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Review

Mammalwatching: A new source of support for science and conservation

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During the 20th century, birding evolved from a little-known hobby into a global phenomenon important for ornithology and bird conservation. More recently a similar change has begun for mammalwatching, which is rapidly gaining popularity and is already providing financial support, observational data, diagnostic information, and a volunteer base for mammalogy and mammalian conservation. The study data suggest that mammalwatching has the potential to end decades of neglect of small mammals in dire need of conservation, to improve our knowledge of mammalian status and distribution, and to increase public support for conservation measures, especially for species not seen as particularly charismatic by the general public. Professional mammologists and conservation workers can benefit from this new trend, but they can also help it. We offer a number of suggestions as to how professionals mammalogists and the amateur community can better work together to promote conservation and science.

Key words: Amateur naturalists, biodiversity, citizen science, ecotourism, mammalogy, mammals, volunteering.

INTRODUCTION

A century ago, watching birds was a little-known hobby, practiced by a small number of people who might be described today as "geeks" (Moss, 2004). There were no pocket-size field guides, and many bird species were believed to be indistinguishable in the wild (Dunlap, 2011). Only professional ornithologists with access to large museum collections were trusted with identifying birds (Moss, 2004). But things gradually changed. Now birding is, along with other forms of wildlife-based tourism, among the fastest growing tourism sectors in the world (Sekercioglu, 2002; Balmford et al., 2009; Cordell and Herbert, 2012).

There are hundreds of thousands, perhaps millions of birders worldwide (La Rouche, 2003). More than a

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quarter of a million people use the eBird software (developed by the Cornell Ornithology Lab to help birders record their sightings) to record bird sightings., and you can find lively birding communities in places like Moscow, Delhi, Mexico City, and Cape Town (de Silva and Reyes, 2010).

Birding has largely replaced destructive activities such as collecting bird eggs and mounted birds (Dunlap, 2011). It creates a wealth of data for ornithologists, incentives for protecting rare bird species, and a market for bird books (Greenwood, 2007). Data from eBird has been used in over a hundred scientific papers in the first five years since its launch in 2004 (Sullivan et al., 2009; website *ebird.org* for bibliography).

Some communities located in particularly “birdy” locations now receive much of their income from birdwatching tourism, and invest considerably in bird conservation (Sekercioglu, 2002). Such places include Mindo in Ecuador, Fraser’s Hill in Malaysia, Tippi in India, and Wundanyi in Kenya (VD pers. obs.). Bialowieza in Poland gets 15 times more income from visiting birders than from logging (Czeszczewik and Walankiewicz, 2017). Even the most cryptic, obscure, hard-to-identify bird species receive considerable public attention if they are in need of conservation (see, for example, Hirschfeld et al., 2013; Hosner et al., 2013). In addition, birders form a sizeable pool of volunteers for various scientific projects, often contributing their money as well as manpower.

Mammalwatching today is arguably where birdwatching was a century ago. In many countries there are few – if any – comprehensive field guides for mammals, and the existing books often include only larger species. Many species are thought to be identifiable only if caught, or only in a genetics lab (Whitaker, 1996).

“Mammal finding” guidebooks are even scarcer than identification guides: the first guidebook devoted specifically to finding all North American mammals in the wild wasn’t published until 2015 (Dinets, 2015), the first one for Australia appeared in 2016 (Andrew 2016), and there is still, to our knowledge, no such book for many parts of Europe or any part of Asia (bird-finding guides exist for all continents, many countries, and some states and provinces).

However in the last few years, the popularity and scope of mammalwatching has begun to grow noticeably worldwide. People are discovering that the hobby can be as rewarding as birding, with many (perhaps even more) diverse experiences and challenging adventures involved in seeing wild mammals (Dinets, 2015). Mammalwatching.com is probably the leading website for the amateur mammalwatcher, sharing trip reports and other relevant information. Its popularity has grown steadily from near-zero a few years ago: site traffic reports show that, for instance, the website has about 2,500 active users each month, while its forum page received almost 70,000 visitors from 136 countries in 2014. The Australian Mammal Watching group on Facebook has around 1,500 members and is very active.

In Africa, where watching large mammals has have been a tourist attraction for decades, smaller species are now increasingly sought by tourists and their guides (Novacovic and Das, 2006). In addition, the proportion of birders who pay attention to mammals and include data on mammal sightings in their trip reports is growing; an informal survey of 200 trip reports from the most popular birdwatching sites has shown that the share of reports containing information on mammals has grown from 5% in 1990 to 55% in 2014 (VD unpublished, 2015).

Does this sudden change have a potential to aid research and conservation of mammals in the same way birding aids research and conservation of birds? This is an important question because such aid is direly needed. The apparent lack of public knowledge or interest for many species of smaller mammals, particularly tropical ones, might well contribute to their seeming neglect by conservation organizations and ministries.

For example, less than 1% of small South American mammals have ever been the focus of any conservation measures (IUCN, 2014). Critically important patches of small mammal habitat are being lost with no – or virtually no – attempts from the conservation community to save them; recent examples include high-altitude forests of Sierra de Cuchumatanes in Guatemala (Matson et al., 2012) and Lake Khasan meadows in Russia (Newell, 2015).

Moreover, scientific knowledge of many species is limited when compared to birds: the IUCN lists 799 species of mammals, or 14.7% of the total number, as data deficient, compared to just 62 species of birds, or 0.6% of the total (IUCN, 2014).

Below we present evidence that mammalwatching is already making a positive impact on science and conservation, and that its impact can be greatly increased if mammalwatching is more widely known, recognized as beneficial, and assisted.

Beneficial effects of mammalwatching

Mammalwatching has a number of benefits – both indirect and direct – for the scientific community and broader wildlife conservation.

Public awareness

Just like other kinds of nature-based tourism, mammalwatching helps bridge the growing disconnect between people and the natural environment (Balmford et al., 2009). Many amateur mammalwatchers are urban residents: for example, among 100 randomly chosen subscribers of Australian Mammalwatching Facebook group who had their residential information listed, 98 lived in cities (VD unpublished 2017). And greater public interest in nature helps pave the way to greater public support for studying it (Novacek, 2008). Local communities are often proud of the attention that even a few mammal-seeking visitors can bring to their area. Knowing that an animal is important to the outside world can provide the impetus for local people to save a species, even if it the tourism dollars do not cover their costs of doing so. 25 years after a visit by three mammalwatchers, local residents of remote Evoron Village in Russia were still aware of the importance of the local endemic, the Evoron vole (*Microtus evoronensis*), and limited annual burning of grass in its habitat (M. Sanchez personal communication).

Eco-tourism revenue

Certain forms of mammal-based tourism, including the safari industry and whale watching, already generate significant revenue. Game watching is probably best established in parts of eastern and southern Africa.

Although it has been focused on larger mammals, as evidenced by the fact that most field guides to African mammals cover smaller mammals only briefly or not at all (Dinets, 2015), it has become the backbone of local tourism in some areas and has generated substantial revenue (Christie and Crompton, 2001; Higginbottom, 2004). In southern Africa, nature-based tourism now generates roughly the same revenue as farming, forestry, and fisheries combined (Scholes and Biggs, 2004).

The money spent by mammal watchers is modest in comparison to that spent on the safari industry in general, but it can still have an important impact. Hundreds of people now visit Ladakh each winter to try to see a Snow Leopard. A cottage industry, employing numerous guides, spotters, porters and cooks, has sprung up as a result, and the leopards are better monitored and protected than ever (Desai, 2016).

But when we talk about mammalwatching, we talk about an interest in mammals that goes beyond charismatic megafauna, to include smaller and rarer species than the Big Five or baleen whales. As mammalwatchers become increasingly interested in small mammals, they more often visit locations outside established tourist routes. Even a handful of visitors to such remote places can be enough to generate livelihoods and promote greater interest in – and awareness of – wildlife conservation among the local population. For example, in a country like Sierra Leone, where Gross National Income per capita is less than $500 (World Bank, 2017), and average income in rural areas is almost certainly much lower, a few mammalwatchers spending a week in a remote area like Gola Forest (where a few rare mammals occur) can make a noticeable contribution to the local economy (JH pers. obs.).

Obtaining scientific data

In addition to generating revenue, providing incentives for local conservation, and generally stimulating interest in nature, mammalwatching creates other direct benefits for conservation and science.

Mammalwatching in Africa produces a wealth of data, including extensive amateur databases and numerous contributions to the Mammals Atlas project (mammalMAP) coordinated by the Animal Demography Unit at the University of Cape Town (http://adu.org.za) (R. Primack personal communication). In Australia, the Dryandra Group is maintaining a database of numbat (*Myrmecobius fasciatus*) sightings and campaigning for creating a national park in the area (www.facebook.com/groups/dryandra/).

Amateur mammalwatchers combine their resources to organize research expeditions, and provide data for professional researchers. Distributional records recently obtained by amateur mammalwatchers (including participants of specialized mammalwatching tours) include the first documented record of Pousargues' mongoose (*Dologale dybowskii*) in Uganda since the 1970s (Woolgar, 2014), the rediscovery of the Javan small-toothed palm civet (Eaton et al., 2010), the first records of two species of *Vulpes* foxes from northeastern Ethiopia (Dinets et al., 2015), the first documented sighting of Arunachal macaques (*Macaca munzala*) in Kaziranga National Park (A. C. Smith in prep.), the first documented records of Altai weasel (*Mustela altaica*) in Ladakh by the members of a 2014 mammalwatching expedition (Ben-Yehuda, 2018), and a significant portion of recent records of rare cetaceans (Wilson and Mittermeier, 2014). Data from amateur mammalwatchers were being used to determine the distribution of the recently described olinguito (*Bassaricyon neblina*) (K. Helgen personal communication), and to obtain the first data on the longevity of the spectral bat (*Vampyrum spectrum*) in the wild (Dinets, 2016).

Other contributions include a unique record of multiple groups of humpback whales (*Megaptera novaeangliae*) taking turns disrupting attempts by killer whales (*Orcinus orca*) to hunt California sea lions (*Zalophus californianus*) (Pitman *et al*., 2017), and multiple records used in a study of surface foraging by *Scapanus* moles (Dinets, 2017).

In 2016 to 2017, two potential new species have been discovered by mammalwatching tour groups: a pencil-tailed mouse (*Chiropodomys*) in Sri Lanka (Reid in prep.) and a harvest mouse (*Reithrodontomys*) in Nicaragua (Martinez *et al*. in prep.).

Data collected by amateurs can be as reliable as data collected by professional zoologists (Kylie et al., 2014). Indeed, just as in birdwatching, the line between amateurs and professionals is increasingly blurry, with amateurs now submitting their data directly to scientific journals, and professional biologists enjoying mammalwatching in their spare time and contributing trip reports: see, for example, trip reports by Stuart Mardsen's Conservation Research Group at Manchester Metropolitan University, UK (https://stuartmarsden.blogspot.ca); by Charles Foley of the Wildlife Conservation Society in Tanzania (Foley, 2005); by Rohan Clarke of Monash University, Australia (Clarke, 2016); and by Andrew Balmford of Cambridge University (Balmford, 2013).

Volunteer work

Volunteering for research projects is a growing trend among mammalwatchers. In the USA and elsewhere, amateur mammalwatchers now regularly volunteer for bat and marine mammal research and conservation projects (Racey, 2013; Thiel et al., 2014). In the UK, amateur mammalwatchers participate in a number of long-term studies, such as Living with Mammals project (http://ptes.org/get-involved/surveys/garden/living-mammals/), which includes rodent and roadkill surveys, and Marine Life (www.marine-life.org.uk/), a program of marine mammal studies. In Western Australia the State government's Conservation and Land Management department was able to fund mammal research trips to remote areas by charging amateur mammalogists for the privilege to volunteer (Buckley 2003). In Russia, amateur mammalwatchers now provide hundreds of man-hours of volunteer work to some nature reserves, such as Kedrovaya Pad' and Kronotsky; they are also campaigning for better protection of nature reserves (M. Krechmar and S. Shpilenok personal communication). It is, therefore, arguably in the interest of professional zoologists and conservationists to encourage the growth of the mammalwatching hobby.

Potential negative effects of mammalwatching

Of course, mammalwatching is not without potential drawbacks from a conservation point of view. The popularity of birdwatching has created benefits for science and conservation, but also problems. The use of tape recordings for playback has altered bird behavior in some popular birding locations, prompting bans on playback of any animal sounds in many protected areas; disturbance by numerous visitors has been blamed for local extinctions (although this has never been proven) and increased nest failure, although the latter results more often from disturbance by photographers than by birders (Sekercioglu, 2002). There are also "secondary" negative effects such as increased greenhouse gas emission by long-distance travelers. Can mammalwatching have negative effects? Probably, if it becomes as popular as birdwatching. So far, although the hobby is growing in popularity, the number of people likely to visit any area is low and so the impact of mammalwatchers is limited (although that is not to say that some mammals are not impacted by ecotourism more generally). Also, many experienced tour guides agree that mammalwatchers tend to be "better-behaved" and less disruptive than wildlife photographers and non-naturalists (N. Black, R. Cameron, T. Collard, B. Eligulashvili, B. Gebretsadik, M. McTurk, E. Razoanantenaina, F. Reid, N. Sfatau, B. Zuwadi, S. !Noxmias personal communication). But it will be important to develop rules and policies ensuring that the positive impacts of mammalwatching outweigh the negative ones. Some efforts to teach novice mammalwatchers ethical conduct are already ongoing: for example, Bat Conservation International runs classes on bat observation techniques (www.batcon.org), while Marine Life has courses for marine mammal observers (www.marine-life.org.uk/). The first books for mammalwatchers have chapters on responsible wildlife viewing (Estes, 1999; Moores, 2007; Dinets, 2015; Andrew, 2016).

Promoting mammalwatching and improving its impact

We have demonstrated that the growing mammalwatching community has the potential to benefit mammalogy and conservation in a number of ways including bringing money, manpower, and knowledge. How, then, can mammalogists leverage this potential to encourage the growth of responsible mammalwatching? We have a number of suggestions.

More publishing

Although some amateur mammalwatchers have published information in scientific literature as we discussed earlier, the vast wealth of data from trip reports is unpublished (JH pers. obs.). There are likely several reasons, but a lack of experience in publishing scientific articles is off-putting for many would-be contributors. Perhaps professional mammalogists would be willing to co-author work, primarily notes of unusual sightings, to build capacity among the amateur community and help ensure current (and future) records enter the literature. Developing some guidelines for potential authors, outlining a general format and set of criteria for publishing work, along with the names of publications, newsletters or websites which could be approached to publish such work would also be helpful. Mammalwatching.com could provide a mechanism to link the amateur and professional worlds. It seems clear that many mammalwatchers feel little incentive to publish records in anything other than trip reports (indeed many do not even write trip reports). The mammalwatching community can provide encouragement, stressing the importance of such contributions to science and also pointing out that stronger relationships with academia can help mammalwatchers: the latter frequently contact academics to ask where best to see certain species and/or to seek help with identification, and are usually met with generous assistance (JH pers. obs.).

Ethical mammalwatching

As mammalwatching grows, it is more important than ever to ensure that it is undertaken ethically. Of course, different people have different views on what is ethical: some might believe that using a spotlight to observe nocturnal species is an unnecessary disturbance; others might oppose using live traps to capture rodents for anything other than strictly scientific reasons (and indeed in some countries legislation seeks to ensure just this). Such arguments are unlikely to be resolved anytime soon, but perhaps we can agree that a guiding principle ought to be to ensure that, on balance, the mammalwatching community is doing significantly more good than harm: perhaps those spotlights are indeed disturbing lemurs in a patch of Madagascan forest, but without the income generated by the tourists holding them it is likely that the forest itself would have been lost. Whether or not mammalwatching indeed makes a positive contribution will depend on many factors, and vary from site to site and species to species. But the more experience a mammalwatcher gains in the field with professionals, the less likely he or she is to inadvertently harm an animal. Mammalwatchers have learned a great deal about many aspects of mammalogy from the academic community, particularly when volunteering to help with field work around the world, including unobtrusive wildlife observation and responsible live trapping of small mammals. And promoting similar opportunities to mammalwatchers could be a triple win for mammalwatching, resource-strapped academics, and conservation. Learning about volunteering opportunities is haphazard to say the least, and in our experience is largely through word of mouth or after directly contacting mammalogists. We encourage professional biologists seeking volunteers for help with field work to contact the mammalwatching community.

More access for mammalwatchers

One issue of great importance to mammalwatchers is access. In recent years, many protected natural areas worldwide have introduced stricter limitations on nighttime and/or unguided access. For example, almost all national wildlife refuges in the USA are now open only during daylight hours (Dinets, 2015).

Spotlighting is often prohibited; this rule is usually introduced to combat nighttime poaching, but it is often interpreted as a ban on any use of flashlights (www.yellowstonepark.com/yellowstone-regulations/). These practices can make mammalwatching difficult or impossible, since many species of mammals are nocturnal and finding them requires silence, which is often problematic in the presence of an unprofessional guide. Organized night drives and guided walks, when available, can be expensive, as in many Indonesian national parks (VD pers. obs.), or focus only on the larger and more charismatic species, with vehicles often not stopping to look at smaller mammals (JH pers. obs.). These rules have resulted in drops in visitation by mammalwatchers, for example, in Corcovado National Park in Costa Rica (Fletcher, 2013).

Indeed some guides of mammalwatching tours now try to avoid national parks and visit private and community reserves with fewer access restrictions (R. Cassidy personal communication). The situation is particularly pronounced in many African parks, where visitors have to remain in fenced camps from sunset to sunrise, supposedly for their own safety. The parks where strict “safety” rules are not applied, such as Mana Pools in Zimbabwe where the campsite is unfenced and people are allowed to walk anywhere, at their own risk, actually have a better safety record than those where “safety” rules are the strictest (Bechky, 1997). Not surprisingly, a recent survey of visitors to Mana Pools National Park has shown that the majority of them chose to visit that park precisely because it allows unlimited unguided walking (The Zambezi Society, 2015).Where mammal watching at night is allowed, its impact on wildlife is minimal (Newsome *et al*. 2005); or at least there is no evidence to the contrary.

Considering the growing importance of mammalwatching as a source of visitor funding and citizen science, the administrators of protected natural areas should consider formulating their rules to ensure mammalwatching is encouraged and suitably managed, for example, by making it possible for responsible mammalwatchers to be exempted from some restrictions or by helping them obtain special use permits.

CONCLUSION

It is time to recognize the benefits mammalwatching can bring to science and conservation, and to make sure that the relationship between amateurs and professionals is mutually beneficial. Current dynamics show that mammalwatching has a great potential; the future will show if it becomes as important and beneficial as birding, which we think is entirely possible.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Plant diversity analysis for conservation of Afromontane vegetation in socio-ecological mountain landscape of Gurage, South Central Ethiopia

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The present study was conducted for the conservation and management of vegetation in a socio-ecological mountain landscape through assessment of floristic composition, community types and structure of woody species in the Wabe River catchment of the Gurage Mountains in Ethiopia. The preferential sampling technique was applied to collect floristic and vegetation structure data, and within each plot, woody species diameter at breast height (DBH) was measured. R statistical software was used to analyze the vegetation cluster, diversity and structure. As a result of the heterogeneous nature of the catchment vegetation, the optimum number of six clusters (community types) were identified which were named through high ranked species. The majority of the community types had high diversity indexes and equitability or evenness. Most of the species had lower DBH classes and frequency. Besides, the important value index (IVI) for most of the species showed high value. This information facilitated for sustaining the biodiversity through identification of high plant diversity spot community types to be protected, degraded vegetation areas to be rehabilitated and fragmented vegetation areas to establish ecological connectivity. Further studies on the ecosystem services provided by the vegetation could be important for understanding their value and to advance the planning and management mechanisms.

Key words: Community type, floristic composition, diversity, equitability, structure, important value index (IVI), landscape planning.

INTRODUCTION

Biodiversity plays a significant role in the ecosystem delivery (Mace et al., 2012), either to ensure ecological processes (for example soil fertility) or to provide provisioning services (for example food and water),

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regulating services (for example climate regulation, erosion mitigation and water purification) and cultural services (for example aesthetic appreciation and recreation). It is fundamental to universal ecosystem functions such as the absorption and transfer of energy and the uptake and loss of carbon dioxide, water, and nutrients (MA, 2005) which, in turn, deliver ecosystem services. Experimental manipulation of biodiversity and ecosystem functioning has shown a consistently positive effect on diversity in the generation of ecosystem services for a range of organisms, habitats and services (Balvanera et al., 2006; Quijas et al., 2010).

Biodiversity has an apparent relationship with ecosystem functions, and measures that protect or enhance biodiversity may also be beneficial to the provision of ecosystem services. Biodiversity loss in turn reduces the efficiency by which ecological communities capture biologically essential resources, produce biomass, decompose and recycle biologically essential nutrients (Cardinale et al., 2012). For services like carbon sequestration, specific key species such as leguminous tree species in grasslands and long-lived trees in forests are important (Harrison et al., 2014). Habitat and species protection improves the chance of sustaining a diverse flora and fauna that, in turn, provides the benefits of biodiversity (Dobson et al., 2006).

Ethiopia is endowed with diverse landscape features and climate, resulting in both floral and faunal diversity and making the country an important centre of diversity and endemism (Woldu, 1999). The number of higher plants is composed of more than 6,500 species, of which about 10.5-12% are probably endemic (CBD, 2009). However, Ethiopia's natural vegetation is under considerable pressure due to the rapidly increasing population, expanding agricultural activities and increasing deforestation (Eshetu, 2014). In the past, most of Ethiopia's highlands were believed to have been covered with dense forests. The existence of numerous isolated mature forest trees of approximately the same species composition in the remaining areas of closed forest and in many churchyards, they evidently indicate that the extent to which the highlands of Ethiopia were once forested (Friis and Demissew, 2001).

In 1930s, about 20% of the land in the Gurage zone, was covered with natural forests. The forest covers successively decreased and reached their peak during the years 1991 and 1992. This could be due to the political system changes in the country. In parallel, since at the beginning early 1960s the inhabitants started to grow eucalyptus on an increasing scale, which increased the amount of land being covered with trees (Bekalu and Feleke, 1996; Zerga, 2016). According to the land use land cover classification of the Gurage zone (EMA, 2011), 18.4% of the area was covered by different types of vegetation (for example Afro-alpine vegetation, shrub land, woodland, eucalyptus plantation and forest with forest covering only 3.8%. Wabe River catchment in the Gurage zone had relatively higher coverage of total vegetation (24%) and forestland (7.6%). Although the Wabe River catchment covers 8.9% of the Gurage zone, it contains 42% of the vegetation coverage of the zone.

The Governments of Ethiopia tried to implement different interventions to rehabilitate the degraded areas and to maintain the remaining forests (Eshetu, 2014). In similar way, forest protection and watershed management activities were implemented in the Gurage Mountains. However, lack of information on plant diversity has hindered the identification of biodiversity hotspots and intervention areas, which require special attention for conservation and management.

Botanical assessments of different vegetation such as floristic composition, species diversity and structural analysis studies are essential for understanding forest ecology and ecosystem functions, and forest management purpose (Giriraj et al., 2008; Pappoe et al., 2010). Knowledge of floristic composition and structure of forest is also useful for conservation by identifying ecologically and economically important plants and their diversities, protecting threatened and economically important plant species (Addo-Fordjour et al., 2009). For proper planning and management of biodiversity, and ecosystem services provided in the Wabe River catchment, the information on plant diversity is required. Thus, the aim of this study was to assess the floristic composition, diversity and structure of woody species and use this information for conservation and management of biodiversity and ecosystem services in the Wabe River catchment of the Gurage Mountains in South Central parts of Ethiopia.

MATERIALS AND METHODS

Study area

The Gurage Mountains extend from the Awash River Basin in the north to the Hadiya zone in the south, partitioning the Gurage Zone in half. The mountains form a watershed boundary between the Omo–Gibe River Basin in the west and the Great East African Rift Valley in the east. Wabe River catchment is a sub-catchment of the Omo–Gibe. The catchment is located between 08° 21′ 30″ and 08°30′ 00″ N and 38° 05′ 40″ and 37° 49′ 00″ E. The Gurage Mountains, with altitudes of 3,611 m above sea level, make up the highest area in the catchment and the lowest altitude of 1,014 m is found in the Western Gibe River (Figure 1). The catchment covers a drainage area of about 1,860 km^2. The five-agroecological zones existing in the catchment are the cool moist mid-highlands, the cool subhumid mid-highlands, the tepid moist mid-highlands, the tepid subhumid mid-highlands, and the warm subhumid lowlands (MOA, 2000). The Wabe River catchment's maximum temperature ranged from 20°C (in the wet season) to 39°C (in the dry season), while the minimum temperature is in the range 0 to 19°C. The average temperature is 18°C. The mean annual rainfall ranges from 1,200 to 1,320 mm (NMA, 2016). The pellic vertisols are the dominant soil type according to the FAO soil classification. Land use within the

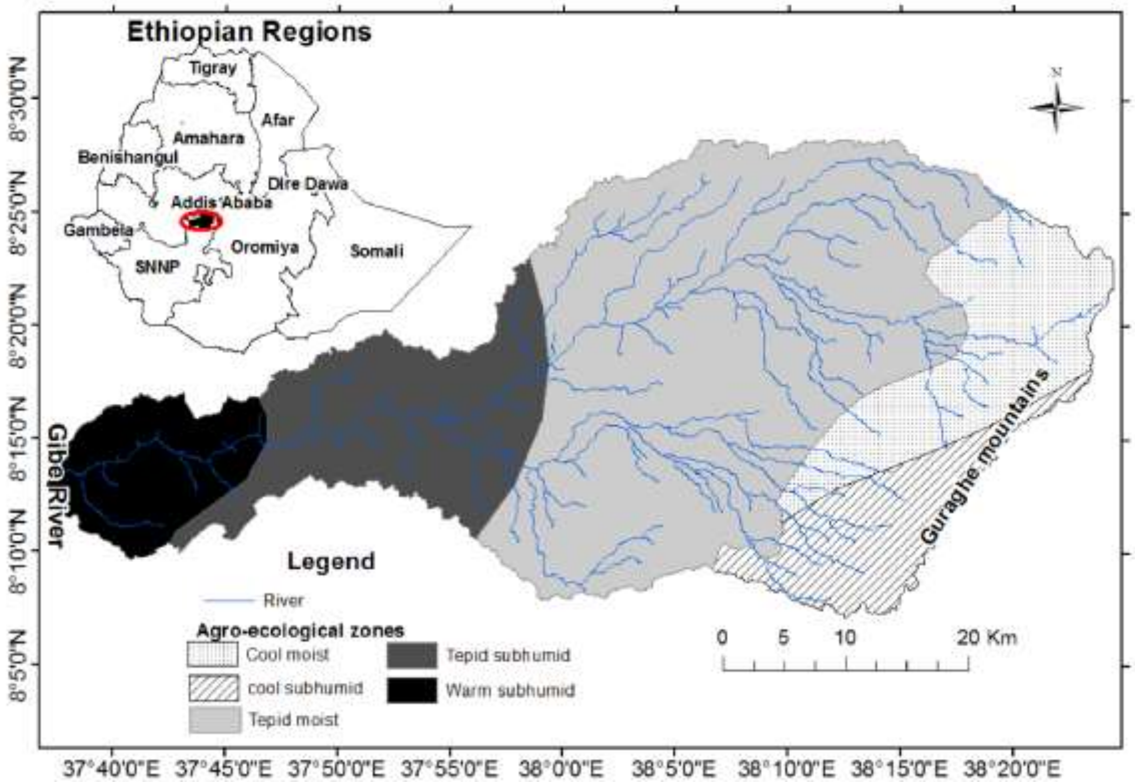

Figure 1. Location map and agroecological zones of Wabe River catchment.

Wabe River catchment is primarily oriented to Enset based subsistence agriculture, though there have been reported increases in the plantation of eucalyptus trees and Khat (*Catha edulis*), and cultivation of cereals (Woldetsadik, 2004). Enset crop plants are the main food source in the Gurage Mountains area.

Vegetation data collection

As a result of large area coverage and habitat heterogeneity, the preferential sampling technique was used to collect floristic and vegetation structure data in the Wabe River catchment. Google Earth and SPOT imageries were used to identify the clear distinction between vegetation and habitat heterogeneity before vegetation sampling. Then at every 100 m altitude difference, the vegetation data were collected along the rivers and in forest patches using 20 × 20 m sample plots. In total, 90 sample plots were examined. Within each plot all woody species with DBH (1.3 m above ground) > 5 cm were measured for their DBH and height. Voucher specimens were collected for identification at the National Herbarium of Addis Ababa University using the Floras of Ethiopia and Eritrea.

Vegetation data analysis

An agglomerative Hierarchical Classification technique using Euclidean distance and Ward's method was used for clustering the vegetation data using R statistical software (Woldu, 2012). Through careful inspection of the dendrogram using K- value, the optimum number of clusters was identified. The K- value was also confirmed for consistency using the partitioning method that was obtained by plotting the sum of squares within the groups versus the number of clusters and observing where there is a sharp break in the graph. The value on the x-axis where there is a sharp break in the graph represents the optimal number of clusters in the dendrogram.

The clusters were considered as "plant community types" and named using two characteristic species having the highest mean abundance values of their community type. The synoptic table of species analyzed using R software was used to obtain information about each cluster's highest cover abundance.

The vegetation structure was described using frequency distribution of density, DBH, basal area, frequency and Importance Value Index (IVI). IVI was computed for all woody species based on relative density (RD), relative dominance (RDo) and relative frequency (RF) to determine their dominant position.

Importance value index (IVI) = Relative density + relative dominance + relative frequency

Where,

$$\text{Relative Density (RD)} = \frac{\text{Total number of all individuals of a species}}{\text{Total number of individuals of all species}} \times 100$$

$$\text{Relative Dominance (RDo)} = \frac{\text{Total basal area of a species}}{\text{Total basal area of all species}} \times 100$$

$$\text{Relative Frequency (RF)} = \frac{\text{Number of quadrats in which a species occurs}}{\text{Total number of quadrats examined}} \times 100$$

Basal area (BA) was calculated to determine the dominance using the following equation:

$BA=\pi d^2/4$, where, π = 3.14; d = DBH (m).

Shannon -Wiener Diversity Index was used to analyze the species diversity, species richness and evenness of the vegetation as:

$$\text{Equitability J (Evenness)} = \frac{H'}{Hmax} = -\sum_{i=1}^{N} \frac{pilnpi}{lnS}$$

Where, H' is the Shannon-Wiener Index; Hmax is the species richness; S is the the number of species; Pi is the proportion of individuals of the i^{th} species or the abundance of the i^{th} species expressed as a proportion of total cover; and ln: natural logarithm Sorensen's coefficient of similarity index was used to compare the floral similarity of community types and calculated as:

$$Ss=\frac{2a}{b+c}$$

Where, Ss is Sorensen's coefficient of similarity, "a" is the number of species common to both community type 1 and 2, "b" is the number of species in community type 1 and "c" is the number of species in community type 2.

RESULTS

Floristic composition

Eighty-eight species belonging to 71 genera and 48 families were recorded from the study area. About 45% of the families recorded from the area were represented by two and more species, while about 54% of the families were represented by only a single species. Fabaceae was the most dominant family and represented by 12 species. The families Myrtaceae and Oleaceae were the next dominant and had four species each. The families Anacardiaceae, Combretaceae, Ebenaceae, Euphorbiaceae, Moraceae, and Salicaceae have three species each. From the investigated vegetation, 25% of the families had two species each. The remaining 26 families that contributed 54% of the total species were represented by one species each. Out of the 3,632 total woody plant individuals which have DBH > 5 cm recorded from the study area, the trees represented 78.5% whereas shrubs were 21.5%.

Vegetation classification

Plant community types

Cluster analysis resulted in grouping of 90 sample plots into six clusters (Figure 2). The resulting clusters were then considered as "plant community types" and named after two characteristic species. These are *Euclea divinorum- Scolopia theifolia* (Community type 1), *Juniperous procera- Olea europaea* subsp *cuspidata* (Community type 2), *Combretum collinum- Grewia villosa* (Community type 3), *Podocarpus falcatus- Euclea racemose* (Community type 4), *Eucalyptus grandis-Croton macrostachyus* (Community type 5) and *Erica arborea-Lobelia rynchopetalum* (Community type 6).

The community type 1 was dominated by *E. divinorum* and *S. theifolia* species. It was represented by 10 plots and comprised 28 species. Species like *J. procera, Schrebera alata, Rhus vulgaris, Olea europaea* subsp. *cuspidata, Bersama abyssinica* and *Prunus africana* were the other most dominant species in the community type.

Large numbers of the investigated plots (35) were under community type 2 wherein 58 woody species were recorded. *J. sprocera- O. europaea* subsp. *cuspidata* community type was found in ranges of 1,500 m altitude difference from warm (1672 m) to cool (3144 m) climatic conditions (Figure 3). In addition to *J. procera* and *O. europaea* subsp. *cuspidata,* there are also other dominant species in this community type such as *Podocarpus falcatus, Euclea racemose, Olinia rochetiana, Carissia spinarum, Prunus africana, Euclea divinorum, Dodonaea viscosa* and *Ficus elastica*.

The dominant species in the community type 3 were *Combretum collinum, Grewia villosa, Combretum molle, Cambretum aculeatum, Lonchocarpus laxiflorus, Lannea fruticose, Acacia polyacantha* and *Celtis africana.* In total, 25 woody species were recorded from this community type.

Podocarpus falcatus - Euclea racemose community type (4) was found at altitudes ranging between 1,667 and 2,647 m in the catchment (Figure 3). This community type composed of 29 species. *Podocarpus falcatus, Euclea racemose, Juniperous procera, Syzygium guineense* and *Jasminum abyssinicum* were the dominant species in this community. This community type respectively shared 13, 18, 10 and 9 species with community types 1, 2, 5 and 6.

Community type 5 dominant species were *Eucalyptus grandis* and *Croton macrostachyus.* In addition, *J. procera* and *P. falcatus* were the other dominant species in this community type. This community type contains 25 species recorded from 16 sample plots. The endemic species of Ethiopia- *Millettia ferruginea* was also found in this community type.

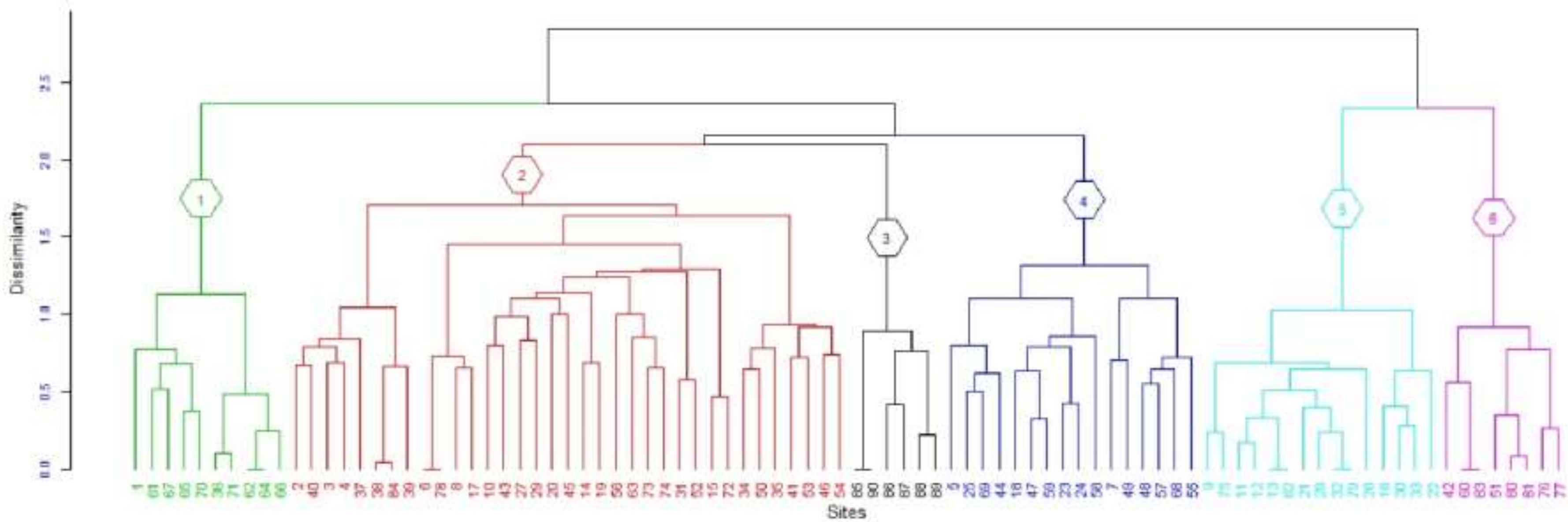

Figure 2. Dendrogram showing the plant community types of Wabe river catchment.

The last community type is found at the top mountain areas of the catchment. The Afro-alpine species *Erica arborea* and *Lobelia rynchopetalum* were the dominant species in this community. Species like *J. procera, C. macrostachyus* and *Eucalyptus globulus* were the other dominant species recorded. Twenty-two woody species were recorded from eight sample plots.

Diversity of woody species in the plant community types

Shannon-Wiener diversity index analysis of the six plant community types shows that community 2 had the highest diversity followed by community 1 while community 5 showed the least diversity (Table 1). Community type 2 had the highest species richness, whereas the last species rich community was community type 6. However, evenness (equitability) which measures the relative abundance of different species present in each community showed relatively the highest value in community 1 followed by community 4 and the lowest was in community 5.

Similarity between plant community types

Based on Sorensen's Coefficient Index (Table 2), the highest similarity was observed between communities 1 and 6 while less similarity was observed between communities 1 and 3, and 3 and 6. The result from the analysis showed community 1 and 6, community 2 and 1, and community 2 and 6 shared about 64, 61 and 56% similarity in species composition, respectively. Community type 1 shared 26, 12, 10 and 16 species with community 1, 4, 5 and 6, respectively. Community type 3 shared five species with community type 2, one species with community type 4 and 6, and two species with community type 5. Twenty species of community type 5 were similar to community 2. Nevertheless, only two of the species were similar to community type 3. Community type 5 shared 12, nine and eight woody species with community types 1, 4 and 6, respectively. The community type 6 shared 16 woody species with community type 1, 10 species with community type 4 and nine species with community type 5.

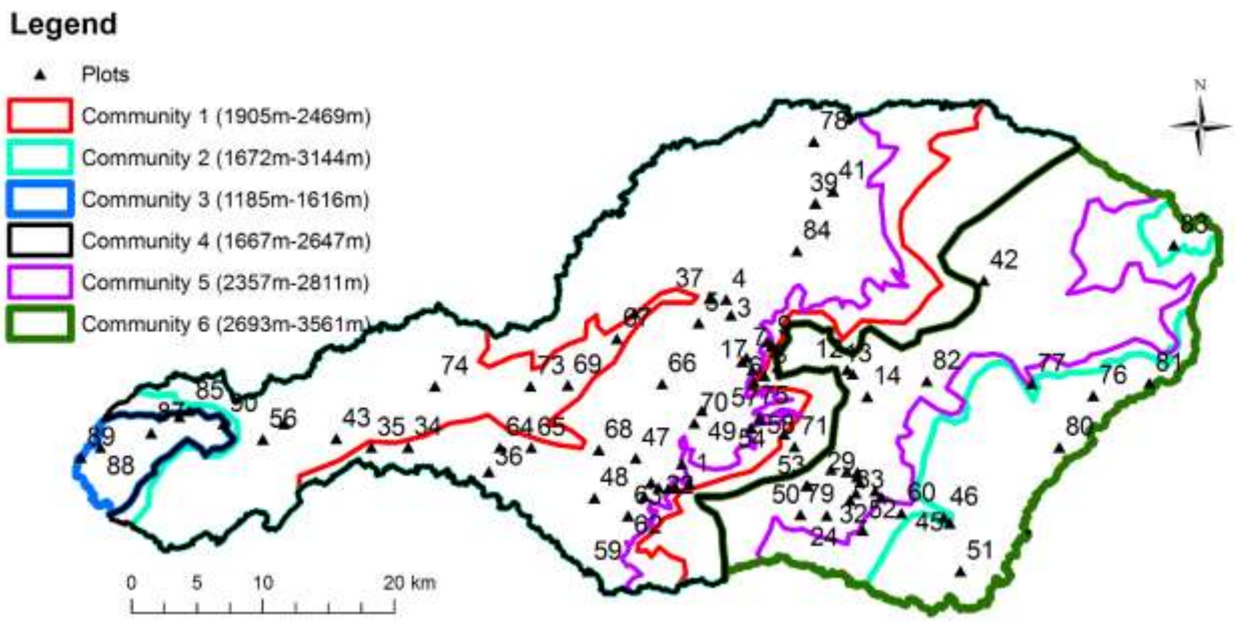

Figure 3. The spatial extent of the six-community types with their sample plots in Wabe River catchment.

Table 1. Shannon-Wiener diversity index.

Community	Species richness	Diversity index (H)	Evenness (Equitability)
1	28	3.1	0.94
2	57	3.5	0.86
3	25	2.8	0.86
4	29	2.9	0.87
5	24	2.6	0.82
6	22	2.7	0.83

Table 2. Sorensen's similarity index between community types (%).

Community type	1	2	3	4	5	6
1	100	61	4	42	46	64
2	61	100	12	44	49	56
3	4	12	100	6	8	4
4	42	44	4	100	38	39
5	46	49	8	38	100	39
6	64	36	4	39	39	100

Structural analysis of woody species

Density

The total stem density of woody species with DBH ≥ 5 cm was 1,008 individuals ha^{-1} (Table 3). From this, 40% of the total density was contributed by 16 species from the density class C. Species which had a higher stem density relative to other species in the Wabe River catchment are *J. procera, E. grandis, Erica arborea, P. falcatus, Ficus elastica* and *Combretum collinum*. Of these species, *J. procera* had a density above 100 densities per ha and contributed to 13% of the total density. Although 69 woody species belonged to density class D, and contributed to only 24% of the total density.

DBH class distribution

Most of the stems (56%) had the highest number of individuals in the lowest DBH class and the number of individuals progressively decreased with increasing diameter class (Figure 4).

Table 3. Stem density distribution of woody plants in different density classes.

Density class (individuals ha^{-1})	Number of species	Number of stems	Stem density	% of density
A (>100)	1	484	134	13
B (51-100)	2	841	237	23
C (11-50)	16	1454	404	40
D (1-10)	69	853	237	24
Total		3632	1008	100

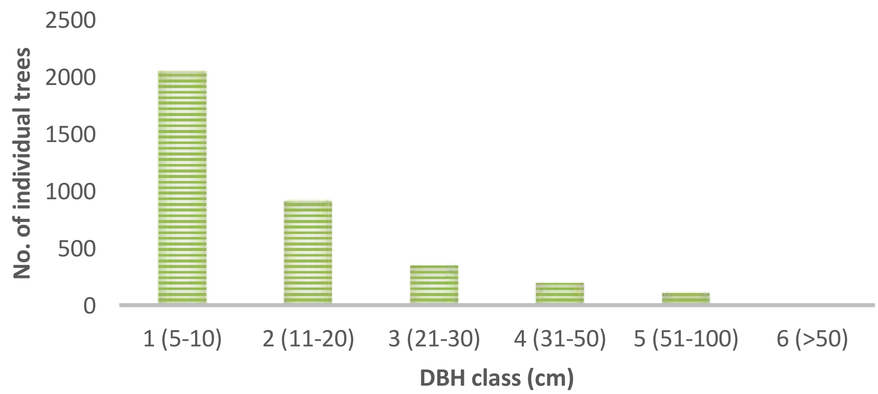

Figure 4. Distribution of woody individuals in different DBH classes.

Frequency

About 84% of the total woody species was distributed in the lowest frequency class, whereas 13% of the individuals was distributed in the second frequency class. With a frequency of 43%, *J. procera* is the most frequent species followed by *P. falcatus* (28%) and *O. europaea* subsp. *cuspidata* is the third most frequent species (23%).

Basal area

The total basal area of the vegetation under study area was 118 m^{2}ha^{-1} for woody species > 5 cm in DBH. About 47% of basal area was contributed by individuals with a diameter above 50 cm and the lowest by individuals with a diameter below 10 cm.

Importance Value Index (IVI)

From the total 88 woody species, 56 species had IVI greater than 5:00. These species are considered dominant because they have higher relative density, relative frequency and relative abundance in comparison with other species in the catchment. *J. procera, P. falcatus* and *E. grandis* with IVI of 206, 114 and 107 respectively were the top three species with the highest IVI values in the Wabe River catchment while *Allophylus abyssinicus, Rhamnus staddo, Oncoba spinosa, Myrica salicifolia, Spathodea campanulata, Acacia abyssinica, Dovyalis abyssinica, Premna schimperi, Pilliostigma thonningii* and *Arundinaria alpina* had the lowest IVI value.

DISCUSSION

Floristic composition

The result of floristic study revealed that Wabe River catchment is very rich in woody plant species diversity. The family Fabaceae, which is dominant in the catchment, was one of the most reported families in the floristic region (Yineger et al., 2008; Alemu, 2011; Dibaba, 2014). The dominance of the family Fabaceae in the study area is also in contour with the assessment results in the Flora of Ethiopia and Eritrea. Fabaceae might have got the dominance position probably due to efficient pollination and successful seed dispersal mechanisms that might have adapted themselves to a wide range of ecological conditions in the past (Kelbessa and Soromessa, 2008). The low number of endemic species in our study areas is because of our focus on woody species with DBH >5 cm, while most of the endemic species of Ethiopia were shrubs and herbs (Hedberg et al*.,* 2006; Tadesse, 2004) with smaller diameter.

Vegetation classification

The six plant community types recognized in our study area is higher than the number of plant community types identified from other vegetation studies in Ethiopia (Alemu et al., 2011; Erenso et al., 2014; Atsbeha, 2015; Kassa et al., 2016). This could be due to the fact that the study area is found in warm, humid, moist and cool agro-ecological zones supporting different vegetation types. In addition, the catchments have a difference in altitude, aspect, soil, human impacts and grazing intensity that can limit the ecological distribution of plant species that might have attributed to variation (Bekele, 1993; Kassa et al., 2016).

The Shannon-Weiner diversity index, normally varies between 1.5 and 3.5 and rarely exceeds 4.5 (Šmilaue, 2001). In the present study, the overall diversity ranges between the lowest 2.6 (in community type 5) and the highest 3.5 (in community type 2) shows that there is a high diversity. There is more or less even representation of individuals of most woody species in the sampled quadrats.

High and low species evenness can be attributed to environmental disturbances, variable conditions for regeneration and selective exploitation of some species (Kidane, 2003). Except community type 5, the other community types in this study had almost the same species diversity (equitability or evenness) with high species evenness. The community type 5 in the upper catchment has a relatively low evenness and it needs much attention.

The similarity between community types in the Wabe River catchment is believed to depend on altitude. The community types with higher similarity were found to overlap in their altitudinal distribution (Figure 3). There was no altitudinal overlap seen by community types with least similarity.

In addition to altitudinal gradient, other environmental factors of the catchment such as aspect, slope, and soil physical and chemical properties could have considerable effects on patterns of vegetation in communities and make the other communities to have good similarity (Derje, 2007). The existence of low similarities between communities indicates that the communities are important in terms of floristic diversity and needs attention from a conservation point of view (Fekadu et al., 2014).

Vegetation structure

Most of the measured stems (56%) existed in the lower DBH class, showing that shrubs and small trees represent the largest portion of the vegetation. The existence of the number of individuals in the lower DBH class was similar to studies in Wof-Washa and Chilimo (Bekele, 1993), Bibita (Derje, 2007), and Magada (Tura and Reddy, 2015) forests of Ethiopia. As the DBH class increased, the density decreased, which means that the vegetation has a small quantity of big trees in the higher DBH classes. The highest proportion of stem density was contributed by a few individuals of woody species that have greater density class. This pattern indicates that Wabe River catchment vegetation has a good natural reproduction and recruitment potential.

The highest number (84%) of the total species was distributed in the lowest frequency class and a few species were distributed in the highest frequency class. This indicates that most of the species were recorded from few plots. The few woody species with highest frequency value are those recorded from most sample plots and are well distributed in the vegetation of the study area. According to Kidane et al. (2003), this situation indicates the dominating position of the species in the vegetation. The most frequently found species in the catchment such as *J. procera, P. falcatus* and *O. europaea* had good distribution status.

Basal area provides a better measure of the relative importance of the species (Bekele, 1994). The high basal area of this study area (118 m^2ha^{-1}) shows that the catchment vegetation had a higher basal area compared to similar studies in Ethiopia; 68.52 m^2ha^{-1} by Bekele (1993) and 81.9 m^2ha^{-1} by Yeshitela and Bekele (2003). Thus, most of the species found in the catchment are important.

The result indicates that the majority of the woody species had IVI greater than 5.00 even though high IVI was attributed to fewer species. These species are those which are well adapted to the high pressure of disturbance, natural and environmental factors, and the effects from local communities. This indicates that most of the species were very important for providing ecological services in the catchment (Fekadu et al., 2014). As those with the greatest importance value are dominant in specified vegetation (Shibru and Balcha, 2004) and might also be the most successful species in regeneration (Kenea, 2008).

Implications for conservation and management of Afromontane vegetation

Protect current patterns of plant diversity

Conservation management is required to protect species

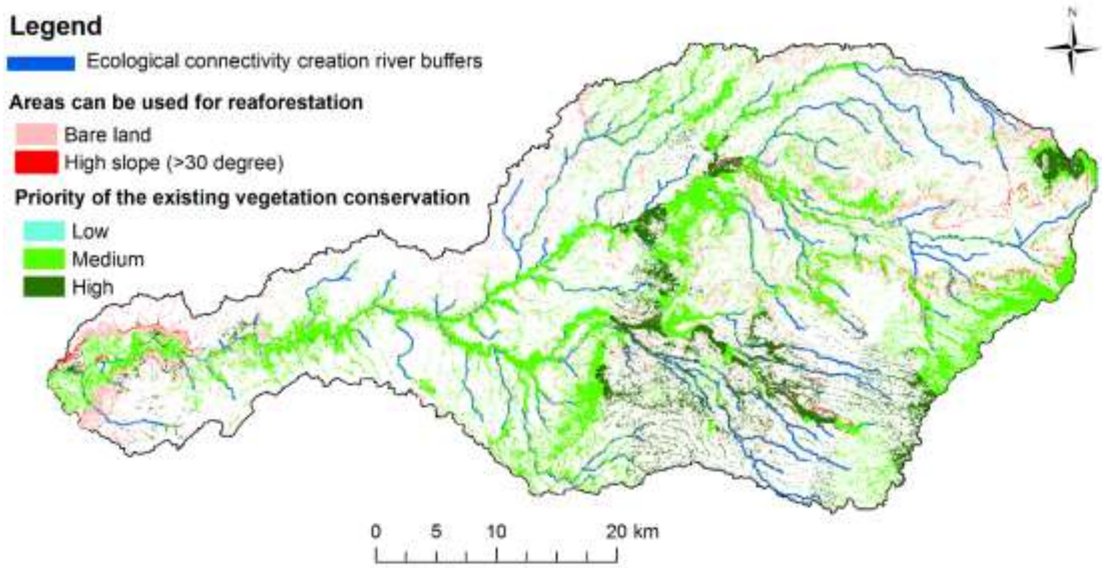

Figure 5. Conservation priority areas in the Wabe River catchment.

where they are today. Without protection, species, especially those that are rare and threatened, will have little chance of persisting until other adaptive approaches are possible or effective (Schmitz et al., 2015). Even though conservation is needed in all parts of the vegetation landscape in this study area, priority is needed for the areas that have high species diversity, found in high altitude areas, low similarity between community types and low species evenness between community types (Figure 5). Thus, community types 3 and 6 are due to low similarity; community type 2 is due to high diversity; and community type 5 due to low evenness should have been given more attention for conservation. High altitudes are given a high priority due to the conservation of the upper catchment that provides a number of benefits to lower catchment, especially regulating the ecosystem services of water, soil erosion and nutrient retention.

Identifying and protecting requiring rehabilitation

The Wabe River catchment has large areas with a high slope due to undulating topography and the bare lands are mostly degraded (Figure 5). Thus, landscape planners and decision makers of the area can use the bare land and high slope areas for rehabilitation to increase biodiversity and ecosystem services.

Maintain and establish ecological connectivity

Even if we succeed in conserving today's portfolio of large natural and semi-natural landscapes and habitat connecting corridors, species will shift their range within these landscapes due to different factors. Connecting areas with corridors, stepping stones, or working lands creates landscape permeability for plant and animal movement (Schmitz et al., 2015). The connected areas sustain gene flow among species populations that can prevent local extinctions (demographic rescue), and facilitate re-colonization after local extinction. Most of the Wabe River catchment vegetation is found along rivers and is thus connected by river buffers. However, some patches of forests remain unconnected. Taking the advantages of the river networks in the catchment, the patches of forests can be reconnected through river buffer afforestation and reforestation using the information on the floristic composition of this study (Figure 5).

Conclusions

Plant diversity study in Wabe River catchment shows that the catchment has a diversified woody species. Since the vegetation is found in various agro-ecological zones of the catchment, the cluster analysis resulted in six community types (clusters). Most of the community types have a good diversity index and equitability or evenness showing that they are under good protection. But, the community types found in the upper catchment have relatively low equitability showing that they are under pressure. While some of the community types have high similarity, those found in the lower and upper catchments were isolated and have no similarity contributing to the diversity of species in the catchment. Therefore, these vegetation types require special conservation attention. Even though the catchment species have a variety of IVI, most of the species have good indexes showing that they are important for ecological services. Thus, proper conservation of the variety of species available in the catchment to maintain and enhance the existing ecosystem services is needed. Assessing plant diversity in this way improves our understanding of vegetation status in a given area. Our approach helps land use planners, local policy and decision makers to enhance vegetation conservation mechanisms and thereby ecosystem services. Such study could also greatly contribute to developing conservation strategies at different scales and embed them in their respective vegetation in the social-ecological environment. Studies on the quantification and mapping of ecosystem services provided by the vegetation would be recommendable to enhance the planning and conservation approach.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Effect of forest management approach on household economy and community participation in conservation: A case of Aberdare Forest Ecosystem, Kenya

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Forest ecosystems are important for ecological and socio-economic wellbeing, particularly for diversification of the livelihoods of adjacent communities. The forest management approach applied in an ecosystem influences availability, access and utilisation of forest products, and community participation in conservation. This study examined the effect of forest management approach on households' economy and participation in forest management. A random sample of 202 households adjacent to Aberdare forest ecosystem was selected for characterisation and interviews using semi-structured questionnaires. Data collected were analysed using Chi-square test, Spearman's rho correlation and multinomial logistic regression. Although the benefits varied with management approach, the majority of the households indicated the forest was beneficial as only 6% reported no benefits. There was a significant association between forest management approach and households' sources of food ($\chi^2 = 27.704$, $p < 0.001$), socio-economic status ($\chi^2 = 20.194$, $p < 0.001$) importance of forest ($\chi^2 = 11.863$, $p < 0.001$), forest dependence ($\chi^2 = 53.580$, $p < 0.001$) and participation in forest management ($\chi^2 = 17.551$, $p < 0.001$) at $\alpha = 0.05$. The factors that significantly influenced the regression model included households' dependence on the forest, socio-economic status and participation in forest management where R^2 was 0.797. These findings depicted that when ecosystems made no substantial contributions to livelihoods, their value and the level of community participation in conservation was lower.

Key words: Conservation management approach, economic importance, forest dependence, household economy, participatory forest management, protection management approach.

INTRODUCTION

Forests are multi-functional ecosystems which provide diverse goods and services, including intrinsic, economic, cultural and aesthetic values essential for socio-economic well-being, particularly to the forest adjacent community (de Groot et al., 2016; Costa et al., 2017). Although forest contribute significantly towards the diversification of livelihoods of communities adjacent to forest ecosystems, inadequate community involvement in the management and governance of the forest resources, has been identified as a major cause of the escalation of ecosystem destruction (Agrawal, 2009; Biedenweg, 2012; Mogoi et al., 2012; Tesfaye, 2017).

Failure to recognise and account for the multiple uses and users has led to patterns of global forest degradation and losses with many detrimental environmental consequences (Lise, 2000; Kipkoech et al., 2011; Langat et al., 2016). This calls for methods of managing forests in a way that preserves ecological integrity and human well-being while addressing the diverse demands (Mbairamadji, 2009; Tesfaye, 2017). This has given rise to development of forest management approaches (FMA) over the past decades based on the sustainable forest management (SFM) concept that recognises the need to balance the ecological, socio-cultural, and economic objectives in management (Costanza, 2014; Rita et al., 2017).

A study of forests and livelihoods in the context of sustainable management requires that we understand the links and interactions between the resource, users, and institutions that mediate between them (Ongugo et al., 2008; Fisher et al., 2011). Mogoi et al. (2012) and Engida and Mengistu (2013) observed that there were two opposite perspectives to the cause of deforestation. Firstly, increased demand for fuel wood, timber, land for agricultural expansion and settlements leads to deforestation. Proponents pinpoint growth in population and the resultant forest dependence and poverty as the main causes. Secondly, the drivers of deforestation lie in the failure of the forest bureaucracy to adequately involve forest adjacent communities and other stakeholders in the management and governance of the forest resources (Mogoi et al., 2012; Musyoki et al., 2013).

The second perception has been gaining popularity and 10 to 12% of the world's natural forests are officially being managed using some degree of community participation. In sub-Saharan Africa, at least 21 countries have embraced various participatory approaches to natural resources management (Langat et al., 2016; Tesfaye, 2017). In some of these cases, the devolution of forest management appear to facilitate improved forest conservation (Lund and Treue, 2008; Costa et al. 2017), though the picture seems uncertain with respect to livelihood impacts (Lund and Treue, 2008; Mogoi et al., 2012; Matiku et al., 2013; Langat et al., 2016). In tropical countries, the diversity of stakeholders depending on forests with different interests makes sustainable forest management difficult to achieve. The concept of SFM therefore lays emphasis on integration of the ecological, economical and sociological issues (Salleh, 1997; Mbairamadji, 2009; Tesfaye, 2017).

SFM advocates for stakeholder participation, particularly the adjacent communities, in forest management and decision-making (Salleh, 1997; Langat et al., 2016). This has been a tendency that has occupied significantly development thinking and practice in the recent years (Ellis and Ramankutty, 2008; Mbairamadji, 2009; Kenter et al., 2015). Governments, funding agencies, civil society and multi-lateral agencies seem to all agree that development can be sustainable only if people's participation is made central to the development process (Agrawal and Gupta, 2005; Tesfaye, 2017). Putting these considerations into account reduces conflicts among stakeholders with respect to access to and use of forest resources as well as guiding the allocation of forest space amongst stakeholders for different purposes (Lund and Treue, 2008).

Consequently, many countries in Africa and Asia are promoting the participation of rural communities in the management and utilisation of state-owned forests and woodlands through some form of Participatory forest management (PFM) (Lund and Treue, 2008; Bush et al., 2011; Engida and Mengistu, 2013). Incorporation of PFM in FMA is considered a dynamic system differing from the traditional approach of forest management in its systemic approach and its integration of ecological, economic and social constraints of forest management (Costanza et al., 2014; de Groot et al., 2016).

Kenya has different types of forests, ranging from the dry forests to the high montane forests, with each type necessitating a different management approach to provide a varied set of benefits to diverse stakeholders (Wass, 1995; KFS, 2010). This was the scenario exhibited in Aberdare forest ecosystem which consists of Aberdare Forest Reserve and Aberdare National Park which were managed through conservation and protection FMA respectively. It borders human inhabited farmlands with a growing population that exerts great pressure on the ecosystem due to the increased demand for forest goods and services. The ecosystem contributed to hydroelectric power generation, agriculture, horticulture and tourism industry that were key economic sectors in Kenya.

According to Bush et al. (2011) and Mogoi et al. (2012), institutional factors are important determinants of socio-economic values of forest ecosystems to local communities. Evidence from several studies carried out globally indicates that issues determining use of resources in protected forests are often related to FMA

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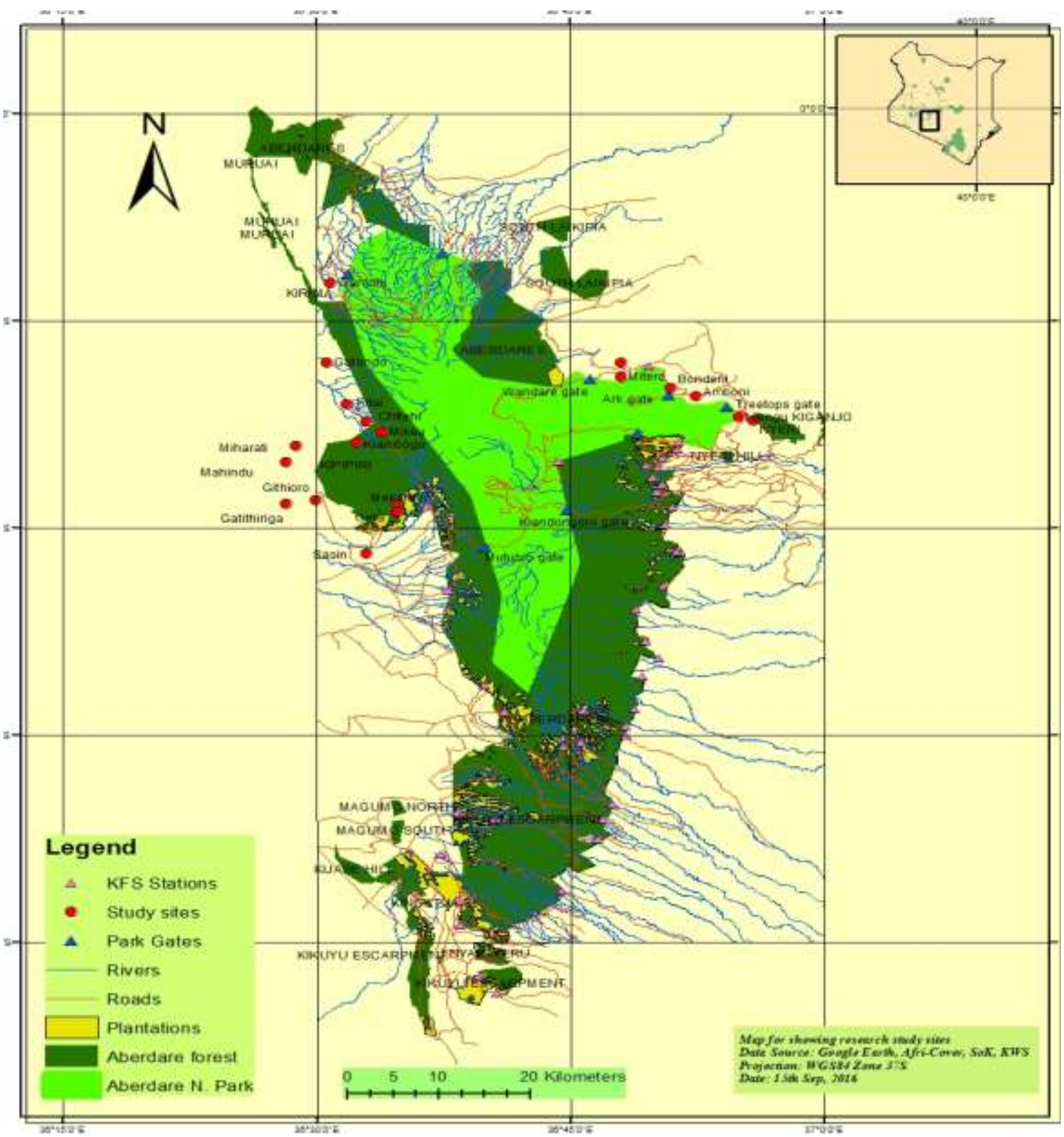

Figure 1. Map showing study sites within Aberdare Forest Ecosystem in Kenya.

and thus are area specific (Cavendish, 1999; Gaveau et al., 2009; Costa et al. 2017).

The study aimed at providing insights into the effect of forest ecosystems FMA on household economy of adjacent community and their involvement in PFM. Thus, the study examined the household dependence on to Aberdare forest ecosystem and their level of involvement in PFM based on FMA. The significance of the study was to recommend ways to promote community involvement in PFM to enhance conservation of forest ecosystems while addressing livelihood improvement.

METHODOLOGY

The study area

The study focused on Aberdare Forest which was a unique ecosystem as a Forest Reserve and a National Park extend and directly border with farmlands (Figure 1). The ecosystem was one of the five major water towers in Kenya. The forest ecosystem as used in this study comprised of Aberdare Forest Reserve, Aberdare National Park and an area of about 5 km of farmlands. It is located between longitude 36°30'E and 36°55'E and latitude 0°05'S and 0°45'S. The forest ecosystem was approximately 226,522 ha, whereby the Forest Reserve covers an area of 149,822 ha and the

Table 1. Community demographic profile.

Demographic factors	Units	N	Minimum	Maximum	Mean
Age of respondent	Years	202	21.00	101.0	54.0
Duration of settlement	Years	202	1.00	50.0	32.0
Household size	No.	202	1.00	30.0	6.7
Household members working in the farm	No.	202	1.00	14.0	2.8
Household members formally employed	No.	44	1.00	6.0	1.5
Distance to Forest Reserve	km	115	1.00	6.0	2.9
Distance to National Park	km	87	1.00	5.0	1.6

National Park covers 76,700 ha (KFS, 2010). Aberdare forest cuts across four local administrative counties, which were Nyandarua, Nyeri, Murang'a and Kiambu. The study was undertaken within the first two counties, based on the fact that Nyeri was the only county where the National Park shares a common boundary with farmlands and giving way to the Forest Reserve which was in Nyandarua County. Nyandarua was selected as it had site where PFM was piloted. Thus, this provided populations that were similar in many aspects, main difference being FMA based on the policies of the managing institutions. The Kenya Forest Service (KFS) managed the Forest Reserve using conservation FMA (allows sustainable extractive use) whereas Kenya Wildlife Service (KWS) managed the National Park using protection FMA (allows mainly non-extractive use). The forest adjacent community depended heavily on the ecosystem and they also played a significant role in conservation either as agents of destruction or catalysts of conservation (Ehrlich et al., 2012).

Data collection methods and analysis

A three level sampling procedure was employed. First, the forest adjacent area was stratified on the basis of being adjacent to Forest Reserve or National Park. Secondly, the area was stratified on the basis of sub-locations directly adjacent to the forest ecosystem. Thirdly, through systematic random sampling, the sample frame (households) was identified within the selected sub-locations. Household selection involved having a transect walk in the farmlands and selecting the eighth household alternately on either side of the route.

On the understanding that the forest adjacent populations in the area were similar in many aspects, the survey was undertaken within a distance of 5km radius. It drew a sample size of 202 households out of 27,070 where 87 were adjacent to the protection area and 115 were adjacent to the conservation area. The decision over the total number of respondents selected was influenced by availability of time, financial and physical resources. It was also guided by World Agroforestry Centre procedural guidelines (Nyariki et al., 2005; Ongugo, 2008) for characterisation of studies at household level. They suggest that a sample size of 40 to 80 households spread over two or three communities which have populations with similar characteristics and attitudes is adequate to make inferences about the larger population.

Socioeconomic data was collected using semi-structured and non-scheduled-structured questionnaires which were administered to the selected households. Some of the key issues raised included demographic variables (household size, age, gender, educational level, gender of household head, farm size), dependent variable (FMA) and independent variables such as sources of household food and income, perception on the economic importance of the forest ecosystem, utilisation of forest products and participation in forest conservation activities.

Based on the annual income levels, socio-economic statuses of households were categorised as very poor (USD 0 to 250), poor (USD 250 to 500), average (USD 500 to 750), rich (USD 750 to 1000) and very rich (USD >1000). To obtain the local communities' dependence on the forest resources, variables that showed household's sources of forest products and interaction with the forest ecosystem were redefined and weighted to obtain dependence levels that showed very low, low, moderate, high and very high. It was considered for example, that those who depend mostly on the forest for various products have a higher value than those who meet their forest products needs from elsewhere.

The quantitative data from the survey was sorted, coded and analysed using the Statistical Package from Social Sciences (SPSS) version 21 and Microsoft Excel 2013. Data were displayed using frequency distribution tables and graphs so as to establish various patterns that characterise the phenomena in the study area. Chi Square was used to test the association and Spearman's correlation was used to establish the relationships between FMA and household socio-economic attributes as well as PFM. Logistic regression was used to determine the influence of FMA on these attributes and level of community involvement in PFM.

RESULTS

Socio-economic characteristics

Out of the whole sample size of 202 respondents, 57% were adjacent to the Forest Reserve whereas 43% were adjacent to the National Park. Males comprised 61%, where 78% were male-headed and the mean household size was 7 members. The average distances were 2.9 km and 1.6 km to the Forest Reserve and to the National Park respectively. The distribution of other demographic factors was shown in Table 1. Results from this study portrayed that the socio-economic statuses of many (27%) households were in the very poor category. That notwithstanding, there were 32% within the very rich category (Table 2).

Sources of household food and income

Majority (85%) of the surveyed households depended on

Table 2. Household socio-economic status.

Social status	Frequency	Percentage
Very poor	54	26.5
Poor	35	17.3
Average	36	17.9
Rich	14	6.8
Very rich	64	31.5
Total	202	100.0

food production from own or rented plots while 14% benefited from cultivation of forest land under the plantation establishment for livelihood improvement scheme (PELIS). The results also showed that 45% of the households depended on sale of agricultural crops as the most important source of income followed by 31% who relied on livestock and livestock products (Table 3). The common livestock kept were mainly cattle, sheep and poultry with a few farmers rearing pigs. Since majority (61%) of the respondents had small land parcels, 23 and 16% depended on forest grazing for cattle and sheep respectively.

Sources of forest products and household utilisation

Survey results showed that the most important forest products derived from the ecosystem were water (98%), firewood (70%) and grazing (67%). Additionally, other products like charcoal, wild game and cedar posts which were not available in the farmlands were illegally extracted from the ecosystem as they were prohibited. However, survey results illustrate that many forest products were predominantly derived from farmlands (Figure 2).

FMA and sources of household food and socio-economic status

The main source of household food for the majority (85%) of the households in the area was from their own or rented private farms. However, 14% of those adjacent to the conservation area obtained household food from forest cultivation under the PELIS. There was a significant association between FMA and household source of food (Table 4). In that very poor category, more (23%) lived adjacent to the conservation area as only 4% were adjacent to protected area. Additionally, more households (17%) within the very rich category lived adjacent to the protected area compared to 14% who lived adjacent to the conservation area. There was a significant association between the management approach and household socio-economic status (Table 5).

FMA and community perception of the importance of the ecosystem

Survey results showed that majority (83%) of respondents adjacent to the forest under both FMAs regarded the forest ecosystem as important mainly for non-economic benefits. However, most (96%) of those who had high regard for economic benefits were mainly adjacent to the conservation area. The results also indicated that there was a strong and significant association between FMA and community perception on the importance of the forest (Table 6).

FMA and households' dependence on the forest and level of involvement in PFM

Results showed that the majority (94%) of the households derived benefits from the ecosystem as only 6% indicated low benefits. However, more (9%) of those living adjacent to the conservation area rated the benefits as very high compared to 2% of those living adjacent to protection area. Additionally, the survey findings portrayed that fewer (1%) respondents adjacent to the protection area were involved fully in PFM compared to 7% of those adjacent to the conservation area (Table 7).

Relationship between FMA and level of dependence on forest ecosystems and involvement in PFM

The relationship between FMA and community perception on the importance of the ecosystem, sources of household food, household socio-economic status, forest dependence and level of PFM involvement were found to be both strong and significant at $\alpha = 0.05$ as shown earlier. Further analysis revealed that on one hand, there was a negative and significant relationship between FMA and importance of the ecosystem ($r = -0.29$, $p < 0.001$), household source of food ($r = -0.32$, $p < 0.001$) and income ($r = -0.35$, $p < 0.001$). On the other hand, the relationship between FMA and community dependence on the forest ($r = 0.44$, $p < 0.001$) as well as level of involvement in PFM ($r = 0.19$, $p = 0.007$), was positive and significant as shown in Table 8.

Influence of FMA on households' economy and PFM involvement level

Results of the multinomial logistic regression analysis showed that FMA significantly influenced various factors such as forest dependence, level of PFM involvement,

Table 3. Sources of household food and income.

Variable	Frequency	Percentage
Sources of household food		
Forest PELIS plot	29	14.4
Own /rented private land	171	84.6
Purchase from market	2	1.0
Total	202	100.0
Sources of household income		
Agricultural crops	91.0	45.0
Livestock and livestock products	62	30.7
Both crops and livestock	41	20.3
Forest products/ecotourism	3	1.5
Casual labour	3	1.5
Salary/remittance/others	2	1.0
Total	202	100.0
Livestock grazing		
No. of households grazing cattle in forest	47	23.3
No. of households grazing sheep in forest	33	16.3

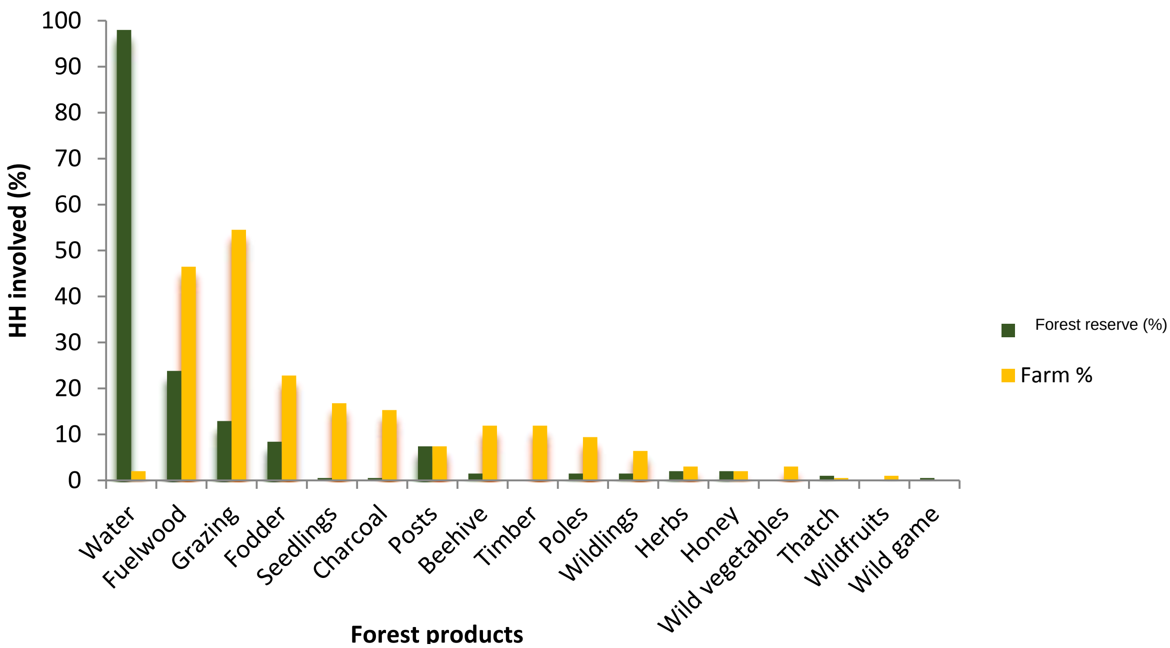

Figure 2. Distribution of household relative utilisation of diverse forest products derived from Aberdare forest ecosystem and farmland sources.

importance, household social status and source of food as shown in Table 9 below. The Cox and Snell pseudo R^2 was 0.797 showing that the regression model was a good fit for the data ($\alpha = 0.05$, $p < 0.05$) as it predicted about 80% of the variance. A significant and positive influence was found between FMA and household sources of food. Conversely, FMA significantly and inversely influenced forest dependence, level of PFM involvement, importance

Table 4. FMA and household sources of food.

Household sources of food	Frequency (f)	Forest management approach		Total
		Protection	Conservation	
Forest cultivation through PELIS	F	0	29	29
	Percentage	0.0	14.4	14.4
Own or rented private land	F	87	84	171
	Percentage	43.1	41.6	84.7
Purchased from Market	F	0	2	2
	Percentage	0.0	1.0	1.0
Total	F	87	115	202
	Percentage	43.1	56.9	100

$\chi^2 = 27.704$, df = 2, $\alpha = 0.05$, $p < 0.001$, n = 202.

Table 5. FMA and household socio-economic status.

FMA	Frequency (f)	Household socio-economic status					Total
		Very poor	Poor	Average	Rich	Very rich	
Protected	F	6	6	12	4	28	56
	Percentage	3.7	3.7	7.4	2.5	17.3	34.6
Conservation	F	37	22	17	7	23	106
	Percentage	22.8	13.6	10.5	4.3	14.2	65.4
Total	F	43	28	29	11	51	162
	Percentage	26.5	17.3	17.9	6.8	31.5	100

$\chi^2 = 20.194$, df = 4, $\alpha = 0.05$, $p < 0.001$, n = 162.

Table 6. FMA and community perception of the importance of the ecosystem.

FMA	Frequency (f)	Importance of forest ecosystem		Total
		Economic	Non-economic	
Protection	F	1	49	50
	Percentage	4.2	40.8	34.7
Conservation	F	23	71	94
	Percentage	95.8	59.2	65.3
Total	F	24	120	144
	Percentage	16.7	83.3	100

$\chi^2 = 11.863$, df = 1, $\alpha = 0.05$, $p = 0.001$, n = 144.

of the ecosystem and household social status. The results further depict that household annual income and sources of income did not contribute significantly to the final model (Table 9). The regression model obtained was:

FMA = -32.092 + 17.551(source of food) –7.747(forest dependence) – 2.51 (PFM involvement level) – 4.528 (importance of ecosystem) – 2.159 (socio-economic

Table 7. FMA and households' forest dependence and level of involvement in PFM.

FMA	Frequency (f)	Forest dependence				Total
		V. High	High	Moderate	Low	
Protected	F	2	20	62	3	87
	Percentage (%)	2.3	23.0	71.3	3.4	100
Conservation	F	10	73	23	9	115
	Percentage (%)	8.7	63.5	20	7.8	100
Total	F	12	93	85	12	202
	Percentage (%)	5.9	46	42.1	5.9	100
		PFM involvement level				
		Low	Moderate	High	Fully involved	Total
Protected	F	56	29	0	2	87
	Percentage (%)	27.7	14.4	0.0	1.0	43.1
Conservation	F	59	30	12	14	115
	Percentage (%)	29.2	14.9	5.9	6.9	56.9
Total	F	115	59	12	16	202
	Percentage (%)	56.9	29.2	5.9	7.9	100

status)

DISCUSSION

FMA and household sources of food and socio-economic status

Forest-adjacent communities operate behind a background of limited economic opportunities. Farmers are faced with multiple problems which include scarcity of land, food, fodder, fuelwood, biomass and increased land degradation (Figure 2 and Table 3). As reported by Langat et al. (2016) and Tesfaye (2017), most of the rural population maintain diversified livelihood strategies because they cannot obtain sufficient income from any single strategy and secondly to distribute risks. The study observed that over 85% of the households depend on food production from own or rented plots as also reported in Mau forests (Langat and Cheboiwo, 2010; Mutune et al. 2015). However, due to the high population and small land parcels, some households looked upon the forest ecosystem as an alternative source of fodder and food as illustrated by the 14% who depended on food from cultivation of forest land under PELIS (Table 4).

According to the survey findings, the majority of the forest adjacent community were within the very poor and poor category (Table 5). Similar findings were also obtained from communities living in various PFM sites in Kenya like Iveti, Museve, Nthangu and Makongo (Musyoki et al., 2013; Thenya, 2014). Those classified as rich or very rich in the area reportedly owned large pieces of land, reliable water for irrigation or more livestock. Subsequently, only about 3% of the households recorded sources of income other than agriculture, livestock or protected area related activities.

Although there was no restriction in increasing income from conservation areas as long as one followed the laid down regulations like applying and paying for licenses and permits (Mbuvi et al., 2009; Thenya, 2014; Mutune et al. 2015), the local community involvement in the forest resources for cash income was also found to be only from sale of horticultural crops from PELIS plots (Table 3). The reasons for this could be; firstly, many products in high demand could be acquired legally, and hence, households acquired them directly from the forest on their own (Figure 2).

Secondly, for products that could not be obtained legally, only a small proportion of the community especially the youth were procuring them for sale to the few people who could afford. The findings revealed that posts, charcoal, poles and game meat were procured from the forest illegally for mainly cash income (Figure 2). These findings portray that, if there are no alternative sources of products, the pressure on the ecosystem would continue unabated, efforts of ecosystem

Table 8. Relationship between FMA between household interaction with the forest ecosystem and level of involvement in PFM.

Variable		FMA
FMA	r	1.000
	Sig	0.000
Sources of household food	r	-0.322
	Sig	0.000
Household annual income	r	-0.345
	Sig	0.000
Forest dependence	r	0.440
	Sig	0.000
PFM involvement level	r	0.191
	Sig	0.007
Perception on the importance of forest ecosystem	r	-0.287
	Sig	0.000

Table 9. Influence of FMA on households' economy and PFM involvement level.

Variable	β	Model fitting criteria	Likelihood ratio tests		
		-2 Log likelihood of reduced model	Chi-Square	Degrees of freedom (df)	P-value
Intercept	-32.092	84.103[a]	0.000	0	.
Household annual income	0.000	84.111	0.008	1	0.929
Forest dependence	-7.747	96.651	12.548	3	0.006
PFM involvement level	-2.510.	88.388	4.285	1	0.038
Importance of ecosystem	-4.528	102.795	18.693	1	0.000
Sources of Food	17.551	94.595	10.492	2	0.005
Sources of income	15.607	100.259	16.156	9	0.064
Socio-economic status	-2.159	115.923	31.820	4	0.000

R^2 = 0.797.

managers notwithstanding.

This study further depicted that many (27%) of the households within the poor livelihood category lived adjacent to the conservation area (Table 5). These findings concur with Vedeld et al. (2004), Ellis and Ramankutty (2008) and Musyoki et al. (2013) that poor people live in remote, forested and fragile areas. In many studies, poverty was linked to increased pressure on forests which leads to forest degradation and destruction (World Bank, 2005; Costa et al., 2017; Rita et al., 2017). This was found to be happening in the study area and thus, it necessitated erection of the electric fence around the ecosystem (Ark, 2011) to curb forest destruction as well as human-wildlife conflicts.

Similarly, a study on households adjacent to Sururu and Eburru forests found that poor community members were engaged in diverse livelihood strategies with crop, livestock, forest and casual labour being the major sources of household incomes which they sought to extend into the adjacent forest (Mutune et al., 2015). This possibly reflects the difference between household dependence for low income households who have few alternatives to forest income versus use as a livelihood alternative for high income households. This calls for attention on addressing poverty reduction, a major factor cited variously as key driver of forest destruction (Fischer et al., 2008; Ongugo et al., 2008; Bush et al., 2011; Rita et al., 2017).

FMA and community perception on the importance of the ecosystem

Forest resources are important components of livelihoods and development opportunities in Africa (Cavendish, 1999; Springate et al., 2003). Therefore, obtaining access to, and control of forest resources was fundamental for alleviation of rural poverty (Coulibaly-Lingani, 2011; Costa et al. 2017). Access to forest goods and services is characterised by, and dependent on FMA (de Groot, 2006; Tesfaye, 2017). Therefore, a change in landuse or management approach leads to a change not only in supply of goods but also for the complete bundle of services provided by the ecosystem.

Although there has been widespread perception that local communities value forest ecosystems predominantly for extractive benefits (Costanza et al., 2014; Ndichu et al., 2015), the findings from this study showed that majority (83%) of the communities adjacent to Aberdare forest ecosystem irrespective of FMA valued the forest ecosystem mainly for non-economic benefits (Table 6). These included biodiversity, water catchment, protection against soil erosion and flooding as well as cultural values.

Comparable observations were made by Kipkoech et al. (2011) based in their study on total economic valuation of Mau forests in Kenya. That notwithstanding, majority (96%) of those who indicated the forest ecosystem was important to them for economic reasons were those adjacent to the conservation area.

The relationship between FMA and perception on the importance of the ecosystem was negative and significant. This can be explained by the fact that communities who derived more benefits from the conservation area regarded it as more important relative to those adjacent to protection area. These findings demonstrated that where a management approach did not allow provisioning benefits, there was a negative bearing on households' perception of value of forest This was elucidated by Mr Kagondu:

'*We value the ecosystem more for non-economic reasons because …… (pause) after all, where are those economic goods? We don't get them!*

Musyoki et al. (2013) obtained similar sentiments from focus group discussions (FGD) where community members' claimed the use of forest ecosystem products was theirs by *de facto* and they felt they should not be denied. Comparable observations were made by Mutune et al. (2015) in a related study based on Sururu and Eburru forests in Mau forest complex where KFS remained in control of the forest resources such as licensing of forest products and decision making whereas in practice the CFA were labour providers for forest rehabilitation and policing.

FMA and forest dependence

In the study area, forests contributed significantly towards the diversification of livelihoods of adjacent communities. The findings showed that the community derived moderate (42%) to high (46%) benefits from the forest ecosystem. The products that were viewed as most important were water (98%), fuelwood (25%) and grazing (13%) (Figure 2). Although the benefits varied between the two management approaches, the majority (94%) of all the households perceived the forest as beneficial to them as only 6% indicated low benefits (Table 7). This was an important finding as when ecosystems do not make substantial contributions to livelihood, this lowers the value placed on them (Engida and Mengistu, 2013; Langat et al., 2016). Hence, forest contribution to household economy and welfare cannot be ignored.

The findings also showed that the value of the ecosystem was low for communities adjacent to the protected area as the FMA did not allow resource exploitation. This was because the National Park was being managed for high biodiversity value and water catchment functions among other regulatory and supportive functions (Costanza et al., 2014; Rita et al., 2017). As also observed by Maingi (2014) and Ndichu (2016), it was evident from this study that forests played a critical role in rural livelihoods, yet given the rising competition over forestland for agricultural production, such information suggest there is dire need to make forest ecosystems economically more meaningful to the local people. This would necessitate total economic valuation of all ecosystem services to enable them to appreciate the importance of conservation particularly regulatory services like biodiversity.

Like recommended by Ark (2011) and Matiku et al. (2013), non-extractive uses can be enhanced like promoting the area as a tourism destination so that revenues from recreation can offset the high costs of maintaining the forest. Therefore, Kenya Forest Service and Kenya Wildlife Service should explore and exploit the full potential to provide more benefits to the community. Benefits to communities adjacent to the park could be improved by initiating income generating activities in the farmlands as well as supporting the community to participate in diverse non-extractive activities. As also suggested by Kipkoech et al. (2011) and Kenter et al. (2015), other avenues like payment for environment services should be explored to compensate the forest adjacent communities and Kenya in general for maintaining the forests because various non-use values accrue to global community and Kenya bears the costs of conservation (EMCA, 2015; KFS, 2016).

FMA and household involvement in PFM

The research findings showed that the community adjacent to Aberdare forest ecosystem irrespective of FMA were all involved in PFM, albeit to various extents. Although the proposition that natural resources need protection from the destructive actions of people is widely accepted, this study showed that communities in the past and increasingly today collaborate with resource managers for long-term resource management as also observed by Engida and Mengistu (2013), Matiku et al. (2013) and Musyoki et al. (2013).

Nevertheless, the level of participation was higher for those adjacent to the conservation area as more (7%) adjacent to forest reserve were fully involved compared to only 1% adjacent to National Park (Table 7). Further, the findings showed that the association between FMA and level of community involvement in PFM was strong and significant (Table 8). This can be attributed to the fact that communities adjacent to the National Park were essentially benefiting from environmental services and few extractive products as FMA was predominantly preservationist (Bush et al., 2011).

This therefore suggests that the high interest in participating in forest management could be driven by some anticipated benefits as has been reported by other studies (Lise, 2000; Ongugo et al., 2008; Costa et al., 2017). Nonetheless, these findings disagreed with Bush et al. *(*2011) who found lower respondents' willingness to accept (WTA) for community adjacent to National Parks in Uganda. The anomaly of their findings was however attributed to the *de facto* access of forest resources from the national park. Like in Kenya, due to the strict national park protectionist management approach, the regulations prohibit extractive use by local communities, but then poor enforcement of the regulations by under resourced park management meant that a *de facto* open access arrangement existed. In the case where regulations are strictly enforced, the WTA is higher due to the foregone benefits.

Similarly, in Kenya, there was little community involvement in management of natural resources in the parks except for a few cases of revenue sharing in some national parks and consultation over government planned initiatives (Mogoi et al., 2012; Matiku et al., 2015). Following these findings, there is need to empower communities to overcome obstacles that may interfere with their efficiency, dynamism, openness and active participation in planning and decision making as observed by Costa et al. (2017). This will make them get a sense of ownership of the forest resources and partner with resource managers to enhance sustainable management of forest ecosystems.

This study therefore, advocates for substantial financial investment for capacity-building (Coulibaly-Lingani, 2011), joint management, income generating activities (Fisher, 2004), and adequate awareness creation, for forest resource managers to increase household support for forest conservation through alternative household livelihood improvement options (Tesfaye et al., 2017). The great interest in PFM involvement as shown by the community requires a strategy for harnessing to sustain it and have it contribute to sustainable forest management.

Influence of FMA on household economy and PFM involvement level

Forest ecosystems provide a wide spectrum of goods and services that contribute to the socio-economic development of forest dependent communities. Since its early stages, the goals of PFM were manifold; to contribute to the socio-economic development of forest dependent communities (Agrawal and Gupta, 2005); reduce environmental degradation (Tesfaye, 2017), and alleviate poverty in developing countries (Engida and Mengiste, 2013; Langat et al. 2016).

In this research, FMA inversely and significantly influenced the level of forest dependence, economic importance and household socio-economic status and involvement in PFM (Table 9). This could be attributed to households' dependency on forest based livelihoods, particularly for those adjacent to the conservation area. Thus, there is need to reduce pressure on forest ecosystems through improved farming practices, as espoused by the "green revolution" in agriculture, technological development can increase productivity on intensively managed land, thereby decreasing pressure on other land for agricultural production (Fischer et al., 2008; Costanza et al., 2014).

Further, FMA negative influence on households' involvement in PFM can be explained by the fact that communities adjacent to protection area had lower access to economic opportunities. In view of the influence of economic benefits on community involvement in PFM, the implementation of PFM especially for those adjacent to the National Park may therefore not be smooth. This is because many issues remain unresolved, such as the transfer of power and resources between the official traditional bureaucracy to community institutions, and the sharing of costs and benefits between KWS and communities.

Further, the benefits that accrue from protected areas may not evident and might not be divided equitably among the different stakeholders. This study calls for broadening of economic benefits, particularly to communities adjacent to the park by supporting income generating activities in the farmlands as well as increasing community participation in non-extractive activities.

CONCLUSION AND RECOMMENDATIONS

Many rural households depend on natural resources for their livelihoods. Therefore, their impacts on natural resource management in areas within and adjacent to forest ecosystems require a clear plan of how conservation goals can be balanced with their economic wellbeing.

Therefore, the main challenge in achieving sustainable forest management consist of finding a sound balance between the increasing pressure on forest resources from divergent community interests and sustainable forest conservation. Such a balance requires that an equilibrium be attained between the forest ecosystem, uses and users of forest resources as well as key institutional regulations taking into account all the ecological and socio-economic constraints. PFM was necessitated by the to create this equilibrium as high degradation of natural resources was caused by high discount rates of the local communities at the household level.

The findings of this study showed that many forest adjacent communities who derived some benefits from the forest ecosystem to supplement household sustenance contributed more in conservation. Therefore, sustainable FMA should contemplate on both the variety of local uses of forest resources and also the diverse views assigned locally to forest ecosystems. Based on these findings, this study therefore suggests that the government and development partners should support livelihood improvement schemes in the farmlands for the community to value and support conservation in the ecosystem. Therefore, Kenya Forest Service and Kenya Wildlife Service should explore and exploit the full potential to provide more benefits to the community. Benefits to communities adjacent to the park could be improved by initiating income generating activities in the farmlands as well as supporting the community to participate in non-extractive activities.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Species diversity, habitat association and abundance of avifauna and large mammals in Gonde Teklehimanot and Aresema monasteries in North Gondar, Ethiopia

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Studies on species composition, distribution and relative abundance of birds and mammals in Gonde Teklehimanot and Aresema Monasteries was carried out from December, 2015 to February, 2016. In these areas, wildlife conservation is directly relevant to the local community, often as a source of livelihood, medicine and spiritual values. To collect data on population status of large mammals, we commenced a line transect while date on distribution, species composition and habitat association of Avifauna were collected by using a point transect, or point count in both Gonde Teklehimanot and Aresema monasteries. Based on these, a total of 95 and 72 species of birds and 21 and 9 species of mammal were recorded, respectively. Duncan's Multiple Range Test showed that mean number of species did significantly differ between the two study sites. However, mean no. of species between habitats did not show a significant in both study areas. During the dry season, the highest species diversity at was recorded in farmlands and its associated habitat, 0.93 and followed by Riverine bushland, 0.75. This might be correlated with the less habitat diversity; i.e a homogenous (Ticket forest) habitat type is a dominantly habitat type in the area. Among the monastries, Gonde Teklehimanot was better in mammalian and Avifauna diversity than Aresema monastery. Both of them are rich in biodiversity, and hence, conservation practices and management innervations should be done at different levels of the local communities.

Key words: Gonde Teklehimanot, Aresema monasteries, species.

INTRODUCTION

Ethiopia is a country endowed with unique endemic fauna, flora and forest resources (Bongers et al., 2006). The sacred monasteries of the Ethiopian Orthodox Church is one of the oldest Christian identities in Africa,

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and has a long history of protecting and preserving indigenous flora as sanctuaries for prayer and burial grounds for church followers (Wassie et al., 2009). In a general sense, the biodiversity found in the monasteries are seen as sacred, with the trees symbolic of angels guarding the monasteries. However, at the community-level each monastery and church operates largely autonomously, with its own contextually-defined approach to natural resources management (Wassie et al., 2010).

Biodiversity would have spiritual, economic, aesthetic, cultural and scientific functions for the local community. Biodiversity conservation is directly relevant to the local community, often as a source of livelihood, medicine and spiritual values. However, it is difficult to reconcile these values. As biodiversity conservation is a precondition for sustainable development, cultural and biological diversity are necessary and equally important prerequisites for sustainable development (UNESCO and UNEP, 2003).

Besides, the recognition of the *cultural and spiritual values* are important factor to enhance the biodiversity conservation efforts, that is, if the people know the cultural significance of wild plants then they would have a crucial role to conserve the biodiversity (Dold, 2006). However, the findings of many anthropologists and sociologists on small-scale societies showed that commonly owned biodiversity are conserved not only by rational institution created for the purpose of economic utilization of resources, but also by various cultural elements like kinship, religion and social organization, which also played vital role in the conservation. Therefore, the recognition of the cultural and spiritual values is an important factor to enhance the sustainable biodiversity conservation efforts.

The holy places have survived for many centuries as islands of biodiversity in a sea of deforested landscape across the Ethiopian highlands (Tamire, 1997). The remaining parts have been occupied or converted into agricultural lands. Biodiversity surveys in monasteries and churches indicate that the holy place serve as key refuge for the endangered plant and animal species (Wassie, 2004; Ermilov et al., 2012).

Monasteries can also be used as site for *in situ* conservation of the endemic species as a seedbanks for native plants that have otherwise vanished from the region (Aerts et al., 2006). In addition, monasteries provide important ecosystem services to local people, including fresh water, honey, shade and spiritual value. It also harbours vast insect biodiversity (Ermilov et al., 2012), providing pollination and hydrological services for nearby farmlands (Lowman, 2011).

The monasteries are among dry evergreen patchy remnant forests. In spite of their ecological and spiritual benefits, due to a combination of economic, environmental, and cultural factors, the integrity of the monasteries forest like many other sacred natural sites has continued to decline. The monasteries forests are decreasing in both size and density, with visible losses in biodiversity due to livestock grazing, fuel wood harvesting and other pressures (Wassie et al., 2010).

Grazing in particular, causes irreversible damage through consumption and trampling of seedlings, soil compaction and erosion (Wassie et al., 2009). Moreover, as small forest fragments are degraded, biodiversity suffers even further from physical edge effects such as lightintensity, wind and temperature variability, and reduced soil moisture and humidity (Aerts et al., 2006).

Like other sacred natural sites, the dwindling of biodiversity in these monasteries has begun to attract regional attention, and now advocate prioritization of these sacred natural sites for conservation. Prioritizing the area for conservation of biodiversity is highly needed, and should be based on sound knowledge of succession pathways of existing ecosystems.

North Gondar Administrative Zone is endowed with a number of ancient churches and monasteries. Among the sacred natural sites, or monasteries that are found inthis Administrative Zone are Acholake Eyessus, Beri Mariyam, Mehaber Selase, Gonde Teklehimanot and Waldeba monasteries (Wassie et al., 2009). However, monasteries are influenced by different anthropogenic activities. In such a shift from a “purely rural” to “industrially rural” society, the need for rural development to be sustainable becomes paramount (Ivolga and Timofeeva, 2014). Sustainability for monasteries areas is more than just a sustainable economic growth (Aerts et al., 2006). The concept of sustainability in monastery areas should integrate environmental, economical, cultural and social factors.

To overcome the problems in biodiversity loss in and around the selected monasteries, stakeholders play vital roles in conservation activities, and are considered as clients to minimize the risk of biodiversity loss. In this context, team members had undertaken intensive research on flora and fauna diversity of the monasteries. In addition, team members undertook the implications of culture and religious on conservation of biodiversity in Gonde Tekelhamanot and Aresema monasteries.

Study area

The present investigation was carried out in Gonde Tekelhimanot and Aresema Monasteries. The study areas are located at the eastern flank of Gondar ridge. Gonde Tekelhimanot is located at an altitude of 2,361 m, 12°24′ 65″ N latitude and 37°41′ 67″ E longitude (Figure 1). Aresema monastery is located west of Gond Tekelhimanot and north of Makesgnt town, near ‘‘Burboakse’’ village at 12°23′ 612″ N latitude and 37°40′ 516″ E longitude (Figure 1).

The ridges of the holy place that surrounds in all

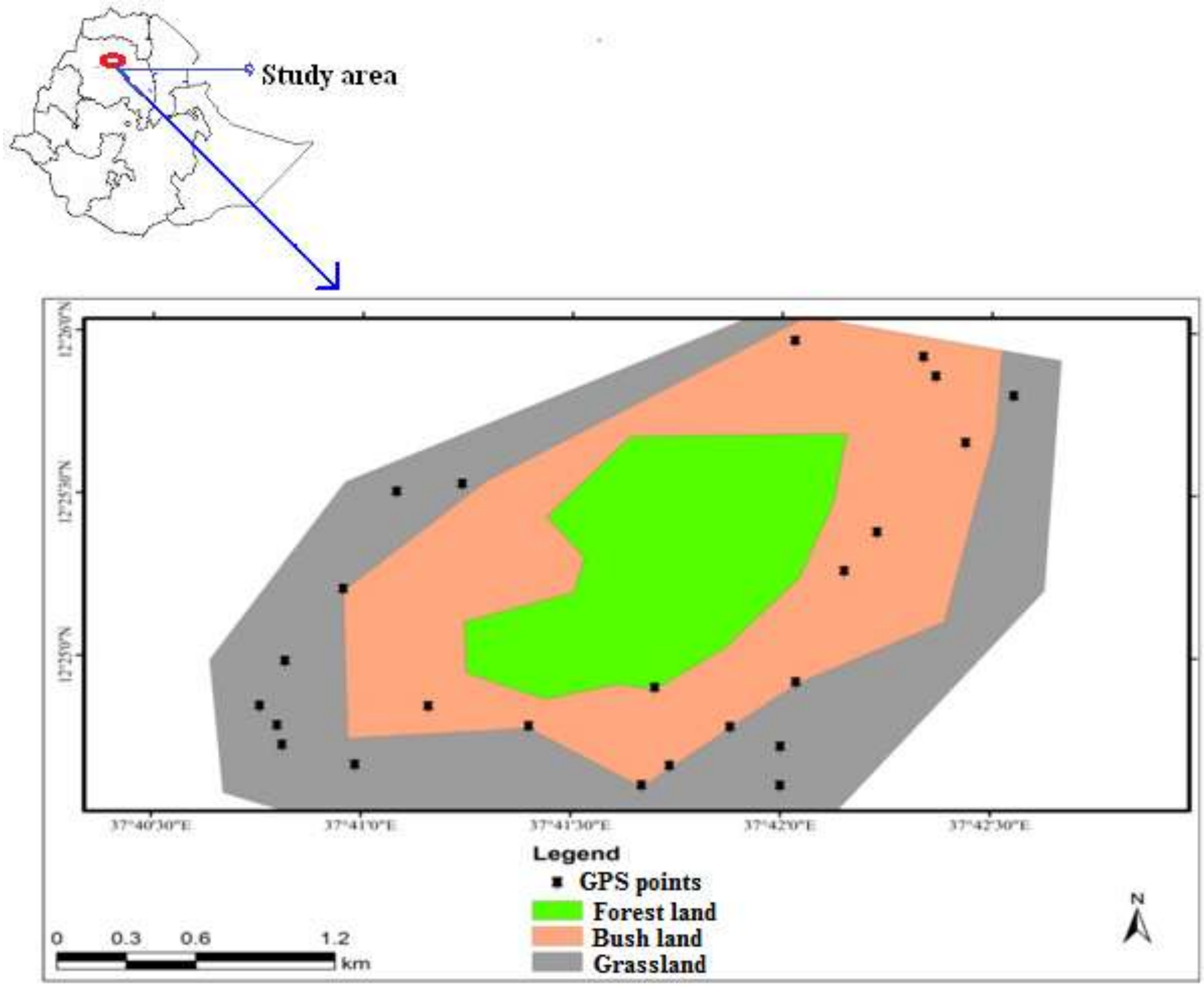

Figure 1. Map of Gonde Teklehimanot monastery.

direction of the monastery shows prominent volcanic activities had occurred in the past several decades of millions of years. There are variations in the habitat diversities of the two study sites. In general, Aresema monastery is relatively less diverse in habitat compositions as compared to Gonde Teklehimanot, where ticket forest is predominant in the area. The distribution of rainfall in the study sites is characterized by a unimodal pattern that occurs during June to September. Average annual rainfall is around 1,440 mm. The study sites possess a complex mix of highland climate zones, with temperature differences of upto 10°C, depending on elevation and the wind patterns. In the high elevation area, temperature is moderate year-round. As the study area is located near the equator, temperatures are more or less constant from month to month. The temperature during the dry season ranges between 22 to 28°C, and during the wet season between 15 to 17°C with an average annual temperature of around 16°C.

METHODOLOGY

Line-transect, focal sampling and point-count methods were used to collect data on birds and large mammals during the present investigation. Surveys were conducted during December 2015 and February 2017. Data collection was carried out during 07:00 to 10:00 h in the morning, and 16:00 to 18:00 h in the evening, when activities of birds and mammals were more prominent.

Birds were identified using field guide of Alden et al. (1995). Transect surveys were made walking slowly along the long axis of the study site treks, and all individuals and species of birds and large mammals observed were recorded. The mean time spent per transect during the survey was 60 min. A total of eight point-count locations (1 to 8) were marked in the study area, each located approximately 300 m away from one another, for detailed observations. Counting sites were made on the transect in each habitat types, forest, open wood land, riverine forest and ticket forest.

At each of the point count locations, all birds seen or heard within a 25 m radius were recorded. To collect data on abundance, repeated observations were made. For population estimation of large mammals and geladas, sweep census technique was used

Table 1. Habitat association of large mammals in GondeTeklehimanot monastery.

Common name	Species name	Habitat types			
		Riverine forest (I)	Grassland(II)	Forest(III)	Open woodland(IV)
Kelip springer	*O. oreotragus*	*	√	*	√
Grey Duiker	*S. grmmia*	√	√	√	√
Rock hyrax	*P. capensis*	*	*	√	*
Leopard	*P. paradus*	*	*	√	*
Common jackal	*C. aureus*	*	√	*	√
Egpt. Mongoose	*H. ichneumo*n	*	*	√	*
African Civet	*V. civeta*	√	√	√	√
Gelada monkey	*T. gelada*	*	√	*	*
Hamadryas baboon	*P. hamadryas*	*	√	*	√
Honey Badger	*M. capensis*	*	√	*	√
Spotted hyena	*C. crocuta*	*	√	*	√
Vervet monkey	*C. aethiops*	√	*	√	*
Aardvark	*O. afer*	*	√	*	√
Wild pig	*S. scrofa*	√	√	√	√
Menlik bush buck	*T. s. meneliki*	*	*	√	*
Unstriped grass rat	*A. abyssinicus*	*	√	*	*
Striped hyena	*H. hyaena*	*	√	*	√

*, absent; √, present; *P. capensis* and *P. paradus* associated with cliffs with forest.

(Beehner et al., 2008) regularly at least once per counting session in each of the study sites across the study period, covering both wet and dry seasons. Geladas and other large mammals were followed walking slowly from a distance of around 50 to 100 m, and data were collected by means of instantaneous scan samples (Altmann, 1974).

In contrast, geladas in rugged and cliffy areas were observed using binoculars at a distance of around 300 m. The study units were differentiated from others by unique body marks on their body and by their sleeping sites. Intact units in different sites were checked every day in order to collect data about population structure and behavioural activities. Data were collected between 07:30 to 18:30 h. Focal samples were observed at random, and the observed activities were recorded during the interval periods.

Shannon-Wiever diversity index (H') and Simpson's similarity Index were used to determine the diversity of species in each habitats in the study areas, hence, SI = 4C/I +II+III+IV,SI = 4C/I +II+III+IV, where I= the number of species observed in riverine habitat, II = the number of species observed in grassland habitat, III= the number of species observed in forest habitat, IV= the number of species observed in open woodland, and C = the number of species common to all habitats.

Data analyses

All statistics related to the types of data were carried out on statistical package for social sciences (SPSS) 20.0 software for Windows Evaluation Version. Statistical tests were one tailed with 95% confidence intervals. Simpson's similarity index was used to compare species diversities between habitats in both study areas. F test was used to compare species composition of birds in dry and wet seasons, and it was also used to compare the diversity of species between different habitats. Duncan's Multiple Range Test was done to compare the differences in species composition and abundance of birds in each of the point count locations, and to find out differences of species composition between two study areas.

RESULTS

A total of 95 and 72 species of birds were observed during the wet and dry seasons in Gonde Tekelhamanot and Aresema monasteries, respectively. Nearly 20 endemic species of birds are identified in both study areas. A few Palaearctic Migrants and Intra-African Migrant were recorded during the study period. Most of the Palaearctic migrants were observed from December 2015 to June 2017, mostly in the cliff and mountains habitats of Gonde Tekelhamanot monastery. Nearly 52 bird species were common to both Gonde Tekelhamanot and Aresema monasteries, and seasonally, 65 and 32 species were exclusive to the dry and wet seasons, respectively.

Simpson's similarity index, in different habitat types shows high similarity in species composition, the value, 0.43 is closer to zero. In addition, in Gonde Teklehimanot monastery grassland habitat types are more diverse in species composition followed by open woodland, while the riverine forest habitat type is less diverse in species composition than other habitat types (Table 1).

The species composition of birds during the dry and

Table 2. Avian species diversity during wet and dry seasons in GondeTeklehimanot monastery.

Study site	Habitat	Seasons	Number of species	Number of individuals	D	H’	H’/H’max
Gonde Teklehimanot	Forest	Wet	41	470	0.52	1.72	0.26
		Dry	39	390	0.62	4.56	0.52
	Riverine forest	Wet	18	212	0.73	3.97	0.29
		Dry	17	198	0.61	5.21	0.38
	Woodland	Wet	25	167	0.81	3.41	0.72
		Dry	24	142	0.67	1.05	0.64
	Bushland/scrub	Wet	14	115	0.68	2.14	0.81
		Dry	12	98	0.72	1.67	0.37

H’ = Shannon_Wiener index; H’/H’max= evenness; D= diversity Index; H’max= ln (s).

Table 3. Number of bird species in different relative abundance categories.

Study site	Habitat	Seasons	Frequent	Common	Abundant
Gonde Teklehimanot	Forest	Wet	23	11	7
		Dry	17	14	10
	Riverine forest	Wet	9	6	3
		Dry	10	5	2
	Woodland	Wet	14	7	4
		Dry	13	8	3
	Bushland/scrub	Wet	8	4	2
		Dry	7	3	2

wet seasons was not significantly different (F_1, 95 = 0.24, $p > 0.05$), but there was a significant difference among habitats (F_2, 95 = 2.23, $p < 0.05$). Season and habitat interaction was, however, not significant (F_2, 95 = 0.12, $p > 0.05$). Duncan’s Multiple Range Test showed that mean number of species did significantly differ between the two study sites. However, mean number of species between habitats did not show significance in both study areas. In forest habitat (Gonde Teklehimanot), mean number of specie was 40 (= 0.387, n = 40) and in Aresema, mean number of species was 20 (= 0.397, n = 20); whereas, the riverine habitat (mean number of species = 0.046, n = 18) was significantly different from the two study sites. The highest species diversity (D) during the wet season was observed in woodland (0.81), followed by riverine forest (0.73) (Table 2).

The relative abundance scores of species in forest habitat showed that 23 and 17 species were frequent; 11 and 14 were common; 7 and 10 were abundant in wet and dry seasons, respectively. The abundance scores of the species in riverine forest showed that 9 and 10 were frequent; 6 and 5 were common; 3 and 2 were abundant in wet and dry seasons, respectively. In woodland habitat type, the abundance scores of the species showed that 14 and 13 were frequent; 7 and 8 were common; 4 and 3 were abundant in wet and dry seasons, respectively. Whereas in Bush-land/scrub 8 and 7 species were frequent; 4 and 3 were common; 2 species were abundant in wet and dry seasons (Table 3).

Similarly, the species composition of birds in Aresema monastery during the dry and wet seasons was not significantly different (F_1, 68 = 0.32, $p > 0.05$), but there was a significant difference among habitats (F_2, 68 = 3.21, $p < 0.05$). The Ticket forest habitat had the least species diversity, 0.58 as compared to other habitat types. During the dry season, the highest species

Table 4. Avian species diversity during wet and dry seasons in Aresma monastery.

Study site	Habitat	Season	No. of species	No. of individuals	D	H’	H’/H’max
Aresema monastery	Ticket forest	Wet	29	380	0.58	1.67	0.28
		Dry	27	265	0.62	4.82	0.47
	Woodland	Wet	17	169	0.78	3.96	0.29
		Dry	15	142	0.72	4.21	0.36
	Riverine bushland	Wet	14	210	0.64	3.86	0.68
		Dry	13	178	0.75	1.23	0.56
	Farmland	Wet	11	134	0.68	2.31	0.81
		Dry	10	105	0.93	1.72	0.41

H’ = Shannon_Wiener index; H’/H’max= evenness; D= diversity index; H’max= ln(s).

Table 5. Number of bird species in different relative abundance categories in Aresma monastery.

Study site	Habitat	Season	Frequent	Common	Abundant
Aresma monastery	Ticket forest	Wet	16	8	5
		Dry	14	9	4
	Woodland	Wet	9	5	3
		Dry	7	5	3
	Riverine bushland	Wet	6	5	3
		Dry	5	6	2
	Farmland	Wet	4	5	2
		Dry	5	4	1

diversity was recorded in farmlands and its associated habitat (0.93), and followed by Riverine bush land (0.75). The highest species evenness was registered in the farmland habitat type (0.81), followed by Riverine bush land (0. 68). However, in both wet and dry season’s the woodland and farmland habitat types had better species diversity, 0.75 and 0.78, respectively (Table 4).

The relative abundance scores of species in Ticket forest showed 16 and 14 species were frequent; 8 and 9 were common; 5 and 4 were abundant in wet and dry seasons, respectively. The abundance scores of the species in woodland showed 9 and 7 were frequent; 5 were common and 3 were abundant in wet and dry seasons. In riverine bush-land habitat type, the abundance scores of the species showed that 6 and 5 were frequent, 5 and 6 were common; 3 and 2 were abundant in wet and dry seasons, respectively. While in farmland, 4 and 5 species were frequent; 5 and 4 were common; 2 and 1 were abundant in wet and dry seasons, respectively (Table 5).

DISCUSSION

A total of 95 and 72 species of birds were recorded in Gonde Teklehimanot and Aresema monasteries, respectively. In addition, the study sites also harbour over 20 species of mammals. Among them, two species are endemic and 4 species are threatened while the others are least concern. High abundance of birds was recorded in dense and ticket forest habitat types in the study areas. While the lowest abundance was recorded in bush-land and farmland habitat types. These might be related with the fact that forest habitats are much conducive than scrub/bush-land and farmland for birds in the availability of food and roosting sites. Similarly, Timossi and Manley had reported that forest habitat is much better in diversity of bird species as compared to other habitat types. In addition, Girma et al. (2016) reported that bird diversity and abundance are high in forest habitat types.

The species diversity in both monasteries did not show a significant variation between wet and dry seasons. This might be related with species diversity, or number that has no direct relationship with seasonal variations rather it has a significant impact on population size of mammals and birds. Green and Hirons (1991) had reported species richness of wildlife may not vary with respect to seasons rather abundance and population size significantly vary in different seasons due to the variation in food availability.

The relative abundance scores of species with respect to seasonal variation did not show any significant change in both monasteries. However, abundance scores of species were varied between habitats. These might be due to the variations in resources/food availability between habitats. Similarly, EWNHS (1996) reported that food availability can determine the variation in abundance of birds' species between habitats. Baker et al. (2010) also reported that variation in abundance of bird species was observed between different habitats but not between seasonal variations. Large mammal's diversity was also varied between study sites. In species diversity, Gonde Teklehimanot monastery is better in diversity of large mammals than Aresema monastery, this might be related with the variation in habitat diversity.

In practical, Aresema mastery has less habitat diversity and ground cover, and these factors might bring some change in diversity of species. Similarly, Jones et al. (1996) reported geographical location and habitat diversity are primary factors in the richness and abundance of large mammals. Moreover, climatic variability in relation to habitat quality can determine species abundance of large mammals. In line with this, the effects of habitat quality can also determine species diversity and abundance of large mammals in the study area.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Spatial-temporal distribution, abundance, diversity and mortality of birds on road network in the Serengeti Ecosystem, Tanzania

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Vehicle collisions with wild animals are acknowledged as a non-negligible source of death of wild birds and often affect their spatial-temporal distribution, abundance and diversity. However, data to ascertain the impact of road kills on wild birds are scarce, especially around the Serengeti Ecosystem in Tanzania. This work aims to investigate the impact of road kills on wild birds and their spatial-temporal distribution, abundance and diversity in the Serengeti ecosystem in Tanzania. Five road transects each with a length of 40 km were established within the main roads of the Serengeti ecosystem. Bird surveys were conducted in the morning and afternoon in both wet and dry seasons (March and August 2015), respectively. The study results indicated that, 1472 birds have been inventoried which belong to 42 families, 62 genera and 98 species. Mean number of individual birds was the highest in wooded grassland and species richness was also the highest in grassland habitats. In addition, more birds were observed during the wet than dry season. Birds' mean abundance was higher during the morning than afternoon, especially in the grassland. In the ecosystem, 31 individual birds belonging to 19 species that were distributed in five families were found killed along the road networks. In the Seronera-Fort Ikoma transect, more bird species were killed in roads with higher traffic volume during the morning than afternoon compared to other transects in the area. On the contrary, the extent of the road kill was the highest in wooded grassland. This study recommends that increased road kills could be regulated within the ecosystem by placing signposts at the entrance and visitors' centre in conjunction with educational programs to raise road users' awareness on the impact of road kills for biodiversity conservation in the area.

Key words: Birds' roadkill, traffic volume, richness, distribution, diversity, habitat type, conservation, Serengeti ecosystem.

INTRODUCTION

Although road networks in protected areas are economically important to the society as a whole (Ferraro and Hanauer, 2014; Mahulu et al., 2015); however, they may also have negative impacts on wildlife conservation due to vehicles noises, related disturbances and vehicles collision with wild animals (da Cunha et al., 2010; Garriga et al., 2012). This is more severe when such road networks cross out protected areas. It is worth mentioning that roads building throughout protected areas do not always have negative significant ecological and environmental effects on terrestrial and aquatic communities. However, road networks can also create new habitats for wildlife as roads retain heat. The latter can contribute to reduce metabolic costs for birds that rest on the road surfaces (Morelli et al., 2014).

Regarding the importance of associated road structures, the study of Forman (2000) has reported that poles, culverts and bridges represents key structure for bird's nesting/resting. In addition, road verges increase availability of food sources that attracts granivore and insectivore types of birds due to the availability of seeds and insects (Lonsdale and Lane, 1994; von der Lippe et al., 2013). Moreover, pot holes along the road can create water points during rainy season, and they often contribute to attract a large number of birds seeking to drink water (Ascensao and Mira, 2006).

On the contrary, roads building and road structures are not always beneficial to the society to some extent, especially with regards to biodiversity conservation. Trombulak and Frissell (2000) reported that protected areas and the existence of roads and vehicle traffic have significant ecological and environmental effects on terrestrial and aquatic communities through ecosystem and habitat fragmentation, and loss of biodiversity in some extent.

Similar results are also driven by anthropogenic activities. Such anthropogenic activities may therefore lead to displacement (spatial distribution) of wildlife population including birds (Kociolek et al., 2011). Birds are known as one of the species that are more sensitive to habitat fragmentation and disturbances. Adapting to its new environment requires that birds might migrate out of the fragmented areas to a relatively less disturbed one.

Implementing an effective conservation approach often calls for understanding factors that determine the distribution patterns of birds especially those related to increase of human activities in protected areas. This is because the periodic road maintenance entails habitat destruction and population fragmentation (Senzota, 2012). As a result, its effects on birds can represent high mortalities of birds on roads passing through protected areas (Ramp et al., 2006; Mkanda and Chansa, 2011; Collinson et al., 2014). For the period between 2013 and 2015, the impact of roads on bird mortality was reported to be 50% in Tarangire-Manyara Ecosystem in Tanzania (Kioko et al., 2015).

However, the Serengeti ecosystem information on bird diversity, distribution and abundance along roads is scanty. In addition, there is little information on road networks influence on bird mortality patterns. Therefore, this study aims at bridging this gap by documenting spatial and temporal distribution, abundance and diversity of birds around the Serengeti ecosystem. More specifically, this paper aims to:

(1) Assess spatial-temporal distribution, abundance, richness and diversity of birds along roads, and
(2) Assess the extent, rate and factors contributing to birds' road mortality.

MATERIALS AND METHODS

Study area

This study was conducted between March and August 2015 in Ngorongoro Conservation Area (NCA) and in Serengeti National Park (SNP), which are parts of the Serengeti ecosystem in the Northern Tanzania. The ecosystem extends to south-western Kenya and between $1^0$15' to $3^0$30' S and $34^0$34' to 36^0 E. The ecosystem has several protected areas under different management categories including Serengeti National Park (SNP), NCA, Maswa Game Reserve (MGR), Loliondo Game Controlled Area (LGCA) and Ikorongo-Grumeti Game Reserves (IGGRs) in Tanzania, and Maasai-Mara National Reserve in Southern Kenya (Sinclair and Norton-Griffiths, 1979). The study focused on the main roads passing through the NCA and Serengeti National Park (SNP) (Figure 1). The study area receives bimodal rainfall generally lower in the south and east of the ecosystem than in the north and west, with an estimate of 500 mm/year, and 950 to 1150 mm/year of rainfall respectively (Norton-griffiths et al., 1975; Sinclair, 1995). The vegetation cover in SNP is influenced mainly by soil type and rainfall. Such vegetation can be broadly classified into the eastern grass plains, central acacia woodlands, and northern broadleaf forests (Sinclair, 1995). The ecosystem is a home of about 70 larger mammal species (McNaughton, 1985), and that more than 617 bird species have already been identified (Jankowski et al., 2015; Werema et al., 2017).

Data collection

Five road transects were established within the main roads of the Serengeti ecosystem in NCA and SNP. The main road segments were selected based on their relatively high usage by vehicles in the Serengeti ecosystem. The selection criteria included both high and low traffic volume transects of 40 km length each. The categorization of traffic volume was based on the results obtained from vehicle traffic volume per day, and was grouped into two classes.
Indeed, transect with >25 vehicle passes/day was considered as high traffic volume transect (that is, Oldupai, Naabi and FortIkoma transects) while transect with <25 vehicle passes/day was considered as low traffic volume (that is, Ndabaka and Lobo transects). The first road transect started from Seronera to FortIkoma (hereof as Fort Ikoma), second transect started from Seronera-airstrip to Naabi gate (Naabi), the third transect started from Naabi gate to Oldupai River in NCA (Oldupai). The fourth transect started from Banagi to Togoro plain (Lobo). The fifth one started from Nyaruswiga hill to Ndabaka (Ndabaka). All the first three roads transect were categorized as high traffic volume while the fourth and fifth ones were classified as roads of low traffic volume. Each road transect was divided into three sections; left-hand edge, center of the road, and right-hand edge. These three sections of the road transect represented the standard road

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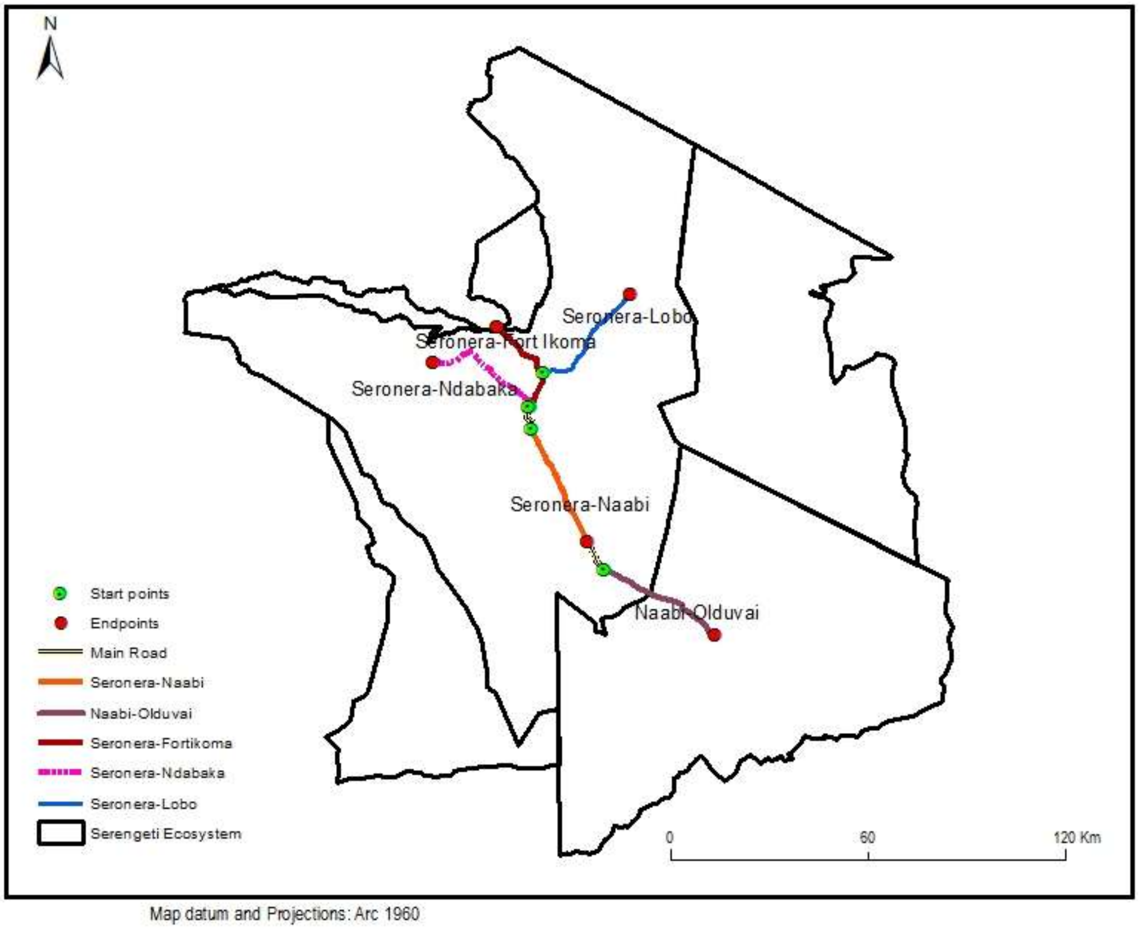

Figure 1. Map of the Serengeti ecosystem study's area.

sampling width in which birds were identified and counted. Nine points were established within a road transect at 5 km intervals. At each sampling point, the width of the road was measured and the mean of the width of the road was calculated to obtain a transect width for birds' observation.

Data collection phases on birds were conducted both in the wet and dry seasons. One transect was surveyed in one day in the morning session starting at 7:30 to around 11:30 am and in the afternoon session, it started from 14:00 to around 18:00 pm. The vehicle was driven at 20 kph or less with stopping to take records of each bird or group of birds encountered (Collinson et al., 2014; Mahulu et al., 2015). A binocular was also used to clearly identify birds. Two observers were seated in a land rover pick-up sighting and recording birds foraging along the roads.

Variables such as transect name, global positioning system (GPS) location, time, landscape factors (that is, distance to water sources or bridge), vehicle odometer reading, habitat type and number of birds were recorded at each encounter of bird species. Birds' activity along the roads (that is, feeding, drinking, resting and crossing), road kills and information on habitat types (that is, woodland, wooded grassland, grassland, riverine, and bushland) were also recorded. To achieve the objective of the study, the following hypotheses were set:

(1) Roads with high traffic volume would decrease birds' abundance and diversity as well as increase road kill of birds than in low traffic roads. This implies that at high traffic volume, birds have higher probability of colliding with moving vehicles than low traffic volume. In the meanwhile, at high traffic volume, birds tend to avoid foraging along roads due to disturbance which resulted from passing vehicles than low traffic volume,
(2) More birds (live or killed) should be observed during the morning hours compared to evening in the wet than in dry season of the year.
(3) More birds (live or killed) should be observed in areas closer to water sources and bridges (bridges provide nesting and roosting sites and are likely to reserve water during wet season) than in non-water related sources and bridges.

Statistical analysis

Comparisons of birds' diversity and evenness across transects and activity type

In this study, data collection on bird species were summarised based on feeding level as explained by Fry et al. (2000) and Fry and Keith (2004):

(1) Insectivores (those that feed on arthropods including insects and other arthropods such as spiders and centipedes).
(2) Granivores (birds that feed on herbs and seeds).

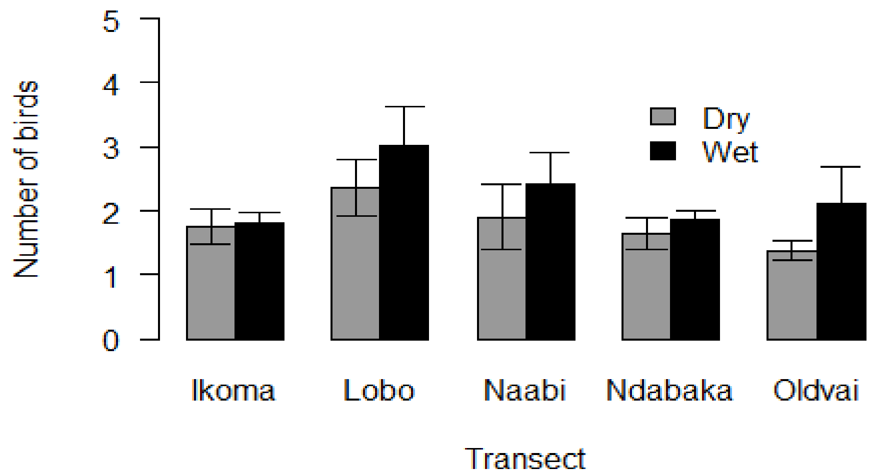

Figure 2. Birds' mean abundance (±SE) recorded from different road transects in the Serengeti ecosystem.

(3) Omnivores (birds that feed on herbs, seeds and arthropods), and
(4) Frugivores (birds that feed on fruits).

In addition, birds that feed on other birds, rodents, reptiles, amphibians and fish were classified as vertebrate feeders (that is, raptor, owl and heron). To determine which road had the greatest bird biodiversity, species richness estimates were obtained following Shannon and Weaver (1998) index. Such index uses four biodiversity indices to appreciate the richness of the species within a given area including, richness, diversity, abundance and evenness. The calculation of such indexes allows one to ascertain which road has the greatest biodiversity community of birds (Hammer et al., 2001). Bird abundance in different roads and time periods were calculated across the nine points established within a road transect, and standard errors were computed. In this case, birds' abundance was represented by the number of individuals counted in a given area per day.

Determinations of risk factors for birds' road kill

We fitted a Generalized Linear Mixed Model (GLMM) in order to assess factors responsible for birds road kill. Transect ID, road segment were defined as random effects in the model, while fixed effects variables identified was the number of live mammals recorded, distance from observed animal to nearby bush, water source and bridge, season of survey (wet or dry), road conditions (good and poor), session (morning or afternoon), verge grass colour, and height as well as habitat type. Pearson correlation analysis was used to assess collinearity between predictor variables. The best approximating model was selected from the global model by using Chi-square test ($p < 0.05$). The significance of excluding or including each predictor variable was evaluated by model update, each time removing one predictor until all possibilities were done, to see if there were predictors that did not cause a significant drop in the goodness of fit of the model. The relative likelihood was evaluated using Akaike Information Criterion (AIC) (Akaike 1973), the small-sample bias adjustment delta AICc (Hurvich and Tsai, 1989). Models were ranked by calculating Akaike weights (w) which ranged from 0 to 1, and considered the subset model with highest weight and delta < 2 as the best approximate model (Burnham and Anderson, 2002).

RESULTS

Spatial-temporal distribution and abundance

In all five road transects surveyed, 1472 individual birds were observed belonging to 42 families, 62 genera and 98 species. For roads with high traffic volume, mean abundance (±SE) of birds was the highest (8.44±1.05) compared to road transects with low traffic volume (5.305±0.64). This means that the Oldupai transect recorded more birds (9.556±2.54) in mean abundance, followed by Lobo transect (9.26±2.2) and Naabi (7.02±1.32). However, no differences in mean abundance of birds were encountered between the two transects of Ndabaka (6.93±1.5) and FortIkoma (6.896±1.49) (Figure 2). Mean birds' abundance was the highest in wooded grassland compared to other habitats types along all the road transects surveyed. Total mean birds' abundance was estimated at 11.08±2.53 (Figure 3). The second habitat type with the highest mean birds' abundance was grassland (8.54±1.52) followed by woodland (7.28±1.41), bushland (3.42±0.74) and riverine (2.0±0.44) habitats. The riverine represents the habitat type that has the least important mean birds' abundance out of the five habitat types (Figure 3). More birds were observed during morning hours than afternoon, and the highest bird mean (±SE) was recorded during morning hours (33.95±1.76) than during afternoon hours (24.58±0.89). The overall species abundance during morning and afternoon differed significantly across the road networks. Morning observations ($Z = 7.03$, $P = 0.0002$) differ significantly from those of the afternoon. More birds were observed during wet season in March ($Z = -3.098$, $P = 0.0019$) with mean abundance of 25.47±2.009; the lowest was observed during the dry season in July ($Z = -6.821$, $P = 0.0009$) and August ($Z = -3.098$, $P = 0.0002$) with mean abundance of 11.75±1.48. The difference was

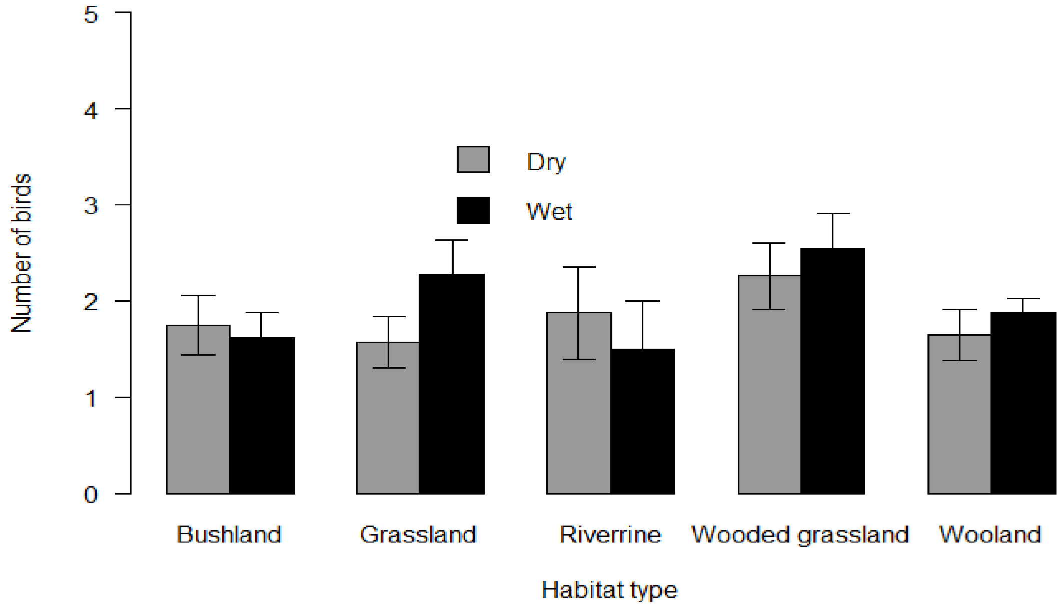

Figure 3. Birds' mean abundance (±SE) recorded from different habitat type along roads transects of the Serengeti ecosystem.

Table 1. Birds diversity and evenness calculated along different road transects of the Serengeti ecosystem.

S/N	Transect name	Number of individuals	Shannon Wiener index (H')	Bird species evenness (E_H)
1	Lobo	361	2.904	0.4681
2	Naabi	302	3.210	0.5761
3	Ndabaka	339	3.302	0.5125
4	Oldupai	172	2.295	0.5516
5	FortIkoma	298	3.083	0.5076

statistically significant.

Richness and diversity of birds along roads

Species richness of birds differs among road transects. A significant difference was found between species richness of birds in Ndabaka (Z = -3.931, P = 0.0001) and Naabi road transect (Z = -3.649, P = 0.0003) but not with other road transects in the Serengeti ecosystem. In Ndabaka road transects, the highest number of species (53) was encountered followed equally by FortIkoma and Naabi with 43 bird species each. Lobo (39) and Oldupai (18) represent the two surveyed road transects that have the least number of species out of the five roads transects sampled. In addition, species richness of birds in grassland (Z = 2.909, P = 0.0036), wooded grassland (Z = 7.612, P = 0.0002) and woodland (Z = 4.940, P = 0.0008) differ significantly from other habitats type. The result shows that the highest species was in grassland (57) followed by wooded grassland (49), woodland (47), bushland (24) and riverine (9) bird species. The results from Generalized Linear Mixed Models (GLMM) revealed that the presence of bridge and water sources away (>10m) from the roads have an influence on birds' abundance, diversity and distribution along the roads of the Serengeti ecosystem. In terms of birds' diversity, Ndabaka had the highest diversity of bird species (H' = 3.302) and the least species diversity was observed in Oldupai (H' = 2.295) (Table 1). The evenness of birds in all road transects surveyed did not reach complete evenness. The overall evenness for five roads transects was generally relatively low (Table 1).

Birds' road kill and activities patterns along the roads

In all surveyed road transects, 31 individual birds were killed along the roads with an average of two species being killed per day. The highest number of road kills was observed in the morning (19 individuals) and the lowest in the afternoon (12 individuals). The FortIkoma transect had more kills with 12 (38.7%) bird species followed by Ndabaka transect with 8 (25.81%) bird species killed. Naabi transect had 5 (16.13%) killed bird species followed by Lobo and Oldupai transects which had 3(9.68%) birds species killed. In all the road transects surveyed, only Naabi Road contributes significantly to road kill (Z = -1.979, P = 0.048) out of the other road transects surveyed. Wooded grassland and woodland habitats are among the habitats where most bird species were killed; the birds species killed belonging to Guineafowl *Numida meleagris* (Helmeted) with the highest percentage were estimated at 19% followed by *Streptopelia capicola* (Ring-necked Dove) (9.7%) (Table 2). In all the road transects surveyed, birds were observed foraging along the roads. Feeding, crossing from one side of the road to another and resting on roads surface were the main activities carried out by birds. Birds that flew away from the road before observers identified their activities were as an 'unidentified activity' and were omitted in the analysis. The result on birds' activities patterns along roads show that feeding (36 species) was the main activity performed by birds. Twenty-four bird species were observed crossing and 11 species were resting on roads. Granivore and insectivore were among the most abundant and diverse type of birds encountered in the study area (Table 3).

Factors influencing birds' mortality

The proportion of bird road kill was higher in the dry than in the wet season. However, model results retained five factors such as the number of animals, distance to water >50m, vehicle speed > 40 km/h, season (wet), lane width >7.5m and distance to bridge >50m. Such variables have either a highly and significant influence on road bird mortality as shown by the Generalized Linear Mixed Models (Table 4).

DISCUSSION

Spatial-temporal distribution and abundance of birds along roadsides

Regarding abundance and richness of bird species, the results of this study did not support our first hypothesis stating that roads with high traffic volume would decrease birds abundance and diversity. We found that high abundance and bird species richness in roads with high traffic volume indicate larger number of some specialized population of birds, particularly granivore (queleas, bishops, widowbirds and whydahs) and insectivorous (that is, larks, plovers and wheatears).

In those roads, the availability of food has certainly attracted bird species (Kociolek and Clevenger, 2009). This means that roadside provides certainly useful foraging habitats to birds sources of food, nesting sites, habitat quality (effect of landscape heterogeneity), good hiding locations to avoid predators, and marginal habitats (ecological corridors) as optimal foraging birds' habitat.

On the contrary, the occurrence of birds along the roadsides could be attributed to how the landscape and traffic volume were structured across the study area. Since field observations have revealed that the studied roads traversed patchy vegetation types and verge conditions therefore such structures have certainly driven a non-uniform distribution of birds along the respective roads. According to the following scholars, Li et al. (2010), Summers et al. (2011) and Morelli et al. (2014), the mean abundance of birds declined during the dry season as a result of the decrease in spatial gradient of the landscape characteristics such as vegetation productivity, reduction of food availability and sometimes low quality of nesting sites for perching birds or songbirds (Passeriformes).

Moreover, the abundance of birds along roadsides might also be driven by the fact that they tend to visit roads to warm up their bodies' temperature from heating road surface. Such practice has also been evidenced elsewhere because it is very important to reduce bird metabolic expenditures, except during dry season (van der Ree et al., 2011).

Richness and diversity of birds along roads

The highest species richness and diversity of birds was observed in Ndabaka and FortIkoma transects due certainly to habitat heterogeneity (woodland, wooded grassland, riverine, grassland and bushland) encountered along the roadside. Such habitat heterogeneity has certainly attracted birds to forage along these road transects.

The relatively low evenness observed for five road transects surveyed demonstrated that the noise of passing vehicles possibly affected the population of birds. The population of birds could have been certainly impacted by noise disturbances and/ or dust produced by passing vehicles, along with injury and/or kill of birds. Although 98 species of birds have been recorded in all five transects of this study, they did not reach or exceed quarter of the 617 species that are known throughout the entire Serengeti ecosystem (Nkwabi et al., 2011; Jankowski et al., 2015). This may suggest that passing vehicles along the roads could have slightly affected the distribution of birds in their ecosystem.

Although the data analysed is from short term observations (during the dry and wet seasons of a single year), the results show that the observed bird species along the roads included some importantly threatened bird species like Bateleur (*Terathopius ecaudatus*), Fischer's Lovebird (*Agapornis fischeri*) and Kori Bustard

Table 2. Ratio of observed killed birds from different road transects of the Serengeti ecosystem.

Birds' feeding category	Common name	Scientific name	FortIkoma	Lobo	Naabi	Ndabaka	Oldupai	Subtotal killed	% killed
Granivore	Fischer's Sparrow-lark	*Eremopterix leucopareia*	0	0	0	0	1	1	3.2
	Chestnut-bellied Sandgrouse	*Pterocles exustus*	0	1	0	1	0	2	6.5
	Grey-capped Social-weaver	*Pseudonigrita arnaudi*	-	0	0	0	0	1	3.2
	Red-cheeked Cordon-bleu	*Uraeginthus bengalus*	-	0	0	0	0	1	3.2
	Ring-necked Dove	*Streptopelia capicola*	-	0	1	1	0	3	9.7
	Speckle-fronted Weaver	*Sporopipes frontalis*	-	0	0	0	0	1	3.2
Insectivore	Croaking Cisticola	*Cisticola natalensis*	-	0	1	0	0	1	3.2
	Rattling Cisticola	*Cisticola chiniana*	-	0	0	1	0	1	3.2
	Lilac-breasted Roller	*Coracias caudatus*	-	0	0	1	0	2	6.5
	Flappet Lark	*Mirafra rufocinnamomea*	-	0	0	1	0	2	6.5
	Red-capped Lark	*Calandrella cinerea*	-	0	0	0	1	1	3.2
	Grey-backed Fiscal	*Lanius excubitoroides*	-	0	0	0	1	1	3.2
	Brown-crowned Tchagra	*Tchagra australis*	-	0	0	0	0	1	3.2
	Superb Starling	*Lamprotornis superbus*	-	0	0	0	0	1	3.2
Omnivore	Helmeted Guineafowl	*Numida meleagris*	-	2	1	0	0	6	19
	Coqui Francolin	*Peliperdix coqui*	-	0	0	2	0	2	6.5
	Crested Francolin	*Dendroperdix sephaena*	-	0	0	0	0	1	3.2
	Grey-breasted Francolin ‡	*Pternistis rufopictus*	-	0	0	1	0	1	3.2
Vertebrate feeder	Secretary Bird †	*Sagittarius serpentarius*	0	0	2	0	0	2	6.5
-		Total birds killed	12	3	5	8	3	31	-
-		Total birds observed	298	361	302	339	172	1472	-
-		$ratio = \frac{Total\ birds\ killed}{Total\ birds\ observed}$	0.040	0.008	0.017	0.024	0.017	0.021	-

NB: ‡ indicates Endemic species to Serengeti National Park and † indicates the species listed by IUCN in 2013 as vulnerable.

(*Ardeotis kori*) species. These species have been listed by IUCN as Near Threatened in 2012.

Similarly, the Secretary Bird (*Sagittarius serpentarius*) have been listed by IUCN as Vulnerable in 2013 (IUCN, 2016). Roadside habitats attracted the mentioned birds to forage; as a result, birds are exposed to high levels of traffic noise, visual disturbance from passing vehicles, and the risk of collision. The study survey has also revealed existence of Grey-breasted Francolin (*Pternistis rufopictus*) along Serengeti roads the endemic species to the ecosystem exposing to risk of vehicle collision.

Bird activities' patterns such as feeding, resting, crossing and other activities performed were

Table 3. Ratio of birds killed by the total number of birds observed by birds feeding category along roads

Transect name	Birds' feeding category	Total species	Birds' killed	Total individuals	Ratio
FortIkoma	Vertebrate feeder	2	0	5	0.000
	Granivore	15	4	182	0.022
	Insectivore	22	4	86	0.047
	Omnivore	4	4	25	0.160
Lobo	Vertebrate feeder	1	0	2	0.000
	Frugivore	1	0	2	0.000
	Granivore	13	1	232	0.004
	Insectivore	19	0	62	0.000
	Omnivore	5	2	63	0.032
Naabi	Vertebrate feeder	3	2	4	0.500
	Granivore	7	1	74	0.014
	Insectivore	31	1	189	0.005
	Omnivore	2	1	35	0.029
Ndabaka	Vertebrate feeder	1	0	1	0.000
	Frugivore	1	0	2	0.000
	Granivore	16	2	162	0.012
	Insectivore	26	3	103	0.029
	Omnivore	6	3	71	0.042
Oldupai	Granivore	5	1	59	0.017
	Insectivore	13	2	113	0.018

Table 4. Results of the generalized linear mixed models (GLMM) on birds' kill along the roads of the Serengeti ecosystem.

Fixed effects	Estimate	Std. Error	df	t value	Pr (>|t|)
(Intercept)	0.105	0.021	23.10	4.94	5.33e-05 ***
Number of animals	-0.006	0.002	701.90	-3.267	0.00114 **
Distance to water >50m	-0.086	0.021	214.30	-4.134	5.11e-05 ***
Vehicle Speed > 40 km/h	0.17	0.038	552.10	4.513	7.82e-06 ***
Season (Wet)	-0.469	0.027	707.10	-17.213	<2e-16 ***
Lane width >7.5m	-0.157	0.037	150.10	-4.204	4.48e-05 ***
Distance to bridge >50m	0.484	0.692	0.027	706.90	<2e-16 ***

frequently observed during the wet season, especially in the morning. All activities were mostly recorded in woodlands and wooded grassland. These results supported our second hypothesis that more birds' activities occur along the road in the morning and during the wet season of the year. A possible explanation is that granivore and insectivore types of birds often visit woodland and wooded grassland for possibly supplementing their diets in food sources such as seeds and insects along road verges (Laursen, 1981; Laurance et al., 2004).

The model run out indicated that landscape factors such as location of roads, habitat type and verge grass characteristics caused a significant direct influence on birds' distribution, abundance and diversity. Birds' distribution was also associated with the distance of 20-50m and >50m and not close from the bridges and water sources. Such results are opposite to our third hypothesis that states that "more birds should be observed in areas close to water sources and bridges". This is explained by the behaviour of birds which select foraging sites by considering quality and quantity of the availability resources needed (Cody, 1981). In terms of roadkill, the results showed that, a distance of 20 to 50 m and greater than 50 m to bridge was highly significant instead of the close distances to bridge (0 to 10 m). This indicates that more birds were killed at longer distances away, not very close or even at zero distances to bridges.

Furthermore, increased road kill of Ring-necked Dove and Helmeted Guineafowl could be attributed to an increased feeding activity of these birds on seeds and dead insects as road kill that might be available along roads. The latter point could make more of these birds be exposed to collision with vehicles (Lambertucci et al., 2009; Husby, 2017). Presence of vertebrate feeders (Bateleur, Secretary Bird, Amur Falcon *Falco amurensis*, Greater Kestrel *Falco rupicoloides*, Lesser Kestrel *Falco naumanni* and Montagu's Harrier *Circus pygargus*) that use road surfaces as hunting substrate (capturing preys or taking advantage of roadkill) suggests that road surface and roadside in the study transects had frequent incidences of dead animals.

Birds' road kill and activities patterns along the roads and opportunities to improve birds' conservation around the Serengeti ecosystem, Tanzania

The study results suggest that, in protected areas, birds are exposed to different factors that may lead to their mortality.These factors include those which are related to traffic especially vehicle speed and road lane width. We found that road mortality was associated with high vehicle speeds. These results are in line with previous findings (Aresco, 2005; Rao and Girish, 2007) that reported the severity of invertebrate/insect casualties on road.

In addition, the study results have indicated that some road features also affect bird mortality which is in line with Laurance et al. (2009). In tropical rainforests, they found that linear infrastructures building up such as roads, highways, power lines and gas lines are sources of vulnerability of tropical species that are susceptible to road kill. In addition, roads have a major role in opening up forested tropical regions to destructive colonization and exploitation of tropical species. For example Goosem (1997) found that wider road widths (which possibly encourage higher speed among drivers) and long distances from bridges in roads (which possibly reduce driver carefulness) were significantly associated with road mortality of birds and concur previous findings. Results confirm that distance to water source is another factor of road birds' mortality; this is in line with Baskaran and Boominathan (2010), who reported more road kills on highway stretches that were close to rivers than those located away from water sources.

However, the fact that this study indicated more bird road mortality occurred at distances greater than 50 m indicated distances within 50m are probably too close to influence road kill. In the wet season, more birds possible forage along road areas because of food availability (Laurance, 2004; Wiącek et al., 2015). Thus increasing exposure to vehicles collision could be the reason for the high association between bird mortality and wet season and the number of birds recorded. The mortality of endangered bird species was listed by IUCN as Vulnerable (IUCN, 2016), especially the *Secretary Bird.* According to Burkey (1989), Allentoft and O'Brien (2010) and Senzota (2012), road mortality could contribute to local extinction of bird species. .

CONCLUSION AND RECOMMENDATIONS

This study has contributed to find that mean birds' abundance was the highest in wooded grassland than in other habitats types along all surveyed transects. This means that roadside provides certainly useful foraging habitats as source of food, nesting sites, habitat quality, good hiding locations to avoid predators, and marginal habitats for birds. Thus, the bird communities appear to be changing in response to human activities occurring along the roads with changes in the structure of birds' habitats. In terms of roadkill, individual birds were killed along the roads with an average of two species per day.

The followings are suggested:

(1) Carrying out conservation efforts to integrate the critical factors of road kill in the design and implementation of mitigation measures to reduce road kill incidences in Serengeti ecosystem in Tanzania by removing roadside use of underpasses, signboards, and speed breakers can help to minimize road kill of animals;
(2) Establishing a monitoring program in order to identify road stretches with high road kill "potential" as well as species at high risk of being killed to set up targeted mitigation actions;
(3) Carrying out monitoring protocols such as longitudinal survey to establish base line data on the taxonomic group of the species that are more vulnerable by quantifying road mortalities and/or determining key habitats.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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