of wildlife species outside the protected areas is at high risk (Largen, 2001; Bekele and Yalden, 2014).

Despite the protection guaranteed to national parks in the most recent Wildlife Proclamation, most parts of the oldest and legally gazetted Ethiopia's protected areas are increasingly degraded and the boundaries are being reviewed. The illegally encroached parts are being converted for subsistence and commercial agriculture, timber used for fuel wood and construction, protected grasslands used for livestock grazing that severely threatening the existing wildlife (Young, 2010). As a result of these, most populations of the medium and large sized mammals are severely depleted and difficult to see almost everywhere in the country, including most protected areas. These issues are crucial when it comes to the young wildlife protected areas.

Dati Wolel is among the few youngest protected areas in the western tropical forest belt of the country with unique ecosystem and diversified faunal resources (Vreugdenhil et al., 2012). More than half of the area of the park is covered by wetland and followed by the woodland, and the riverine forest covers the least (Figure 1). The park is reputed for harboring the highest population of Hippos and African Buffalos in the country (Bekele and Yalden, 2014). The park was initially designated as a controlled hunting area. However, as there was no well-established regulation for such activity associated with poor enforcement of the existing legislation, the mammalian resources were severely threatened (Young, 2010). To correct these problems, the area was upgraded to the regional park level in 2008 and to the national park status with all the logistics in 2010 (Vreugdenhil et al., 2012; Young, 2010). However, beyond the observational records, no attempts were made to assess the faunal diversity of the area, particularly of the most vulnerable larger and medium sized mammals.

Knowledge of the faunal diversity records, their abundance and the preferred habitats are basics for the status determination and to propose appropriate conservation measures (Galetti et al., 2009). In particular, medium and large sized mammals are intolerant for human interference, and remain the best indicators for most isolated healthy habitats (Costa et al., 2005; Galetti et al., 2009; Tabarelli et al., 2010; Mohammed and Bekele, 2014). Hence, we hypothesized that the area is rich in mammalian fauna that prefer to live in grassland and woodland close to water source.

Therefore, the present study was aimed to document the mammalian diversity of the area as base line information for better management of the resources.

MATERIALS AND METHODS

Study area

This study was conducted in the Dati-Wolel National Park, Oromia National Regional State, Western Ethiopia. The area is located between 67° 55' 49"and 72° 45' 03" E longitude and between 10° 05'25"and 10°51'01" N latitude (Figure 1). The altitude within the park ranges between 1390 and 1500 masl and covers an area of 1035 km^2 (Vreugdenhil et al., 2012). The study area was classified into four habitat types: the wetland, woodland, riverine forest and savanna grassland. The national park shares the northwestern portion of the southwestern tropical forest part of the country and receives over 1350 mm average annual rainfall. The area is relatively hot, with mean maximum and minimum temperature ranging between 27 and 29°C and between 15 and 17°C, respectively (EMA, 2013).

Methods

The data to study the diversity, relative abundance and habitat association of medium and large sized mammals in the Dati-wolel National park were collected through direct observation from the established transect lines in each habitat type. In total, seven study centers were selected (Burkasabato, Doleti, Lophi, Kumbabe, Kiltubanti, Badatoko and Garaarba) (Figure 1). Forty transect lines were established, being 18 for wetland, 12 for woodland, 7 for the riverine and 6 for grassland habitats depending on the area cover of each habitat. In the woodland, transect length of 1.5 km and width of 100 m, in Wetland transect length of 3.5 km and width of 200 m, in Reverine forest transect length of 3 km and width of 50 m and in Grassland transect length of 2 km and width of 200 m were used.

Each transect in each habitat was surveyed once every two months for eight months (from September/2012 through April/2013). Transects were visited two times during every survey. Two individuals were assigned per transect and all transects in each habitat were surveyed at the same time (between 06:00 and 10:00 am in the morning and between 16:00 and 18:00 in late afternoon). The identity of the observed species, group size, sex and age of individuals were recorded. For the species identification of the mammals, field guides (Kingdon, 1997; Yirga, 2008) and local people were consulted. Body size, pelage coloration, horn and dominant behavior were used to categorize sex and age of the observed mammal. In addition, indirect evidences observed within the transect lines (pug marks, hooves, foot marks, scats/pellets, calls, quills and burrows) were also used according to Sutherland (2007). During this study, body weight was a parameter used to categorize mammals into medium and large sized. Accordingly, mammals weighing between 2 and 7 kg were considered medium and all above this were categorized large sized (Emmons and Feer, 1997). The numbers of individuals of each species observed, time and habitat type were recorded during the survey. Observations were made with naked eye or aided by binocular (7 x 50 mm).

The identified mammals were grouped as common (if probability of seeing was 100% in every time of the fieldwork), uncommon (if probability of seeing was more than 50%), and rare (if probability of seeing was less than 50%) according to Hillman (1993). Shannon-Wiener Index (H') ($H'= -\sum [(\frac{ni}{N}) \times \ln (\frac{ni}{N})]$) and Simpson similarity index ($SI=\frac{nc}{a+b+c}$) were used to compare mammalian diversity and their similarity among habitats, respectively ((Krebs, 1978). The evenness (J) of mammalian species was calculated as $J = \frac{H'}{H\,max}$; where Hmax= ln(S) and S is the number of species (Krebs, 1978). The abundance of mammalian species in each habitat was computed using the formula (Negussie, 2009):

Abundance = Total number of individuals of species/sampled habitat

RESULTS

Species composition

During this survey, we recorded 3021 individuals of 28 mammalian species distributed in seven orders and 14 families (Table 1). Of these, about 15% (4 species): crested porcupine (*Hystrix cristata*), stark's hare (*Lepus starcki*), bush hyrax (Hetro*hyrax brucei*) and rock hyrax (*Procavia capensis*) were medium-sized mammals while the remaining 85% (24 species) were large-sized mammals. Carnivora was represented by the largest number of families (six) and species (11). More mammalian species was recorded for the families Bovidea (five specie), followed by Felidae and Cercopitheci (each with four species). The families Procaviidae, Suidae and Hyaenidae contained 2 species each. The remaining families were represented by single species (Table 1).

Relative abundance

Among the 28 species of mammals, *Hippopotamus amphibius* (hippopotamus) was the most abundant, comprising 43.92% of the recorded individuals, followed by *Syncerus caffer* (African buffalo), with 33.3%. *Icheumia albicauda* (black-backed jackal) and *Mellivora capensis* (honey badger) contributed only 0.099% each of the total recorded individuals (Table 2).

Diversity indices of mammals in the four habitat types

Among the four habitat types, woodland supports the greatest diversity of mammalian species (H'= 2.643), wetland being with the lowest (H'= 1.04086). The species

Table 1. Mammalian species identified in the Dati Wolel National Park, Ethiopia.

Order	Family	Common name	Scientific name	Local name
Carnivora	Felidae	Lion	*Pantheraleo*	Lencha
		Leopard	*Pantherapardus*	Qeransa
		Africa wild cat	*Felisservestris*	Adala
		Serval cat	*Felisserval*	Dero
	Hyaenidae	Spotted Hyaena	*Crocutacrocuta*	Worabessa
		Striped hyena	*Hynaehynae*	Worabessa
	Canidae	Common jackal	*Canisaureus*	Jedala
		Black-backed jackal	*Canismesamolas*	Jadala
	Hyrpestidae	White-tailed mongoose	*Icheumiaalbicauda*	*Fochi*
	Mustelidae	Honey badger	*Mellivoracapensis*	Hama
	Viverridae	African civet	*Civettictiscivetta*	Xirinyi
Artidactyla	Bovidae	African buffalo	*Synceruscaffer*	Gafarsa
		Common bushbuck	*Traglaphusscriptus*	Bosonu
		Klipspringer	*Oreotagusoreotagus*	Borte
		Tora hartebeest	*Alcelaphusbuselaphus*	Korke
		Common reedbuck	*Reduncaarundinum*	*Worabo*
	Hippopotamidae	Hipoppotamus	*Hippopothamusamphibus*	Robi
	Suidae	Bush pig	*Potamochoeruslarvatus*	Boye
		Warthog	*Phacochoerus africanus*	Karkaro
Primate	Cercopitheci	Vervet monkey	*Chlorocebusaethiops*	Qamale
		Colobus monkey	*Colobusabyssinicus*	Weni
		Debraza monkey	*Cercopithecusneglectus*	----
		Olive baboon	*Papioanubis*	Jaldesa
Hyracoidea	Procaviidae	Bush hyrax	*Hetrohyraxbrucei*	Osoleholka
		Rock hyrax	*Procaviacapensis*	Osoledaga
Tubulidentata	Oryctestidae	Aardvark	*Orycteropusafer*	Waldigesa
Lagomorpha	Leporidae	Stark's hare	*Lepusstarcki*	Hileti
Rodentia	Hystricidae	Crested porcupine	*Hystrixcristata*	Xade

evenness was highest in woodland (J=0.936), and lowest in Grassland habitat (Table 3).

Species similarity index

Among the four habitat types, more similarity of mammalian species was observed between woodland and grassland (SI=0.76) followed by woodland and riverine forest (SI = 0.59). The similarity was lower in woodland and wetland species (SI = 0.4) and wetland and riverine forest (SI = 0.48) (Table 4).

DISCUSSION

Dati Wolel National Park has unique ecosystem, being at north western edge of the southwestern tropical forest of the country. The large extent of woodland savanna grassland, the Reverine forest associated with wetland form ideal habitats for medium and large sized mammals. However, the total number mammalian species (28) recorded during the present study was relatively low when compared with other relatively younger national parks in Ethiopia. For instance, Woldegeorgis (2010) reviewed 37 species for Nechisar, 38 for Mago and 40 for Omo National Parks. The mammalian diversity seems less probably because the list does not include all mammalian species especially medium sized mammals as they can be overlooked and no special method is employed for them separately.

Several scholars (Tews et al., 2004; Matias et al., 2011) showed the positive correlation between habitat hetero-geneity and animal species diversity. Among the four habitats in the study area, the heterogeneous plant species

Table 2. Number of each mammalian species recorded and their relative abundance in the Dati Wolel National Park, Ethiopia.

Species	Habitat				Total	Abundance (%)
	WTL	WL	GL	RF		
H. cristata (Crested porcupine)	-	5	1	-	6	0.198
L. starcki (Stark's hare)	-	7	4	5	16	0.529
H. brucei (Bush hyrax)	-	-	7	9	16	0.529
P. capensis (Rock hyrax)	-	35	-	-	35	1.155
O. afer (Aardvark)	-	5	2	-	7	0.23
C. aethiops (Vervet monkey)	18	20	32	16	94	3.1
C. abyssinicus (Colobus monkey)	-	-	-	32	32	1.056
C. neglectus (Debraza monkey)	-	-	-	16	16	0.52
P. panubis (Leopard)	27	20	14	15	76	2.5
S. caffer (African buffalo)	701	46	65	194	1006	33.3
T. scriptus (Common bushbuck)	-	3	4	4	11	0.36
O. oreotagus (Klipspringer)	-	3	2	-	5	0.165
A. buselaphus (Tora hartebeest)	25	-	13	-	38	1.25
R. arundinum (Common reedbuck)	58	-	28	-	86	2.84
H. amphibus (Hippopotamus)	727	-	600	-	1327	43.92
P. larvatus (Bush pig)	-	4	9	-	13	0.42
P.africanus (Warthog)	18	16	15	3	52	1.7
P. leo (lion)	10	5	-	7	22	0.72
P. pardus (leopard)	-	14	-	6	20	0.66
C. crocuta (Spotted hyaena)	-	47	22	4	73	2.4
H. hynae (Stripped hyaena)	-	18	5	-	23	0.75
F. servestris (Africa wild cat)	-	4	2	-	6	0.198
I. albicauda (White-tailed mongoose)	-	1	4	2	7	0.23
C. aureus (Common jackal)	5	3	2	2	12	0.39
C. mesamolas (Black-backed jackal)	-	-	3	-	3	0.099
M. capensis (Rock hyrax)	-	-	-	3	3	0.099
C. civetta (African civet)	-	7	2	-	9	0.297
F. serval (African wild cat)	-	6	-	1	7	0.23
Total (28)	1559	279	834	319	3021	100

Table 3. The mammalian species diversity (H') and evenness (J) in different habitat types in the Dati Wolel National Park, Ethiopia.

Habitat	Number of spp.	Abundance	Diversity (H')	Evenness (J)
Wetland	9	317.8	1.04086	0.50054
Woodland	21	55.8	2.643	0.936
Riverine forest	16	79.75	1.60677	0.579
Grassland	21	208.5	1.0677	0.350

Table 4. The similarity of mammalian species among the four habitat types in the Dati Wolel National Park, Ethiopia.

Habitats	Wet land	Woodland	Riverine forest
Wet land	-	-	-
Wood land	0.4	-	-
Riverine forest	0.48	0.59	-
Grass land	0.533	0.76	0.54054

assemblage available in woodland and riverine forest contributed to the recorded high diversity of mammals in these habitats. Chane (2010) reported a high diversity and evenness of medium and large-sized mammals from Woodland and Riverine forest in Borena-Sayint National Park, South Wollo, Ethiopia. On the contrary, habitat homogeneity was reported for lower diversity (Mekonnin et al., 2011).

The distribution and habitat association of mammals are often correlated mainly with the availability of water, food and cover (Yaba et al., 2011; Girma et al., 2012). The high abundance of mammalian species in Grassland, in this study, might be due to these factors. The highest species similarity record between woodland and grassland might be due to the high similarity of vegetation between the two habitats. Similar result was reported by Mengesha and Bekele (2008) for the Alatish National Part, Ethiopia.

Dati Wolel National Park is unique in harboring the highest number of mega herbivores specially the African buffalo (*S. caffer*) and hippopotamus (*H. amphibious*) relative to any of the parks in the country (Bekele and Yalden, 2014). The extensive grassland surrounding the wetland may contribute to the abundance. Some mammalian species like Warhog (*Phacochoerus africanus*), Vervet monkey (*Chlorocebus aethiops*), Olive baboon (*Papio Anubis*), Common jackal (*Canis aureus*) including the African buffalo (*S. caffer*) were considered more adaptive and recorded from all habitats in the study area. The distribution of these mammals in all habitat types indicates their adaptation to a variety of habitat types. However, some such as hippopotamus (*H. amphibious*) and common reedbuck (*Reduca arundinum*) have highly restricted distribution (around wetland and grassland). In this regards, the ecological preference and evolutionary adaptation of the mammalian species play a role in their distribution in different habitat types (Bailey, 1984).

During this study, some nocturnal and cryptic species such as Honey badger (*Mellivora capensis*) and Black backed jackal (*Canis mesomelas*) were under reported. Particularly, these two carnivores are considered vermin known for raiding goats, sheep and poultry, hence easily targeted for human persecution. Local informants reported that, Honey badger is also in a continuous conflict with farmers for breaking hives. Similar observation was reported by Chane (2010), who recorded the least number of both species from Borena-Sayint National Park, located in the Northern Ethiopian.

The adverse effect of livestock and human settlement on the distribution of wild animals has been reported (Bonnington et al., 2007; Gundogdu, 2011). The high number of mammalian species in woodland might be due to the movement of many species from the peripheral area towards the inner in search of food and cover as this habitat is the most inaccessible for human activities and livestock. Regardless of this minor human encroachment into the park areas and the prevailing poaching activities by sporadic hunters, Dati Wolel National Park possesses unique habitat with high potential of conserving biodiversity. The park contains diversities of habitats suitable for diversities of flora and the associated fauna. Hence, thorough inventory for faunal diversity, involving multiple seasons and all vertebrates, strengthening the now loose park management will ensure the sustainability of the ecosystem in supporting the riche biodiversity components.

Conflict of interests

The authors did not declare any conflict of interest.

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Full Length Research Paper

Abundance and community composition of small mammals in different habitats in Hugumburda forest, northern Ethiopia

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Tropical forest ecosystems harbor several species of small mammals. Diversity and abundance of small mammals in these forests reflect the quality and diversity of the ecosystems. The current study was carried out to assess abundance and species composition of small mammals (rodents and shrews) in three habitat types (*Pterolobium, Juniperus* and *Cadia* habitats) in Hugumburda forest, a dry afromontane forest in the Tigray region of North Ethiopia. The habitat types were selected based on the floristic compositions (plant species diversity) and level of human disturbance. All together, 179 individual small mammals belonging to seven rodent and one insectivore species were captured in 4,320 trap nights. The rodent species, with their relative abundance, were *Stenocephalemys albipes,* 55 (30.7%); *Mastomys awashensis,* 53 (29.6%); *Arvicanthis dembeensis,* 26 (14.5%); *Lophuromys flavopunctatus,* 22 (12.3%); *Mus (Nannomys) setulosus,* 14 (7.8%); *Arvicanthis abysinicus* 4 (2.2%); *Dendromus mystacalis*, 3 (1.7%) and the insectivore *Crocidura olivieri*, 2 (1.1%). There was significant variation in the small mammal abundance among the habitat types (χ^2=29.45, *P*= 0.009), with more individuals caught in *Pterolobium* habitat, which has relatively highest plant species composition and lowest human disturbance than the other two habitats. The highest small mammal species diversity was also recorded in this habitat (H'=1.76). Vegetation diversity and level of human interference are likely the major factors affecting small mammal abundance and composition in Hugumburda forest.

Key words: Small mammals, Hugumburda forest, human disturbance, diversity indices.

INTRODUCTION

Ethiopia encompasses a broad range of ecosystems and habitats that contribute to high mammalian diversity and endemism. Of the 284 Ethiopian mammals, 31 are endemic (Yalden and Largen, 1992). Small mammals (mammals that weight < 5 kg) account for about 39% of Ethiopia's mammals, and 85% of its endemics (Bekele and Leirs, 1997).

The abundance and community composition of small mammals depends on the vegetation structure and complexity of the habitat (Muck and Zeller, 2006; Glennon and Porter, 2007; Garratt et al., 2012) with high vegetation diversity and dense ground cover supporting greater small mammal species diversity (Mulungu et al., 2008).

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In contrast, small mammal diversity tends to be lower in less diverse and open habitats (Oguge, 1995; Pearson et al., 2001). Thus, small mammal assessment is an important component of the study of forest ecosystems because they are indicators of habitat condition.

There are 58 forested areas in Ethiopia that have been given priority conservation status (Kidane et al., 2010), but small mammals have been assessed in only some of these (Senbeta and Teketay, 2003). Most of these assessments have been confined to those forests in the central and southern highland areas (Bekele et al., 1993; Bekele, 1996; Yalden et al., 1996; Wube and Bekele, 2001; Shenkut, et al., 2006; Datiko, et al., 2007), probably owing to better accessibility. Hugumburda and Dessa forests, which are the only two priority forests in the Tigray region (province) of northern Ethiopia, are less studied.

In view of these scenarios, we initiated investigation of small mammal diversity and abundance study in Hugumburda forest to assist regional conservationists and foresters in developing management practices for the protection of the forest. We hypothesize that small mammals abundance and diversity will be higher in habitats where vegetation diversity is higher and human disturbances are minimal.

MATERIALS AND METHODS

Description of the study area

Hugumburda forest is located in Tigray region of northern Ethiopia (Figure 1), 160 km south of Mekelle, the provincial capital. The forest covers an area of 17,800 ha, between 12°36' and 12°40' N and 39°31' and 39°34' E and has an elevation range of 1600 and 3,000 m above sea level (a.s.l). The mean annual minimum and maximum temperatures are 9°C and 22°C, respectively. The hottest month is May with a mean maximum temperature of 24°C, and the coldest month is December with a mean temperature of 6°C. The mean annual precipitation is 998 mm. The rainy season runs from June to September (Kidane et al., 2010).

Hugumburda forest is a dry afromontane forest representing the only significant expanse of remnant dry coniferous forest in Tigray (Darbyshire et al., 2003; Aerts et al., 2006). The forest suffers from continued human interference (Aynekulu, 2011). Particularly the rate of deforestation has intensified in the last decades mainly to acquire land for agriculture, grazing, settlement and wood charcoal production. Three habitat types (*Pterolobium, Juniperus* and *Cadia*) were identified in the forest on the basis of difference in floristic composition and level of human disturbance as described (Aynekulu, 2011). Floristic composition (plant species diversity) was determined according to the greater occurrence of dominant plant species and difference in life form (Figure 2, Table 1). Level of human disturbance was assessed subjectively as less disturbed, moderately disturbed, and highly disturbed, based on grazing intensity (understory cover), cut trees,- and human trails (Aynekulu, 2011).

Pterolobium habitat was found predominantly at lower elevation, between 1600 and 2100 m a.s.l. and was characterized by a gentle slope closely associated with streams and riparian vegetation (Aynekulu, 2011). *Pterolobium stellatum* (Forssk) Brenan and *Celtis africana* (Burm. f) are the dominant plant species in this vegetation type (Table 1). This habitat is less disturbed by people compared to the other two (Aynekulu, 2011). *Juniperus* habitat is located next to the *Pterolobium* habitat, on gentle to steep slopes at middle elevations (from 2200-2700 m a.s.l). *Juniperus procera* (Hochst, ex Endl)*, Olea europea cuspidata* (Wall ex G. Don.) and *Maytenus senegalensis* (Lam) are the dominant plant species in this habitat type (Table 1). Compared to the former habitat type, *Juniperus* habitat suffered a moderate human disturbance. The *Cadia* is the third habitat located next to *Juniperus* habitat at the upper elevations (>2800 m a.s.l). This habitat is categorized as degraded shrub vegetation dominated by *Cadia purpurea* (Picc.) Ait and *Opuntia ficus-indica* (L.) Mill (Table 1) (Aerts et al., 2006; Aynekulu, 2011). This habitat suffered the highest human disturbance compared to the other two habitat types (Aynekulu, 2011).

Small mammals trapping

Small mammals were trapped in the three habitats once in a month from November 2012 to January 2013. According to Gebresilassie et al. (2006) and Meheretu et al. (2014) the population abundances of rodents in Tigray peak in months which correspond to the post rainy season that is beginning of the dry season. In each trapping occasion, two transect lines were set per habitat, making 18 transects lines in total in all the three habitats. Transect lines were set such that the two lines were parallel to each other, 600m long and spaced 100 m apart. Each month, the transect lines were moved approximately 100 m away from the previous transect line within the same habitat. Each transect line had 120 trap stations located 5 m apart. Trapping was conducted with Sherman LFA live traps (7.5 x 9.0 x 23.0 cm, HB Sherman Trap Inc, Tallahassee, USA) baited with peanut butter. The overall trapping activity in the three habitats lasted for seven days every month: in the first two consecutive days, traps were set in the first habitat and captures were checked in the mornings of the second and third days. In the afternoon of the third day, traps were moved to the second habitat and set there. Captures were check here in the mornings of the fourth and fifth days, and then in the afternoon of the fifth day the traps were moved to third habitat. Captures in the third habitat were check in the mornings of the sixth and seventh days. Note that, at every trapping occasion traps were set around 16:00hr and captures were checked around 08:00hr the next morning.

Small mammal identification and data analysis

All captured small mammals were anaesthetized in a plastic bag with a small amount of ether soaked in cotton wool. The animals were removed from the bag and a preliminary identification was carried out in the field using morphological characteristics. The identification was later confirmed using appropriate identification keys (Yalden and Largen, 1992; Yalden et al., 1996; Kingdon, 1997; Happold, 2013). The following morphological measurements were taken from each of the trapped small mammals: body, tail, hind foot and ear lengths as well as weight. Furthermore, habitat type, trap location, sex and reproductive condition of the small mammals were determined according to Barnett and Dutton (1995) and Pearson et al. (2001).

Trap success (TS) was calculated using the following formula (Stanley et al., 1996):

$$TS(\%) = \frac{Tc}{Tn} * 100$$

Where, Tc = total catch (the total number of animals of species *i* caught) and Tn = trap nights (a product of the number of traps used and trapping effort, where trapping effort = number of days of trapping). A trap night was defined as a single trap set for one night. Small mammals species diversity was determined using Shannon-Wiener diversity index (H') (Shannon and Wiener, 1949),

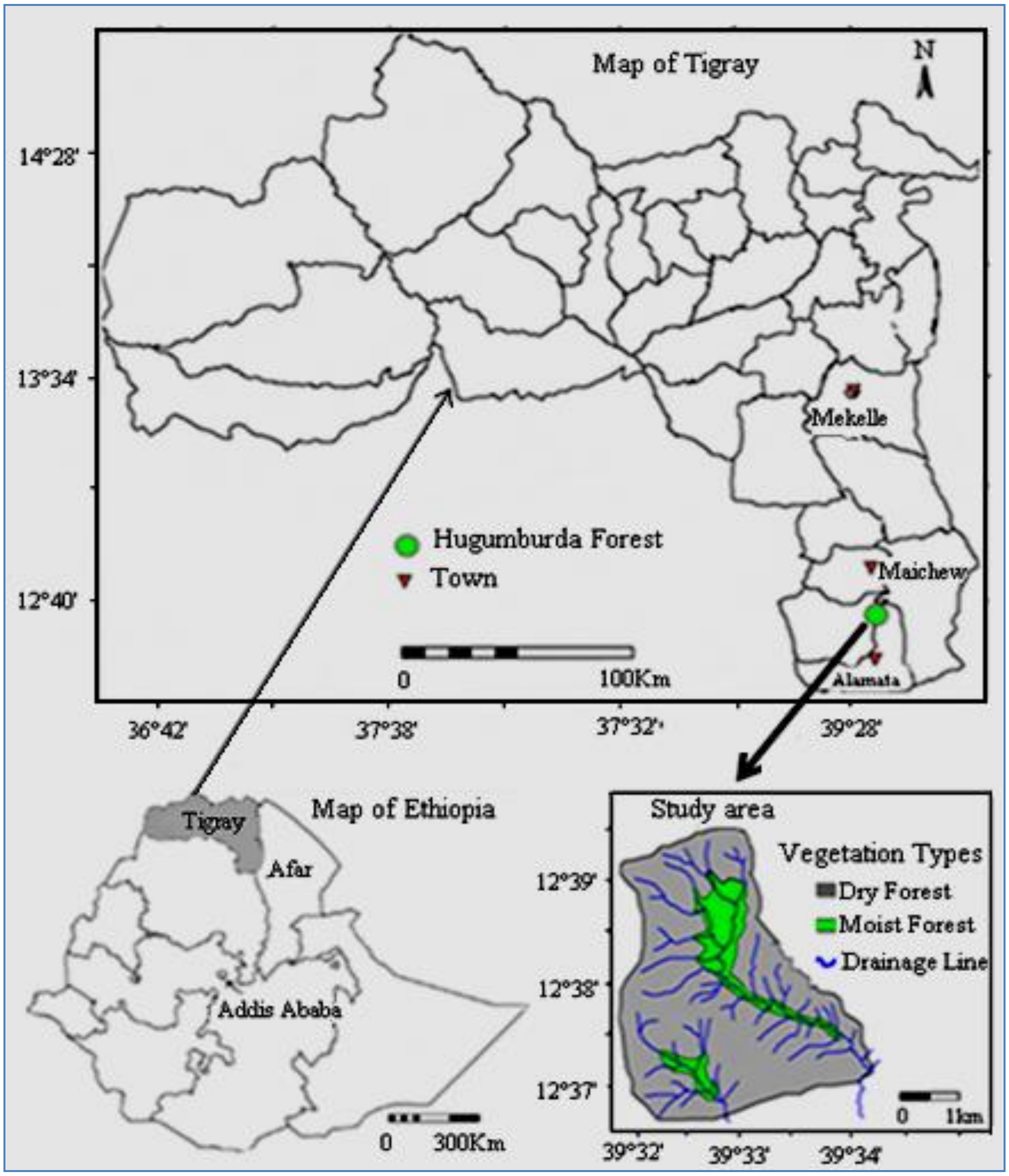

Figure 1. Location of Hugumburda forest in the Tigray region, Ethiopia. Adopted from Aynekulu (2011).

a b c

Figure 2. Pictures of the three habitat types in Hugumburda forest. **(a)** *Pterolobium.* **(b)** *Juniperus* and (c) *Cadia.*

Table 1. Indicator flora species of the three habitats in Hugumburda forest, Ethiopia.

Pterolobium	*Juniperus*	*Cadia*
Pterolobium stellatum (s)	*Juniperus procera* (t)	*Cadia purpurea* (s)
Celtis africana (t)	*Maytenus senegalensis* (s)	*Opuntia ficus-indica* (s)
Rhus natalensis (s)	*Dodonaea viscose* (t)	*Solanum schimperianum* (s)
Bersama abyssinica (t)	*Acacia abyssinica* (t)	*Clerodendrum myricoides* (s)
Ficus palmate (s)	*Pittosporum viridiflorum* (t)	*Canthium setiflorum* (s)
Allophylus abyssinicus (t)	*Osyris quadripartite* (s)	*Euclea racemosa schimperi* (s)
Ficus thonningii, (t)	*Dovyalis verucosa* (s)	
Afrocarpus falcatus (t)	*Olea europaea cuspidate* (t)	
Rosa abyssinica (s)	*Myrsine Africana* (s)	
	Clutia abyssinica (s)	

Superscripts indicate species life forms: shrub (s) and tree (t). Adapted from Aynekulu (2011).

$H' = -\sum_{i=1}^{s}(Pi)(\ln pi)$, where S = number of species, Pi = is the proportion of individuals of the total sample belonging to the ith species. H' is influenced both by number of species as well as by evenness. Evenness (J) refers to how close in numbers each species in a habitat type. Evenness was calculated as, $J = \frac{H'}{H'max}$, where $H'max = \ln(S)$, S is the number of species and H' is refers to Shannon-Wiener diversity index . This

measure varies between 1 (complete evenness) and 0 (complete unevenness).

The percent abundance of each species in each of the habitat types was calculated as the ratio between the number of species found in each habitat and the total number of species recorded in that habitat.

The similarity in small mammal community among the habitats was estimated by Sørensen's coefficient of community similarity (CCS); $CCS = \frac{2C}{(S1+S2)}$, where S1 and S2 are the number of species occurring in each of the habitat type compared and C refers to the number of species occurring in both habitat types (Sørensen, 1948).

Differences in overall abundance of small mammals among the habitat types were computed using SPSS-version 18 and χ^2-test (Levesque, 2006). Levels of significance were determined at *P* = 0.05.

RESULTS

Small mammal species composition and abundance in relation to vegetation type

About three-quarters of the small mammals were represented by three rodent species that are endemic to Ethiopia namely the Ethiopian white footed mouse (*Stenocephalemys albipes)* (Rüppell, 1842), the Awash multimammate mouse (*Mastomys awashensis* (Lavrenchenko et al., 1998), and the grass rat (*Arvicanthis dembeensis,* Rüppell, 1842) (Tables 2 and 3). In *Pterolobium* and *Juniperus* habitats the Ethiopian white footed mouse was the most dominant species (about 14 and 9% respectively), in *Cadia* habitat the Awash multimammate mouse was the most abundant species (15%). Three rodent species *Lophuromys flavopunctatus* (Thomas, 1888*), Arvicanthis abysinicus* and *Dendromus mystacalis* were trapped only in *Pterolobium* and *Juniperus* habitats.

Overall, 179 small mammals (rodents and shrew) belonging to eight species were trapped from the three habitat (Table 3). Abundance of the small mammals was significantly different among the habitat types (χ^2= 29.46, df= 14', *P* = 0.009). About 41% of the small mammals, belonging to eight species, were trapped from the *Pterolobium* habitat. A comparable abundance of small mammals were trapped from *Juniperus* (31%) and *Cadia* (28%) habitats, although they belonged to seven and four species, respectively. Trapping success ranged from 3.5% in *Cadia* to 5.1% in *Pterolobium* habitat and the overall trap success was 4.1%.

Diversity indices

The *Pterolobium* habitat recorded the highest Shannon-Weaver Index (H') of 1.76 while *Cadia* habitat recorded the lowest H'(1.15) (Table 4). Analysis of the Sørensen's coefficient of community similarity yielded the highest index between *Pterolobium* and *Juniperus* habitats (0.93) and lowest similarity index between *Pterolobium* and *Cadia* habitats (0.67)

DISCUSSION

Small mammals abundance versus habitats

The abundance of small mammals significantly varied among the habitats. About 10-13% more small mammals were captured in the *Pterolobium* habitat compared to the other habitats. This was justifiable since *Pterolobium* habitat had the highest floristic composition and the lowest human disturbance. Not surprisingly, *Cadia* habitat, with less floristic composition and higher human disturbance

Table 2. Morphological measurements of the small mammals trapped in Hugumburda forest.

Adult male						Adult female					
Species	**WT (g)**	**HBL (cm)**	**TL (cm)**	**HFL (mm)**	**EL (mm)**	**Species**	**WT (g)**	**HBL (cm)**	**TL (cm)**	**HFL (mm)**	**EL (mm)**
S. albipes (n=16)	64	12	15	24	18	*S. albipes* (n=7)	65	13	16	24	19
M. awashensis (n=14)	62	13	13	26	18	*M. awashensis* (n=4)	68	13	17	25	19
A. dembeensis (n=11)	64	13	14	27	15	*A. dembeensis* (n=2)	73	14	14	26	17
L. flavopunctatus (n=12)	59	12	5	20	13	*L. flavopunctatus* (n=1)	65	15	9	18	13
M. (Nannomys) setulosus (n=6)	10	6	6	16	9	*M. (Nannomys) setulosus* (n=0)	-	-	-	-	-
A. abysinicus (n=2)	91	14	11	26	18	*A. abysinicus* (n=2)	105	15	10	27	17
D. mystacalis (n=1)	12	6	9	18	12	*D. mystacalis* (n=1)	11	7	9	17	13
C. olivieri (n=1)	24	15	6	16	0.8	*C. olivieri* (n=1)	24	9	6	16	0.8

WT = weight; HBL = head-body length; TL = tail length; HFL = hind foot length; EL = ear length; n = number of adult male and female captures.

Table 3. Abundance of small mammals trapped in the three habitats in Hugumburda forest. Relative abundances in % of overall total captures are indicated in bracket.

Species	**Small mammals abundance**			**Total**
	Pterolobium	***Juniperus***	***Cadia***	
S. albipes	25 (14)	16 (8.9)	14 (7.8)	55 (30.7)
M. awashensis	13 (7.3)	14 (7.8)	26 (14.5)	53 (29.6)
A. dembeensis	12 (6.7)	8 (4.5)	6 (3.4)	26 (14.5)
L. flavopunctatus	12 (6.7)	10 (5.6)	-	22 (12.3)
M. (*Nannomys*) *setulosus*	4 (2.2)	6 (3.4)	4 (2.2)	14 (7.8)
A. abysinicus	3 (1.7)	1 (0.6)	-	4 (2.2)
D. mystacalis	2 (1.1)	1 (0.6)	-	3 (1.7)
C. olivieri	2 (1.1)	-	-	2 (1.1)
Overall	73 (40.8)	56 (31.3)	50 (27.9)	179 (100)
Trap success (%)	5.1	3.9	3.5	4.1

Table 4. Indices of species diversity and Sørensen's coefficient of community similarity (CCS) in and between the three habitat types.

Habitat Type	**Shannon-Wiener Diversity Index (H')**	**Evenness (J)**	**Sørensen's Coefficient of Similarity (CCS)**	
Pterolobium	1.76	0.85	*Pterolobium* vs. *Juniperus*	0.93
Juniperus	1.67	0.87	*Pterolobium* vs. *Cadia*	0.67
Cadia	1.15	0.83	*Juniperus* vs. *Cadia*	0.73

(more spaced out), harbored the least number of small mammals. Less heterogeneous forest blocks with open habitats support small number of small mammals since they expose small mammals to potential predators and may not provide sufficient food supply (Yalden and Largen, 1992; Mulungu et al., 2008). In similar studies in Ethiopia (Girma et al., 2012; Yihune and Bekele. 2012) variation in small mammal abundances have been reported in response to variations in vegetation diversity and human disturbances since both factors influence availability of food and shelter (against potential predators) for small mammals. In the contrary, however, habitat fragmentation and disturbance such as selective logging in tropical forests do not necessarily result in a reduction in small mammals species diversity (Malcolm and Ray, 2000). Disturbed and transitional habitats in Australia supported comparatively diverse species assemblages by creating a mosaic of heterogeneous habitats compared to a large block of continuous 'primary' rainforest (Johnson and Mighell, 1999).

Species composition

The predominant species, the Ethiopian white footed mouse (*Stenocephalemys albipes*), was trapped in all the habitats. However, most individuals of this species (45%) were captured in *Pterolobium* habitat. Bekele (2013) reported that *S. albipes* prefers a dense forest that has diverse vegetation. Hence, the species may serve as an indicator to reveal the situation of forest vegetation cover and diversity.

The second most abundant species, the Awash multimammate mouse (*M. awashensis*), was also trapped in all of the habitats. However, unlike the former species, most individuals of this species (49%) were trapped in *Cadia* habitat which was characterized by less floristic composition and higher human disturbance. This was in line with Lavrenchenko and Leirs (2013) who reported the common habitat of the species as degraded vegetation and arable land.

The grass rat (*A. dembeensis*) was the third abundant species. Individuals of this species were also trapped in all of the habitats, but more (46%) in *Pterolobium* habitat. According to Wube and Bekele (2001), the species can live in a variety of vegetation types though it prefers dense vegetation cover most probably to avoid potential predators as consequence of its being diurnal.

Comparable numbers of Yellow-spotted brush-furred rat (*L. flavopunctatus*) were trapped in *Pterolobium* and *Juniperus* habitats. Dieterlen (2013) described the species as less tolerance of human disturbed forest habitats, which could be the reason why the species was not trapped from *Cadia* habitat.

Arvicanthis abysinicus, the Peters's mouse (*Mus* (*Nannomys*) *setulosus*), the African climbing mice (*Dendromus mystacalis*) and the African giant shrew (*Crocidura olivieri*) were also recorded in the present study but in smaller numbers. Therefore, their number was not enough to reach any conclusion on their distribution in each of the habitats.

Diversity indices

The results of the Shannon-Wiener diversity index indicated that the *Pterolobium* habitat has higher small mammal species diversity than the *Cadia* habitat. This was in agreement with the abundance of small mammals where it was also higher in *Pterolobium* habitat. The result of the Sørensen's coefficient of community similarity analysis also showed variation between the habitats. Consistent with the abundance and diversity of small mammals, habitats with relatively better plant species composition and lower human disturbances scored the highest Sørensen's coefficient of community similarity compared to habitats with relatively lower plant species composition and higher human disturbances.

In the present study seven species of rodents and one species of insectivore were identified. Overall, species abundance, diversity, evenness and community similarity varied among the habitats in response to variation in floristic composition and level of human disturbance. There was clear indication that the higher the vegetation diversity and the least the level of human disturbance, the higher the small mammals abundance, species composition, evenness and community similarity. This in turn suggested that more conservation efforts may improve the abundance and species diversity of small mammals in Hugumburda forest. We suggest measures be taken to improve the vegetation diversity of the forest and to mitigate the level of disturbance. Creating awareness among local people around the forest may help to reduce cutting trees and keep livestock away from the forest.

Conflict of interests

The authors did not declare any conflict of interest.

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