The effects of land use on the avifauna and its conservation in a Kenyan coastal forest ecosystem, and the significance of the Arabuko Sokoke Forest to the local community

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ABSTRACT

This study examines the effects of land use on the bird community of Arabuko Sokoke Forest, the largest area of coastal forest remaining in East Africa and a major Important Bird Area in mainland Kenya. Bird species diversity in three land use types (primary forest, plantation and farm lands) was compared using multivariate analysis to determine the response of different feeding guilds to habitat characteristics. The effect of habitat characteristics on overall bird diversity and specific feeding guilds was tested using linear mixed models. A total of 2600 bird observations were recorded during point counts, representing 97 bird species including 25 fruit-eating birds, 17 nectar feeders; and 60 species belonging exclusively to other feeding guilds. Land use had a significant effect on overall bird diversity and abundance. The distribution of frugivorous birds was primarily influenced by the presence of fruiting trees rather than land use type, while nectarivores were significantly affected by vertical habitat heterogeneity and vegetation type. Although the distribution of insectivorous birds is influenced by many habitat factors, proximity to natural forest, habitat heterogeneity, and the presence of large trees and fruiting trees appear to be most important to this guild. The natural forest has the greatest avian diversity and a distinctive community compared to plantation and farmlands. Patterns of habitat use by birds in the area suggest that vertical vegetation heterogeneity and complexity is especially significant in sustaining diverse and abundant bird populations, if they are in close proximity to native forests. Improvement of conservation management for the plantation and farmlands is thus critical for connectivity with other remnant primary forest patches in the area.

Socio-economic data was collected from 109 forest adjacent households to determine the value of the forest to the local community and their perception of conservation issues. Arabuko Sokoke Forest is important in supplementing the livelihood needs of the local community. However, the community lacks information on the forest management plan and many people have little knowledge of local birds, which could limit their capacity to participate in conservation projects. Drivers for local community participation in conservation projects are primarily a sustainable income and the fulfillment of basic household needs. Community conservation education is needed to promote local knowledge of forest biodiversity, as well as clear frameworks for the active involvement of the local community in forest management. Support of community based projects is vital to achieve both the conservation and livelihood objectives of the Arabuko Sokoke Forest management plan.

DEDICATION

I dedicate this work to my daughter Mitchelle. Her interest in the activities during this study was a great motivation. Such statements as: “Daddy you are going to the forest, next time we go with you”, her interest in the first binoculars I used in the field, now in her possession, drew our attention. She is only seven and aspires to be a scientist and a professor. I dedicate this work to her, to inspire her to greatness in science or any other field, and humility in life.

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CHAPTER ONE

INTRODUCTION

1.1 Background information

Land use changes, habitat fragmentation, climate change and species invasion are major threats to biodiversity at local and global scales. In addition, infrastructural factors and biomass demands will influence the response of forestry biodiversity to changing climate parameters. Land use and habitat fragmentation which are the focus of this study will affect ecological processes, ecosystem functioning, species composition and habitat utilization of many species including birds. Ecosystem functioning can be defined as the rate, level or temporal dynamics of one or more ecosystem processes (Loreau et al. 2001). However, most information on changing bird species richness in tropical land use systems is available for North and South America (e.g. Renner et al. 2006) and there have been relatively few studies in Africa (e.g. Aerts 2007; Munyekewe et al. 2008; Borghesio & Laiolo 2014). There is evidence of declines of some migratory bird species in the northern hemisphere which migrate to tropical regions (e.g. Robbins et al. 1989; Terborgh 1989; Discoll & Donovan 2003; Sanderson et al. 2006; Ockendon et al. 2012; Morrison et al. 2013), prompting studies on possible effects of habitat change in the tropics on bird populations.

Birds that offer important ecosytem services e.g. seed dispersal, pollination and pest control are likely under threat due to habitat fragmentation. There has been extensive research on insects that offer pollination services, following an unprecedented pollination crisis with catastrophic declines in bee populations (Potts et al. 2003; Kremen et al. 2007; Gikungu et al. 2011). However, birds that offer such services have received less attention. There is a need to know both the direct and indirect effects that habitat disturbance and proximity to intact forest may have on the relationship between biodiversity and ecosystem services, like pollination and seed dispersal (Kirika et al. 2008).

Thus, effective land use management is increasingly becoming important for biodiversity conservation. Maintenance of some natural habitat within farmlands creates habitat heterogeneity which is beneficial for birds (Benton et al. 2003). Allowing stands of trees to remain and senesce following harvesting may increase nest site availability for cavity nesting species in farmlands, while planting polycultures in plantations may improve structural diversity encouraging their use by a wide range of birds (Sweeney et al. 2010). Tropical agro-ecosystems with substantial amounts of remnant trees (Fischer 2002) and agroforestry plots (Schroth et al. 2004) consequently have greater conservation value to birds. In addition, reduced impact logging practices in plantation forests are significant for forest bird conservation (Thiollay 1999). However, the negative effects of fragment size and isolation on the original sets of species may not become evident until the landscape consists of only 10-30% of the original habitat (Andrén 1994). For this reason, conservation biologists suggest at least 10-20% set-aside land to maintain and stabilize farmland bird populations (Tscharntke et al. 2008). Land set aside for conservation has been shown to be important in providing safe nesting sites, refuge during harvesting and valuable food resources for animal populations (Lukasch et al. 2011). To counteract the negative effects of intensive agricultural land use practices on biodiversity, there is a need to maintain a significant proportion of semi-natural or natural habitats (Lukasch et al. 2011).

Bird species associated with native habitats may decline in abundance and eventually go extinct due to habitat disturbance and fragmentation (Andrén 1994; Turner 1996; Johnson 2001; Marini 2001; Kurosawa & Askin 2003; Sam et al. 2014). Traditional agroforests with a mix of cultivated and natural shade trees in close proximity to natural forest can support a high number of bird species including many forest specialists (Renner et al. 2006). Forest specialists comprise 53 % of all the bird species found in the tropics, whereas 14 % of tropical species are agroforest species and 3 % are agricultural specialists (Sekercioglu 2012). There is need for effective management of natural forests for conservation of forest specialists that account for the greatest proportion of birds in the tropics.

In Kenya, population growth, coupled with increasing demands for timber and land for agriculture, have contributed to a reduction in the extent and condition of forests (Kenya Wildlife Service 2013). Population growth rate in Kenya is estimated at 1.5 percent per year and a predicted population size of about 39 million in 2009 (Government of Kenya 2013). Kenya's population has therefore doubled over the last 40 years between 1969-2009 with a major trend in population increase recorded for Nairobi and Coast (the location of Arabuko Sokoke Forest) regions (Government of Kenya 2013). As the population increases, requirement for agricultural land and pressure on natural resources increase, leading to degradation and adverse impacts on forest biodiversity. In this chapter I review the effects of major threats to biodiversity, bird populations and ecosystem services including climate change, invasive species and habitat fragmentation.

1.2 Effects of climate change on biodiversity

There is overwhelming evidence that climate change will lead to massive species extinctions (e.g. Thuiller et al. 2006; Bässler et al. 2010) and alter the distributions of many species (e.g. (e.g. Hickling et al. 2005). Although change is inevitable (Maclean et al. 2008; Anderson et al. 2009), detailed knowledge of a species' natural history, and information on availability of their suitable habitat (Hu et al. 2010) will be significant for adequate conservation management. Anthropogenic stresses such as human and livestock population pressures, land use changes, infrastructural factors, biomass demands and the fragmented nature of forests will all affect forestry responses to changing climate parameters (Ravindranath & Sukumar 1996). In the case of migratory species, their conservation and protection should target breeding grounds, stopover sites and the non-breeding range (Bibby 2003; Walther et al. 2007). Migratory bird species often exhibit predictable responses to shifts in temperature and precipitation, so that any change in these two parameters could alter the timing of the arrival on the breeding grounds, affecting their reproductive success, survivorship and fitness (Both & Visser 2001; Murphy-Klassen et al. 2009). Climate change is also expected to affect behavioural adaptations, species interactions, range shifts, and overall community composition (Tingley et al. 2012). The response of each species to future changes in climate will depend on its rate of survival, growth and reproduction (Miles et al. 2004).

Climate change could potentially result in a shift of forest boundaries along altitudinal and rainfall gradients, with species shifting from lower to higher elevations (Ravindranath & Sukumar 1996). Forests may also suffer growth losses and climate change driven shifts, as well as increasing stress from human factors such as settlements, roads, communication structures and artificial water bodies (Kirilenko & Sedjo 2007). In case of climate driven shifts, coastal forests in East Africa, which are the focus of this study, will have nowhere to go since they occur at low altitude and cover a very small altitudinal range from the Indian Ocean inland. It is projected that climate change will increase global timber production through location changes of forests, i.e., through a poleward shift of the most important forestry species (Kirilenko & Sedjo 2007). Climate change can also accelerate vegetation growth through a warmer climate, longer growth seasons, and elevated atmospheric CO_2 concentrations (Kirilenko & Sedjo 2007). It is now clear that climate change is the major new threat that will confront biodiversity this century (Naeem 2005) and should be a significant factor in conservation planning for adaptation measures to be compatible with biodiversity conservation and the provision of multiple forest products to local communities (Ravindranath & Sukumar 1996).

In Kenya and Africa, populations that depend on climate-sensitive natural resources, experience high poverty, and have insufficient access to the social, environmental and economic resources needed to adapt (Parry et al. 2012). Along coastal Kenya, fishermen are concerned about climate change induced cyclones and sudden storms (Parry et al. 2012), while in arid and semi-arid areas expanding populations and intensification of land use has exacerbated vulnerability to the effects of climate (Khandji et al. 2006) e.g. drought has encouraged deforestation as people increasingly clear forests for agricultural lands, use forested lands for grazing, and produce charcoal for their energy and economic needs. This may increase conflicts between people and large mammals such as elephants (Thirgood et al.

2005). Forest fires also become more frequent, with adverse economic consequences in terms of lost timber and the cost of fire suppression (Parry et al. 2012).

Other effects of climate change such as sea level rise could have adverse effects on the human population along the Indian Ocean coast. Sea-level rise along coastal areas where high human populations occur is likely to disrupt economic activities such as tourism, mining and fisheries. Warm sea surface temperatures, extreme weather events, and sea-level rise can lead to the destruction of coral reefs, which absorb the energy of ocean swells leading to coastal erosion and destruction of mangrove forests (IPCC 2001). Coral reef loss is a significant cause of coastal erosion and a major coastal management issue in both Kenya and Tanzania (Magadza 2000).

Tropical climates may experience seasonal anomalies due to climate change and could severely affect ecosystems (Root et al. 2003). The effects of climatic fluctuations on tropical ecosystems are likely to be severe in human-modified landscapes where tropical forests have been converted into agro-ecosystems (Morris 2010; Mulwa et al. 2013). Severe seasonal climatic fluctuations have been shown to have effects on fruit and invertebrate abundance, leading to cascading effects on bird frugivores and insectivores (Mulwa et al. 2013). Furthermore, climate change has the potential to alter migratory routes and timing of migratory birds and those that use seasonal wetlands (Thirgood et al. 2005). Thus, migration pattern of Palearctic migrants that come to Arabuko Sokoke Forest during non-breeding period may also be affected.

1.3 Effects of invasive species on biodiversity

Exotic invasive plant species threaten biodiversity and ecosystem processes and could change community compositions and abundance of many native species (Ehrenfeld 1997; Wolfe & Klironomos 2005; O'Donnell et al. 2009). Invasive species drive ecological dynamics at multiple spatial scales by causing local and regional shifts and extinctions of native species (Mack et al. 2000; Crowl et al. 2008). New trade routes among previously disconnected countries as well as enhanced transportation technology have increased both the frequency and magnitude of invasion (Aide & Grau 2004). Invasive species are the second leading cause (after human population growth and associated activities) of species extinction and endangerment in the USA (Pimentel 2002).

Invasive species may displace native species (Sherry & Brewer 2008), reduce native species diversity (Parker et al. 1999; Yurkonis & Meiners 2004), and modify the existing structure and ecosystem services upon which people rely (Crowl et al. 2008; Wright 2011). Invasive species can directly eliminate local populations of native species e.g. the brown tree snake *Boiga irregularis* introduced to Guam has eliminated several bird species native to Guam Island (Burdick 2006), or alter the local environment in ways that native species are unable to adapt e.g. buffalo grass from Africa, in the Sonoran desert in Arizona is a clear example of an invasive species that has changed ecosystem functions (Niibus 2007) and is out-competing the youngest native trees and cacti (Wright 2011). The presence of invasive species is considered one of the two major causes of extinctions, alongside habitat destruction (Wilcove et al. 2000). Worldwide, an estimated 80% of endangered species could suffer losses due to competition with or predation by invasive species (Pimentel 2002; Franklin 2008). Invasive species have caused large economic losses e.g. the estimated damage and control cost of invasive species in the U.S.A. alone amounts to more than $ 138 billion annually (Pimentel 2002; Franklin 2008).

The success of invasive plant species is partly attributed to fruit traits that favour effective seed dispersal (Buckley et al. 2006). Some studies have shown that invasive species in their exotic range are superior to native congeners in terms of traits influencing fruit removal and in both cases the invasive species had higher removal rates (Sallabanks 1993; Vilà & D'Antonio 1998). Agricultural practices associated with habitat fragmentation can increase frugivore dispersal of invasive plant species, as many invasive plants and dispersers readily use disturbed environments and fragment edges (Buckley et al. 2006). There are no studies that have assessed the extent of invasive species in Kenya's coastal forests, although there has been a dramatic spread of *Prosopsis juliflora*, especially in the Tana Delta region north of Malindi, and the neem tree (*Azadirachta indica)* has become invasive in some parts of coastal Kenya, especially around Diani Beach (Birdlife International 2013). The spread of these species is likely influenced by land use patterns and agricultural practices. In farmlands adjacent to Arabuko Sokoke Forest, the seeds of the neem tree are likely dispersed by birds that were observed foraging on its fruits including Common Bulbul (*Pycnonotus barbatus*), Fischer's Turaco (*Tauraco fischeri*), Zanzibar Sombre Greenbul (*Andropadus importunes*) among others. However there are some alien invasive in settlements adjacent to the forest, which are likely to be regarded as pests culminating in human-bird conflict, e.g. House Crow (*Corvus splendens*). In Singapore, the House Crow reached pest proportions calling for integrated system of population control measures (Soh et al. 2002), and there has been a major attempt at eliminating it in coastal areas of Tanzania (Archer 2001). However, no documentation is currently available on invasive bird species around Arabuko Sokoke Forest.

1.4 Effects of habitat fragmentation on biodiversity

In the tropics, land use is characterised by road construction, habitat conversion for agriculture, and demand for natural resources leading to clearing of primary forests and habitat fragmentation (e.g. Mustard et al. 2004). Habitat fragmentation has been defined as the process of subdividing a continuous large habitat into smaller and more isolated pieces, which may be natural or human mediated through intensification of land use (Andrén 1994). Habitat fragmentation has three major properties, namely loss of the original habitat, reduction in habitat patch size, and increasing isolation of habitat patches, all of which contribute to a decline in biodiversity within the original habitat (Andrén 1994). In some areas, increases in wealth, technology, and population density are leading to more rural settlement in previously wild areas (Hansen & DeFries 2007) causing fragmentation of natural habitats. While the number of species that are found in a habitat fragment is a function of its area (Hansen & DeFries 2007), many fragments are currently experiencing reduction in size. Brooks et al. (1999) recorded extinction of forest birds in upland forest fragments in Kenya due to a change in the area of forest fragments over time. Habitat fragmentation is considered a leading cause of plant extinction (Bruna et al. 2009) by pollen limitation and lowered fruit production (Lopes & Buzato 2007; Vamosi et al. 2006). Thus, reduction in the effective size of native habitats is predicted to result in losses in species due to change in landscape dynamics and species-area effects (Hansen & DeFries 2007).

Many forest communities currently have declining populations of native species due to degraded environmental conditions, resulting from current or historical land use practices such as cultivation, clearcutting, fire suppression, and forest fragmentation (e.g. Brewer 2001; Bellemare et al. 2002; Flinn & Vellend 2005). Forest fragmentation is thought to favour disturbance dependent species and negatively affect disturbance sensitive species (Alverson et al. 1994; Meier et al. 1995). It is associated with an increase in harmful edge effects (Donovan & Flather 2002) and contact between native and invasive species (Sherry & Brewer 2008). Habitat fragmentation affects not only the rare species in an ecosystem but also reduces the survival probabilities and population size of common species (Hooftman et al. 2004), prompting conservation goals to mitigate fragmentation of natural habitats in order to increase population sizes and habitat connectivity. A decrease in population size can lead to a reduction in the number of alleles in a population resulting in genetic drift (Ellstrand & Elam 1993), and erosion of the quantitative genetic variation necessary for adaptive evolution (Keller & Waller 2002). Smaller fragmented populations are expected to exhibit higher levels of inbreeding and genetic drift and consequently to have lowered individual fitness (Ellstrand & Elam 1993; Keller & Waller 2002). Consequently, fragmented populations become more vulnerable to stochastic processes and environmental changes (Schemske et al. 1994), placing them at risk of extinction.

The impact of fragmentation on forest cover in Coastal Kenya is unprecedented. A once extensive coastal forest mosaic has been reduced to about 107 forest fragments. Currently, Arabuko Sokoke Forest, the focus of this study and Shimba Hills forest system are the last remaining true closed single blocks exceeding a coverage of 9000 ha each (Burgess & Clarke

2000; Githitho 2004), separated by a distance of about 190 km. Other remaining closed forests occur as medium to much smaller fragments. The Kayas (over 50) and sacred groves are very small fragments covering less than 500 ha and are widely distributed over the whole coastal area. The medium size fragments covering 500-1500 ha are mostly gazetted as forest reserves and occur primarily in Kwale, South Coast (Robertson et al. 1993; Burgess & Clarke 2000), approximately 200 km from Arabuko Sokoke Forest (Table 1).

Table 1: Kenya coastal forest fragments and estimated distance from Arabuko Sokoke Forest

Forest	Area (sq. km)	Vegetation type	Approximate distance from Arabuko Sokoke Forest
Arabuko Sokoke Forest	370	Forest	
Dodori/Boni	220	Forest/ Woodland	200 km
Shimba Hills	214	Forest/Grassland	11 km
Boni/Lungi	95	woodland	200 km
Madunguni	53	Forest	23 km
Medium Kwale	51	Forest	117 km
Marafa Brachystegia	30	Forest/ Woodland	35 km
Kaya-47 sites	28	Forest/ Woodland	131 km
Ras Tenawi	20	Thicket/ Forest/ Woodland	178 km
Witu Lamu	15	Forest	120 km
Mwangea	15	Forest	146 km
Tana Gallery Forest	11	Forest/ Woodland	160 km
Tana River Delta	10	Forest/ Woodland	164 km
Mwangea Hill	5	Forest	169 km
Kilibasi	2	Forest	125 km

A significant proportion of the coastal forest fragments have no formal protection e.g. Ras Tenewi, Tana Delta, North Kilifi Brachystegia Woodland, Mangea Hill and Kilibasi Hill. In terms of biodiversity, the most important blocks are: Arabuko Sokoke Forest, Shimba Hills, Lower Tana River forests, Witu Forest Reserve; Diani Forest and Kaya Ribe). However, all coastal forests in Kenya have globally unique biodiversity values and most contain at least one endemic species (Burgess & Clarke 2000).

Despite the rising threats from high population growth including expanding agriculture, charcoal burning, fuel wood collection and illegal logging, only less than 50 % of all the coastal forest vegetation cover is under some form of protection (Githitho 2004). Numerous forest fragments covering an area of 652 km^2 have no legal protection and fall under the local authority or private land owners (Githitho 2004). In Kenya, forests within private land are at the mercy of individual land owners and are highly vulnerable to extreme disturbance and fragmentation.

1.4.1 Effects of habitat fragmentation on bird populations

Habitat fragmentation has led to a decline of many bird populations in forested ecosystems (Donovan 1995; Walters et al. 1999; Lens et al. 2002; Luck 2003). Some bird species like Rufous Tree-creepers (*Climacteris rufa*) in Western Australia survive better in continuous forests than in fragmented ones (Luck 2003). Fragmented habitats limit the ability of females to find mates in many bird species (Dale 2001) and disrupt bird dispersal and connectivity among patches (Githiru & Lens 2006). Habitat fragmentation may reduce regional population sizes more than expected from the loss of habitat alone (Hinsley et al. 1996). This has been linked to the disruption of species interrelationships e.g. the collapse of plant-pollinator mutualisms with a resultant decrease in plant reproduction (e.g. Lamont et al. 1993; Kearns & Inouye 1997; Donaldson et al. 2002).

Patterns of resource availability like food, shelter, and mating sites may affect the distribution and abundance of species within and among habitat patches (Caley et al. 2001). Habitat fragmentation may differ in its impact on avian communities depending on the matrix of habitats that surround remaining fragments. Edge effects due to fragmentation tend to increase access by nest predators which then cause higher nest loss than is found in the forest interior (Gentry et al. 2006). A return to natural disturbance regimes in addition to the conservation of remaining habitat areas may be crucial to maintaining native bird populations.

While primary forests are important to conservation of forest birds, secondary forests can also be of significance (Mordecai et al. 2009). A study by Harvey & Villalobos (2007) in the indigenous reserves of Talamanca in Costa Rica revealed that secondary forests in close proximity to primary forest patches can maintain landscape connectivity for bird movements contributing to high bird diversity. Increasing habitat heterogeneity improves landscape connectivity for forest birds and therefore becomes an effective instrument for conserving species in fragmented landscapes (Aerts et al. 2007). A marked reduction in forest dependent species and overall shifts in species composition have been reported in agroforestry systems (e.g. Harvey & Villalobos 2007). Nonetheless, some studies indicate that cacao, coffee and traditional rubber plantations can sometimes conserve high numbers of plant and animal species (Harvey & Villalobos 2007; Muhamad et al. 2013), although the population numbers are lower than in native woodlands (Kirika et al. 2008). Avian functional diversity, the range and value of birds and their organizational traits that influence ecosystem functioning (Loreau et al. 2001), is higher in tropical forests and tree-dominated agroforestry systems than open agricultural systems with few or no trees (Renner et al. 2006; Harvey & Villalobos 2007), implying that structure of the habitat may be more important to the birds than plant species composition. However, predicting the response of bird communities to habitat disturbances is still a challenge (Donnley & Marzluff 2004).

Past studies have indicated a strong relationship between forest area and the number of species of forest birds (e.g. Turner 1996; Kurosawa & Askin 2003; Frank & Batistti 2005). Agroforests having a mix of cultivated and natural shade trees will attract a considerable number of bird species (Waltert et al. 2004, 2005). Compared to primary forests, species richness of large frugivorous and insectivorous birds (especially terrestrial and understorey species) often declines in agroforests (Sekercioglu 2012). As habitats become more disturbed and open, forest-dependent species are replaced by generalists and open-area species (e.g. Harvey & Villalobos 2007). Such disturbed habitats may therefore only be valuable to forest birds after a certain level of regeneration (Mordecai et al. 2009). Thus even small changes in the structure and composition of the tree cover may have a significant impact on bird assemblages (Harvey & Villalobos 2007), leading to changes in bird diversity and community composition (Collard et al. 2009).

There is increasing evidence that small fragmented areas of natural or semi-natural habitats may provide important refuge areas for a sub-set of the pre-fragmentation bird assemblage (Collard et al. 2009). Other studies, however, have confirmed that some bird species like hummingbirds are dependent on large forest fragments (Stouffer & Bierregaard 1995) and sites with flowering herbs which are usually found in large natural gaps in primary and secondary vegetation (Arriaga-Weiss et al. 2008). Habitat changes particularly affect less abundant and range-restricted birds, rainforest specialists and altitudinal migrants (Raman 2001). Apart from habitat specialization, life history traits such as large territories; sedentary lifestyles and a preference for mature forest (Stratford & Stouffer 1999), and body size (Arriaga-Weiss et al. 2008), may also influence species vulnerability. The ultimate effect of habitat fragmentation and degradation is a reduction in population size and increased vulnerability to extinction (e.g. Stratford 1999; Thiollay 1999; Raman & Sukumar 2002; Waltert et al. 2004; Arriaga-Weiss et al. 2008). Habitat fragmentation on the individual scale is related to area requirements of individuals, home-range boundaries and movement patterns of individuals (Haila et al. 1993).

1.4.2 Effects of habitat fragmentation on ecosystem services offered by birds

Replacement of forests and agroforests with simplified agricultural systems can result in shifts towards less specialized bird communities with altered proportions of functional groups which may lead to a reduction in ecosystem function and loss of the ecosystem services provided by birds (Sekercioglu 2012). A functional group is a set of species that have similar traits and are likely to be similar on their effects on ecosytem functioning (Loreau et al. 2001). Ecosystem services are natural processes that benefit humans (Sekercioglu 2006; Wenny et al. 2011). Bird feeding guilds such as predators, pollinators, scavengers, seed dispersers, and seed predators offer many services and birds may also serve as ‘ecosystem engineers’ (Sekercioglu 2006). Although most bird species avoid agricultural areas, nearly a third of all birds regularly to occasionally use such habitats, where they often provide important ecosystem services like pest control, pollination, and seed dispersal (Sekercioglu 2012). However, the economic value of many of these services offered by birds to humans is yet to be quantified (Sekercioglu 2006; Wenny et al. 2011). Birds are the best known class of vertebrate animals that occur worldwide in nearly all habitats, and provide many services (Sekercioglu 2006; Whelan et al. 2008). Scavengers contribute regulating services, as efficient carcass consumption helps regulate human disease (Sekercioglu 2002). Bird watching is one of the most popular outdoor recreational activities in the United States and around the world. In the United States, in 2001, 45 million bird watchers spent $32 billion in retail stores, generating $85 billion in overall economic impact, and supporting over 860,000 jobs (La Rouch 2003; Sekercioglu 2002).

In Jamaica, West Indies, pest reduction by insectivorous birds on a coffee farm was estimated to be worth US$310 per hectare in a single harvest season (Johnson et al. 2010). Several studies indicate that birds can reduce overall arthropod numbers e.g. coffee berry borer (*Hypothenemus hampei*) in traditionally managed coffee farms (Greenberg et al. 2000; Borkhataria et al. 2006; Johnson et al. 2009; Wenny et al. 2011), directly benefiting coffee production and farm income (Kellermann et al. 2008; Johnson et al. 2010). The recent catastrophic decline of vultures in South Asia lead to carcasses remaining on the landscape for longer periods causing diseases to spread to humans and domestic livestock (Wenny et al. 2011). Human health costs attributable to this population crash in India alone were estimated at $34 billion over the years 1993-2006 (Markandyaa et al. 2008). Several sudden losses of such services (e.g., carrion scavenging in India, pest control in China when sparrows were locally exterminated, forest plant pollination in New Zealand) provide a sense of the scope of the negative consequences should such services be lost (Wenny et al. 2011). The challenge, however, is to calculate the value of ecosystem services in meaningful and relevant ways that can be used to justify the protection of ecosystem services in land use recommendations and policy decisions (Daily 2000; Daily et al. 2009). Therefore, loss of habitat of these birds will likely cascade to loss of these ecosystem services which may be of high economic value.

Excessive disturbance due to logging operations has been shown to reduce the total avian diversity and increase species rarity with adverse long term effects likely for forest species (Thiollay 1997) and ecosystem services they offer. In highly fragmented forest patches, birds can link ecosystem processes that are separated by great distances as they respond to irruptive resources more rapidly than other vertebrates (Whelan et al. 2008). Disturbance may lead to reduced species richness in an area, affecting its ecological stability (Frost et al. 1995; MacArthur 1995; Tillman 1996). Species richness drives ecosystem function (Garry et al. 1998) by increasing the numbers of ecological functions present (MacArthur 1995). However, a wide mix of species from different functional groups (Ewel et al. 1991; Frost et al. 1995) may significantly contribute to ecosystem stability by duplicating ecological flows in a diverse rainforest (Ewel et al. 1991). Therefore, resilience of ecological processes and the ecosystems they maintain depends upon the distribution of these functional groups within and across scales.

Habitat fragmentation may also cause isolation of suitable food patches or changes in landscape connectivity hampering food tracking behaviour and adversely affecting populations of both frugivores and their associated food plants (Lehouck et al. 2009). Disruption of fruit-frugivore interactions can therefore be expected to affect the persistence, colonization probability, and dynamics of fleshy fruit-bearing tree species at the population, meta-population and community level (Cain et al. 2000; Clark et al. 2007). Frugivore populations and communities, too, can be adversely affected when fruit-frugivore interactions become disrupted due to habitat fragmentation, since frugivores heavily rely on fruits as their prime energy source (Lehouck et al. 2009). A study in the Taita Hills by

Lehouck et al. (2009) indicated that some frugivores had lower densities and smaller temporal fluctuations in forest fragments surrounded by cultivation, an indication that habitat fragmentation could decrease frugivore mobility. There is need to minimize the influence of humans if natural ecosystems are to maintain ecological processes. This study investigates the effect of land use on the avifauna in Arabuko Sokoke Forest and neighbouring areas, which are under different land use activities.

1.5 General objective

To determine the effect of land use on the diversity and abundance of birds in a coastal forest environment in Kenya.

1.6 Specific objectives

i. To determine the composition of the avian community in Arabuko Sokoke Forest reserve and adjacent modified habitats.

ii. To assess the effect of land use type and vegetation structure on the diversity and abundance of birds, especially those providing ecosystem services.

1.7 Justification for the study

Tropical forests are deteriorating rapidly through deforestation and habitat fragmentation (e.g. Daily et al. 2001; Arriaga-Weiss et al. 2008; Laube et al. 2008). These two factors are important in conservation planning for both protected area management and conservation management outside protected areas (Muhamad *et al.* 2013), especially in Kenya where deforestation and habitat fragmentation are on the rise. This study aims to identify land use activities that influence the retention of forest birds at an internationally-recognised

Important Bird Area (IBA) (Fishpool & Evans 2001). Avian pollinators and frugivores, which are likely contributing to the maintenance of the Kenyan coastal forests include some threatened East African coast endemic species like the Amani Sunbird (*Anthreptes pallidigaster*). Identifying those local land use activities which pose threats to these feeding guilds and the overall bird community can highlight the role of local habitat conservation and contribute to effective land use management.

Forest degradation in Kenya has been attributed to a high increase in the human population (Kenya Wildlife Service 2013). The population density of Kilifi County, where Arabuko Sokoke Forest is located, rose from 47 to 60 people per km^2 between 1989 and 1997 (Newmark 2002; Gordon & Ayiemba 2003; Matiku et al. 2013) with the current density expected to be higher. The people immediately adjacent to the forest settled in the area over 100 years ago and the current average household size is more than 13, and 55% of the households consisting of multiple families (Gordon & Ayiemba 2003; Matiku et al. 2013). Today this population is mostly small-scale subsistence farmers with a mean farm size of 6.9 ha or 0.5 ha per capita (Kenya Wildlife Service 2013). However, the agricultural land here is generally poor, and crop yields are low. Therefore, the forest is highly valued by this community for a range of their livelihood needs, including fuelwood, poles, fruits, medicinal plants, bush meat and fodder. Much of the forest is now degraded, particularly through the removal of commercial timber species for carving and general construction (Kenya Wildlife Service 2013).

Other areas in Kenya also experience forest fragmentation e.g. Taita Hills were originally covered by continuous cloud forest vegetation, but have experienced major forests loss and fragmentation since 200 years ago, resulting in a reduction of the original forest cover by 70 - 98% (Beentje 1988; Myers et al. 2000). At a more local scale, forests in Kenya are being disturbed by firewood collection, cutting of undergrowth and selective logging (Lehouck et al. 2009). Overall, of the forest-dependent and nationally threatened species in Kenya's forests, about 50 % of the plants, 60 % of the birds and 65 % of the mammals are found in the coastal forests (Githitho 2004), which shows the national, regional and global importance of this region despite its reduced forest cover.

Therefore, this study seeks to explain the role of the Arabuko Sokoke Forest as a conservation area for birds and specifically those guilds that offer important ecosystem services. With increasing numbers of studies reporting taxon-specific responses to land uses within agricultural landscapes, understanding the nature of responses of bird groups to different land uses is a pressing issue for achieving their conservation within human-dominated landscapes. Thus, I have investigated the comparative assemblage and distribution of bird populations in the primary forest, neighbouring plantation forest and farmlands with a view to informing effective land use management for bird conservation.

1.8 Frugivore biology and plant interactions

Frugivores disperse some seeds driving the natural regeneration cycles of about 60–80% of all plant species, and few natural vegetation types could persist in their present state without animal-mediated seed dispersal (Jordano et al. 2011). These mutualisms involve reciprocal benefits, and many animal species depend on fleshy fruits or seeds as food resources, an interdependence driving co-evolutionary interactions between frugivores and associated plants in natural habitats (Jordano et al. 2011). A significant relationship has been shown to exist between the number of seeds in fecal samples of bird frugivores and the number of reproductive tropical trees (Figueroa-Esquivel et al. 2009). Their study confirmed that seeds defecated by frugivores had higher germination rates than seeds obtained directly from fruits, highlighting the significance of frugivorous birds in sustaining plant populations. The effectiveness of seed dispersal is defined by the relative contribution of frugivores to plant fitness. Schupp (1993) explained that frugivore effectiveness is dependent on the frequency of visits to the fruits, number of dispersed seeds and seed germination quality (seed germination after gut passage, seed fate in sites where they are deposited).

However, avian digestive traits vary markedly between species and even minor chemical differences in fruit pulp composition may have major effects on fruit preference (Levey & Del Rio 2001). Fruit preference and selection behaviour is dynamic and may vary often in complex ways (Denslow et al. 1986). Specialized frugivores feed on high quality fruits, rich in fats and proteins, which provide a full diet, whereas unspecialized or opportunist frugivores feed on less nutritious fruits, which provide mainly carbohydrates (Snow 1981). Fruits adapted for dispersal by specialized frugivores are typically very different. The seeds are usually large, sometimes very large in relation to the size of the fruit, as the parent plants are typically forest trees which need to produce seeds with ample food reserves if the seedlings are to have any chance of establishing themselves on the forest floor (Snow 1981). The two major families Lauraceae and Palmae are very poorly represented in Africa, with figs (*Ficus spp.*) the most important fruit trees in the region; consequently Africa is relatively poor in specialized frugivorous birds (Snow 1981; Snow & Texeira 2005).

1.9 Nectarivore biology and plant interactions

Many generalist nectar feeders may play a significant role in plant pollination (Brown et al. 2011; Ollerton et al. 2011; Rocca & Sazima 2008). In South Africa for some winter-flowering aloes, specialist nectar feeders like sunbirds are effectively nectar robbers while opportunistic nectar feeders such as weavers pollinate the plants (Craig 2014, Kuiper *et al.* 2015). Land use affects pollinator behaviour, visitation rate and consequently the number of pollen grains that are transferred. The quality of the surrounding habitat matrix, habitat size, density, and shape are likely factors that could influence pollinator behaviour (Smith-Ramirez & Armesto 2003).

Secondary metabolites in nectar could attract effective pollinators while deterring nectar robbers (Johnson *et al.* 2006). Deterrence of ineffective pollinators might be of benefit to plant reproductive success, but in addition unpalatable nectar could shorten visit time and encourage pollinators to move between plants (Kessler *et al.* 2008). Different pollinators have different tolerance limits for the metabolites influencing the ecological interactions of both generalist and specialist pollinators with associated plants (Lerch-Henning & Nicolson 2013). The behaviour of nectar foraging birds can also be affected by the quality and quantity of floral rewards, enhanced rewards increase visitation rate which is linked to seed set of some plant species (Burd 1995).

1.10 Arabuko Sokoke Forest as an Important Bird Area (IBA)

Arabuko Sokoke Forest is one of the key Important Bird Areas (IBAs) in Kenya. Sites are identified as IBAs using a set of internationally agreed criteria based on four categories (1) the presence of bird species of global conservation concern, (2) a significant component of restricted-range species; (3) a significant component of birds which are restricted to a single biome; (4) regularly holding a significant portion of the global population of migratory bird species, or congregatory water birds, seabirds, or terrestrial birds (Fishpool & Evans 2001). Arabuko Sokoke Forest as an IBA meets all the four criteria indicated. The forest is rich in rare fauna with substantial numbers of small and distinctive mammals being near endemic, and many endemic invertebrates. The concentration of rare species accounts for its status as the second most important forest for conservation of threatened bird species on the African mainland (Fishpool & Evans 2001). The study aims to answer basic ecological and conservation questions regarding habitat use by bird nectarivores, frugivores, insectivores and other guilds and how the local land use change affects the composition and distribution of overall bird community an that of the important guilds. This in turn will inform conservation management for birds in Arabuko Sokoke Forest and the surrounding land use systems.

CHAPTER TWO

2. STUDY AREAS AND METHODS

2.1 Study area

Arabuko Sokoke Forest is the largest surviving single block of previously extensive indigenous dry coastal tropical forest in Eastern Africa. It is situated in Coastal Kenya at, 3° 20’ S and 39° 50’ E, 7 km inland from Watamu between Kilifi and Malindi and 110 Km North of Mombasa (Figure 1).

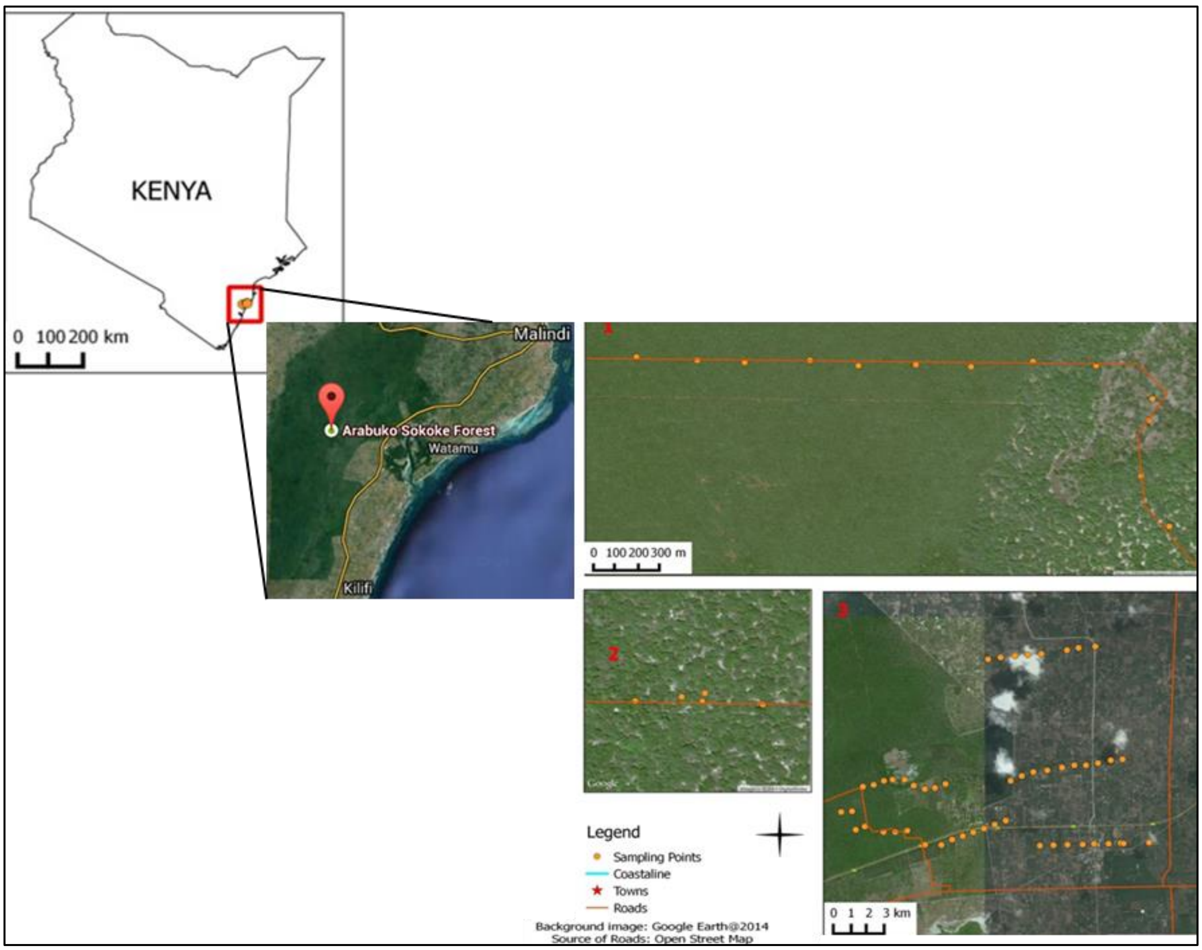


Figure 1: Map of the study area and location of sampling points along transects. Location of Arabuko Sokoke Forest between Kilifi and Malindi. Label 1 shows two adjoining transects and points located in *Cynometra* thicket and relatively open *Brachystegia* woodland, 2 shows a transect and sampling points in Mixed Forest and label 3 shows point counts along transects in planation forest and farmland. Farmland is characterized by low vegetation cover and a road and footpath network.

Arabuko Sokoke Forest was proclaimed a Crown Forest in 1932 and gazetted as a forest reserve in 1943 during the colonial period. It was gazetted as a strict nature reserve in the 1960s (Fishpool & Evans 2001), under the colonial government. Within the forest area about 4,300 ha was designated as a strict Nature Reserve in 1977. The total area of the forest is approximately 41,600 ha and the protected area was extended in 1979 by 1,635 ha (Kenya Wildlife Service 2013). Arabuko Sokoke Forest is surrounded on all sides by village communities. There is a total population of about 104,000 people around the forest, with 54 villages actually bordering on the forest (Kenya Wildlife Service 2013). Levels of unsustainable forest use have intensified, with increasing human populations resulting in higher levels of resource degradation; since traditional subsistence use of Arabuko Sokoke Forest predates its gazettement as a reserve. Human impact on the forest can be dated to 1900 when the Mijikenda people settled around the forest (Robinson & Bennett 2000; Githitho 2004). Deforestation of East African coastal forests was estimated at 139.17 Km^2 over a 7 year period between 2000 and 2007 (Birdlife International 2013). It estimated that 66% of the coastal forest in East Africa, including Tanzania was lost between 1990 and 2011 (Birdlife International 2013). There were no corresponding data for most of the other Kenyan coastal forests. However, indications are that large tracts of coastal forests continued to be lost through charcoal extraction and conversion to agriculture e.g. pineapple farming in Dakatcha Woodlands (Birdlife International 2013).

At present, most subsistence use is illegal, although in practice it cannot be controlled by regulation alone. Local households depend on the forest for domestic use through direct harvesting for fuel-wood, building poles, mushrooms and bush-meat; and commercial use through products such as carving wood, poles, butterflies and honey. Arabuko Sokoke Forest is rapidly gaining a reputation in ecotourism for tourists who have interest in birds. It has attracted tourists since the early 1970s, and currently specialist birdwatching tourists regularly visit the forest, and the number of such visits is increasing (Kenya Wildlife Service 2013).

More than 260 bird species have been recorded within the protected area (Jackson 2008), although this includes waterbirds which were effectively excluded from this study. The avifauna includes six globally threatened species: Clarke's Weaver (*Ploceus golandi*), Sokoke Scops Owl (*Otus ireneae*), Amani Sunbird (*Anthreptes pallidigaster*), East Coast Akalat (*Sheppardia gunningi*), Spotted Ground Thrush (*Zoothera guttata*) and Sokoke Pipit (*Anthus sokokensis*). While the forest is a protected area, the surrounding region has been subjected to intense land use change including plantations and subsistence agriculture. Arabuko Sokoke Forest is under the management of Kenya Forest Service and Kenya Wildlife Service. It consists of three distinct vegetation types; Mixed Forest, *Brachystegia* woodland and *Cynometra*.

Mixed Forest is relatively dense, tall and undifferentiated, with a high diversity of tree species (Plates 1 and 2). It has a diverse tree flora including *Afzelia quanzensis, Hymenaea verrucosa, Combretum schumannii* and *Manilkara sansibarensis* and the cycad *Encephalartos hildebrandtii.* It extends on the wetter coastal sands in the east of Arabuko-Sokoke to about 7,000 ha, forming 16.8% of the total forest cover. *Brachystegia* woodland runs in a strip through the approximate center of the forest, it is relatively open with relatively large trees and dominated by *Brachystegia spiciformis* (Plates 3 and 4). It covers about 7,700 ha on drier and infertile white sands through the centre of the forest and contributes 18.5% of the total forest cover. *Cynometra* thicket is dense, and almost impenetrable on red Magarini sand (Plate 5). It extends on the North-West side of the forest, covering about 23,500 ha. It forms a proportion of 56.5% of the whole forest cover. It is dominated by trees of *Cynometra webberi* and *Manilkara sulcata*, and the euphorbia species *Euphorbia candelabrum*. *Brachylaena huillensis* also used to be abundant in this zone, but its numbers have been severely reduced by extraction (Kenya Wildlife Service 2013; Arabuko Sokoke Forest Management Team 2002).

The plantation forest is under the management of Kenya Forest Service. Major portions of plantation forest consisted of trees for commercial timber including *Eucalyptus sp.* and *Casuarina sp.* (Plates 6 and 7). Wide gaps and open areas due to logging and clearing characterize the plantation forest. A small portion of the plantation area was still under indigenous tree cover. Farmlands are characterized by subsistence agriculture; bush clearing, burning, logging of trees, annual crops and few tree stands (Plate 8).

Plate 1: Mixed Forest vegetation on sand & clay

Plate 2: Dense vegetation cover in Mixed Forest forming complex strata.

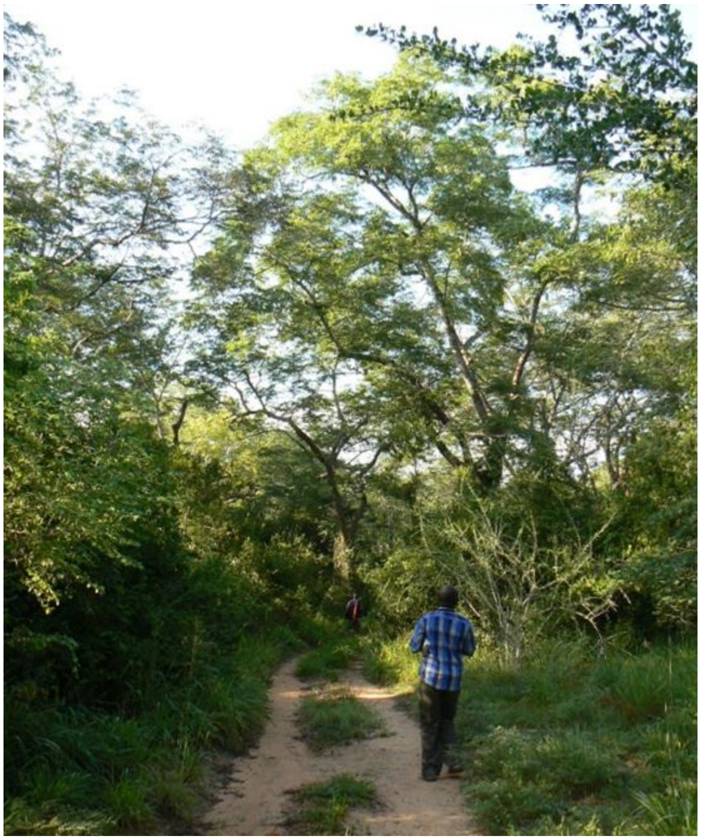


Plate 3: Open *Brachystegia* woodland on poor sandy soil

Plate 4: Large trees in *Brachystegia* vegetation

Plate 5: Impenetrable *Cynometr*a thicket on red sand

Plate 6: *Casuarina* plantation adjacent to the primary forest

Plate 7: *Eucalyptus* plantation adjacent to the primary forest

Plate 8: Clearing of indigenous vegetation in farmland for subsistence farming

2.2 Site layout and sampling

The surveys covered three land use systems: primary forest, plantation forest, and farmlands. I used point counts as described by Bibby et al. (2000) to survey birds. The point count method has some challenges including the risk of double counting, and the difficulty in detecting some species due to their behavior, particularly canopy species in the forest interior. There is also the possibility of birds moving into the area during the count, so that numbers are overestimated (Bibby et al. 2000; Buckland et al. 2001). In order to cope with such challenges, I did all the counts accompanied by experienced assistant (Willy Kombe) with long experience in bird surveys in Arabuko Sokoke Forest. Willy and I worked together in all repeat visits for the full period of field work. Repeat visits are the number of times each point was visited during the survey period. Competent and well trained observers reduce bird count variability (Bibby et al. 2000). Despite the limitations of point counts, the method is widely used by many ornithologists and conservation managers with over 95 % reported as using this method by preference (Rosenstock et al. 2002). I made the following assumptions; 1 Birds at the point are detected with certainty before any evasive movement, 2 there was no double count and 3 calling distance was estimated correctly as prescribed by Rosenstock et al. (2002). I recorded the coordinates of point count sites on each route using a Garmin 20 GPS.

Three transects per land use type were set up according to habitat heterogeneity in farmland and plantation forest and vegetation type in the primary forest. Points were spaced 100 m apart along each transect in an alternating manner on either side of each transect. The points were located 30m off the transect line to enhance site coverage and to minimize edge effects particularly in the case of primary forest. Bird counts lasted for 20 minutes at each point in all the three land use systems. Points within primary forest were distributed equally in the three vegetation types (Mixed Forest, *Brachystegia* woodland and *Cynometra*), 9 points in each vegetation type. There were no replication plots in this study apart from the three transects in every land use type. I used a longer time period to increase the likelihood of recording inconspicuous species in the dense vegetation as suggested by (Lee & Marsden 2008). All birds seen or heard within a 50 m radius were recorded; their distances from the center of the point count and the perching heights were estimated. The radius was selected based on the Effective Detection Radius (EDR) that has been used in many surveys comparing forest and farmland birds in Kenya (e.g. Lehouck et al. 2009; Mulwa et al. 2013). Birds seen or heard beyond this radius were ignored and did not form part of our data. It is assumed that the area of a circle with the radius of EDR was equivalent to the area where all birds have been censused (Meadows et al. 2012). Birds detected only in flight were also excluded from the data and did not form part of the analysis. I conducted surveys on days without persistent or heavy rain from 0630 - 1100 when birds were most active.

The direction of travel through counts was rotated to minimize any potential bias from the time of day. Transects followed established footpaths and forest tracks and where possible at least nine points were located along each transect to standardize survey effort. In total 99 point counts were surveyed in the three land use systems; farmland (FM), n = 39, Primary forest (PF), n = 27, Plantation (PL), n = 33. Each point count was surveyed once on each monthly visit during the whole survey period from May 2012 to September 2013, and in May 2015. However, data were analyzed from an equal number of points (n=27) chosen randomly from farmland and plantation forest to avoid any bias due to unequal sampling efforts. The initial plan was to survey equal numbers of points in the three land use systems; however, 6 points were lost in plantation forest and 11 in primary forest due to technical error with GPS records and could not be traced in subsequent visits and were therefore excluded from the survey. All the points in farmland could be traced in all visits due to its openness.

Points to be surveyed on each day were selected randomly; codes representing points in the field were randomized in excel spread sheet where at most 12 points were randomly picked. Codes representing points that had been surveyed were removed from the remaining pool to avoid choosing them again. The process was repeated every evening before the next day of survey until all points were surveyed in every month of the field visits. Points for each land use type were surveyed on alternate days; therefore, points for each land use category were randomized separately. This limited movement to short distances between points in one land use in each morning of survey. This removed any bias in point selection and avoided long distance movements between points that could arise from visiting points in different land use types in each morning of field visit.

All birds at each point count were identified, and then later grouped into different feeding guilds. Guilds were based on the diet information provided for these species in (Keith et al. 1992; Urban et al. 1997; Del Hoyo et al. 2009; Del Hoyo et al. 2010). Vertical perching height of birds detected by both calls and sight was estimated within the limits of 0-3 m, 3-12 m, and > 12 m. The total number of individual birds seen and heard at each point count was considered to be the count of individuals at each visit. Individual counts from each point were pooled per land use type to obtain the total counts of each species. The abundance of each species in the area surveyed for each land use type was calculated according to (Buckland et al. 2008). The overall bird community and all the guilds of interest (frugivores, nectarivores, insectivores, granivores and carnivores) were analyzed in relation to land use type (primary forest, plantation forest and farmland) and determined the effect of habitat factors on each guild.

To obtain data on habitat structure, I did habitat assessment around each point by quantifying vegetation structure and other habitat variables including vertical vegetation heterogeneity, number of large trees, number of keystone plant species (specifically figs), and nearness of each point to settlement and forest and number of fruiting trees. To determine vertical vegetation heterogeneity within each point, plant cover at each point was estimated to the nearest 5% at heights of 0, 1, 2, 4, 8 and 16 m (Laube et al. 2008). Vertical vegetation heterogeneity was then defined as the diversity of vegetation layers using the Shannon–Wiener diversity index (Bibby et al. 2000; Laube et al. 2008).

2.3 Data analysis

Species richness was calculated as the cumulative number of species recorded in each point count. ANOVA and Tukey HSD post hoc tests were used to test for differences in bird diversity and abundance among the land use systems. Species diversity at each point count was calculated based on the Shannon diversity index (*H*) (Hill 1973)

$$H = -\sum_{i=1}^{S} p_i log_b p_i$$

I estimated Renyi diversity profiles for each land use to compare bird diversities among the land use systems. Renyi profiles are used to visually compare diversities; land use type with its diversity profile higher than others from start at (alpha=0) to the end (alpha=Inf.) is considered to be more diverse (Kindt & Coe 2005). I analyzed the difference in diversities among the categories of land use systems using beta diversity measured as the average steepness (z) of the species area curve (Anderson et al. 2006). I performed non-metric multidimensional scaling (NMDS) for two dimensional representation of similarity between point counts and for multivariate community analysis to depict how bird community composition varies across different land use systems.

I estimated bird abundance of each bird species encountered in each land use by multiplying bird density by the area of each land use surveyed (Buckland et al. 2008);

$$\hat{N} = A\hat{D}$$

Where, $\hat{N}$ = bird abundance, A= total area of land use surveyed and $\hat{D}$ = species density. Species density $\hat{D}$ was estimated by:

$$\hat{D} = \frac{n}{a} = \frac{n}{k\pi\omega^2}$$

Where, k=total number of points in each land use surveyed, n= number of birds (for each species of interest) counted summed across all points and ω = the fixed radius of the point, and $k\pi\omega^2$= the total area of the surveyed points, termed the ‘covered area’.

I used General Linear Mixed Models (GLMM) to test the mixed effect of habitat factors on richness of birds based on Akaike's Information Criterion (AIC), the model with the lowest AIC value is considered to be the best (Laube et al. 2008; Kindt & Coe 2005). This approach has recently received increasing attention as a useful tool for model selection in ecology (Laube et al. 2008). I did the analysis first for the whole bird community and subsequently for each of the guilds (frugivores, nectarivores, insectivores, carnivores and granivores). All statistical analysis was done with R statistical software (R Development Core Team 2011).

CHAPTER THREE

3. RESULTS

3.1 Species composition

Overall I recorded a total of 97 bird species at 99 points, over the whole survey period. There were 11 regular frugivore species and 14 occasional frugivores, for a total of 25 fruit-eating birds and 5 specialist nectarivores with 12 other occasional nectar feeders, while 60 species belonged exclusively to other feeding guilds (Table 1). The survey covered 4.8 km^2 in primary forest, 5.4 km^2 in plantation forest and 6.4 km^2 in farmland. A Jacknife procedure estimated the expected bird species richness for the area covered by the counts to be 114.82. Thus, the number of species I obtained was close to the expected, suggesting that the counts had sampled the whole bird community.

To be able to compare species richness and diversity among the land use types (primary forest, plantation forest and farmland) without bias due to different sampling efforts, I did an analysis on data from 81 points, 27 chosen at random from each land use type. All the figures and tables resulting from the analysis are based on these 81 points, where a total of 93 species was recorded. Most species (69) were recorded in primary forest, 65 species in plantation forest and 58 species in farmlands (Figure 2).

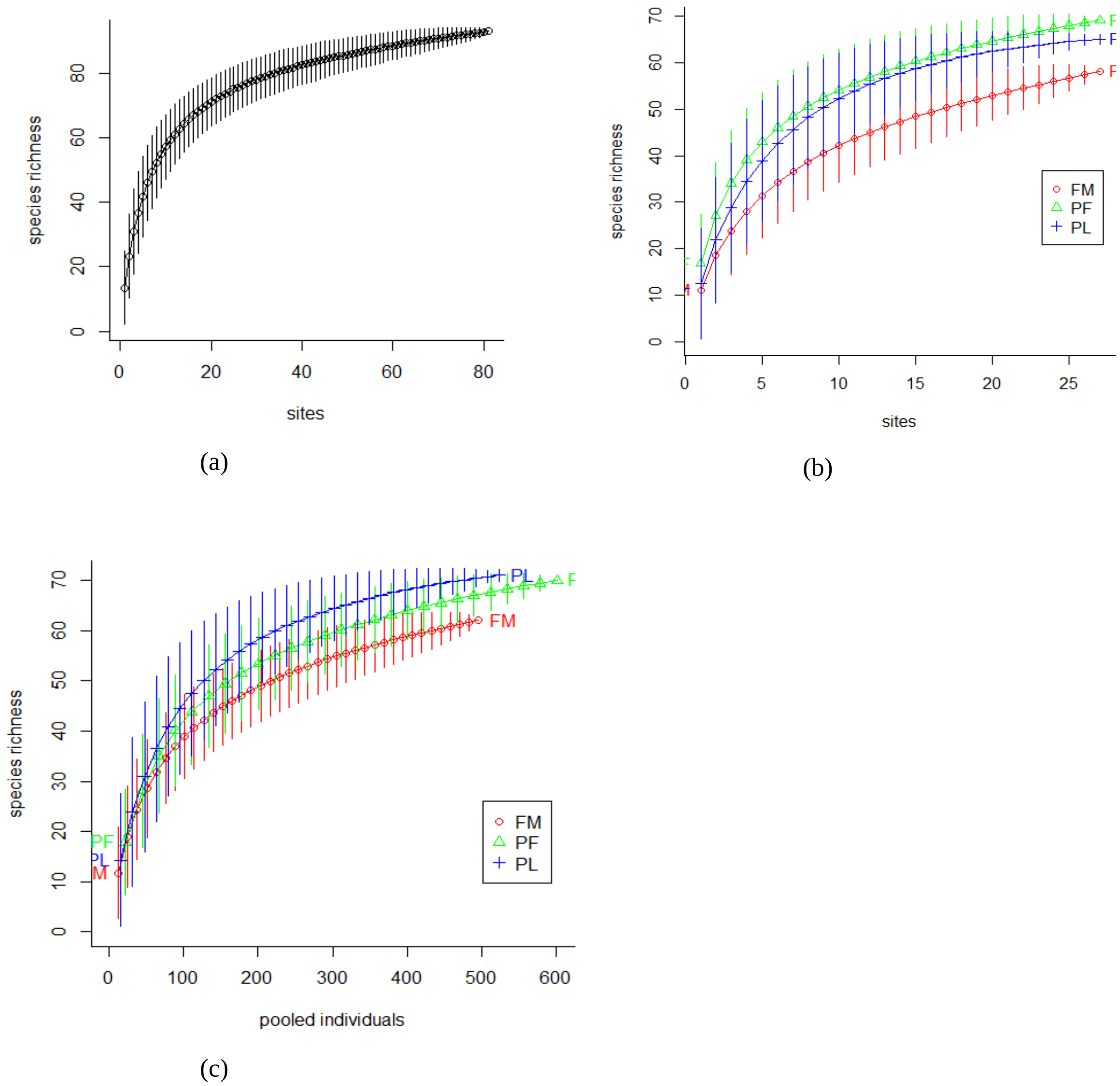


Figure 2: Accumulation curves of the total number of bird species recorded from 81 points, 27 each from primary forest, plantation forest and farmland for the bird survey in Arabuko Sokoke Forest and surrounding farmlands in coastal Kenya from May 2012 – September 2013. (**a**) Accumulation curve of the overall bird community in 81 points within 4.8 km^2 in primary forest, 5.4 km^2 in plantation forest and 6.4 km^2 in farmland, (**b**) Species accumulation curves for each land use type. (**c**) Species accumulation curves plotted against pooled number of bird individuals observed per land use type. PF = primary forest, FM = farmland, PL = Plantation forest. Species accumulation curve appeared to reach the asymptote.

Some species were forest dependent and were only recorded in the primary forest, including Kenya Crested Guineafowl (*Guttera pucherani pucherani*), Black Cuckoo-shrike

(*Campephaga flava*), African Pygmy Kingfisher, Plain-backed Sunbird (*Anthreptes reichenowi*), Sokoke Pipit (*Anthus sokokensis*), Pale Batis (*Batis soror*), Blue-mantled Crested-flycatcher (*Trochocercus cyanomelas*), Clarke's Weaver (*Ploceus golandi*), East Coast Akalat (*Sheppardia gunningi*), Tiny Greenbul (*Phyllastrephus debilis*) , Slate-coloured Bobou (*Laniarius funebris*) and Thick-billed Cuckoo (*Pachycoccyx audeberti*). Three of the forest dependent species recorded namely Clarke's Weaver, Sokoke Pipit and East Coast Akalat are red listed (IUCN 2014). However, the Collared Sunbird (*Hedydipna collaris*), Tropical Boubou (*Laniarius aethiopicus*) and Common Bulbul (*Pycnonotus barbatus*) were well distributed across the three land use systems. Many frugivores were occasional nectar feeders, while some primary granivores and insectivores were occasional fruit or nectar feeders (Table 1).

Table 2: Bird species recorded in Arabuko Sokoke forest and neighbouring land use types. Species recorded between May 2012 – September 2013. Guild assignment according to diet information in standard handbooks. Land use key: FM=Farmland, PL=Plantation forest, PF=Primary forest. Guild key: FR=Frugivore, NT=Nectarivore, INS=Insectivore, CN= Carnivore, GR=Granivore, OM=Omnivore, n=total abundance.

Guild Category	Common Name	Scientific Name	Guild Symbol	Fruit	Nectar	n	FM	PL	PF
	Great Sparrowhawk	*Accipiter melanoleucus*	CN			2	0	2	0
Carnivore	African Goshawk	*Accipiter tachiro*	CN			8	1	5	2
	Black-headed Heron	*Ardea melanocephala*	CN			1	1	0	0
	Hadeda Ibis	*Bostrychia hagedash*	CN			3	3	0	0
	White-browed Coucal	*Centropus superciliosus*	CN			27	15	9	3
	Southern Banded Snake-Eagle	*Circaetus fasciolatus*	CN			5	0	2	3
	African Fish Eagle	*Haliaeetus vocifer*	CN			4	4	0	0
	Lizard Buzzard	*Kaupifalco monogrammicus*	CN			28	16	9	3
	Black Kite	*Milvus migrans*	CN			7	4	3	0
	Sacred Ibis	*Threskiornis aethiopicus*	CN			2	1	1	0
Frugivore	Trumpeter Hornbill	*Ceratogymna bucinator*	FR	Regular		35	12	15	8
	Speckled Mousebird	*Colius striatus*	FR	Regular	Occasional	13	11	2	0
	Fischer's Turaco	*Tauraco fischeri*	FR	Regular		18	3	12	3
	Green Pigeon	*Treron australis*	FR	Regular		21	16	5	0
Frugivore-Insectivore	Zanzibar Sombre Greenbul	*Andropadus importunus*	FR, INS	Regular	Occasional	111	68	30	13
	Yellow-rumped Tinkerbird	*Pogoniulus bilineatus*	FR, INS	Regular	Occasional	18	5	9	4
	Eastern Green Tinkerbird	*Pogoniulus simplex*	FR, INS	Regular		13	0	4	9
	Common Bulbul	*Pycnonotus barbatus*	FR, INS	Regular	Occasional	101	76	22	3
	Green Barbet	*Stactolaema olivacea*	FR, INS	Regular		77	24	42	11
	Crowned Hornbill	*Tockus alboterminatus*	FR, INS	Regular		2	0	2	0
	Black-bellied Starling	*Lamprotornis corruscus*	FR,INS	Regular	Occasional	91	19	34	38
Granivore	Grey-headed Sparrow	*Passer griseus*	GR			4	0	3	1
	Yellow-fronted Canary	*Serinus mozambicus*	GR		Occasional	58	35	23	0
	Ring-necked Dove	*Streptopelia capicola*	GR	Occasional		18	14	4	0
	Red-eyed Dove	*Streptopelia semitorquata*	GR	Occasional		18	12	6	0
	Emerald-spotted Wood-dove	*Turtur chalcospilos*	GR	Occasional		42	21	11	10
	Tambourine Dove	*Turtur tympanistria*	GR	Occasional		21	4	9	8
Granivore-Insectivore	Common Waxbill	*Estrilda astrild*	GR, INS			2	0	2	0
	Crested Francolin	*Francolinus sephaena*	GR, INS			1	1	0	0

	Kenya Crested Guineafowl	*Guttera pucherani*	GR, INS	Occasional		10	0	0	10
	Red-billed Firefinch	*Lagonosticta senegala*	GR, INS			1	1	0	0
	Bronze Mannikin	*Lonchura cucullata*	GR, INS			72	46	19	7
	Helmeted Guineafowl	*Numida meleagris*	GR, INS			1	1	0	0
	Black-headed Weaver	*Ploceus cucullatus*	GR, INS		Occasional	25	18	2	5
	Red-cheeked Cordon-bleu	*Uraeginthus bengalus*	GR, INS			12	12	0	0
	Peters's Twinspot	*Hypargos niveoguttatus*	GR, INS			10	0	9	1
Insectivore	Sokoke Pipit	*Anthus sokokensis*	INS			10	0	0	10
	Black-headed Apalis	*Apalis melanocephala*	INS			91	2	9	80
	Narina Trogon	*Apaloderma narina*	INS			9	0	3	6
	Forest Batis	*Batis mixta*	INS			19	2	0	17
	Pale Batis	*Batis soror*	INS			25	0	0	25
	Green-backed Camaroptera	*Camaroptera brachyura*	INS			2	0	1	1
	Grey-backed Camaroptera	*Camaroptera brevicaudata*	INS			69	12	21	36
	Black Cuckoo-shrike	*Campephaga flava*	INS			8	1	3	4
	Mombasa Woodpecker	*Campethera mombassica*	INS			22	3	10	9
	Eastern Bearded Scrub-Robin	*Cercotrichas quadrivirgata*	INS			19	0	5	14
	Yellowbill	*Ceuthmochares aereus*	INS	Occasional		15	4	9	2
	Klaas's Cuckoo	*Chrysococcyx klaas*	INS			1	0	0	1
	White-browed Robin-Chat	*Cossypha heuglini*	INS			34	7	18	9
	Red-capped Robin-Chat	*Cossypha natalensis*	INS	Occasional		47	8	23	16
	African Palm Swift	*Cypsiurus parvus*	INS			13	5	2	6
	Fork-tailed Drongo	*Dicrurus adsimilis*	INS		Occasional	79	44	23	12
	Black-backed Puffback	*Dryoscopus cubla*	INS	Occasional		50	23	8	19
	Little Yellow Flycatcher	*Erythrocercus holochlorus*	INS			56	0	22	34
	Grey-headed Kingfisher	*Halcyon leucocephala*	INS			1	1	0	0
	Mangrove Kingfisher	*Halcyon senegaloides*	INS			7	2	3	2
	Lesser Striped Swallow	*Hirundo abyssinica*	INS			6	0	6	0
	Pallid Honeyguide	*Indicator meliphilus*	INS			12	0	11	1
	Lesser Honeyguide	*Indicator minor*	INS			6	0	6	0
	Scaly-throated Honeyguide	*Indicator variegatus*	INS	Occasional		10	0	8	2
	African Pygmy Kingfisher	*Ispidina lecontei*	INS			1	0	0	1
	Tropical Boubou	*Laniarius aethiopicus*	INS			78	30	13	35
	Slate-coloured Boubou	*Laniarius funebris*	INS			1	0	0	1
	Four-coloured Bush-shrike	*Malaconotus quadricolor*	INS			21	0	0	21
	White-throated Bee-eater	*Merops albicollis*	INS			7	0	5	2
	Northern Carmine Bee-eater	*Merops nubicus*	INS			2	2	0	0
	African Pied Wagtail	*Motacilla aguimp*	INS			9	8	1	0
	Ashy Flycatcher	*Muscicapa caerulescens*	INS			4	2	0	2
	Red-tailed Ant-Thrush	*Neocossyphus rufus*	INS			17	0	4	13
	Eastern Nicator	*Nicator gularis*	INS			36	3	11	22
	African Golden Oriole	*Oriolus auratus*	INS	Occasional		25	10	15	0
	Black-headed Oriole	*Oriolus larvatus*	INS	Occasional	Occasional	47	12	23	12
	Eurasian Golden Oriole	*Oriolus oriolus*	INS	Occasional		1	1	0	0
	Thick-billed Cuckoo	*Pachycoccyx audeberti*	INS			27	27	0	0
	Green Wood-hoopoe	*Phoeniculus purpureus*	INS		Occasional	4	0	3	1
	Tiny Greenbul	*Phyllastrephus debilis*	INS			23	0	0	23
	Fischer's Greenbul	*Phyllastrephus fischeri*	INS	Occasional		56	0	2	54
	Northern Brownbul	*Phyllastrephus strepitans*	INS			46	6	28	12
	Terrestrial Brownbul	*Phyllastrephus terrestris*	INS			18	0	5	13
	Dark-backed Weaver	*Ploceus bicolor*	INS		Occasional	33	2	8	23
	Clarke's Weaver	*Ploceus golandi*	INS	Occasional		4	0	0	4
	Tawny-flanked Prinia	*Prinia subflava*	INS			60	51	9	0
	Retz's Helmet-shrike	*Prionops retzii*	INS			19	0	15	4
	Chestnut-fronted Helmet-shrike	*Prionops scopifrons*	INS			94	0	19	75
	Common Scimitarbill	*Rhinopomastus cyanomelas*	INS		Occasional	10	1	4	5
	East Coast Akalat	*Sheppardia gunningi*	INS			11	0	0	11
	Black-crowned Tchagra	*Tchagra australis*	INS			25	18	2	5
	African Paradise-flycatcher	*Terpsiphone viridis*	INS			13	3	7	3
	Blue-mantled Crested-flycatcher	*Trochocercus cyanomelas*	INS			17	0	0	17
	Scaly Babbler	*Turdoides squamulutus*	INS			79	31	48	0
Nectarivore	Amani Sunbird	*Anthreptes pallidigaster*	NT		Regular	26	0	4	22
	Plain-backed Sunbird	*Anthreptes reichenowi*	NT		Regular	11	0	1	10
Nectarivore-Insectivore	Collared Sunbird	*Hedydipna collaris*	NT, INS		Regular	155	41	53	61
	Olive Sunbird	*Nectarinia olivacea*	NT, INS		Regular	114	21	32	61
	Amethyst Sunbird	*Nectarinia amethystina*	NT, INS		Regular	1	1	0	0
Omnivore	Pied Crow	*Corvus albus*	OM			8	8	0	0
	House Crow	*Corvus splendens*	OM			7	7	0	0

3.2 Effect of land use on species richness

Primary forest registered the highest number of bird species detected followed by plantation forest then farmlands (Figure 3).

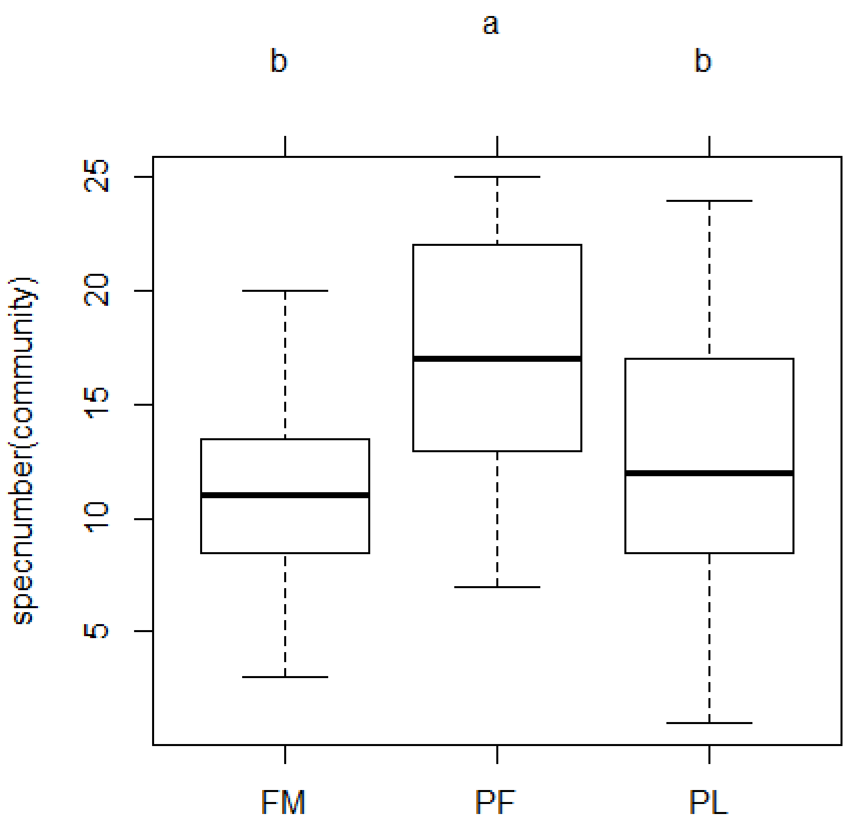


Figure 3: Box plots of mean avifauna richness per point compared between three land use types. PF = primary forest, FM = farmland, PL = Plantation forest. Land use types indicated with similar letters are not statistically different in bird species richness, while that with a different letter is significantly different. The box plots for each land use indicate the Mean ±SE.

There was a highly significant difference between primary forest and farmland, Tukey test ($P < 0.001$), a significant difference between primary forest and farmland ($P<0.05$) but no significant difference between plantation and farmland ($P>0.05$) (Table 3).

Table 3: Tukey HSD test for pairwise comparison of mean bird species richness between primary forest, plantation forest and farmland. PF = primary forest, FM = farmland, PL = Plantation forest. Significant difference at 95% confidence interval (*P*=0.05).

	Estimate difference	Std. Error	t value	P value
PF - FM	5.704	1.439	3.963	< 0.001 ***
PL - FM	1.444	1.439	1.004	0.577
PL - PF	-4.259	1.439	-2.959	0.011 *

Different vegetation types within the primary forest (*Brachystegia*, *Cynometra* and Mixed Forest) showed significant differences in bird species composition, ANOVA ($F_{2, 24}$ = 14.13, P < 0.001, n=27), with *Cynometra* vegetation having significantly lower species numbers than the other two (Figure 4).

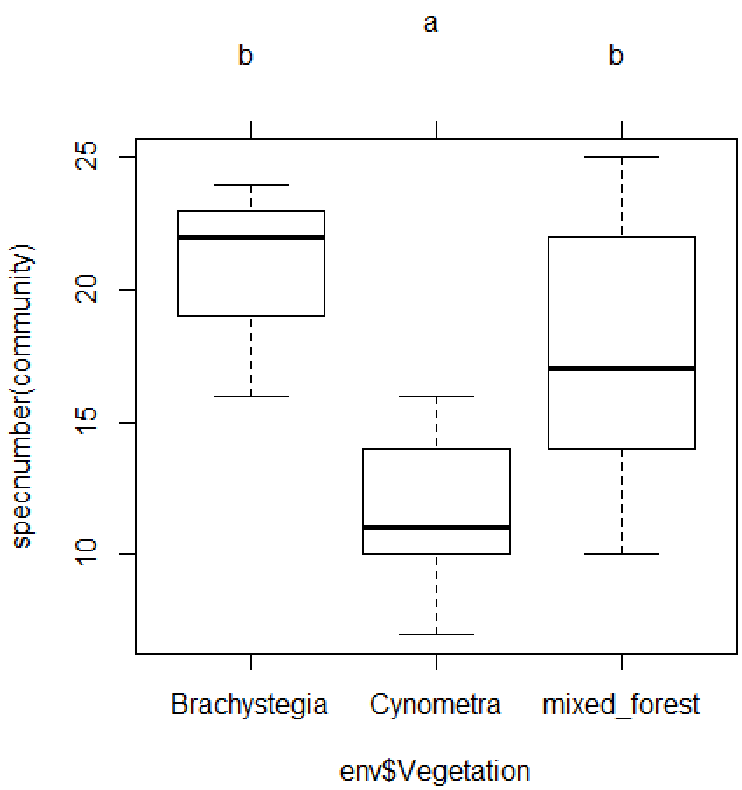


Figure 4: Box plots of mean bird species richness compared between three vegetation types (*Brachystegia*, *Cynometra* and Mixed Forest) in primary forest. Vegetation types marked by similar letters show no significant difference in number of species, while that marked with a different letter is significantly different. The box plots indicate the Mean ±SE.

Multiple comparison of mean species composition using Tukey HSD revealed a highly significant effect of *Cynometra* vegetation, with a highly significant difference between *Cynometra* and *Brachystegia* (P < 0.001) and no difference between Mixed Forest and *Brachystegia* woodland (P>0.05) (Table 4).

Table 4: Tukey HSD result for pairwise comparison of mean bird species richness between *Cynometra*, *Brachystegia* and Mixed Forest vegetation types in Arabuko Sokoke Forest.

	Estimate difference	Std. Error	t value	P value
Cynometra - Brachystegia	-9.222	1.765	-5.225	< 0.001
Mixed Forest - Brachystegia	-3.111	1.765	-1.763	0.20343
Mixed Forest - Cynometra	6.111	1.765	3.462	0.005 **

3.3 Effect of land use on avian diversity

The highest species diversity (H) was recorded in primary forest (H = 2.75) and the lowest in farmland (H = 2.30). Plantation had an intermediate diversity (H = 2.48). Avian diversity was significantly different among the three land use categories, ANOVA ($F_{2, 78}$ = 5.04, P = 0.009, n=81), with the difference caused by primary forest (Figure 5).

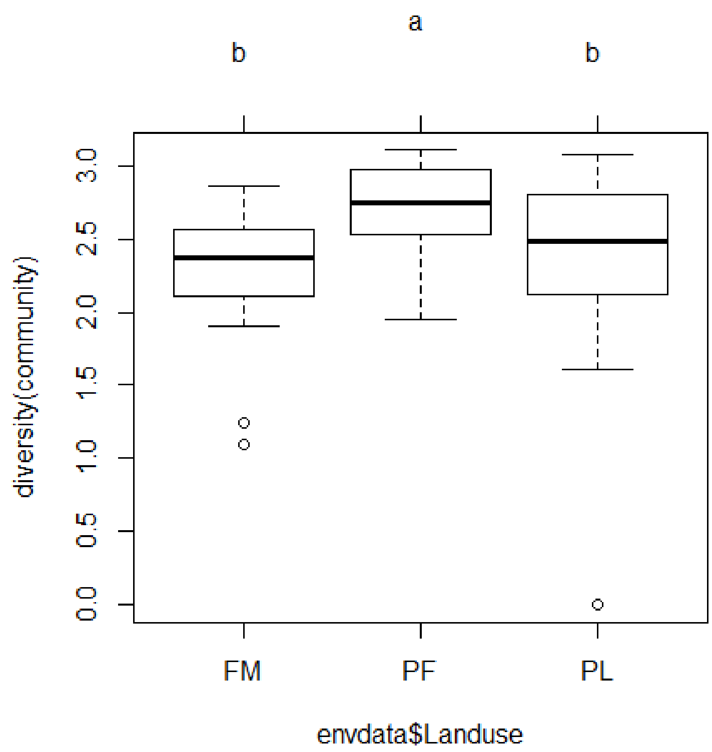


Figure 5: Box plots of mean Shannon diversities in farmland, primary forest and plantation forest. PF = primary forest, FM = farmland, PL = Plantation forest. Land use types marked by similar letters are not significantly different in mean Shannon diversity (H) while that marked with a different letter is**.** The box plots for each land use indicate the Mean ±SE.

Tukey test revealed significant difference between two pairs, primary forest and farmland and primary forest and plantation forest (P < 0.05) (Table 5).

Table 5: Tukey HSD test for pairwise comparison of mean diversity (H) between land use types. PF = primary forest, FM = farmland, PL = Plantation forest. Significant difference at 95% confidence interval (*P*=0.05). Significant difference between two pairs, PF-FM and PL-PF.

Estimate	Std. Error	t value	P value	
PF - FM	0.43403	0.15218	2.852	0.015 *
PL - FM	0.03361	0.15218	0.221	0.974
PL - PF	-0.40043	0.15218	-2.631	0.027 *

Analysis of Beta diversity (z) confirmed a higher diversity in primary forest, indicated by the shortest average distance to the median at 0.48, then farmland at 0.53. Plantation forest had the longest calculated average distance to the median at 0.56, indicating the lowest Beta diversity (z) (Figure 6).

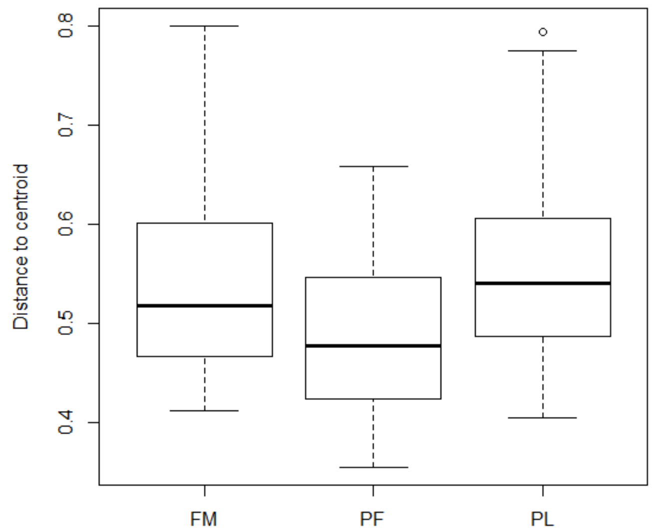


Figure 6: Box plots of Beta diversity measured as an average steepness (z) of the species area curve for separate land use systems. PF = primary forest, FM = farmland, PL = Plantation forest. The shortest mean distance to the centroid shows high diversity. The box plots for each land use indicate the Mean ±SE.

3.4 Effect of land use on avian species abundance

Some birds occurred in high abundance across the three land use types including Collared Sunbird, Olive Sunbird, Red-capped Robin-Chat (*Cossypha natalensis*), Black-bellied Starling (*Lamprotornis corruscus*), Green Barbet (*Stactolaema olivacea*), Tropical Boubou (*Laniarius aethiopicus*) , and Grey-backed Camaroptera (*Camaroptera brevicaudata*) among others. Some species were more abundant in farmland and plantation forest including the Zanzibar Sombre Greenbul (*Andropadus importunus*), Yellow-fronted Canary (*Serinus mozambicus*), Bronze Mannikin (*Lonchura cucullata*), Fork-tailed Drongo (*Dicrurus adsimilis*). Ashy Flycatcher (*Muscicapa caerulescens*), Northern Carmine Bee-eater (*Merops nubicus*), Grey-headed Kingfisher (*Halcyon leucocephala*), Green-backed Camaroptera

(*Camaroptera brachyuran*) and Red-billed Firefinch (*Lagonosticta senegala*) were recorded infrequently. Fischer's Greenbul (*Phyllastrephus fischeri*), Four-coloured Bush-shrike (*Malaconotus quadricolor*), Dark-backed Weaver (*Ploceus bicolor*), Amani Sunbird (*Anthreptes pallidigaster*) and Chestnut-fronted Helmet-shrike (*Prionops scopifrons*) were common in the primary forest and scarce in plantation and farmland; they seemed to be restricted to primary forest. Lesser Striped Swallow (*Hirundo abyssinica*), Pallid Honeyguide (*Indicator meliphilus*), Lesser Honeyguide (*Indicator minor*), Scaly-throated Honeyguide (*Indicator variegatus*) and African Pygmy Kingfisher (*Ispidina lecontei*) are among the species that were more common in the plantation (Table 6).

Table 6: Distribution of bird species by density and abundance in farmland, plantation and primary forest in Arabuko Sokoke Forest and neighboring land use types. n= total count of individual species, $\hat{D}$ =species density, $\hat{N}$ =species abundance. Area surveyed in farmland =6.4 km^2, plantation =5.4 km^2 and primary forest = 4.8 km^2.

Guild Category	Common Name	Scientific Name	Farmland			Plantation			Primary forest		
			n	$\hat{D}$	$\hat{N}$	n	$\hat{D}$	$\hat{N}$	n	$\hat{D}$	$\hat{N}$
Carnivore	Great Sparrowhawk	*Accipiter melanoleucus*	0	0.00	0.00	2	9.44	50.96	0	0.00	0.00
	African Goshawk	*Accipiter tachiro*	1	4.72	30.20	5	23.59	127.39	2	9.44	45.29
	Black-headed Heron	*Ardea melanocephala*	1	4.72	30.20	0	0.00	0.00	0	0.00	0.00
	Hadeda Ibis	*Bostrychia hagedash*	3	14.15	90.59	0	0.00	0.00	0	0.00	0.00
	White-browed Coucal	*Centropus superciliosus*	15	70.77	452.94	9	42.46	229.30	3	14.15	67.94
	Southern Banded Snake-Eagle	*Circaetus fasciolatus*	0	0.00	0.00	2	9.44	50.96	3	14.15	67.94
	African Fish Eagle	*Haliaeetus vocifer*	4	18.87	120.78	0	0.00	0.00	0	0.00	0.00
	Lizard Buzzard	*Kaupifalco monogrammicus*	16	75.49	483.13	9	42.46	229.30	3	14.15	67.94
	Black Kite	*Milvus migrans*	4	18.87	120.78	3	14.15	76.43	0	0.00	0.00
	Sacred Ibis	*Threskiornis aethiopicus*	1	4.72	30.20	1	4.72	25.48	0	0.00	0.00
Frugivore	Trumpeter Hornbill	*Ceratogymna bucinator*	12	56.62	362.35	15	70.77	382.17	8	37.74	181.17
	Speckled Mousebird	*Colius striatus*	11	51.90	332.15	2	9.44	50.96	0	0.00	0.00
	Fischer's Turaco	*Tauraco fischeri*	3	14.15	90.59	12	56.62	305.73	3	14.15	67.94
	Green Pigeon	*Treron australis*	16	75.49	483.13	5	23.59	127.39	0	0.00	0.00
Frugivore-Insectivore	Zanzibar Sombre Greenbul	*Andropadus importunus*	68	320.83	2053.31	30	141.54	764.33	13	61.34	294.41
	Yellow-rumped Tinkerbird	*Pogoniulus bilineatus*	5	23.59	150.98	9	42.46	229.30	4	18.87	90.59
	Eastern Green Tinkerbird	*Pogoniulus simplex*	0	0.00	0.00	4	18.87	101.91	9	42.46	203.82
	Common Bulbul	*Pycnonotus barbatus*	76	358.58	2294.88	22	103.80	560.51	3	14.15	67.94
	Green Barbet	*Stactolaema olivacea*	24	113.23	724.70	42	198.16	1070.06	11	51.90	249.12
	Crowned Hornbill	*Tockus alboterminatus*	0	0.00	0.00	2	9.44	50.96	0	0.00	0.00
	Black-bellied Starling	*Lamprotornis corruscus*	19	89.64	573.72	34	160.42	866.24	38	179.29	860.58
Granivore	Grey-headed Sparrow	*Passer griseus*	0	0.00	0.00	3	14.15	76.43	1	4.72	22.65
	Yellow-fronted Canary	*Serinus mozambicus*	35	165.13	1056.85	23	108.52	585.99	0	0.00	0.00
	Ring-necked Dove	*Streptopelia capicola*	14	66.05	422.74	4	18.87	101.91	0	0.00	0.00
	Red-eyed Dove	*Streptopelia semitorquata*	12	56.62	362.35	6	28.31	152.87	0	0.00	0.00
	Emerald-spotted Wood-dove	*Turtur chalcospilos*	21	99.08	634.11	11	51.90	280.25	10	47.18	226.47
	Tambourine Dove	*Turtur tympanistria*	4	18.87	120.78	9	42.46	229.30	8	37.74	181.17
Granivore-Insectivore	Common Waxbill	*Estrilda astrild*	0	0.00	0.00	2	9.44	50.96	0	0.00	0.00
	Crested Francolin	*Francolinus sephaena*	1	4.72	30.20	0	0.00	0.00	0	0.00	0.00
	Kenya Crested Guineafowl	*Guttera pucherani*	0	0.00	0.00	0	0.00	0.00	10	47.18	226.47
	Red-billed Firefinch	*Lagonosticta senegala*	1	4.72	30.20	0	0.00	0.00	0	0.00	0.00
	Bronze Mannikin	*Lonchura cucullata*	46	217.03	1389.01	19	89.64	484.08	7	33.03	158.53
	Helmeted Guineafowl	*Numida meleagris*	1	4.72	30.20	0	0.00	0.00	0	0.00	0.00
	Black-headed Weaver	*Ploceus cucullatus*	18	84.93	543.52	2	9.44	50.96	5	23.59	113.23
	Red-cheeked Cordon-bleu	*Uraeginthus bengalus*	12	56.62	362.35	0	0.00	0.00	0	0.00	0.00
	Peters's Twinspot	*Hypargos niveoguttatus*	0	0.00	0.00	9	42.46	229.30	1	4.72	22.65

Insectivore	Sokoke Pipit	*Anthus sokokensis*	0	0.00	0.00	0	0.00	0.00	10	47.18	226.47
	Black-headed Apalis	*Apalis melanocephala*	2	9.44	60.39	9	42.46	229.30	80	377.45	1811.75
	Narina Trogon	*Apaloderma narina*	0	0.00	0.00	3	14.15	76.43	6	28.31	135.88
	Forest Batis	*Batis mixta*	2	9.44	60.39	0	0.00	0.00	17	80.21	385.00
	Pale Batis	*Batis soror*	0	0.00	0.00	0	0.00	0.00	25	117.95	566.17
	Green-backed Camaroptera	*Camaroptera brachyura*	0	0.00	0.00	1	4.72	25.48	1	4.72	22.65
	Grey-backed Camaroptera	*Camaroptera brevicaudata*	12	56.62	362.35	21	99.08	535.03	36	169.85	815.29
	Black Cuckoo-shrike	*Campephaga flava*	1	4.72	30.20	3	14.15	76.43	4	18.87	90.59
	Mombasa Woodpecker	*Campethera mombassica*	3	14.15	90.59	10	47.18	254.78	9	42.46	203.82
	Eastern Bearded Scrub-Robin	*Cercotrichas quadrivirgata*	0	0.00	0.00	5	23.59	127.39	14	66.05	317.06
	Yellowbill	*Ceuthmochares aereus*	4	18.87	120.78	9	42.46	229.30	2	9.44	45.29
	Klaas's Cuckoo	*Chrysococcyx klaas*	0	0.00	0.00	0	0.00	0.00	1	4.72	22.65
	White-browed Robin-Chat	*Cossypha heuglini*	7	33.03	211.37	18	84.93	458.60	9	42.46	203.82
	Red-capped Robin-Chat	*Cossypha natalensis*	8	37.74	241.57	23	108.52	585.99	16	75.49	362.35
	African Palm Swift	*Cypsiurus parvus*	5	23.59	150.98	2	9.44	50.96	6	28.31	135.88
	Fork-tailed Drongo	*Dicrurus adsimilis*	44	207.60	1328.62	23	108.52	585.99	12	56.62	271.76
	Black-backed Puffback	*Dryoscopus cubla*	23	108.52	694.50	8	37.74	203.82	19	89.64	430.29
	Little Yellow Flycatcher	*Erythrocercus holochlorus*	0	0.00	0.00	22	103.80	560.51	34	160.42	769.99
	Grey-headed Kingfisher	*Halcyon leucocephala*	1	4.72	30.20	0	0.00	0.00	0	0.00	0.00
	Mangrove Kingfisher	*Halcyon senegaloides*	2	9.44	60.39	3	14.15	76.43	2	9.44	45.29
	Lesser Striped Swallows	*Hirundo abyssinica*	0	0.00	0.00	6	28.31	152.87	0	0.00	0.00
	Pallid Honeyguide	*Indicator meliphilus*	0	0.00	0.00	11	51.90	280.25	1	4.72	22.65
	Lesser Honeyguide	*Indicator minor*	0	0.00	0.00	6	28.31	152.87	0	0.00	0.00
	Scaly-throated Honeyguide	*Indicator variegatus*	0	0.00	0.00	8	37.74	203.82	2	9.44	45.29
	African Pygmy Kingfisher	*Ispidina lecontei*	0	0.00	0.00	0	0.00	0.00	1	4.72	22.65
	Tropical Boubou	*Laniarius aethiopicus*	30	141.54	905.87	13	61.34	331.21	35	165.13	792.64
	Slate-coloured Boubou	*Laniarius funebris*	0	0.00	0.00	0	0.00	0.00	1	4.72	22.65
	Four-coloured Bush-shrike	*Malaconotus quadricolor*	0	0.00	0.00	0	0.00	0.00	21	99.08	475.58
	White-throated Bee-eater	*Merops albicollis*	0	0.00	0.00	5	23.59	127.39	2	9.44	45.29
	Northern Carmine Bee-eater	*Merops nubicus*	2	9.44	60.39	0	0.00	0.00	0	0.00	0.00
	African Pied Wagtail	*Motacilla aguimp*	8	37.74	241.57	1	4.72	25.48	0	0.00	0.00
	Ashy Flycatcher	*Muscicapa caerulescens*	2	9.44	60.39	0	0.00	0.00	2	9.44	45.29
	Red-tailed Ant-Thrush	*Neocossyphus rufus*	0	0.00	0.00	4	18.87	101.91	13	61.34	294.41
	Eastern Nicator	*Nicator gularis*	3	14.15	90.59	11	51.90	280.25	22	103.80	498.23
	African Golden Oriole	*Oriolus auratus*	10	47.18	301.96	15	70.77	382.17	0	0.00	0.00
	Black-headed Oriole	*Oriolus larvatus*	12	56.62	362.35	23	108.52	585.99	12	56.62	271.76
	Eurasian Golden Oriole	*Oriolus oriolus*	1	4.72	30.20	0	0.00	0.00	0	0.00	0.00
	Thick-billed Cuckoo	*Pachycoccyx audeberti*	27	127.39	815.29	0	0.00	0.00	0	0.00	0.00
	Green Wood-hoopoe	*Phoeniculus purpureus*	0	0.00	0.00	3	14.15	76.43	1	4.72	22.65
	Tiny Greenbul	*Phyllastrephus debilis*	0	0.00	0.00	0	0.00	0.00	23	108.52	520.88
	Fischer's Greenbul	*Phyllastrephus fischeri*	0	0.00	0.00	2	9.44	50.96	54	254.78	1222.93
	Northern Brownbul	*Phyllastrephus strepitans*	6	28.31	181.17	28	132.11	713.38	12	56.62	271.76
	Terrestrial Brownbul	*Phyllastrephus terrestris*	0	0.00	0.00	5	23.59	127.39	13	61.34	294.41
	Dark-backed Weaver	*Ploceus bicolor*	2	9.44	60.39	8	37.74	203.82	23	108.52	520.88
	Clarke's Weaver	*Ploceus golandi*	0	0.00	0.00	0	0.00	0.00	4	18.87	90.59
	Tawny-flanked Prinia	*Prinia subflava*	51	240.62	1539.99	9	42.46	229.30	0	0.00	0.00
	Retz's Helmet-shrike	*Prionops retzii*	0	0.00	0.00	15	70.77	382.17	4	18.87	90.59
	Chestnut-fronted Helmet-shrike	*Prionops scopifrons*	0	0.00	0.00	19	89.64	484.08	75	353.86	1698.51
	Common Scimitarbill	*Rhinopomastus cyanomelas*	1	4.72	30.20	4	18.87	101.91	5	23.59	113.23
	East Coast Akalat	*Sheppardia gunningi*	0	0.00	0.00	0	0.00	0.00	11	51.90	249.12
	Black-crowned Tchagra	*Tchagra australis*	18	84.93	543.52	2	9.44	50.96	5	23.59	113.23
	African Paradise-flycatcher	*Terpsiphone viridis*	3	14.15	90.59	7	33.03	178.34	3	14.15	67.94
	Blue-mantled Crested-flycatcher	*Trochocercus cyanomelas*	0	0.00	0.00	0	0.00	0.00	17	80.21	385.00
	Scaly Babbler	*Turdoides squamulutus*	31	146.26	936.07	48	226.47	1222.93	0	0.00	0.00
Nectarivore	Amani Sunbird	*Anthreptes pallidigaster*	0	0.00	0.00	4	18.87	101.91	22	103.80	498.23
	Plain-backed Sunbird	*Anthreptes reichenowi*	0	0.00	0.00	1	4.72	25.48	10	47.18	226.47
Nectarivore-	Collared Sunbird	*Hedydipna collaris*	41	193.44	1238.03	53	250.06	1350.32	61	287.80	1381.46
Insectivore	Olive Sunbird	*Nectarinia olivacea*	21	99.08	634.11	32	150.98	815.29	61	287.80	1381.46
	Amethyst Sunbird	*Nectarinia amethystina*	1	4.72	30.20	0	0.00	0.00	0	0.00	0.00
Omnivore	Pied Crow	*Corvus albus*	8	37.74	241.57	0	0.00	0.00	0	0.00	0.00
	House Crow	*Corvus splendens*	7	33.03	211.37	0	0.00	0.00	0	0.00	0.00

3.5 Effect of seasonality

High abundance and diversity of birds were recorded during rainy seasons. The highest abundance and diversity values were recorded in May, June and November, which coincided with rainy seasons when Afrotropical migrants come to Arabuko Sokoke Forest for breeding.

May and June also recorded moderate mean daily temperatures and high humidity during the survey period (Fig. 7 a, b). This high abundance and diversity can be attributed to favorable physical conditions. Birds were recorded in very low numbers during the dry months of February, August and September which recorded low rainfall, low humidity and higher mean daily temperatures (Fig. 7 c). A few species first appeared during this season or occurred in greater numbers including two intra-African migrants; Black Cuckoo-shrike and African Pygmy Kingfisher and one Palearctic non-breeding visitor species; the Eurasian Golden Oriole (*Oriolus oriolus*).

Several species were most abundant during the rainy season including; intra-African migrants e.g. African Golden Oriole (*Oriolus auratus*), and resident species e.g. Black-backed Puffback (*Dryoscopus cubla*), Black-bellied Starling, African Pied Wagtail (*Motacilla aguimp*), Yellowbill (*Ceuthmochares aereus*), Collared Sunbird, Black-headed Weaver and African Paradise-flycatcher (*Terpsiphone viridis*) among others. The effect of seasonality on the abundance of birds was highly significant ($P < 0.01$).

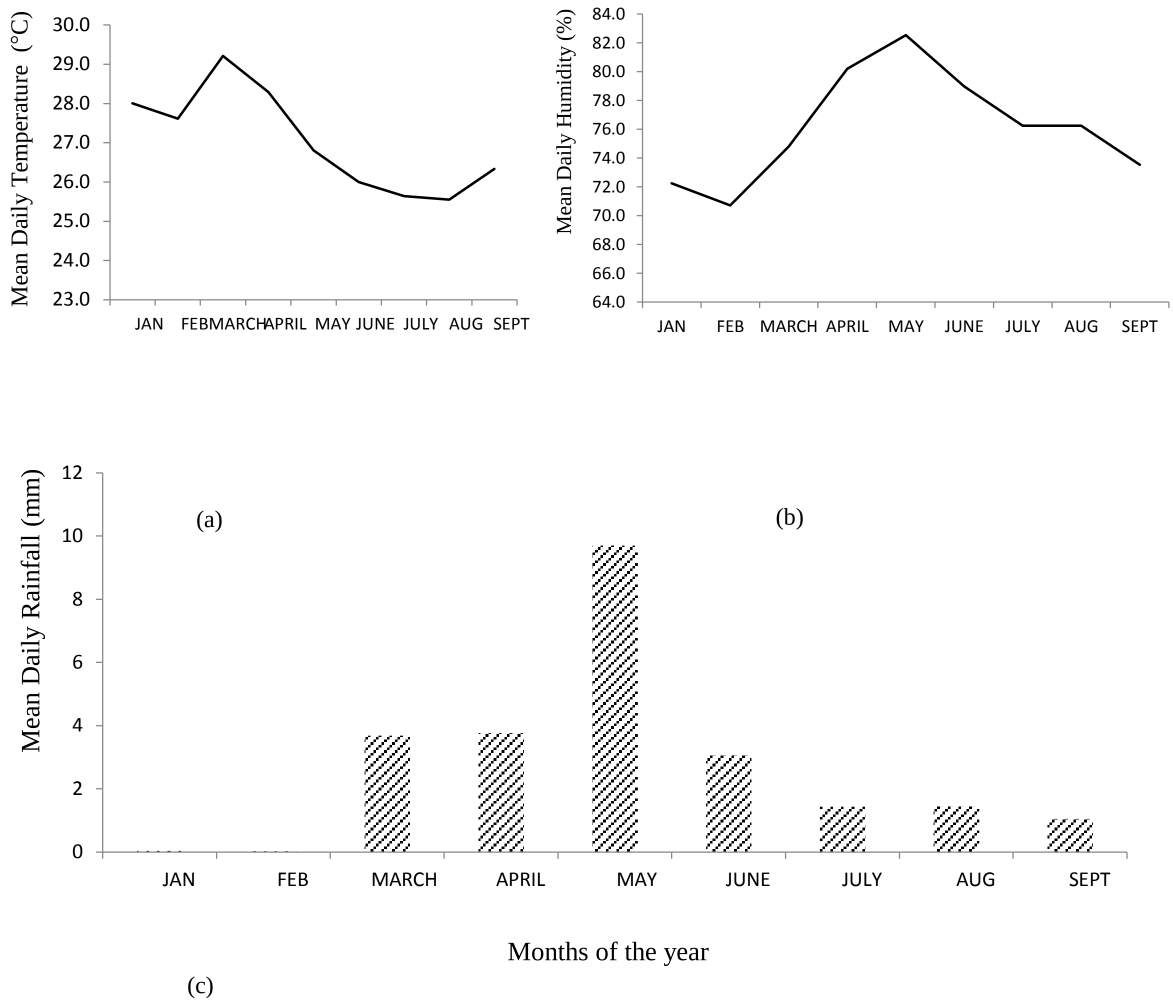


Figure 7: Physical data for Arabuko Sokoke Forest and surrounding area courtesy of Msabaha Metrological station for the survey period, May 2012 – September 2013. (**a**) Mean daily temperature for each month of the survey period, (**b**) mean daily humidity for each month of the survey period, (**c**) Mean daily rainfall for each month of the survey period.

3.6 Avian community similarity analysis

Primary forest seems to hold a different bird community compared to plantation forest and farmland. While I expected more overlap between plantation forest and primary forest in bird species composition, I found on the contrary more overlap between plantation forest and farmlands. High similarity in bird species composition was recorded between plantation forest and farmlands with 55 out of 99 sampling points showing similarity in species composition as indicated by shared clusters (Fig. 8).

Bird species composition in primary forest appears to be largely distinct from that of farmlands. Other than Collared Sunbird and Zanzibar Sombre Greenbul that were well distributed across the three land use types, they shared only few other species as indicated by limited overlap of the ordination ellipses and sampling points of the two land use systems. Ordination ellipse encloses points of the same land use type. Level of overlap of ordination ellipses indicates level of similarity or dissimilarity in species composition. One point in farmland was transformed to bare field in the course of survey period and was ignored in subsequent surveys, while the coordinates of two points in plantation forest were lost in the GPS tracking systems and these spots were not visited during repeat surveys. These three points consequently show false dissimilarity in species composition and are considered outliers (Fig. 8).

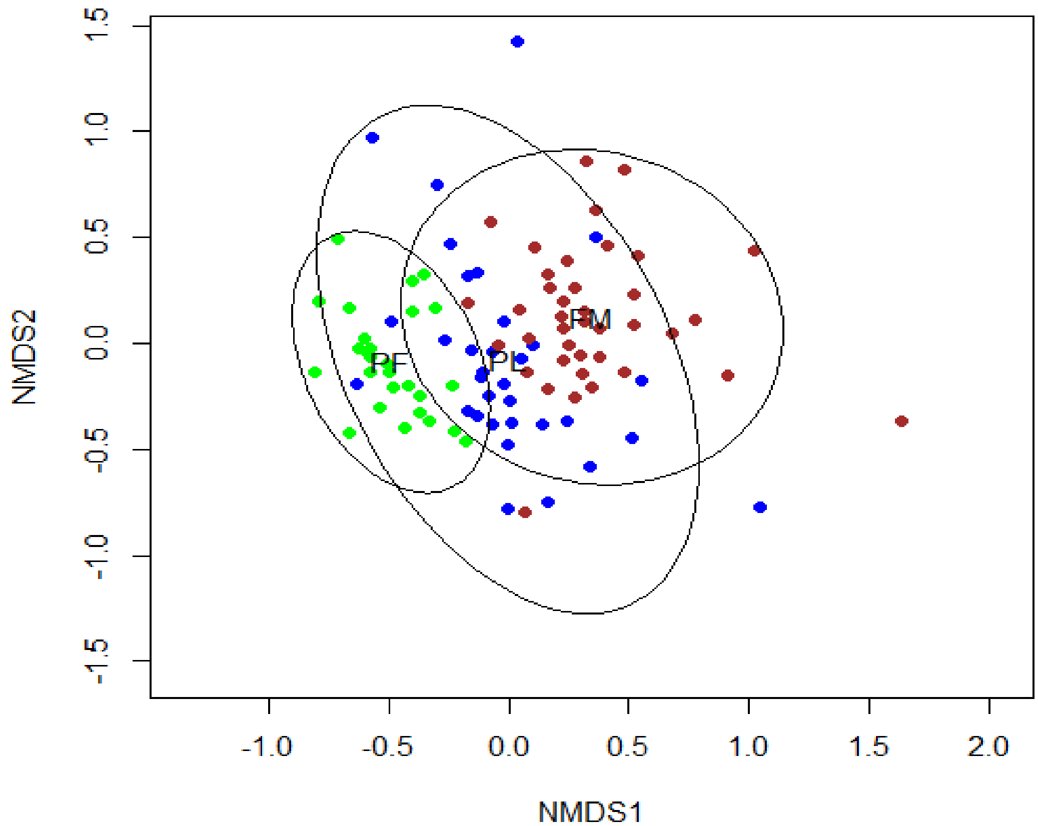


Figure 8: Ordination plot of sampling points for avifaunal similarity. Ordination ellipse indicates where 95% of points of the same land use type are expected to occur. PF = primary forest, FM = farmland, PL = Plantation forest. Ordination based on species occurrence data from Arabuko Sokoke Forest and surrounding land use types. One outlier in farmland and two in plantation forest.

3.7 Habitat factors influencing bird species diversity

Vertical vegetation heterogeneity had the strongest positive influence on overall bird species richness ($P<0.001$, $R^2=0.152$). Also, the number of fruiting trees had a significant influence on species richness ($P<0.05$, $R^2=0.0898$). However, the number of large trees had no significant influence ($P>0.005$) (Table 7). There were no fig trees encountered at each point, therefore, no analysis was done on this factor.

Table 7: Effects of habitat factors on richness of overall bird species. –ve estimate indicates negative effects and +ve estimate indicate positive effect. SE= Standard Error**.**

Habitat factor	F statistic	df	n	*P* value	R^2	Estimate	SE
Vertical vegetation heterogeneity	14.214	1, 79	81	< 0.001***	0.15249	3.43144	0.91015
Number of fruiting trees	7.793	1, 79	81	< 0.05**	0.08979	0.9170	0.3285
Number of large trees	0.21694	1, 79	81	0.07631	0.039231	0.21694	0.12079

None of the studied habitat factors in farmland independently influenced species richness of farmland birds (P>0.05) (Table 8).

Table 8: Effects of habitat factors on richness of overall bird richness in farmland. –ve estimate indicates negative effects and +ve estimate indicate positive effect. SE= Standard Error**.**

Habitat factor	F statistic	df	n	*P* value	R^2	Estimate	SE
Vertical vegetation heterogeneity	0.04102	1, 25	27	0.841	0.001638	-0.256	1.264
Proximity to forest	0.1041	1, 25	27	0.75	0.004146	0.6296	1.9514
Number of large trees	2.824	1, 25	27	0.105	0.1015	-0.2820	0.1678
Proximity to settlement	0.1776	1, 25	27	0.677	0.007054	-15.128	35.897
Number of fruiting trees	1.483	1, 25	27	0.234	1.483	-0.6778	0.5565

However, the best habitat model for increased richness of bird species in farmlands was obtained from a mixed effect model with the number of fruiting trees and the number of large trees (Table 9).

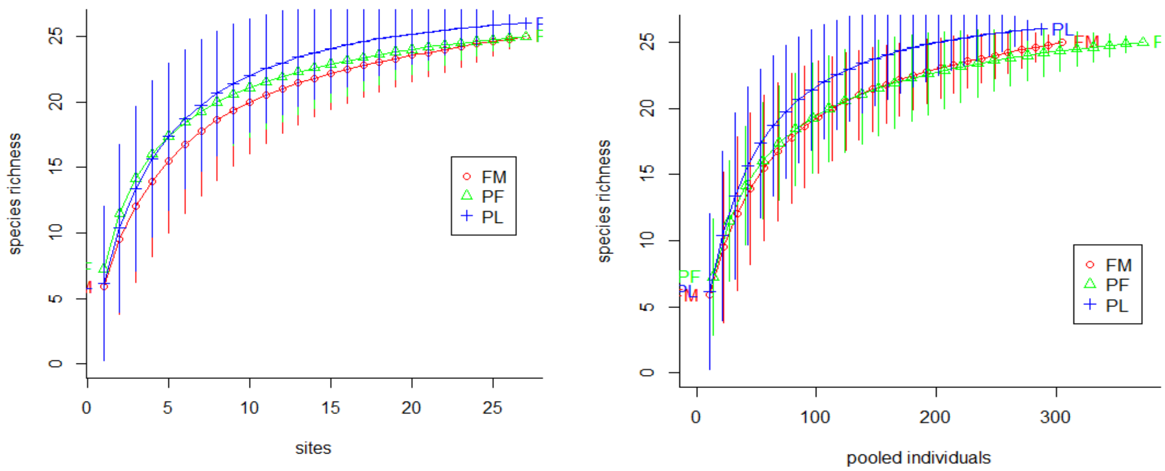
Table 9: Akaike's Information Criterion (AIC) of different models for mixed effect of habitat factors. Large number of trees and fruiting trees were counts of individuals. Vertical vegetation heterogeneity was based on Shannon diversity index of % cover of vegetation layers. The models are ranked based on the AIC value. The lowest AIC value indicates the best model.

Mixed effect model of habitat factors	AIC value	Deviance
1. Farmland + Fruit trees + Large trees	159.58	28.401
2. Farmland + Fruiting trees + Large trees + Vertical vegetation heterogeneity	161.1	28.173
3. Farmland + Fruiting trees + Large trees + Proximity to settlement	161.22	28.272
4. Farmland + Fruiting trees + Large trees + Proximity to forest	161.58	28.404
5. Farmland + Fruiting trees + vertical vegetation heterogeneity	162.89	29.011

3.8 Frugivore richness and distribution

3.8.1 Effect of land use and vegetation type on frugivore richness

Frugivore species richness was higher in plantation forests and primary forest and lower in farmland (Figure 9).



(a) (b)

Figure 9: Species accumulation curves of total number of frugivore species recorded from 81 points, n=27 for each land use type (primary forest, plantation forest and farmland) for bird survey in Arabuko Sokoke Forest and surrounding farmlands in coastal Kenya from May 2012 – September 2013. PF = primary forest, FM = farmland, PL = Plantation forest. (a) Accumulation curve of frugivorous bird community for each land use. (b) species accumulation curves plotted against pooled number of bird individual frugivore birds observed in 27 points in each land use type. Species accumulation curves appeared to reach asymptote.

Land use type had no significant influence on species richness of regular frugivores ($F_{2, 78}$, =2.29, P >0.05, n=81), or occasional frugivores ($F_{2, 78}$, =0.06, P >0.05, n=81). The lowest number of regular frugivorous species was recorded in *Cynometra* vegetation while mixed-forest had the lowest number of occasional frugivorous species. Vegetation type also had no significant effect on frugivorous richness ($F_{2, 24}$, =2.266, P =0.091, n=27) (Figure 10).

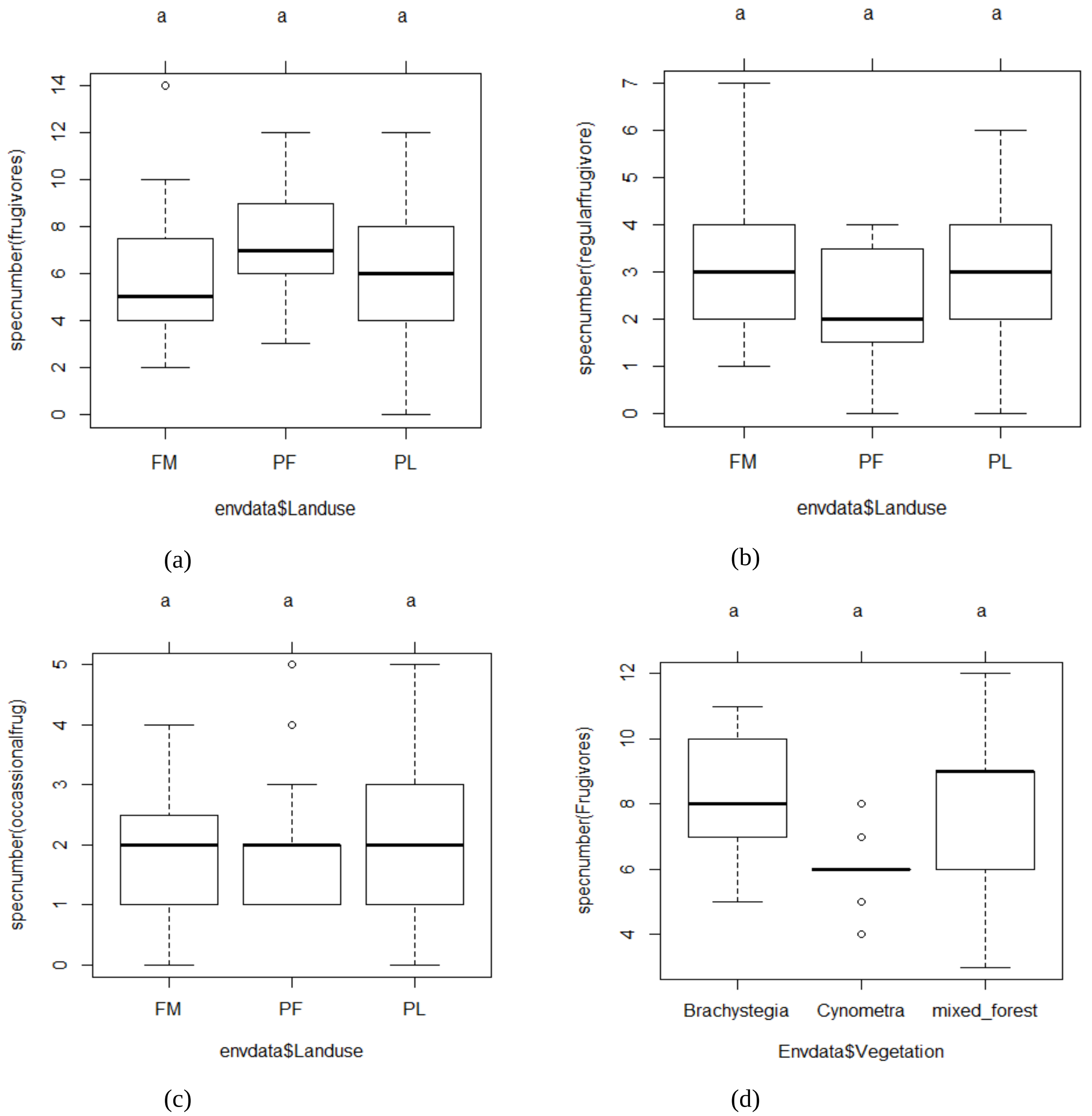


Figure 10: Box plots showing the distribution of the number of frugivorous species. Comparison based on land use and vegetation types. PF=Primary forest, FM=Farmland, PL=Plantation forest. Categories marked with similar letters are not significantly different. (**a**) box plot of number of overall frugivore species compared between land use types, (**b**) box plots of regular frugivore species compared between land use types, (**c**) box plots of occasional frugivores compared between land use types, (**d**) box plots for overall frugivore richness compared between vegetation types in the primary forest. The box plots indicate the Mean ±SE.

I found the Green Barbet feeding on *Strychnos madagascarensis* in *Cynometr*a vegetation in the primary forest (Plate 9). *Strychnos madagascarensis* is a dominant tree species in *Cynometra* vegetation and is likely a major food resource for other frugivore species. Some plants that are likely to provide fruit resources to frugivores in plantation forest include; *Gmelina arborea*, *Lannea schweinfurthii, Grewia sp.* and others in plantation and farmland like neem tree (*Azadirachta indica*). Cashew nut (*Anacardium occidentale*) and Mango (*Mangifera indica*) fruits were important food resources in farmlands. The Common Bulbul was observed feeding on fruits of *Cissampelos pareira* in farmland.

(a) (b)

Plate 9: (a) Green Barbet feeding on *Strychnos madagascarensi* fruit, (b) *Strychnos madagascarensis* fuit (one of the fruit plants in *Cynometra* vegetation) on which foraging was observed in Arabuko Sokoke Forest.

Regular frugivores, e.g. Zanzibar Sombre Greenbul, Common Bulbul, Green Barbet, Black-bellied Starling, were recorded in high numbers while Crowned Hornbill (*Tockus alboterminatus*) was recorded in low numbers. The occasional frugivores recorded in low numbers include; Clarke's Weaver, Eurasian Golden Oriole and Scaly-throated Honeyguide (Table 10). Three occasional frugivores were forest restricted; Kenya Crested Guineafowl, Fischer's Greenbul and Clarke's Weaver, while two regular frugivores showed forest dependence; Eastern Green Tinkerbird (*Pogoniulus simplex*) and Fischer's Turaco (*Tauraco fischeri*).

Table 10: Frequencies of regular and occasional frugivores. Frequency is the total number of individuals observed during repeat counts also considered as the abundance.

Regular Frugivores	Frequency	Occasional Frugivores	Frequency
Zanzibar Sombre Greenbul	111	Fischer's Greenbul	56
Common Bulbul	101	Black-backed Puffback	50
Black-bellied Starling	91	Black-headed Oriole	47
Green Barbet	77	Emerald-spotted Wood-dove	42
Trumpeter Hornbill	35	Tambourine Dove	21
Green Pigeon	21	Ring-necked Dove	18
Yellow-rumped Tinkerbird	18	Red-eyed Dove	18
Fischer's Turaco	18	Yellowbill	15
Speckled Mousebird	13	Scaly-throated Honeyguide	10
Eastern Green Tinkerbird	13	Kenya Crested Guineafowl	10
Crowned Hornbill	2	Clarke's Weaver	4
		African Golden Oriole	4
		Eurasian Golden Oriole	1

While there was no significant effect of land use on frugivore richness, overall diversity seemed to be higher in plantation forest followed by primary forest with the lowest diversity in farmlands. A Renyi profile higher than others along its entire length f is considered more diverse as shown by the Renyi profile of plantation forest (Figure 11).

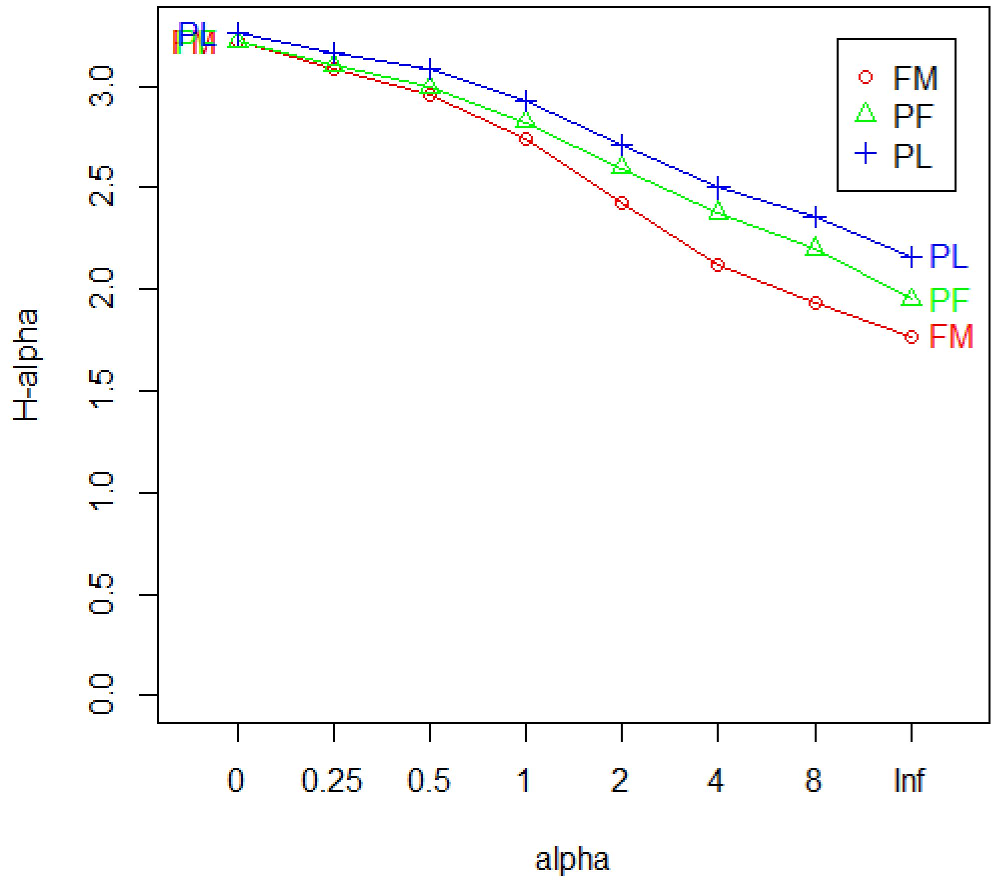


Figure 11: Renyi profiles comparing diversity of frugivorous birds in three land use types in Arabuko Sokoke Forest and neighboring land use types. PF=Primary forest, FM=Farmland, PL=Plantation forest.

3.8.2 Habitat factors influencing richness of frugivorous birds

The number of fruiting trees had a significant positive influence on the species richness of frugivorous birds ($P<0.05$) while the number of large trees had no influence on the diversity of this guild. Also, species richness of frugivorous birds was not influenced by proximity to settlement, proximity to forest nor vertical vegetation heterogeneity ($P>0.05$) (Table 11).

Table 11: Effects of habitat factors on richness of frugivorous bird species. –ve sign indicates negative effects and +ve sign indicates a positive effect. SE= Standard Error.

Habitat factor	F statistic	df	n	*P* value	R^2	Estimate	SE
Vertical vegetation heterogeneity	2.837	1,79	81	0.096	0.03467	0.7552	0.4484
Proximity to forest	3.124	1,79	81	0.081	0.03803	-0.9485	0.5367
Number of fruiting trees	4.195	1,79	81	0.044 *	0.05042	0.3172	0.1549
Number of large trees	0.8991	1,79	81	0.346	0.01125	0.05656	0.948
Proximity to settlement	0.10264	1,79	81	0.055	0.04595	0.10264	0.05262

The best model for richness of frugivorous birds was obtained from the mixed effect of land use type and number of fruiting trees; this had the lowest Akaike's Information Criterion value (AIC 390.83) (Table 12).

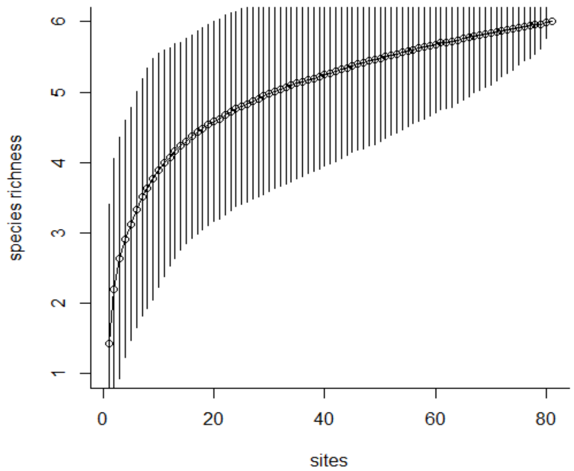
Table 12: Akaike's Information Criterion (AIC) of different models for mixed effect of habitat factors on frugivore birds. Large number of trees and fruiting trees were counts of individuals. Vertical vegetation heterogeneity was based on Shannon diversity index of % cover of vegetation layers. The models are ranked based on the AIC value. The lowest AIC value indicates the best model.

Mixed effect model of habitat factors	AIC value	Deviance
1. Land use + Fruiting trees	390.83	87.652
2. Land use + Fruiting trees + Proximity to settlement	392.81	87.647
3. Land use + Fruiting trees + Proximity to forest	393.96	87.651
4. Land use + Large trees + Fruiting trees + Proximity to forest	394.309	87.7762
5. Land use + Large trees + Fruiting trees + Proximity to forest + vertical vegetation heterogeneity	396.3	87.749

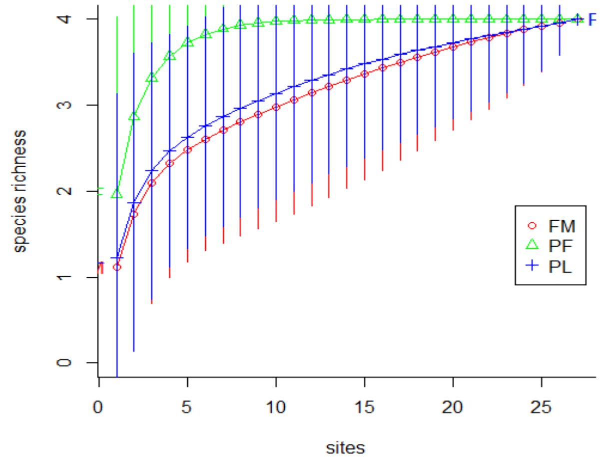
3.9 Nectarivore richness and distribution

3.9.1 Effect of land use and vegetation type on nectarivorous birds

There were more regular nectarivores in primary forest compared to both farmland and plantation forests. However, most occasional nectarivores were distributed in all land use systems, but with low numbers in the primary forest. The overall number of nectarivores was generally low (Fig. 12).



(a)



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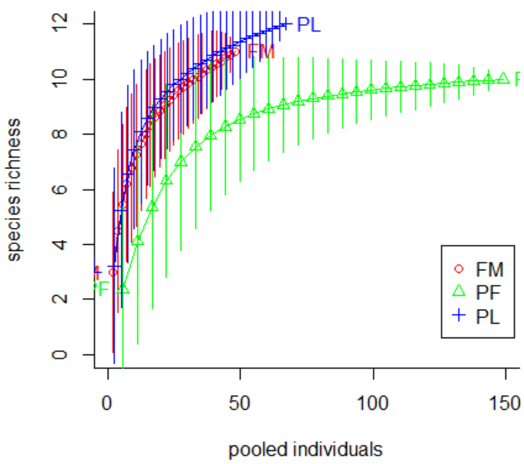


(c)

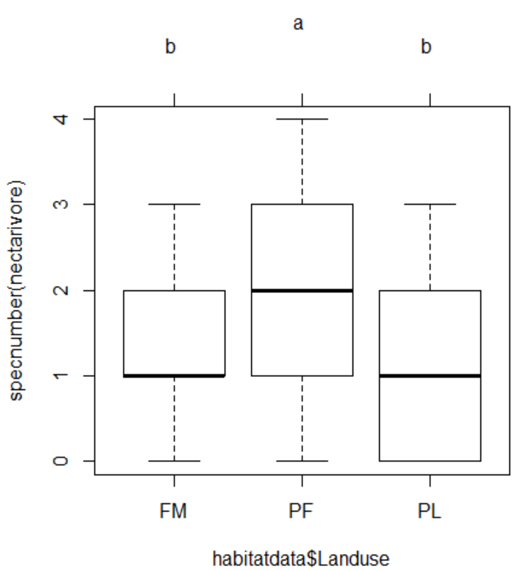
Figure 12:Figure 12: Species accumulation curves of total number of nectarivore species recorded from 81 points, n=27 for each land use type (primary forest, plantation forest and farmland) for bird survey in Arabuko Sokoke Forest and surrounding farmlands in coastal Kenya from May 2012 – September 2013. PF = primary forest, FM = farmland, PL = Plantation forest. (a) Accumulation curve of overall nectarivore community (b) Species accumulation curves for each land use (n=27) (c) Species accumulation curves plotted against pooled number of regular nectarivore individuals in each land use type (d) Species accumulation curves plotted against pooled number of occasional nectarivore individuals in each land use type.

Overall, land use had a significant effect on nectarivore species richness ($F_{2, 78}$, =6.42, P = 0.003, n=81). This difference was caused by primary forest as revealed by the Tukey test (Table 13).

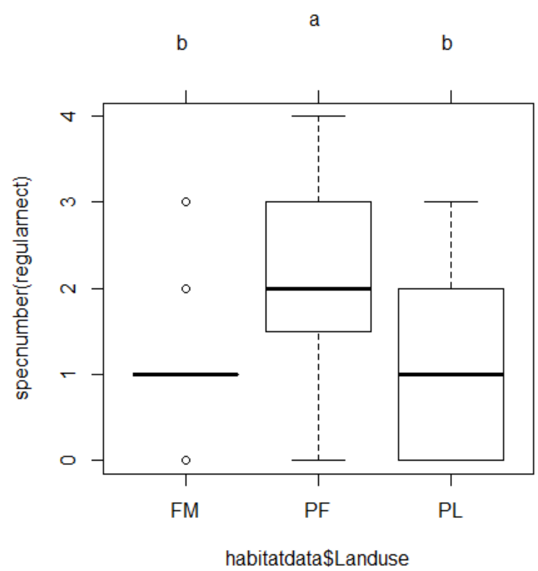
Table 13: Tukey HSD test for pairwise comparison of mean species richness between land use types PF = primary forest, FM = farmland, PL = Plantation forest.

	Estimate	Std. Error	t value	p value
PF - FM	0.85185	0.25838	3.297	0.004146 **
PL - FM	0.11111	0.25838	0.430	0.903213
PL – PF	-0.74074	0.25838	-2.867	0.014486 *

Land use type influenced the species richness of regular nectarivores ($F_{2,\ 78}$, =1.813, P<0.001, n=81 but not occasional nectarivores ($F_{2,\ 78}$, =1.877, P >0.05, n=81). No pattern was observed in the utilization of vegetation types (*Cynometra*, *Brachstegia* and Mixed Forest) by nectarivore species (Fig 13).



(a)



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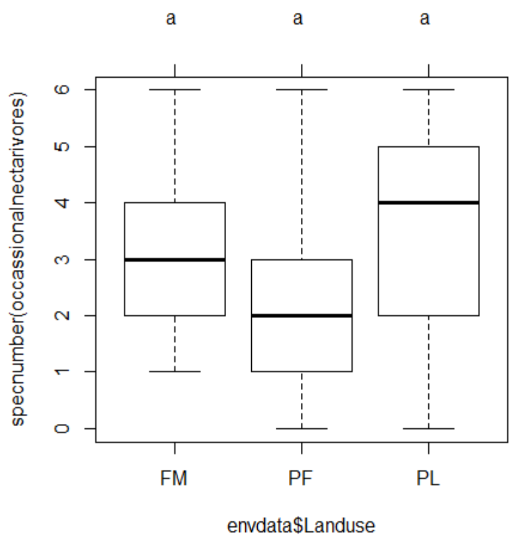

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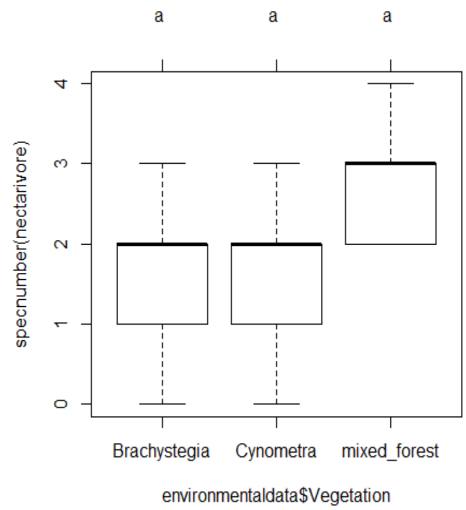


(d)

Figure 13: Box plots showing distribution of number of nectarivorous species at 81 points. Species numbers compared among the three land use type and three vegetation types. PF =Primary forest, FM=Farmland, PL=Plantation forest. (**a**). Box plots of regular nectarivorous species encountered during the counts (**b**) and occasional nectarivore (**c**) species in land use types. PF =Primary forest, FM=Farmland, PL=Plantation forest. Nectarivore species compared between vegetation types in Primary Forest (**d**). Categories marked with similar letters are not significantly different, while the one marked with a different letter is significantly different. The box plots indicate the Mean ±SE.

Among the regular nectarivores Amani Sunbird and Plain-backed Sunbird showed a marked dependence on primary forest while Collared Sunbird and Olive Sunbird utilised resources in all three land use systems. The only record of the Amethyst Sunbird was of a bird foraging in farmland close to a settlement (Plate 10).

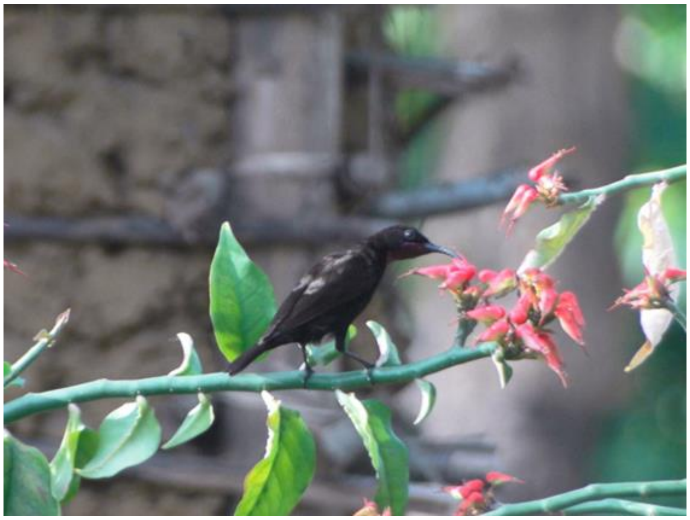


Plate 10: Amethyst Sunbird (*Nectarinia amethystina*) foraging close to settlement. This was the only Amethyst Sunbird recorded during the survey period.

Occasional nectarivores were well distributed across the three land use systems apart from the Green Wood-hoopoe (*Phoeniculus purpureus*) that was mainly recorded in the primary forest (Table 14).

Table 14: Frequencies of regular and occasional nectarivores recorded during the survey period. Frequency is the total number of individuals observed during repeat counts also considered as the abundance.

Regular Nectarivore	Frequency	Occasional Nectarivore	Frequency
Collared Sunbird	155	Zanzibar Sombre Greenbul	111
Olive Sunbird	114	Common Bulbul	101
Amani Sunbird	26	Black-bellied Starling	91
Plain-backed Sunbird	11	Fork-tailed Drongo	79
Amethyst Sunbird	1	Yellow-fronted Canary	58
		Black-headed Oriole	47
		Dark-backed Weaver	33
		Yellow-rumped Tinkerbird	18
		Speckled Mousebird	13
		Common Scimitarbill	10
		Green Wood-hoopoe	4
		Black-headed Weaver	4

Renyi diversity profiles confirmed that nectarivores were more diverse in primary forest compared to both farmlands and plantation forest. Farmland had a higher diversity of nectarivores compared to plantation forest. All the three land use types had the same total species richness (all Renyi profiles starting at the same point at alpha=0) (Figure 14).

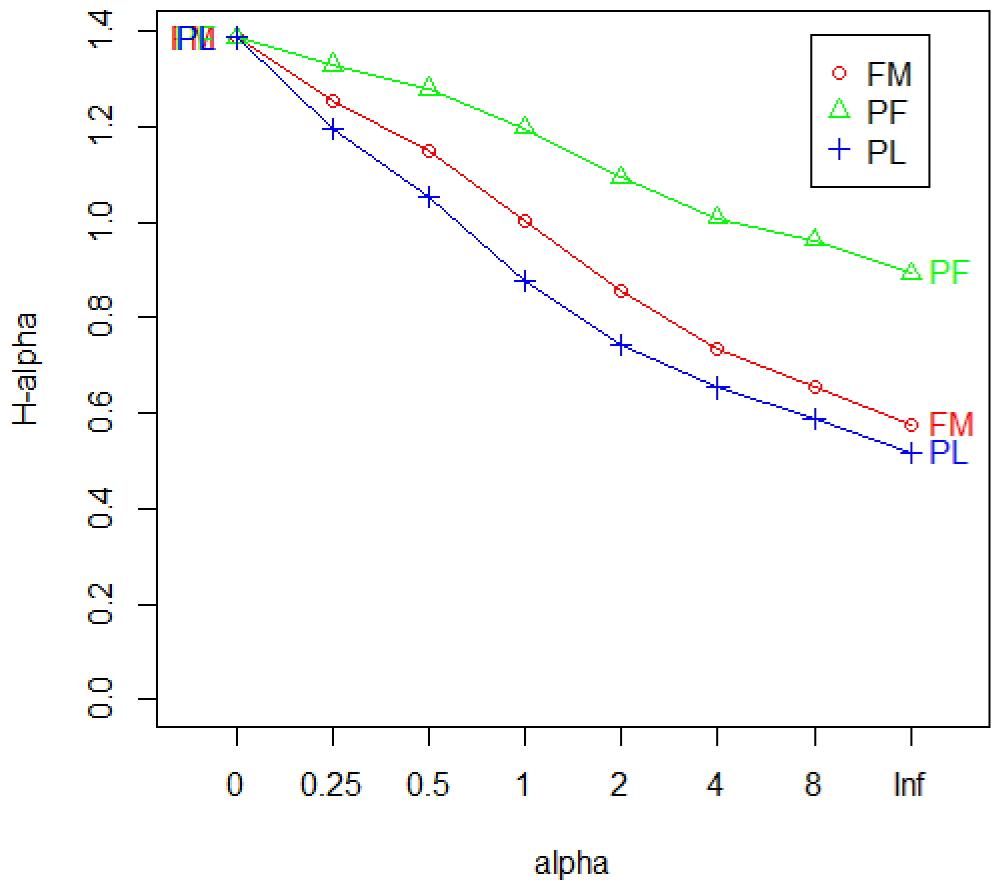


Figure 14: Renyi profiles comparing diversity of the three land use types. PF=Primary forest, FM=Farmland, PL=Plantation forest. As the three profiles do not cross each other throughout their lengths, their diversity can be compared.

3.9.2 Habitat factors influencing nectarivorous bird species

Vertical vegetation heterogeneity had a strong positive influence on species richness of nectarivorous birds (P<0.063, R^2=0.09062). While this was not influenced by the number of large trees (*P*<0.05, R^2=0.04055). Whereas proximity to settlement had a significant positive influence on nectarivorous birds (*P*<0.001, R^2 =0.1555), proximity to forest had a negative influence on this category of birds (*P*=0.0029, R^2=0.10). The number of fruiting trees also had a significant positive effect on nectarivorous birds (P<0.05, R^2=0.091) (Table 15).

Table 15: Effects of habitat factors on richness of nectarivorous bird species. –ve estimate indicates negative effects and +ve estimate indicate positive effect. F statistics at *P*=0.05. SE= Standard Error.

Habitat factor	F statistic	df	n	*P* value	R^2	Estimate	SE
Vertical vegetation heterogeneity	7.873	1,79	81	0.00632 **	0.09062	0.4645	0.1655
Proximity to forest	9.487	1,79	81	0.00285 **	0.1072	-0.6057	0.1967
Number of fruiting trees	7.903	1,79	81	0.00622 **	0.09094	0.16204	0.05764
Number of large trees	3.903	1,79	81	0.07145	0.04055	0.038772	0.02119
Proximity to settlement	14.54	1,79	81	0.00027 ***	0.1555	0.07181	0.01883

The best habitat model for species richness of nectarivorous birds was obtained from a mixed effect of land use, proximity to forest and vegetation heterogeneity, which had the lowest Akaike's Information Criterion value (AIC 12) (Table 16).

Table 16: Akaike's Information Criterion (AIC) of models for mixed effect of habitat factors on nectarivores. Large number of trees and fruiting trees were counts of individuals. Vertical vegetation heterogeneity was based on Shannon diversity index of % cover of vegetation layers. The models are ranked based on the AIC value. The lowest AIC value explains the best habitat model.

Mixed effect model of habitat factors	AIC value	Deviance
1. Land use + Proximity to forest + vertical vegetation heterogeneity	12	66.748
2. Land use + Proximity to settlement + vertical vegetation heterogeneity	12	65.337
3. Land use + Fruiting trees + Proximity to settlement	68	65.03
4. Land use + Fruiting trees + Proximity to forest	234	66.138

3.10 Insectivore richness and distribution

3.10.1 Effects of land use and vegetation types on insectivores

More insectivorous birds species and number of individuals were recorded in primary forest (40 species, n=27) followed by plantation forest (34 species, n=27) then farmland (24 species, n=27) (Figure 15).

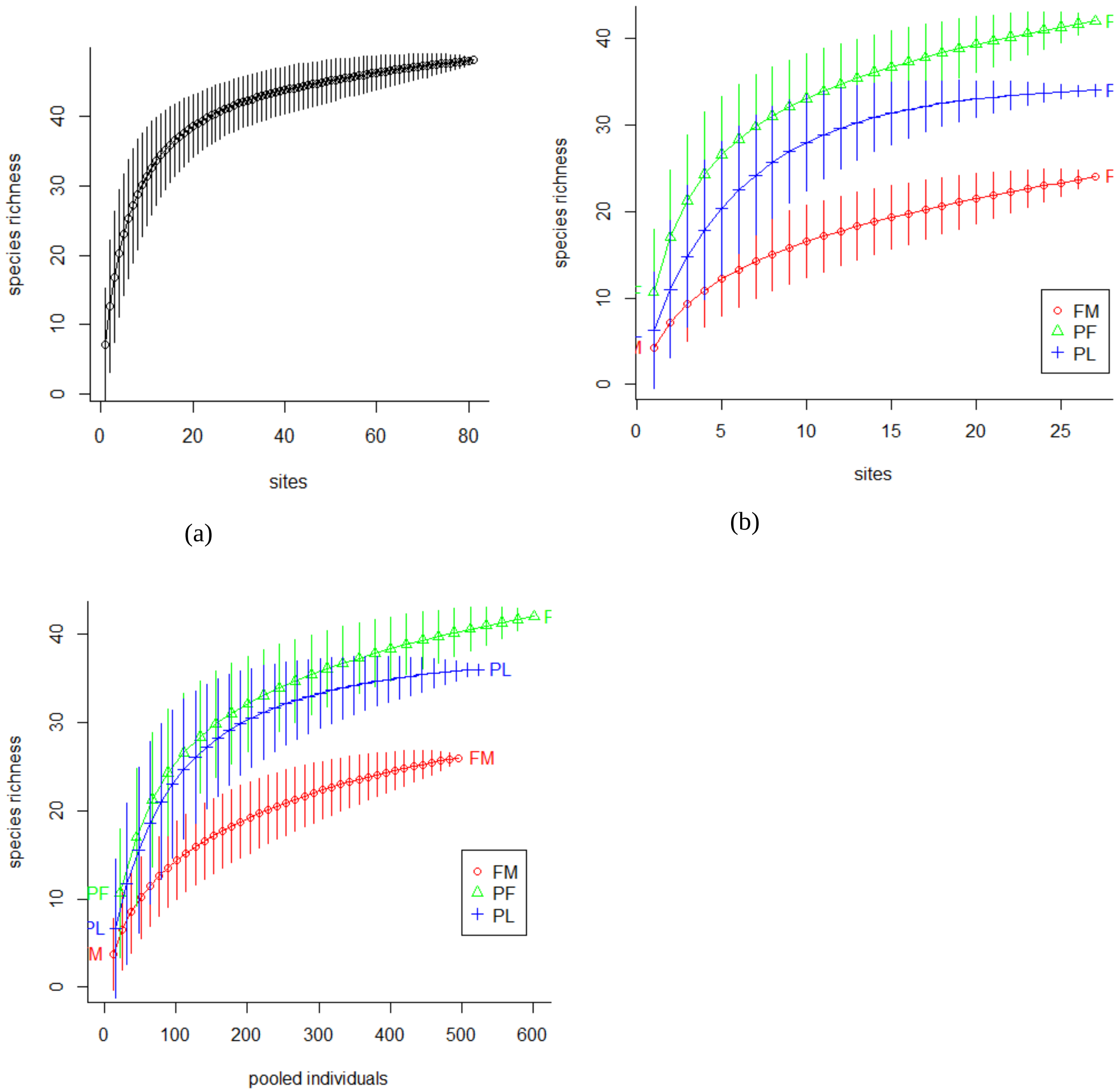


Figure 15: Species accumulation curves of total number of insectivore species recorded from 81 points, n=27 from each land use type (primary forest, plantation forest and farmland) in Arabuko Sokoke Forest and surrounding farmlands in coastal Kenya. PF = primary forest, FM = farmland, PL = Plantation forest. (a) species accumulation curve of overall bird insectivore community, (b) species accumulation curves for each land use (n=27), (c) Species accumulation curves plotted against pooled number of insectivore individuals for each land use type**.**

Analysis of species richness was based on 81 points, 27 from each land use type to avoid bias in the calculation. Effect of vegetation type was determined based on 27 points, 9 in each vegetation type (*Brachystegia*, Mixed Forest, *Cynometra)* within the primary forest. Results showed that the species richness of insectivorous birds was significantly different between the three land use types (P = 0.001, $F_{2, 78}$ = 29.79, n=81). Farmland recorded the lowest diversity. The three vegetation types within the forest also showed significant differences in insectivorous bird species composition (P<0.001) (Figure 16).

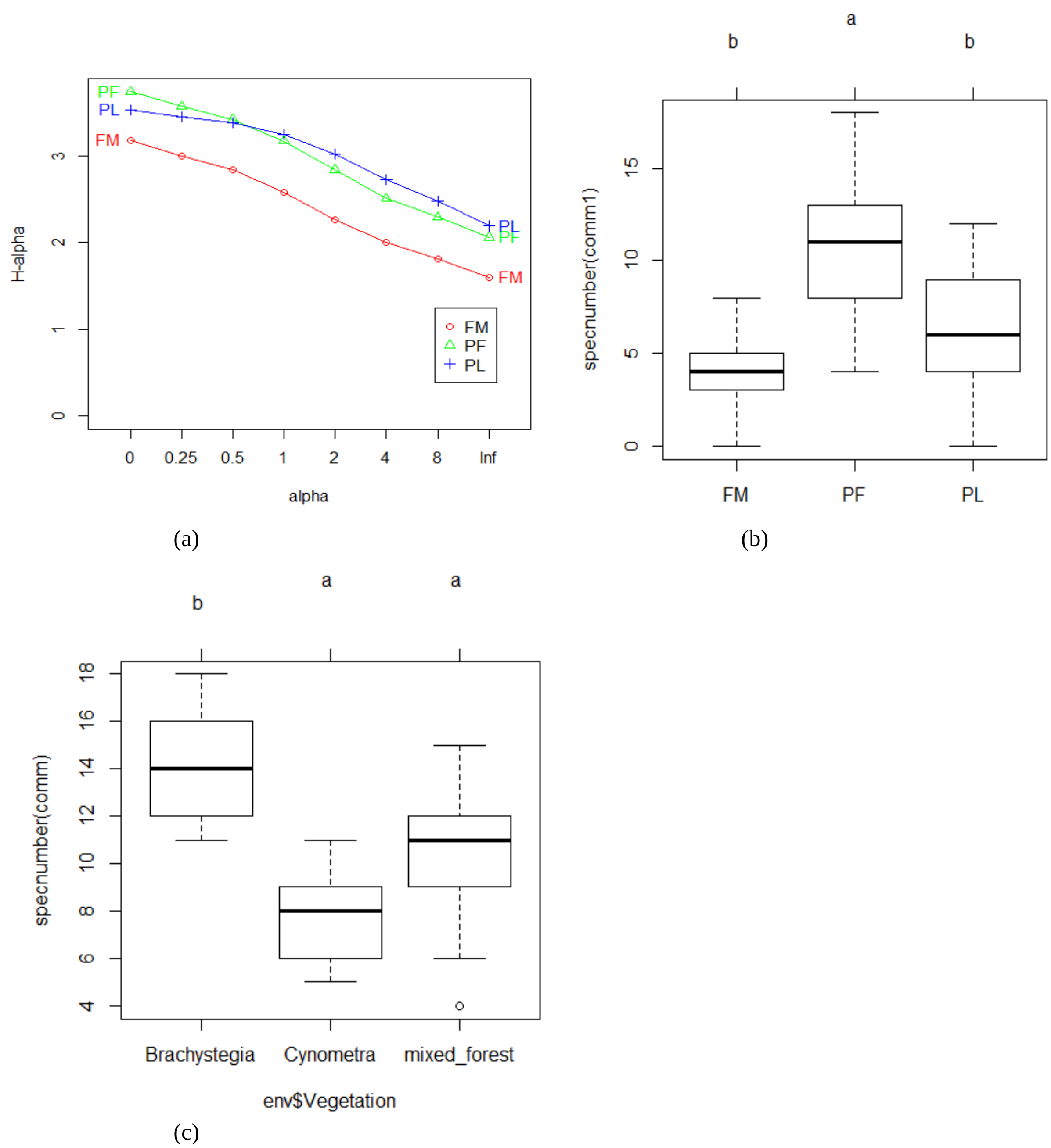


Figure 16: Boxplots comparing mean species richness of insectivorous birds in three land use systems, FM=farmland, PF=primary forest, PL=plantation forest surveyed in Arabuko Sokoke Forest and surrounding farmlands. Species richness compared based on equal sampling points per land use (n=27). Land use systems sharing the same letter are not significantly different at p = 0.05. The box plots indicate the Mean ±SE.

Post-Hoc (Tukey) test revealed no difference in species richness of insectivorous birds between farmland and plantation forest, but a highly significant difference between primary forest and the two land use types ($P < 0.001$) (Table 17).

Table 17: Multiple comparisons of means: Tukey contrasts between land use types, PF=primary forest, FM=farmland, PL=plantation forest.

	Estimate difference	Std. Error	t value	P value
PF - FM	6.4074	0.8506	7.533	<1e-04 ***
PL - FM	1.9630	0.8506	2.308	0.0605.
PL - PF	-4.4444	0.8506	-5.225	<1e-04 ***

While the composition of insectivorous birds in *Brachystegia* was significantly different from that in *Cynometra* and Mixed Forest, the difference between Mixed Forest and *Cynometra* was not significant, (Table 18).

Table 18: Multiple comparisons of means: Tukey contrasts between vegetation types (*Cynometra, Brachystegia* and *mixed forest*) the primary forest (Arabuko Sokoke Forest). Highly significant difference revealed between the pair, Cynometra – Brachystegia.

	Estimate difference	Std. Error	t value	P value
Cynometra – Brachystegia	-6.444	1.256	-5.130	<0.001 ***
Mixed forest - Brachystegia	-3.889	1.256	-3.096	0.0131 *
Mixed forest - Cynometra	2.556	1.256	2.034	0.1257

3.10.2 Habitat factors influencing richness of insectivorous species

Three habitat factors had a strong positive influence on the species richness of insectivores including vertical vegetation heterogeneity, proximity to the forest and proximity to settlement ($P<0.001$). The influence of proximity to the forest was negative for this guild. Diversity of insectivorous birds was also influenced by the number of large trees and fruiting trees ($P<0.05$) (Table 19).

Table 19: Effects of habitat factors on richness of insectivorous bird species. –ve sign indicates negative effects and +ve sign indicates positive effect. SE= Standard Error.

Habitat factor	F statistic	df	n	*P* value	R^2	Estimate	SE
Number of large trees	4.448	1,79	81	0.038 *	0.0533	0.17987	0.08529
Number of fruiting trees	6.508	1,79	81	0.013 *	0.07611	0.6006	0.2354
Proximity to settlement	43.25	1,79	81	4.77e-09 ***	0.3538	0.43886	0.06673
Vertical vegetation herogeneity	29.18	1,79	81	6.77e-07 ***	0.2697	3.246	0.601
Proximity to forest	29.06	1,79	81	7.08e-07 ***	0.2689	-3.8865	0.7210

The best model for species richness of insectivorous birds was obtained from a mixed effect of land use and large trees, which had the lowest Akaike's Information Criterion (AIC 417.33) (Table 20).

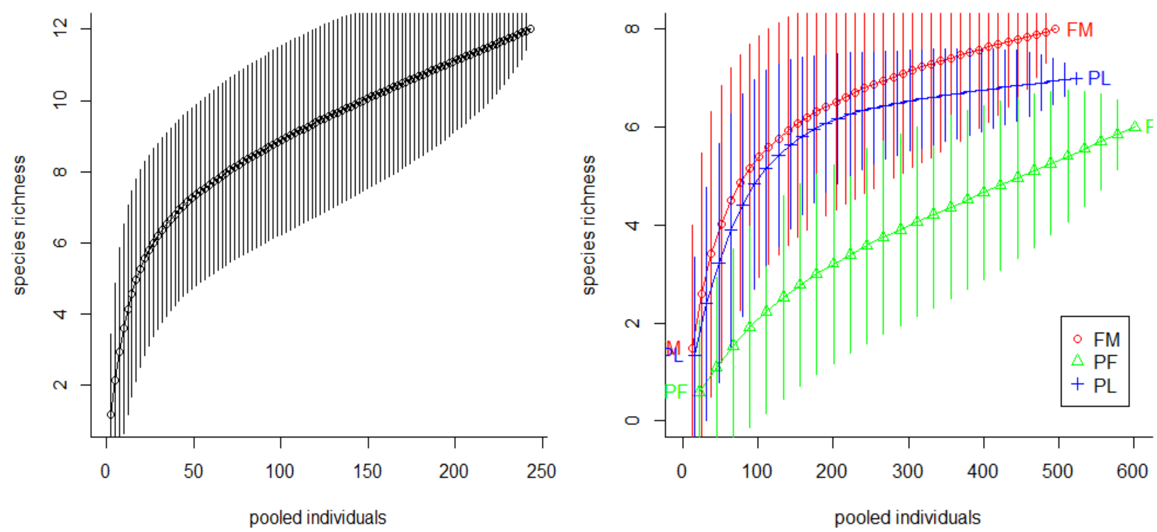
Table 20: Akaike's Information Criterion (AIC) of models for mixed effect of habitat factors on insectivores. Large number of trees and fruiting trees were counts of individuals. Vertical vegetation heterogeneity was based on Shannon diversity index of % cover of vegetation layers. The models are ranked based on the AIC value. The lowest AIC value explains the best habitat model.

Mixed effect model of habitat factors	AIC value	Deviance
1. Land use + Large trees	417.33	100.588
2. Land use + Large trees + proximity to settlement	417.53	101.38
3. Land use + Vegetation heterogeneity	418.76	99.626
4. Land use + Large trees + Fruiting trees + Proximity to settlement	419.19	101.10
5. Land use + Large trees + vertical vegetation heterogeneity	419.25	100.83
6. Land use + Large trees + Fruiting trees + Proximity to forest	421.197	100.345

3.11 Granivore richness and distribution

3.11.1 Effects of land use and vegetation types on granivores

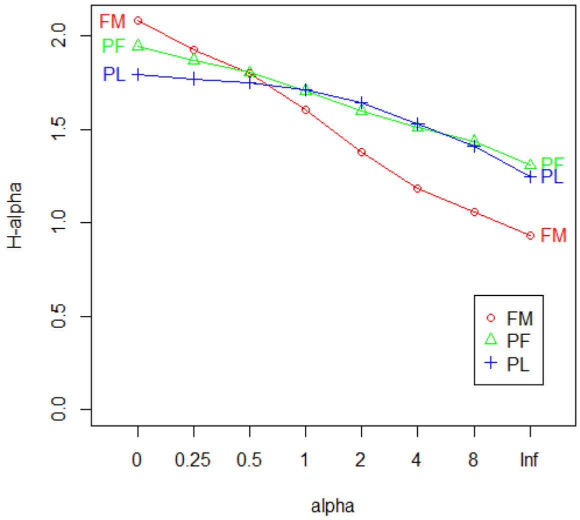
Farmland recorded 8 granivorous bird species, plantation and primary forest 7 species, and plantation forest 6 species, each with 27 counts. Primary forest recorded the lowest number of individual granivores, with the highest number in farmlands (Figure 17).



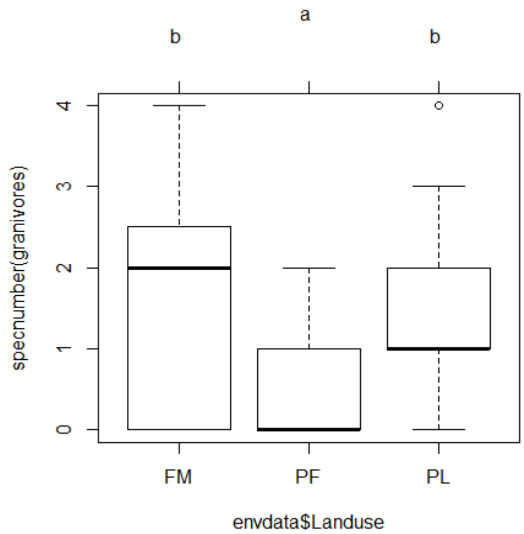
(a) (b)

Figure 17: (**a**) species accumulation curves of granivorous birds recorded in 81 points in Arabuko Sokoke Forest and neighbouring farmlands. (**b**) species accumulation curves per land use type (n=27). (**c**) species accumulation curves showing distribution of number of individuals in each land use type.

A total of 13 granivorous bird species was recorded. I found land use type to have a significant effect on granivorous species richness ($F_{2, 78} = 6.548$, $P < 0.05$, n=81). However diversity could not be compared among the land use systems due to intercepting Renyi profiles, which invalidates this method of comparison. Vegetation type had no significant effect of granivore species richness (Figure 18).



(a)



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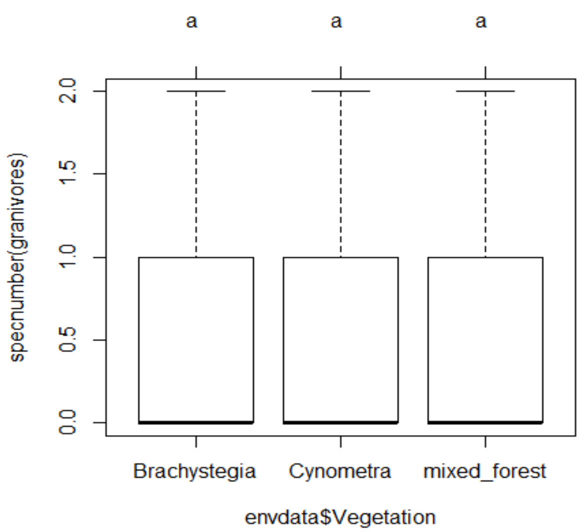


(c)

Figure 18: Renyi diversity profiles and box plots comparing granivore birds richness in three land use types.(**a**) Renyi diversity profiles for granivore birds per land use type. (**b**) Box plots comparing granivore richness in the three land use types. FM=farmland, PF=primary forest, PL=plantation forest. Land use types marked by similar letters are not different, while that marked with a different letter is statistically different. (**c**) Box plots comparing richness of granivores in three vegetation types in primary forest (*Brachystegia*, *Cynometra and* Mixed Forest*).* The box plots indicate the Mean ±SE.

The difference between primary forest and farmland was significant, Tukey test ($P<0.05$) (Table 21). Vegetation type within the primary forest (*Brachystegia, Cynometra and* Mixed Forest) had no significant effect on the species richness of granivorous birds ($F_{2, 24} = 0.06$, $P > 0.05$, n=27).

Table 21: Tukey HSD test for pairwise comparison of mean species richness the land use types. PF = primary forest, FM = farmland, PL = Plantation forest. Significant difference at 95% confidence interval (*P*=0.05). Significant difference between two pairs, PF-FM and PL-PF.

	Estimate	Std. Error	t value	P value
PF - FM -	0.9259	0.2749	-3.369	0.003 **
PL - FM	-0.1481	0.2749	-0.539	0.852
PL - PF	0.7778	0.2749	2.830	0.016 *

3.11.2 Habitat factors influencing richness of granivorous birds.

Proximity to forest had significant positive influence on richness of granivorous bird species ($P<0.05$) in farmland. However, proximity to settlement had a strong negative effect on richness of this guild ($P<0.001$). Presence of large trees and vertical vegetation heterogeneity had no influence on richness of this bird category ($P>0.05$) (Table 22).

Table 22: Effects of habitat factors on richness of granivorous bird species, –ve estimate indicates negative effects and +ve estimate indicate positive effect. SE= Standard Error.

Habitat factor	F statistic	df	n	*P* value	R^2	Estimate	SE
Number of large trees	1.157	1,79	81	0.287	0.01437	-0.02455	0.0228
Number of fruiting trees	0.902	1,79	81	0.345	0.03803	-0.06082	0.06404
Proximity to settlement	13.45	1,79	81	< 0.001***	0.04595	-0.07399	0.02018
Vertical vegetation herogeneity	1.666	1,79	81	0.201	0.03467	-0.2362	0.1830
Proximity to forest	4.674	1,79	81	0.034 *	0.03803	0.4658	0.2154

The best model for richness of granivorous birds was obtained from mixed effect of land use and proximity to settlement, which had the lowest Akaike's Information Criterion value (AIC 10) (Table 23).

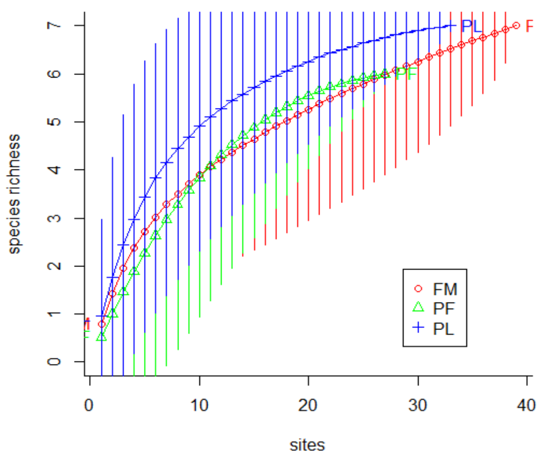
Table 23: Akaike's Information Criterion (AIC) of models for mixed effect of habitat factors on granivores. Large number of trees and fruiting trees were counts of individuals. Vertical vegetation heterogeneity was based on Shannon diversity index of % cover of vegetation layers. The models are ranked based on the AIC value. The lowest AIC value explains the best habitat model.

Mixed effect model of habitat factors	AIC value	Deviance
Land use + Proximity to settlement	10	85.312
Land use + Large trees + vertical vegetation heterogeneity	12	82.927
Land use + Proximity to forest + vertical heterogeneity	195	84.126

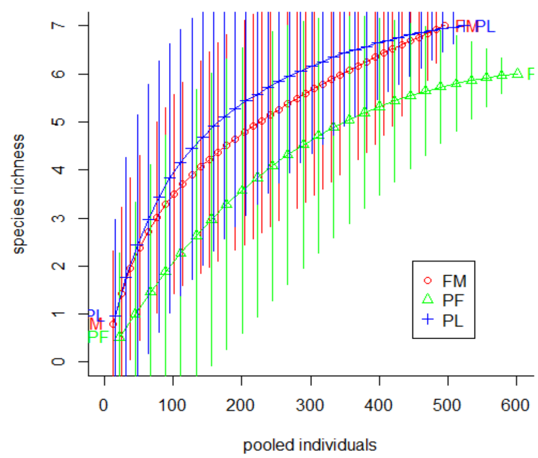
3.12 Carnivorous bird species richness and distribution

3.12.1 Effects of land use and vegetation types on carnivore bird species

A total of 10 species of carnivorous bird species was recorded at the 81 points. Plantation forest and farmland recorded more species than primary forest. More individuals were recorded in Plantation forest followed by farmland than in primary forest (Figure 19).



(a)



(b)

Figure 19: Species accumulation curves of carnivorous bird species. (a) Species accumulation curves of carnivorous birds per land use type, (n=27). (b) Species accumulation curves showing distribution of pooled individuals of carnivorous birds in each land use.

Overall diversity of carnivorous birds was higher in plantation forest as shown by its Renyi profile. However the diversity in farmland and primary forest could not be compared due to intersecting Renyi profiles (Figure 19). Land use had no significant effect on species richness of carnivorous birds ($F_{2, 78}$ = 1.591, P > 0.05, n=81). Similarly, there was no significant difference in the number of species of carnivorous birds between the three vegetation types within Arabuko Sokoke Forest (*Brachystegia*, *Cynometra* and Mixed Forest) ($F_{2, 24} = 2.55$, $P > 0.05$, n=27) (Figure 20).

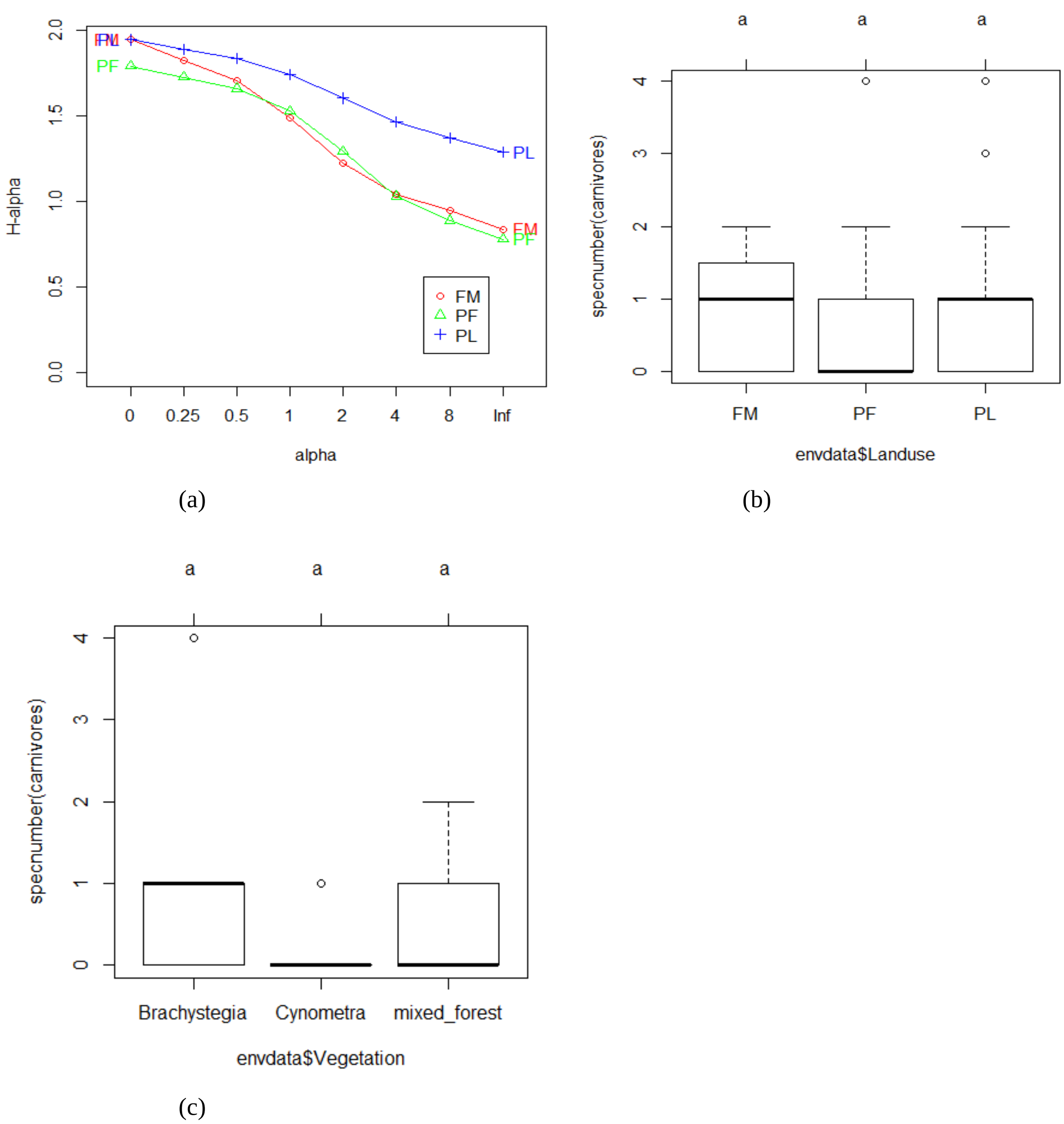


Figure 20: Comparing diversity of carnivorous birds in land use and vegetation types (a) Renyi diversity profiles for carnivorous birds per land use type. (b) Box plots comparing carnivore richness in the three land use types. FM=farmland, PF=primary forest, PL=plantation forest. (c) Box plots comparing richness of granivores in three vegetation types in primary forest (*Brachystegia*, *Cynometra* and Mixed Forest*)*. All land use types are marked by similar letters showing no significant difference in species richness between land use and vegetation types. The box plots indicate the Mean ±SE.

3.12.2 Habitat factors influencing species richness of carnivorous birds

Vertical vegetation heterogeneity had no influence on species richness of carnivorous birds. Also proximity to settlement or proximity to forest did not influence the richness of this guild, nor did the number of large trees and the number of fruiting trees (P>0.05) (Table 24).

Table 24:Table 24: Effects of habitat factors on species richness of carnivorous bird species, –ve estimate indicates negative effects and +ve estimate indicate positive effect. SE= Standard Error.

Habitat factor	F statistic	df	n	*P* value	R^2	Estimate	SE
Number of large trees	0.2909	1,79	81	0.591	0.003669	-0.01081	0.02005
Number of fruiting trees	1.198	1,79	81	0.277	0.01493	0.06095	0.05569
Proximity to settlement	3.13	1,79	81	0.081	0.03811	-0.03300	0.01865
Vertical vegetation herogeneity	0.01342	1,79	81	0.908	0.0001699	0.01866	0.16111
Proximity to forest	1.593	1,79	81	0.211	0.01976	0.2414	0.1913

The best model for richness of carnivorous birds was obtained from a mixed effect of land use, proximity to settlement and vegetation heterogeneity, which had the lowest Akaike's Information Criterion value (AIC 195.84) (Table 25).

Table 25: Akaike's Information Criterion (AIC) of different models for mixed effect of habitat factors. Large number of trees and fruiting trees were counts of individuals. Vertical vegetation heterogeneity was based on Shannon diversity index of % cover of vegetation layers. The models are ranked based on the AIC value. The lowest AIC value explains the best habitat model.

Mixed effect model of habitat factors	AIC value	Deviance
1. Land use + Proximity to settlement + vertical vegetation heterogeneity	195.84	84.278
2. Land use + Proximity to settlement	196.05	85.651
3. Land use + Large trees + Proximity to settlement+ vertical vegetation heterogeneity	197.37	84.152
4. Land use + Large trees + Proximity to settlement	198.05	85.655

CHAPTER FOUR

4. DISCUSSION

4.1 Response of the avian community to land use at Arabuko Sokoke Forest

I found a species-rich bird community in the primary forest while the disturbed farmlands held fewer species. Similar findings have been documented by Beier et al. (2002), Newmark (2006) and Arriaga-Weiss et al. (2008). High bird species diversity in primary forest can be attributed in part to high vertical vegetation heterogeneity and the presence of fruiting trees. Primary forest at Arabuko Sokoke consisted of diverse vegetation layers ranging from the understorey to the upper canopy. With similar sampling effort in the three vegetation types in the primary forest, I recorded greater species diversity in *Brachystegia* and Mixed Forest, and lower diversity in the *Cynometra* zone. This could be partly explained by the difference in vertical vegetation heterogeneity observed between the vegetation types. *Brachystegia* and Mixed Forest had a higher heterogeneity due to presence of many large trees and a dense understory, favorable for the foraging and nesting of many bird species as compared to the *Cynometra* thicket which had no large trees and vegetation at a uniform height.

Bird communities in Arabuko Sokoke Forest and farmlands were found to be distinct, matching the marked difference in habitat structure. Contrary to my expectation, there was limited species overlap between the bird community in the primary forest and the nearby plantation forest. I noted a marked difference in habitat structure between primary forest and plantation forest:, whereas points in primary forest were characterized by high vertical vegetation heterogeneity and a high number of fruiting trees, many points in the plantation forest were characterized by wide open spaces, low tree density and a low number of fruiting trees (Appendix I), indicative of low habitat quality. This could explain the reduced bird species diversity in plantations. This is similar to the findings of Andrén (1994) on review of effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat; Renner et al. (2006) in tropical montane cloud forest in Guatemala; Harvey & Villalobos (2007) at the indigenous reserves of Talamanca, Costa Rica, and Muhamad et al. (2013) in West Java, Indonesia, where a marked reduction in forest dependent species and an overall shift in bird species composition was noted in agroforestry systems. Some forest bird species in Arabuko Sokoke appear to be highly specialized and sparsely distributed e.g. Pale Batis, Tiny Greenbul, Four-coloured Bush-shrike; and are wholly dependent on the forest for nesting (Plate 11), food resources and refuge from predators.

Plate 11: Weavers nest in the Mixed Forest in Arabuko Sokoke Forest showing preference to mixed vegetation type for nesting. Photo taken on 24th May 2013.

Forest interior species have been reported to be highly sensitive to disturbance and will shun clearings or gaps resulting from treefalls (Thiollay 1999). Among the species found exclusively in the forest were Kenya Crested Guineafowl, Fischer's Greenbul, Clarke's

Weaver, Amani Sunbird and Plain-backed Sunbird. These birds are likely dependent on less disturbed habitats, hence restricted to primary forest. The decline in bird species diversity in plantation forest and farmlands can be linked to the extent of disturbance and reduction of native vegetation in these two land use systems. Disruption of native habitats in farmlands around the forest has reduced the population of native plant species on which birds and other animals may depend for wild fruits, so that farmlands support fewer species (Sodhi et al. 2004; Arriaga-Weiss et al. 2008). Low tree cover in plantations and farmlands due to intensive disturbance leading to low vertical vegetation heterogeneity, could be a major contributor to the low number of species and reduced density and abundance of many bird species at survey points in plantation and farmland. However, I found evidence of increased diversity at points in farmlands with remnant native vegetation patches and high vertical vegetation heterogeneity (Appendix I). Other studies have also shown that even small changes in the structure and composition of tree cover may have a significant impact on bird assemblages (Harvey & Villalobos 2007), leading to changes in bird diversity and community composition, with fewer species and foraging guilds present in more intensively managed landscapes (Collard et al. 2009).

Large scale disturbance in plantation forest resulting in clear-felled areas could be a major contributing factor to low species counts. Excessive disturbance brought about by logging operations usually reduces total avian diversity (Thiollay 1997). Such changes have been documented to particularly affect less abundant, range-restricted birds and rainforest specialists (Raman 2001). Life history traits, such as large territories; sedentary lifestyles, and a preference for mature forest (Stratford & Stouffer1999) could apply to bird populations in Arabuko Sokoke Forest. The type of trees in the plantations, mainly *Eucalyptus sp*. and *Casuarina sp*. (Plate 12) could be less effective in meeting foraging requirements for birds due to scarcity of fruit resources from these tree species.

Plate 12: *Casuarina sp.* plantation at a survey point in the plantation forest

A study in East Usambara in Tanzania by John and Kabigumila (2007) also recorded significantly lower diversity of forest birds in *Eucalyptus* plantations compared to primary forest, which they attributed to limited nesting opportunities and reduced understorey cover. However, low tree diversity and density in the plantation could also have contributed to low bird counts in the plantations. Plantation forest was associated with reduced variation in the vegetation structure, which lacks an intermediate stratum to provide the nesting and foraging habitat which many bird species require. Many bird species in farmlands were recorded within intact native habitat patches and particularly those with stands of fruiting trees despite their proximity to settlements, confirming the importance of fruiting trees in farmlands for bird diversity. Trees found to be significant to birds particularly frugivores in farmlands were neem tree and cashew nut.

Planting of native tree species is unlikely to be adopted by farmers without either financial incentives, or demonstrating the additional benefits of native trees for farmers (Douglas et al. 2014). This study has confirmed the positive influence of vertical vegetation heterogeneity and presence of fruiting trees in maintaining higher diversity of bird populations. Farmers do plant a few exotic fruiting trees like the neem tree, cashew nuts and mangoes for their household use, which are then also utilized by frugivores, but no incentives are currently in place to improve retention of native vegetation in farmlands. Native forest patches create habitat heterogeneity for protection, nesting and provide perch sites from which birds can defend their territories (Kutt & Martin 2010). Native vegetation patches in farmlands could provide specific high-quality resources that cannot be found readily in the open farmlands (Aerts *et al*. 2007), and stands of tall indigenous trees are favoured for foraging and roosting by many species of African birds (Thiollay 2006). The General Linear Modelling analysis of this study found a significant positive influence of the mixed effect of the number of large trees and the number of fruiting trees on bird diversity.

Heterogeneous vegetation structure will provide a range of perching heights for different bird species including forest dependent species like Plain-backed Sunbird, Sokoke Pipit, Pale Batis, Blue-mantled Crested-flycatcher, Clarke's Weaver and Thick-billed Cuckoo. The importance of understorey vegetation to bird diversity was also emphasized by Munyekewe e*t al.* (2008) in Kakamega forest in western Kenya. High diversity of birds in mixed vegetation may imply that the structure of the habitat or land use system may be more important for bird conservation than the plant species composition (Appendix I). Past studies have also documented the importance of habitat structure to bird conservation e.g. Harvey & Villalobos (2007) in Talamanca, Costa Rica, Ding Li Yong et al. (2011) on land-bridge forest islands in Peninsular, Malaysia, Munyekewe et al. (2008) at Kakamega forest in Western Kenya, and (Sweeney et al. 2010) on Sitka spruce plantations in Ireland. While conservation of the primary forest is important for bird conservation in this area, breeding areas outside the forest may be equally significant. The breeding area for Clarke's Weaver has been a mystery for many years and the nest had never been described (Craig 2010). Only recently the birds were discovered nesting low down within the sedges of a seasonal wetland in the Dakatcha woodland at a site which is threatened by harvesting for thatch; this is the first known breeding record for Clarke's Weaver (Jackson et al. 2015). While the Dakatcha woodland is a designated Important Bird Area (IBA), the forests and wetlands have no formal protection, but fall under the management of a local community conservation group (Jackson et al. 2015). Formal protection of this woodland and the adjacent wetland is thus essential for protection of the breeding sites of this endemic, which at other times is apparently restricted to Arabuko Sokoke Forest.

4.2 Response of birds to seasonality

Increased diversity and abundance of birds were also recorded during the rainy seasons. The wet season in June and light rains in November are likely to promote both plant growth and insect emergence. Where the annual cycle includes one long dry and one long wet season, most bird species breed around the rainy season with only a few specialists laying during the dry period. Breeding duration ranges from one month to over two months. Forested areas in

East Africa typically have annual rainfall between 1500-2500mm and many birds will breed in the wettest part of the year (Brown & Britton 1980). In Arabuko Sokoke the wettest month is June when half the total annual rainfall falls on the Kenyan coastal belt. This is likely to determine the breeding season of most birds in the area. However, in areas with two wet seasons, some species tend to breed twice a year, whereas others nest during the short rains, but avoid the long rains; in West African rainforest, many birds avoid breeding in the wettest months of the year (Serle 1981). However, most East African data do not show this pattern except for Eastern Tanzania which has clearly defined bimodal rainfall peaks (Brown & Britton 1980). Thus, one main breeding season around the month of June could be expected for birds in Arabuko Sokoke Forest.

Species recorded in high numbers during the wet season as compared to the dry season included; African Golden Oriole, Black-backed Puffback, Black-bellied Starling, African Pied Wagtail, Collared Sunbird, Amethyst Sunbird, and Black-headed Weaver. Some migrant species such as; Yellowbill, Black Cuckoo-Shrike and African Pygmy Kingfisher were only recorded during the wet seasons. More food resources including fruits, flowers, and arthropods are readily available to birds of different guilds during the rainy seasons. A similar response of birds to seasonality was recorded by Faaborg (1982), in Puerto Rico where bird breeding was primarily synchronized to the rainy season and a lack of rainfall drastically affected both breeding success and population levels. Since the reproduction of African birds can be seasonal or aseasonal depending on the species considered (Borghesio *et al.* 2014), we need long term studies on the population dynamics and seasonal distribution of key resident and migrant bird species in this area. A significant increase in fruits; flowers and vegetation cover with onset of the rainy season, and a concomitant increase in bird populations has been reported in Northern Kenya by (Borghesio & Laiolo 2014).

4.3 Response of birds to habitat factors

Some species of high conservation concern were forest restricted including the Sokoke pipit, Clarke's Weaver and the Kenya Crested Guineafowl; many others showed high forest dependence (Table 7). The observed forest dependence of many species could be attributed to the high disturbance in the adjacent plantation and farmlands with many forest species particularly scarce in farmland.

Table 26: Percentage distribution of species in the three land use systems, n=total abundance of each species. Percentage occurrence calculated based on the total occurrence of all observed individuals during the survey period. FM=Farmland, PL=Plantation, PF=Primary forest. Some species occurred in significant numbers in more than one land use.

Species	n	Occurrence (%)	Preference
Black-headed Heron	1	0.04	FM
Crested Francolin	1	0.04	FM
Grey-headed Kingfisher	1	0.04	FM
Red-billed Firefinch	1	0.04	FM
Amethyst Sunbird	1	0.04	FM
Helmeted Guineafowl	1	0.04	FM
Eurasian Golden Oriole	1	0.04	FM
Klaas's Cuckoo	1	0.04	PF
African Pygmy Kingfisher	1	0.04	PF
Slate-coloured Boubou	1	0.04	PF
Northern Carmine Bee-eater	2	0.08	FM
Sacred Ibis	2	0.08	FM
Green-backed Camaroptera	2	0.08	PF,PL
Great Sparrowhawk	2	0.08	PL
Common Waxbill	2	0.08	PL
Crowned Hornbill	2	0.08	PL
Hadeda Ibis	3	0.12	FM
African Fish Eagle	4	0.15	FM
Clarke's Weaver	4	0.15	PF
Ashy Flycatcher	4	0.15	PF,FM
Grey-headed Sparrow	4	0.15	PL
Green Wood-hoopoe	4	0.15	PL
Southern Banded Snake-Eagle	5	0.19	PF,PL
Lesser Striped Swallows	6	0.23	PL
Lesser Honeyguide	6	0.23	PL
House Crow	7	0.27	FM
Black Kite	7	0.27	FM,PL
White-throated Bee-eater	7	0.27	PF,PL
Mangrove Kingfisher	7	0.27	PF,PL,FM
Pied Crow	8	0.31	FM
Black Cuckoo-shrike	8	0.31	PF,PL
African Goshawk	8	0.31	PL
African Pied Wagtail	9	0.35	FM

Narina Trogon	9	0.35	PF,PL
Sokoke Pipit	10	0.38	PF
Kenya Crested Guineafowl	10	0.38	PF
Common Scimitarbill	10	0.38	PF,PL
Peters's Twinspot	10	0.38	PL
Scaly-throated Honeyguide	10	0.38	PL
Plain-backed Sunbird	11	0.42	PF
East Coast Akalat	11	0.42	PF
Red-cheeked Cordon-bleu	12	0.46	FM
Pallid Honeyguide	12	0.46	PL
Speckled Mousebird	13	0.5	FM
Eastern Green Tinkerbird	13	0.5	PF,PL
African Palm Swift	13	0.5	PF,PL,FM
African Paradise-flycatcher	13	0.5	PF,PL,FM
Yellowbill	15	0.58	PL,FM
Red-tailed Ant-Thrush	17	0.65	PF
Blue-mantled Crested-flycatcher	17	0.65	PF
Ring-necked Dove	18	0.69	FM
Red-eyed Dove	18	0.69	FM
Terrestrial Brownbul	18	0.69	PF,PL
Yellow-rumped Tinkerbird	18	0.69	PF,PL,FM
Fischer's Turaco	18	0.69	PL
Forest Batis	19	0.73	PF
Eastern Bearded Scrub-Robin	19	0.73	PF,PL
Retz's Helmet-shrike	19	0.73	PL
Green Pigeon	21	0.81	FM
Four-coloured Bush-shrike	21	0.81	PF
Tambourine Dove	21	0.81	PF,PL,FM
Mombasa Woodpecker	22	0.85	PF,PL
Tiny Greenbul	23	0.88	PF
Black-crowned Tchagra	25	0.96	FM
Black-headed Weaver	25	0.96	FM,PF
Pale Batis	25	0.96	PF
African Golden Oriole	25	0.96	PL,FM
Amani Sunbird	26	1	PF
Thick-billed Cuckoo	27	1.04	FM
White-browed Coucal	27	1.04	FM,PL
Lizard Buzzard	28	1.08	PF,PL,FM
Dark-backed Weaver	33	1.27	PF,PL
White-browed Robin-Chat	34	1.31	PF,PL,FM
Trumpeter Hornbill	35	1.34	PF,PL,FM
Eastern Nicator	36	1.38	PF,PL
Emerald-spotted Wood-dove	42	1.61	PF,PL,FM
Northern Brownbul	46	1.77	PF,PL,FM
Red-capped Robin-Chat	47	1.81	PF,PL,FM
Black-headed Oriole	47	1.81	PF,PL,FM
Black-backed Puffback	50	1.92	PF,PL,FM
Fischer's Greenbul	56	2.15	PF
Little Yellow Flycatcher	56	2.15	PF,PL
Yellow-fronted Canary	58	2.23	FM,PL
Tawny-flanked Prinia	60	2.31	FM
Grey-backed Camaroptera	69	2.65	PF,PL,FM
Bronze Mannikin	72	2.77	PF,PL,FM
Green Barbet	77	2.96	PF,PL,FM
Tropical Boubou	78	3	PF,PL,FM
Fork-tailed Drongo	79	3.03	PF,PL,FM
Scaly Babbler	79	3.03	PL,FM
Black-headed Apalis	91	3.5	PF
Black-bellied Starling	91	3.5	PF,PL,FM
Chestnut-fronted Helmet-shrike	94	3.61	PF,PL
Common Bulbul	101	3.88	FM,PL
Zanzibar Sombre Greenbul	111	4.26	PF,PL,FM
Olive Sunbird	114	4.38	PF,PL,FM
Collared Sunbird	155	5.95	PF,PL,FM

Farmland and plantation are currently subject to frequent large scale disturbance and would likely not support habitat sensitive forest species. A decline of forest specialists in degraded farmland around Arabuko Sokoke Forest has also been reported by (Matiku et al. 2013). Forest dependent species are the first to be lost from degraded areas, whereas widespread, generalist species may increase in abundance (Lambert 1992). Tree cover in the plantation forest is low while native vegetation cover in farmland has been greatly reduced for small scale subsistence agriculture with only a few tree stands and narrow strips of remnant natural vegetation. Resident forest species are often behaviourally inhibited to enter open farmlands, which thus act as barriers for their dispersal (Harris & Reed 2002). Continuous turnover of plantation vegetation and large scale transformation in farmland has likely contributed to the replacement of forest dependent bird species by open habitat species. A marked decrease in forest species composition along a gradient from primary forest to farmland has also been reported in South West Cameroon (Waltert 2005) and in Sumatra where up to half of the total number of forest birds was lost in open farmlands (Muhamad et al. 2013).

4.4 Response of frugivorous birds to land use type

While there was no significant effect of land use on frugivore bird species diversity in the statistical analysis, the number of fruiting trees had a significant positive influence on their diversity, whereas the number of large trees had no influence on the diversity of this guild. Diversity of frugivorous birds was also not influenced by proximity to settlement, proximity to forest nor vertical vegetation heterogeneity. Overall, I found no significant difference in frugivore diversity among the land use types. This could be attributed to feeding behavior of many frugivorous birds, which shows dependence of fruit resources and will move across a wide geographical range in search of the resource. However, primary forest is likely preferred by local frugivorous birds for foraging, nesting and perching requirements (Harvey & Villalobos 2007; Arriaga-Weiss et al. 2008). The abundance of frugivores is especially dependent on tree height and in some cases on the presence of large tree species e.g. *Brachystegia weberi* with cavities for nesting (Arriaga-Weiss et al. 2008. Large, tall *Brachystegia* trees which are absent from the plantations and farmlands are likely to provide nesting requirements for large frugivores like the Trumpeter and Crowned Hornbills. The secondary cavity-nesters are likely to be affected by uncontrolled firewood removal from the forest; extensive wood collection from the forest edge which is easily accessible by the local community could compel these species to move to more favourable sites in the forest interior. Cavity-nesting birds, mammals and invertebrates are all negatively affected by firewood collection (Du Plessis 1995). Nonetheless, it seems that habitat utilization by bird frugivores is more dependent on the availability of fruit resources than vegetation structure, hence no significant difference in diversity of frugivore species were detected among the three land use systems.

Between 35 and 50% of resident forest bird species in southern Africa have been reported to rely on tree cavities for roosting or breeding (Du Plessis 1995). Presence of tree cavities could significantly influence the distribution of up to 40 % of the avifauna in a forested area (Scott et al. 1980). Cavity nesting species are highly dependent on old trees or dead wood for nesting, roosting and feeding, which may represent a limiting resource for them (Martin & Eadie 1999). In Arabuko Sokoke Forest some of the obligate secondary cavity-nesters which are likely to be affected include Crowned Hornbill, Trumpeter Hornbill, Green Wood-hoopoe, Green Barbet, Narina Trogon and Black-bellied Starling.

Apart from birds, mammals such as duikers, Syke's monkeys, yellow baboons, some rodents and elephants could also be playing important role in fruit dispersal and plant recruitment. There is direct evidence of plants germinating from elephant dung from seeds passed out in the dung, an indication of their role in seed dispersal (Plate 13).

Plate 13: Tree seedlings germinating for elephant dung in Arabuko Sokoke Forest. A confirmation of the role of elephants in seed dispersal and native plant recruitment. Photo taken along elephant track in the Arabuko Sokoke Forest on 24th May 2013.

Fruiting native trees could be particularly important to specialist frugivores in the area e.g. I observed Green Barbets actively foraging on *Strychnos madagascarensis* in the primary forest. The diet for Barbets is almost exclusively made up of fruit, especially figs (Shanahan et al. 2001), they defecate viable seeds and are considered to be significant fig seed dispersers in Africa (Craig 1996). Assemblages of large frugivores worldwide show a preference for intact forests and they are highly vulnerable to forest disturbance (Arriaga-Weiss et al. 2008; Sekercioglu 2012). However, Green Barbet was well distributed across the three habitats. Many frugivores recorded in farmlands were associated with the few remaining native fruiting trees (Table 8).

Table 27: Tukey test result of mean number of fruiting trees between the land use systems. Number of fruiting trees indicated in farmland and plantation include both native and domesticated. Fruiting trees in primary forest were all native. N = 27, number of points. *.The mean difference is significant at the 0.05 level.

Land use category	Mean number of fruiting trees	N	Pairwise comparison	Mean Difference	P value	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Plantation	3.81	27	Primary Forest	-1.556*	.003	-2.65	-.46
			Farmland	.481	.549	-.62	1.58
Primary Forest	3.33	27	Plantation	1.556*	.003	.46	2.65
			Farmland	2.037*	.000	.94	3.14
Farmland	5.37	27	Plantation	-.481	.549	-1.58	.62
			Primary Forest	-2.037*	.000	-3.14	-.94

Frugivore composition can be rapidly altered by forest fragmentation (Figueroa-Esquivel et al. 2009), and large canopy frugivores are the most vulnerable group within the guild (Thiollay 1999; Arriaga-Weiss et al. 2008), since many prefer moist forests (Aerts et al. 2007) and those with a high tree density (Arriaga-Weiss et al. 2008; Sekercioglu 2012). Mangoes, guavas and cashew nuts were important to this guild in farmlands as they provided fruit resources. It is unlikely that these birds will breed in farmlands due to the intensity of human activity.

I did not test frugivore preference for specific tree species, and the different fruit tree species were lumped together. However, avian digestive traits vary strongly between species and even minor chemical differences in fruit pulp composition may have major effects on fruit preference (Levey & Del Rio 2001; Lehouck et al. 2009). This needs to be investigated further for local frugivorous birds. Fig trees (*Ficus* sp.) were scarce in the areas surveyed, and none were recorded at the sampling points, so that the effect of figs on bird frugivore distribution patterns could not be tested. To infer about ecosystem services, the loss of fruiting and large trees in farmland around Arabuko Sokoke Forest could likely reduce the pool of available avian seed dispersers, limiting seed dispersal service. Enhancing landscape connectivity across the two land use types by planting fruiting and sustaining large trees may promote movement of frugivore birds and dispersal of seeds (Guevara & Laborde 1993; Lens 2002; Levey 2005; Berens 2008).

Plantation areas with needle leaved trees e.g. *Casuarina sp.*, *Eucalyptus sp.* and bamboo registered low numbers of frugivores and bird species in general (Appendix). Numbers of large fruiting wild trees were eliminated by vegetation clearance and many large canopy regular frugivores may have been affected by lack of food resources, and only persisted in the primary forest. Similar results were also found by (Thiollay 1999) on effect of disturbance on frugivores in tropical rain forest of French Guiana. Based on AIC models, increasing the number of fruiting trees in farmland will likely improve food availability for frugivores.

4.5 Response of nectarivorous birds to habitat factors

Similar sampling effort in each land use type showed higher diversity of regular nectarivores in primary forest. Two regular nectarivores the Amani Sunbird and Plain-backed Sunbird showed a marked dependence on primary forest while the Collared Sunbird and Olive Sunbird utilised resources in all three land use systems. While, this study did not test the influence of number of flowering trees of nectarivore diversity, the positive influence of the number fruiting trees on diversity of this guild can be used to infer this. The wide distribution of occasional nectarivores such as the Zanzibar Sombre Greenbul, Dark-backed Weaver and Black-headed Weaver in the three land use types suggest that occasional nectarivores are not severely affected by land use change. This result is in agreement with Ribon et al. (2003) in Atlantic forest fragments in south eastern Brazil. A positive influence of proximity to farmland suggests that nectarivores also utilize flowers from plants at the forest edges, where increased plant productivity may be found, which is consistent with the findings of Thiollay (1999) in French Guiana and Arriaga-Weiss et al. (2008) on guild response to habitat variables in Tabasco, Mexico.

Other studies have found higher nectarivore diversity and abundance in Mixed Forest which was moist with high density tree cover (Aerts et al. 2007). It is possible that Mixed Forest has more flowering tree species as compared to other vegetation types. Within the farm lands, *Thevetia pruviana* provided flowers for foraging nectarivores. There was however a major decline in abundance and diversity of nectarivores in farmlands, as found also by Martin et al. (2006) and Sekercioglu (2012). However, we need to determine if these nectar feeding birds have preferences for particular native plants in the forest, which could be restricting their occurrence. In New Guinea, a large proportion of flowering plant species visited by birds were canopy tree species (Brown & Hopkins 1995); in South America whereas hummingbirds dominated the lower levels in the forest, the canopy nectar feeders were primarily from other guilds, and represented occasional nectarivores (Rocca & Sazima 2008).

The Amani Sunbird and Plain-backed Sunbird, specialist nectarivores, were restricted to the primary forest. This could be indicative of either limited food resources in farmland or habitat sensitivity to degraded farmlands. Plant diversity in the primary forest also provides an opportunity to supplement their diet with insects on flowering trees. When feeding, they move continuously, searching leaves for arthropods and visiting flowers. They usually occur in pairs while gleaning insects from foliage, but larger numbers may gather at flowering trees (Oyugi et al. 2012). Agroforestry interventions in farmland planting flowering trees might increase the use of farmland by nectarivorous birds. With proper management, many cultivated tree species may provide nectar that will attract bird nectarivores (Collazo & Groom 2004) and while in the farms offer pollination, and pest control services (Jacobson et al. 2003). Vertical habitat heterogeneity was the most important model element for increased diversity of nectarivore bird species. Therefore, the best habitat for utilization by nectarivore birds will need high vertical vegetation heterogeneity and proximity to primary forest.

4.6 Response of insectivorous birds to habitat factors

A rich understorey with shrubs, ranging upwards to large canopy trees in the forest provided diverse foraging zones for this guild, with an abundance of insects. A similar pattern was found by Johns (1991), and Thiollay (1994) in Amazonian rain forest. Insectivores were the dominant group in all the land use types. Large trees in Mixed Forest and *Brachystegia* could be important particularly to bark gleaning bird insectivores because of the increased surface area for feeding e.g. Dark-backed Weaver and Green Woodhoopoes. This study showed that diversity of insectivorous bird species was influenced by many habitat factors including vertical vegetation heterogeneity, the number of large trees and the number of fruiting trees. Modelling suggested that increasing the number of large trees within farmlands and limiting the felling of well-established ones would improve insectivorous bird diversity here.

A reduction in the number of large trees is associated with fewer large insectivorous species such as Drongos and flycatchers which hunt from perches (Seymour & Dean 2009). The high diversity of insectivorous birds in *Brachystegia* can be attributed to high vertical heterogeneity the presence of large trees that ensured abundant insects such as caterpillars, grasshoppers, and other flying insects that were abundant in *Brachystegia* and Mixed Forest. Low diversity of this insectivore guild in *Cynometra* can be explained by low heterogeneity, the lack of large trees a poorly developed understorey.

4.7 Response of granivorous birds to habitat factors

More species of granivorous birds were recorded in farmland compared to primary forest. Granivores are mainly ground feeders and rely largely on grass which is progressively reduced by vegetation cover in the primary forest, leading to a reduction in open areas and light at ground level. Farmland by contrast offered good feeding habitat for ground-based seed eaters. There was a significant relationship between species diversity of granivores and proximity to forest. However, proximity to settlement had a strong negative effect on this guild, while the presence of large trees and vertical vegetation heterogeneity had no influence.

Hunting pressure on large granivores like Guineafowl probably explains the decline of this guild with proximity to settlement. While granivorous birds forage beyond the forest into farmlands, the primary forest constitutes a refuge from predation. Early in the morning during field survey, I regularly observed large groups of Kenya Crested Guineafowl along the forest tracks Naidoo (2004) also reported a decline of bird diversity with increasing distance from Mabira forest in Uganda, where smallholder agriculture is characterised by a low number of trees. This is an indication that many guilds are less diverse in open farmlands with low vegetation cover like the farmlands around Arabuko Sokoke Forest. The linear modelling confirms the importance of proximity to primary forest for the survival of this guild. Improving vegetation cover within farmlands could therefore be important for granivores around Arabuko Sokoke Forest. Using on-farm agroforestry trees and fruiting trees to increase vegetation cover could be adopted easily by local farmers due to the economic value of these trees rather than planting native trees.

4.8 Response of carnivorous birds to habitat factors

There was no significant effect of land use on carnivorous birds, and none of the habitat variables noted was found to influence the diversity of this guild. Vertical vegetation heterogeneity, proximity to settlement and proximity to forest did not influence their diversity, nor did the number of large trees and fruiting trees. Similar results were obtained by Muhamad et al. (2013) who found no effect for distances less than 3 km from primary forest. It is possible that in my survey the short distance from the forest could have meant that species diversity of carnivorous birds did not decline with increasing distance from the forest. However, many predatory birds are known to be sensitive to habitat fragmentation and human disturbance because of their need for large territories (Arriaga-Weiss et al. 2008).

CHAPTER FIVE

5. HUMAN SOCIO-ECONOMICS, KNOWLEDGE OF LOCAL BIRDS AND FOREST CONSERVATION

5.1 Introduction

5.1.1 Local population and forest use

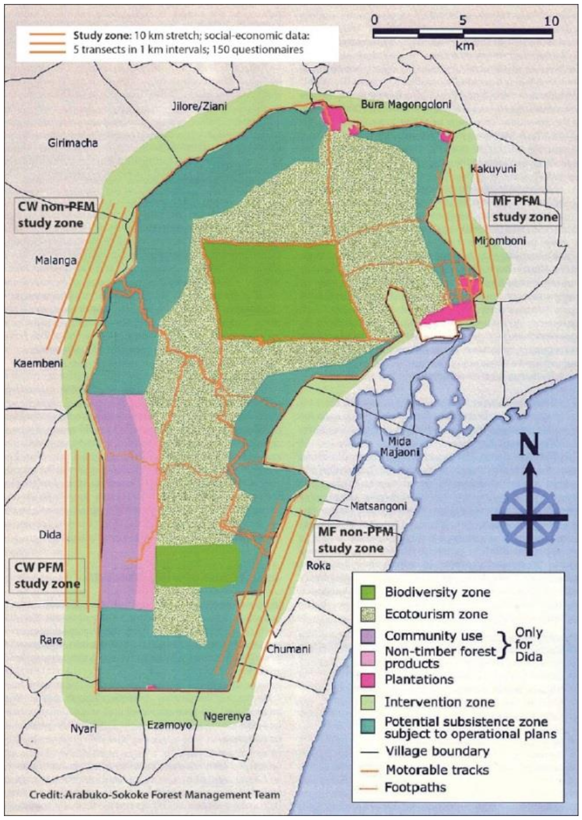
The average population density of the community around Arabuko Sokoke Forest in 2002 was estimated at 10-80 people per Km^2 on the Western side of the forest, 80-180 people per Km^2 on the Eastern side and 180-280 people per Km^2 on Southern side (Arabuko Sokoke Forest Management Team 2002). These figures have certainly increased in recent years, with increasing demands for timber and land for agriculture, leading to a reduction in the extent and condition of the forest (Arabuko Sokoke Forest Management Team 2002). Past studies e.g. Emerton (1994) and Matiku et al. (2013) indicated that communities adjoining the forest within a 5 km buffer zone depended heavily on the forest for their livelihood. It is critical that their socio-economic values be considered in any conservation intervention, if conservation of the forest is to be sustainable. The current level of involvement of the local community remains low with regard to forest-based commercial agroforestry and ecotourism projects. During this study I assessed the local knowledge of birds, the household level of income, and use of resources from Arabuko Sokoke Forest by people in the area.

Traditional benefits obtained by the local community from Arabuko Sokoke Forest include firewood extraction, medicinal plants, building materials, and income from employment related to the forest and non-timber-related forest products. Matiku et al. (2013) reported significant benefits from the forest through forest related employment including actual monthly income from Kipepeo market, casual labour in the bee keeping project, tour guiding and paid assistance in conservation projects. There is however clear evidence of illegal hunting and poaching of forest mammals, so that their numbers are well below the normal carrying capacity (Fitz-Gibbon et al. 1995); about 63% of households around the forest were reported to be involved (Fitz-Gibbon et al. 1995), representing a real threat to forest resources (Kenya Wildlife Service 2013). Animals hunted include elephant shrews, duikers, Syke's monkeys, yellow baboons and bush pigs. Furthermore, elephants in the forest are currently threatened by poaching.

Land around the forest is privately owned but the soils are impoverished leading to poor agricultural returns, which is likely aggravating overdependence on forest resources by the locals for their basic livelihood. Although households have rights to access the forest for extractive uses that include butterflies, honey, mushrooms, medicinal plants and basic materials for household use, including firewood and poles for construction (Matiku et al. 2012), there is evidence of illegal logging and hunting to supplement their household needs. Arabuko Sokoke Forest remains an important source of protein and income to the local community with the harvested biomass estimated at 350 kg/km^2 with an economic value of KES 1.3 million (USD 35,000) in 1991 (Fitz-Gibbon et al. 1995). In the year 2009 (Table 8), mean annual income from the forest was estimated at KES 36, 715 (USD 415) per household per year (Matiku et al. 2013). However, this is likely a minimum figure as benefits from illegal harvests like bush meat were not indicated. Indirect benefits also remain unquantified like ecosystem services including regulation of the water cycle and rainfall in the area, climate regulation, and carbon sequestration among others. I would rate the true benefits of the forest to the local households at much higher values with more potential still untapped in ecotourism, community conservation projects and agroforestry.

5.1.2 Arabuko Sokoke Forest zonation and management plan

Arabuko Sokoke Forest master plan proposes four zones in and around the forest namely, non-extractive zone, divided into a biodiversity conservation sub-zone and eco-tourism sub-zone, subsistence zone, divided into a community use sub-zone and non-timber forest products sub-zone, commercial zone; and intervention zone (Figure 22). Strategies for management of Arabuko Sokoke Forest are categorised in nine thematic areas; biodiversity conservation, subsistence use, eco-tourism and environmental education, problem animal management, forest protection, commercial use, human resource development, research and monitoring (Arabuko Sokoke Forest Management Team 2002). In order of priority, the strategies focus on three main objectives; 1. To conserve and enhance the unique biodiversity of the forest 2. To contribute towards meeting subsistence need and improving the livelihoods of forest-adjacent communities. 3. To improve and develop the condition and potential for utilisation of the forest.



(Source: Arabuko Sokoke Forest Management team 2002)

Figure 21: Four management zones of Arabuko Sokoke Forest

5.1.3 African elephant (*Loxodonta africana*) and conservation planning

The African elephant in Arabuko Sokoke Forest is facing both ecological and conservation challenges including limited water, poaching, and restricted movement due to ring fencing. While ring fencing has reduced human and elephant conflict, it has blocked migration corridors leading to confinement of the elephants with likely genetic isolation of the population. The most recent estimate of forest elephant populations in Africa indicates a decline of approximately 62 percent between 2002 and 2011 and a 30 % loss in their geographical range (Omeja et al. 2014).

Even though the elephant population in Arabuko Sokoke Forest is projected to be within manageable limits at 150-180 (Kenya Wildlife Service 2013), there is already evidence of damage such as uprooting of trees in the Mixed Forest and *Brachystegia* vegetation zones raising concern about forest destruction by the elephants if their numbers increase by natural recruitment. Documentation of the impact of this elephant population on the forest is currently lacking and should be a research priority. In areas where elephant populations are modifying the habitat making it unsuitable for biodiversity conservation, management strategies may call for elephant culls to maintain ecosystem integrity (Shannon et al. 2008); this may apply to this population in the long term. However, such management programs have only been applied in savanna/woodland systems, where estimates of elephant populations are relatively easy (Dickson & Adams 2009). A study on this population should focus on its impacts on the forest, an accurate census, the potential increase by natural recruitment and a model of carrying capacity to inform long term conservation interventions.

Maintaining an elephant population in the forest will require close monitoring of their population dynamics and impacts on the forest. Because elephants are selective in their foraging behaviour targeting areas with high soil quality rather than particular plant species (Holdo 2003), mixed forest is likely to be most at risk of destruction by the elephants. This could result in the loss of several bird species restricted to the forest like Clarke's Weaver, Sokoke Pipit, Amani Sunbird, Plain-backed Sunbird and Fischer's Greenbul. Only at smaller spatial scales when resources are limited do elephants feed unselectively to maintain sufficient food intake (Shrader et al. 2012), which is not currently the case in Arabuko Sokoke Forest. It is expected that Arabuko Sokoke Forest will not have the capacity to support an elephant population enclosed by the perimeter electric fence in the long term, with constant natural recruitment in the absence of any factors regulating the population. They will become locally overabundant prompting the need to urgently plan for their management. Innovative management options will be required to avoid significant disturbance to the forest ecosystems which may include culling, translocation, and establishment of migration corridors. Merely enclosing the elephants within the forest to prevent them from raiding farms is not a long-term solution for the people or for the elephants.

5.1.4 Socio-economic data collection and analysis

Forest use and local knowledge of birds were examined using questionnaires for a socio-economic survey of households. In total 109 households were interviewed. People were asked about the resources they obtain from the forest and related socio-economic parameters including monthly income and monthly financial benefits from the forest resources (see a copy of the questionnaire in Appendix II). Also, the level of knowledge of local birds and possible ways of advancing it was determined. The study focused mainly on household conservation knowledge and livelihoods in terms of the self-reported level of monthly income and income obtained from the forest (Gobeze et al. 2009). This structured questionnaire was administered to randomly selected households within 5 km of the forest. Heads of households were interviewed to be able to obtain reliable information. I did a rapid survey in May 2015 with limited time and resources to investigate forest benefits, income from the forest, household income from other sources, knowledge of local birds and participation in conservation projects (Emerton 1992; Matiku et al. 2013). Due to time limitation, the study focused mainly on the Eastern side of the forest. Rapid surveys have become popular for baseline data of this kind considering the utility, design and costs in terms of time and resources (Ryan 2013). I selected a sample size of 109 based on a 10 percent proportion, of the total population around the forest using Channels (1985) criterion.

Households were asked to estimate their material benefits and direct financial gains from the forest in Kenya shillings (KES) over a period of one month, which was then extrapolated to one year. Also, they were asked about challenges and possible motivations for participation in local conservation projects. Their level of awareness of the Arabuko Sokoke Forest management plan was also assessed to explain their pattern of forest utilization and participation in conservation projects. Benefits were converted from KES to US dollars at the rate (1$= KES 100.07) which applied at the time of survey. Relevant themes and concepts from survey data were identified and summarised. A Pearson correlation test was performed to determine the significance of the relationship between household variables and monthly benefits from the forest. Survey data were analysed using SPSS 16.0 software for both descriptive and inferential statistics.

5.3 Results

5.3.1 Household characteristics and level of income

The survey requested information on land size, family size, monthly income and income from the forest for each household. Most households are subsistence farmers with a mean farm size of 4.5 acres and family size of 6. Mean monthly income was estimated at KES 11577.98 per month (USD 115.70) and benefit from the forest at KES 8963.3 (USD 89.57) (Table 27).

Table 28: Descriptive statistics of sampled household and socio-economics. Income determined in Kenya shillings per month (1USD=KES100.07 at the time of survey).

	N	Minimum	Maximum	Mean	Std. Deviation
Estimated income (KES/month)	109	3000	30000	11577.98	8763.660
Estimated economic benefit from the forest (KES/month)	109	0	30000	8963.30	7498.057
Family size	109	1	20	6.38	3.294
Farm size	109	0	44	4.51	6.522
Valid N (list wise)	109				

5.3.2 Knowledge on local birds

Only 39 percent of the households interviewed had very good knowledge of local birds, 29 percent had good knowledge and 32 percent had only poor to average knowledge. Among the households that participated in the study, 44 percent had a problem with birds in their farms, while 56 percent had no problem.

The main issues raised by households about birds on their farms were related to crop destruction by granivorous birds and predation on poultry by raptors (Table 28, Plate 14).

Table 29: Summary of issues raised about some birds among the households around Arabuko Sokoke forest.

Issues why some locals have a problem with birds in their farms
1. Weavers including Clarke's Weaver feed on grain crops (Millet, maize)
2. Raptors and owls take chicks
3. Guineafowl remove planted maize seeds from the soil, uproot germinating seedlings
4. Weavers and sunbirds are noisy around the homesteads
5. House Crow feed on chicken and fish
6. House Crow litter roofs by dropping garbage there
7. Hornbills and mousebirds feed on fruits (damaged fruits cannot be sold)
8. Some birds have brought invasive guava seeds which have then produced guava trees in their farms

Plate 14: Alien House Crow (*Corvus splendens*) in homestead around the forest

Knowledge on birds can be improved among the local community members mainly by education and awareness on benefits of birds which was noticeably low among the locals, promoting local avian tourism and having guide books in local language. Other ways of promoting knowledge on local birds have are illustrated below (Figure 23).

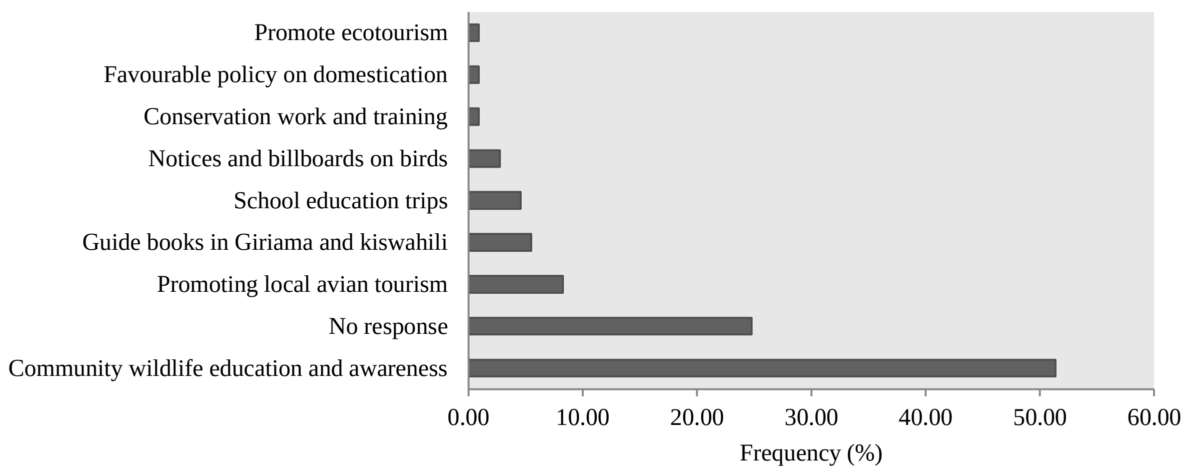


Figure 22: Questionnaire suggestions of methods to improve knowledge of birds among the local community.

5.3.3 Local participation in projects

Local community members are certainly motivated to participate in projects, and some ongoing projects have attracted good participation from local households. One eco-lodge under the management of the community, Arabuko Sokoke Forest Adjacent Dwellers Association (ASFADA) jamii villas is funded by the European Union and has involved 300 of the local community. Other projects which have made progress through local participation are butterfly farming, bee keeping and tree nurseries. Local households traditionally obtained honey from wild hives in the forest, and modern hives have now been installed as well (Plate 15). Bees, from these hives forage both on mangrove trees outside the forest and from native flowers in the primary forest.

a

b

c

d

Plate 15: Community-based conservation projects around Arabuko Sokoke Forest. **a** - Signboard of EU supported ASFADA Jamii Villa Project for a conservation group near Arabuko Sokoke Forest. **b**- ASFADA Jamii Villa. **c** - Bee keeping project at the ocean coast adjoining Arabuko Sokoke Forest. Bee keeping is one of the conservation activities involving the local community in the buffer zone. d - Nursery project of native tree seedlings managed by a group of women.

Characteristics of projects that attracted more participation from the local community are summarised below (Figure 24).

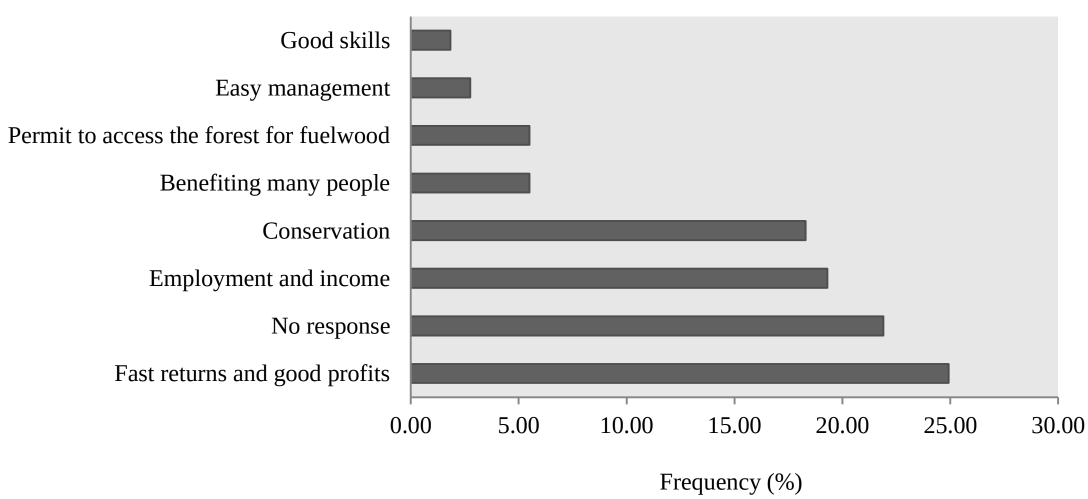


Figure 23: Factors considered important for participation in local projects

Youths and women were the most active members of the community in many conservation related projects like butterfly farming (Plates 16 a, b).

a

b

Plate 16: Conservation projects at the edge of Arabuko Sokoke Forest. **a**- Two young men checking butterfly baits in the plantation area at the edge of Arabuko Sokoke Forest for the butterfly farming project (Kipepeo). **b**- a woman heading to inspect butterfly baits at the edge of Arabuko Sokoke Forest.

While some households are keen to continue participating in conservation projects that benefit the forest, 44 percent had no knowledge of the forest management plan, (Table 29) and 60 percent of those interviewed had no idea of how the forest was divided into zones.

Table 30: Respondents knowledge on forest management plan

Response	Respondents count	Proportion (%)
No	48	44
Yes	60	55

5.3.4 Local community participation in conservation of the Arabuko Sokoke Forest

There are challenges restricting household participation in conservation of the forest; the points raised by the people interviewed are summarised in the table below (Table 30). There is growing interest in community conservation based projects, like bee keeping, butterfly farming (Kipepeo project), tree nursery and tree planting, Community Forest Association (CFA) projects, the Mida Creek Conservation and Awareness Group (MCCAG) project, and the ASFADA Jamii Villa Eco-lodge Project.

Certain concerns could be limiting the participation of the local community in conservation of the forest e.g. difficulty in getting permits for firewood collection from the forest. Local groups have alleged bias in the issuing of these permits. While some have been refused permits for valid reasons; at the moment the permit system is open to abuse by both the locals and the forest management. Currently, more than half of the fuelwood collected from the forest is sold commercially, contrary to the initial intention of subsistence use only. This needs to be addressed as the firewood collection is already unsustainable. Currently, a permit is issued to registered groups, upon payment of KES 120 by each member of the group. Each member of the group is then allowed to collect a head load (a bundle one can manage to carry) of firewood for three days in one week for one month. Permits are also issued to at different rates for special occasions e.g. weddings and parties, at costs ranging from KES 1500 to KES 3000. However, there is no mechanism to control this, and the collection points in the forest are un-controlled, while members of the local groups make multiple visits to the forest for firewood collection beyond the allotted three times each week.

There are allegations of corruption by some Kenya Forest Service officials and heads of working groups e.g. some officials are perceived to collude with poachers and issue illegal permits for illegal logging of trees in the forest. Moreover some heads of conservation projects have been accused of misappropriating project funds for their personal gain at the expense of the local groups, raising concerns about the management of community projects. Community projects thus require careful monitoring. Locals complain about the employment of people from outside the local community in areas perceived to be local jobs such as the maintenance of the electric fence around the forest, management of the plantation forests, and working in the Kenya Forest Research Institute tree nursery. Local members stated that vacancies are not openly advertised, while limited or no training is available to enable them to qualify for more rewarding opportunities

5.3.5 Economic benefits from the forest by local households

Mean estimated benefit from the forest was KES 8963.3 (USD 89.57) for each house hold, per month (Figure 25 a), KES 107,559.6 (USD 1068.12) per year. It is important to note that this was lower than mean monthly income per household which was estimated at KES 11577.98 per month (USD 115.70) (Figure 25 b), KES 138,935.76 (USD 1,379.70) per year.

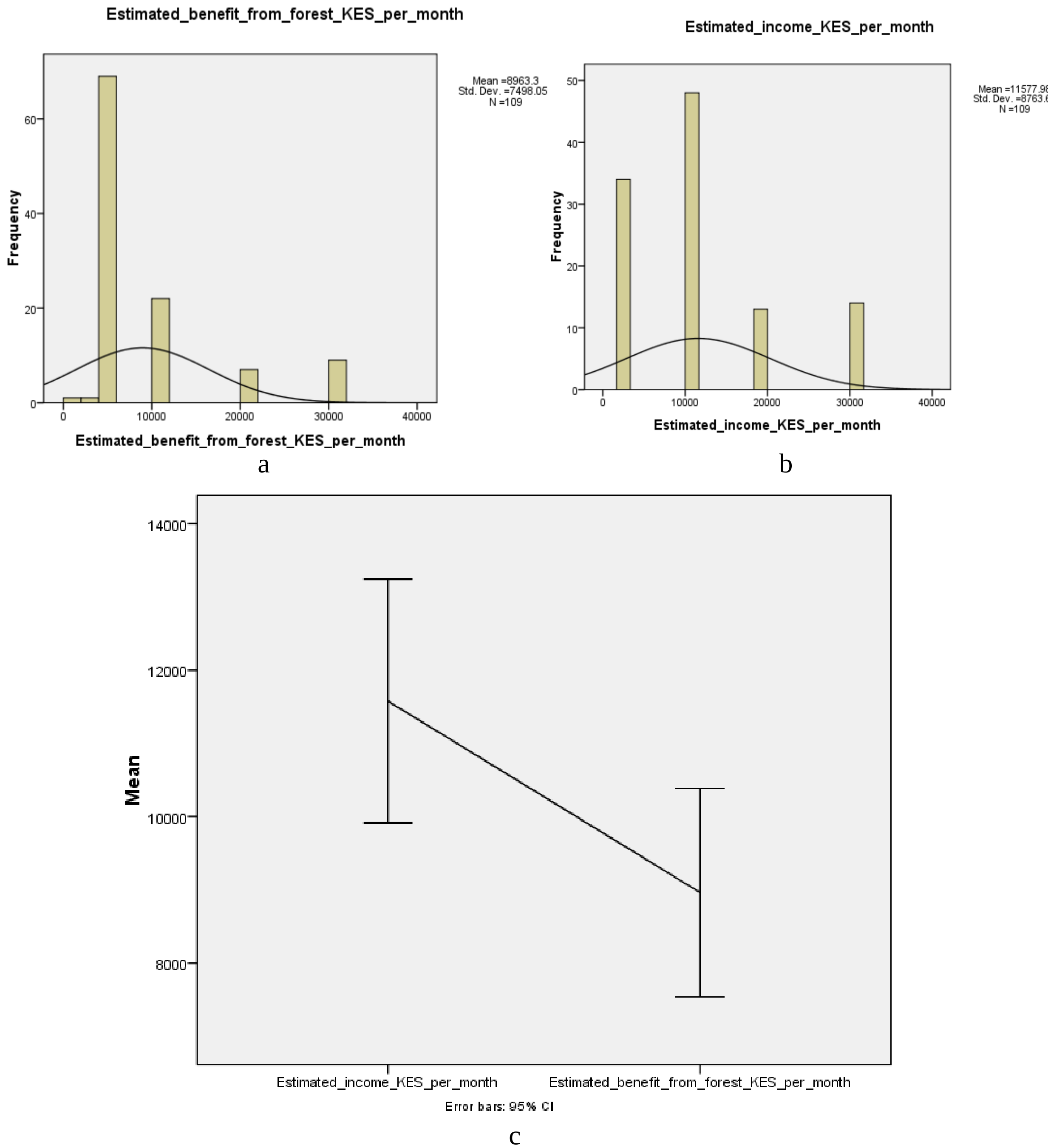


Figure 24: Comparing mean household income and benefit from the forest, a-estimated mean benefit from the forest, b-estimated mean income per month, c-comparing mean ± SE of income per month for each household and mean ± SE of monthly benefit from forest.

The main benefits obtained from the forest include; firewood, adult butterflies and larvae, wild honey, medicinal plants, timber and building poles from e.g. Cynometra (*Cynometra* *webberi*, Lowveld Silver Oak (*Brachylaena huillensis*), *Oldfieldia somalensis*, Pod Mahogany (*Afzelia quanzensis*), wild fruits, leaves for rearing butterflies, income from ecotourism and tour guiding, frequent rains for crops in fields near the forest, wild seeds, flowers for bees in bee projects, and game meat.

5.3.6 Relationship between household variables and perceived benefits from the forest

The estimated benefit from the forest was found to be positively and significantly correlated with farm size, r=0.342, P<0.01. Family size had a negative relationship with benefit from the forest, however, this relationship was not significant, r= - 0.91, P > 0.05. Household monthly income had a significant positive correlation with perceived monthly benefits from the forest, r = 0.368, P < 0.01 (Table 31).

Table 31: Results of Pearson correlation testing the relationship between household variables (farm size, family size, estimated monthly income) and estimated benefits from the forest, (**. Correlation is significant at the 0.01 level (1-tailed), N=109.

Household variable		Estimated benefit from forest per month
Farm size	Pearson correlation (r)	0.342**
	N	109
	Sig. (1-tailed)	.000
Family size	Pearson correlation (r)	-0.91
	N	109
	Sig. (1-tailed)	.177
Estimated income per month	Pearson correlation (r)	0.368**
	N	109
	Sig. (1-tailed)	.000

5.4 Discussion

5.4.1 Local knowledge on birds.

A large proportion of households (32 %) had limited knowledge of local birds. Although this alone may not explain the ongoing human bird conflict reported among 44 % of the households, it could explain their inability to appreciate the behavior and habitat requirements of many bird species for effective farm management. This knowledge could be useful in farm planning; knowledge of birds which have come into conflict with local households (e.g. guineafowl, weavers, owls, raptors and House Crow) will be essential both for protection of local livelihoods and for bird conservation. There is a need for Kenya Wildlife Service to work with the local community in developing strategies for awareness and management programmes, Promoting local avian tourism, translation of bird guide books into the local "Giriama" language and Kiswahili, school field activities and community wildlife education have been recommended for promotion of local knowledge on birds. Ignorance could be the main reason why ecotourism and avian tourism activities in the forest have attracted limited participation among the local population, who consequently do not appreciate the benefits to be gained from these activities. The concept of 'tourism flagship species' (Ver´ıssimo et al. 2009) could increase the potential of avian tourism in Arabuko Sokoke forest, since this is highly dependent on international tourism markets. We must identify which bird species are most appealing to visitors, and have most potential for fundraising among international tourists.

5.4.2 Farm management planning for bird conservation

Agroforestry practices and native tree stands could improve tree cover and habitat quality in farmlands, where a mix of native and cultivated trees could provide sites for nesting, foraging and roosting of birds. Orchards in farmlands could attract smaller frugivores and nectarivores to fruit and flowers. Although some farmers complained of some birds especially Mousebird is destroying certain fruits, the overall benefits from diverse bird species will be more e.g. lowering the population of insect pests on farm, hence reducing the cost of pest management. In Florida, many farmers were interested to attract birds in their farms as alternative methods of pest control (Jacobson et al. 2003). Increased tree cover and reduction of impact logging in the plantation forest in close proximity to Arabuko Sokoke forest, along with polycultures to improve the structural diversity and vertical heterogeneity of plantations to mirror the structure of native forests would improve its connectivity to primary forest for bird movement. Narrow strip logging is preferable to the current practice of big patch logging and clearance. Narrow strip logging hastens recovery and reduces ecological damage; however, growth models have predicted low timber yields in second harvest for clear-cut strips, but could be greatly improved to increase yields and overall economic income by enrichment planting of valuable and fast-growing timber species (Rondon et al. 2010; Scott et al. 1980; Schulze 2008). Pure stand plantations prone to frequent and large scale timber harvesting could alternatively be located away from the forest edge. Local bird experts and other conservation working groups like Arocha Kenya have generated significant data that are yet to be incorporated in conservation planning. Local land use planning for agroforestry practices should be negotiated so as to benefit both the local community and bird populations. Application of hybrid conservation knowledge involving local knowledge and scientific data will be important in planning and management of community based projects (Haenn et al. 2014).

5.4.3 Sustainable conservation management

Workshops on forest management could take place in conjunction with agroforestry programs which should form a regular part of local socio-economic activities. The forest management plan proposes to improve human resource development in order to build an efficient team for the management of the forest. On biodiversity conservation, the plan proposes to conserve and enhance the unique biodiversity of the forest, increase understanding and knowledge of the forest ecosystem and improve local awareness of biodiversity. However, the rate of implementation of these plans seems to be slow and may need to be improved. Local knowledge on forest zonation is still low and could be a barrier towards achieving the planned conservation objectives.

Regarding subsistence use, the plan proposes to enhance the sustainable livelihoods of the forest-adjacent community, address causes of poverty amongst forest-adjacent communities and develop partnerships between government and forest adjacent communities for shared benefits and responsibilities and to develop a more systematic approach to local utilisation of forest resources. The forest adjacent community still lack basic resources e.g. clean water for drinking and for household use, poverty still characterises their lifestyle including poor housing, lack of food, poor healthcare among others. The underlying causes being low income and lack of employment which may need to be addressed urgently. The approach in utilization of forest resources and sharing of benefits from the forest need to be reviewed to be able to attract maximum participation and support from the local community towards conservation of the forest.

To reduce damage caused by wildlife in forest adjacent villages while maintaining conservation importance of the forest. Arabuko Sokoke Forest management plan aims to control animal movement, improve effectiveness of patrolling and reduce impact of animal damage (Arabuko-Sokoke Forest management Team 2002). While electric fence around the forest has been a major achievement in controlling the movements of elephants, baboons are still a problem to the forest adjacent community, they raid crops and settlements. Other interventions and accompanied by extension programmes could be effective in reducing the impacts of human-wildlife conflict around the forest. On forest protection, the plan aims to significantly reduce levels of poaching and illicit forest product harvesting. The plan targets to involve forest-adjacent communities in forest protection by improving the effectiveness of patrolling and encourage more appropriate legislation and deterrents. There is need to plan for rewards, facilitation and incentives to motivate the participation of the local community in forest protection and patrol and to ensure firm and fair application regulations. The current protection plan may not be effective as the locals perceive it as voluntary and they have nothing to directly benefit after engaging their time. Those involved have complained of lack of support from Kenya Forest Service on the right attire for patrolling and with little or no pay. People connected to high authority carry out illegal logging and lack of confidentiality on reported cases leading to fear of harm by illegal forest users and rejection by harsh community members. To maximise the commercial potential of available forest resources whilst ensuring their sustainable use the plan intends to utilise the productive potential of established plantations and support local involvement in commercial forest-based activity. The plan aims to add value to the forest through revenue generation and improved awareness through eco-tourism and environmental education. To achieve this, it focuses on increasing sustainable eco-tourism revenues, improve local benefits from ecotourism and focus on the longer-term benefits of environmental education

Other possible improvements to the conservation master plan should target the rate of implementation of strategies towards sustainable agriculture in local farms, training and awareness, agroforestry and forest management awareness. Rural development working groups need to step up viable agroforestry programs (beneficial flowering and fruiting trees), while tourism and education working groups increase the capacity of local youths to serve as guides for bird tourism, ethno-botany and other ecotourism activities. The forest management plan strategies focuses on forest zonation, ecotourism, environmental education, problem animal management, subsistence use of the forest, biodiversity conservation, commercial use of the forest, infrastructure development, human resource development, and monitoring and research. The overriding principle for the strategy is sustainability. Acknowledging that communities adjacent to the forest have continued to depend on the forest for subsistence use, which they consider as their biggest benefit from the forest, some income-generating projects have been introduced to reduce the poverty levels; the most successful have been butterfly-farming and bee-keeping. The planned intention to develop partnerships among stakeholders, to improve the skills base for effective forest management and build teams and encourage team-work, has yet to be carried out. The working relationship between the local community, and the three management institutions, Kenya Forest service, Kenya Wildlife

Service and Kenya Forestry Research Institute needs to be improved. If the community and working groups are involved as key partners in management, many locals can benefit from forest conservation projects. Transparency and equitable sharing of tourism benefits with the local community will greatly improve the working relationship; ecotourism projects can provide jobs for the youth. There could be official licensing for organised community groups to use the forest for ecotourism and recreational activities. Facilitating conservation groups and funding community projects needs serious consideration by the forest management.

Knowledge of medicinal plants and their cultivation, as well as planting vegetables and edible wild fruits could be increased. The local capacity for agroforestry and on-farm tree planting programmes could be enhanced, and through education and conservation to improve their knowledge on forest resources and zonation. Community working groups on ecotourism and sustainable community project management will require training for maximum benefits and sustainability of the projects. Increased funding and monitoring of community projects could enhance their capacity to create employment, hence providing a sustainable source of income to many households. Bee keeping could be expanded, jobs like patrolling the forest and maintaining, the electric fence restricted to the locals. Part of the benefits from ecotourism in the forest could be used to promote community development projects e.g. water supply. The current permit system for firewood collection must be reviewed, and collection restricted to household use. Firewood collection using trucks, pickups and "tuk tuks" for commercial purposes is not sustainable and should be prohibited. Funding women and youth group projects should be promoted, since a report on community projects in

Amani, Tanzania indicated that projects dominated by females have been shown to progress faster than those dominated by men (Morgan-Brown et al. 2010).

5.4.4 Economic benefits from the forest and conservation

Mean monthly household income was higher than estimated benefit from the forest, suggesting that the forest plays an important role in poverty reduction among the local households through supplementing their income. This is encouraging for forest conservation as it indicates that forest resources only supplement the needs of the local people, while ruling out over-dependence. While Matiku et al. (2013) estimated household income from the forest at KES 36, 715 (USD 415) per household per year in a survey involving 600 households, 150 households from each zone, this study has estimated the income at KES 107,559.6 (USD 1068.12) per year, a value much higher than the previous estimate. This may represent a possible increase in dependence on forest resources by the local households.

While more prosperous households could have a greater capacity to exploit forest resources, this area is dominated by rural poor who are more interested in meeting their basic livelihood needs. Opportunities for employment and income could reduce their reliance on forest resources, relieving further pressure on forest. Addressing local community livelihood concerns could minimize conflicts and ensure efficient implementation of conservation projects (Knight et al. 2006; Whitehead et al. 2013). Agroforestry projects that focus on improving habitat quality in farmlands and connectivity to the primary forest should be given priority. We need to identify significant trade-offs in order to harmonise the competing socio-economic objectives of the local community and conservation objectives set by Kenya Forest

Service. Public participation approaches, interviews and workshops can significantly improve effective conservation planning for the forest (Whitehead et al. 2013) and community participation. Factors to consider in this area include tourism benefits to the locals, participation by women and youths, food security, water availability and employment opportunities for locals.

While the current strategic plan identifies the strategies for community participation, the level of awareness about the forest management plan, zonation and local birds need to be improved among the locals to increase their support for conservation of the forest. I commend the zoning in and around the forest, however, it could be more ecologically viable to redesign biodiversity sub-zone to include the current plantation areas in close proximity to the forest, this area could be marked for low impact conservation projects of significant value to the local community like bee keeping in order to limit the effect of high impact activities like mass deforestation due to timber harvesting, and native vegetation clearance that are currently associated with the plantation forest.

Agroforestry and ecotourism remain under-exploited among the local households with great potential to complement the benefits from the forest, thus reducing pressure on extracting resources from the forest. Large farms are often left fallow and under-utilized for extended periods with only seasonal planting making subsistence agriculture less productive. Agroforestry has the potential to support bird conservation in farmlands (Douglas et al. 2014) by provision of flowers and fruits from agroforestry trees and increasing the level of income of the households and benefits from biological pest control by bird populations. Currently, utilization of farmland by frugivores and nectarivores is only sporadic, with a decline of forest bird species already recorded and many nectarivores of conservation concern restricted to the forest.

Low impact ecotourism projects could be encouraged in the management of this zone, rather than the current emphasis on commercial *Eucalyptus* plantations which have no local ownership. Proposed low impact activities in this subsistence zone include agroforestry, ecotourism, and farm tree planting. While beekeeping and butterfly farming are currently being practiced, their implementation has not reached its full potential and currently the market for butterfly farming is declining. We should increase local capacity in bee keeping, and address the decreasing international markets for butterfly farming. The current market for butterfly pupae sales depend on European and American markets, there is need to explore on alternative market sources and diversifying to produce for science laboratories beyond individual farmers in Europe and America. However, there will be need for scientific expertise to produce pupae that will penetrate the laboratory markets (Dereemer 2000). Formation of cooperative societies for collective marketing and working with brokerage companies for brokerage service to penetrate more in European markets like the case of Amani butterfly farms in Usambara, Tanzania (Morgan-Brown et al. 2010) could be important. There is need to collaborate with established butterfly companies like butterfly World Inc. for wider markets. Online marketing strategies and contacts, internet web page and advertising, Amani butterfly project has recorded improved sales since 2002 when the project created its internet web page (Morgan-Brown et al. 2010). There is need to do market research on the market needs e.g. butterfly exhibits close down in Northern Hemisphere during winter with demand for butterfly pupae mostly between March and October each year (Dereemer 2000; Morgan-Brown et al. 2010). Promoting tourism trade involvement for local butterfly farms could also increase their visibility.

5.4.5 Community participation in conservation projects

Community members showed a clear preference for projects with high profits that offered fast returns at short intervals, with easy management. They also wanted more opportunity to access permits to collect firewood from the forest. Many households were interested in projects which had conservation implications, but they preferred projects which involved many members of the community. This could be attributed to a desire to work in teams and share resources and responsibilities in the projects, an opportunity which conservation societies might exploit. Possibly this makes the management of projects easier and enables people to meet project goals that translate directly to their livelihoods. Many households involved in a project could also be a possible indication of their interest in project sustainability. However, it is important to note that income generating ecotourism projects have not extensively been explored by the local community, while eco-lodge and forest recreation activities have good potential. Arabuko Sokoke Forest jamii villa eco-ledge supported by European Union has been successful with the local working groups. Training for viable and sustainable ecotourism projects will be necessary. Community involvement agroforestry in intervention zone, to supplement income; on farm-trees e.g. woodlot to supplement firewood demands.

On research and monitoring the plan targets to fill knowledge and information gaps for management and monitor the activities carried out under the strategic plan. There is need to use effective methods to communicate research findings to the community, where the level of formal literacy is still low through extension and communication centres. Involving community in biodiversity research for employment and to raise awareness will add value to the management. Research on, beneficial on-farm trees, sustainability of ecotourism and conservation projects and community interests could significantly contribute towards sustainable forest management at the same time meeting community livelihood needs.

More funding to community projects and equitable sharing of returns from tourism in the forest between Kenya Forest Service and the local community would increase the level of engagement of the local community. There is an opportunity to train youths in tour guiding with a specific focus on avian tourism and ethnobotany, which are high value tourism products provided by Arabuko Sokoke Forest. There is potential for poor households in this area to meet their needs through a combination of livelihood strategies and community-based tourism. In addition, the rich local culture can become a tourism resource using indigenous foods, arts, and crafts as attractions to complement the existing ecotourism products. Community Based Tourism projects with indigenous communities make sense only if undertaken within their cultural context (Ife 2002) and culture plays a critical role in determining the response of the local community (Giampiccoli & Kalis 2012). However, community based tourism projects usually need external facilitation to succeed and become sustainable (Ramsa Yaman & Mohd 2004).

Poor households are more likely to be members of forest user groups and therefore participate more in forest activities than the more affluent (Kabubo-Mariara 2013). Their participation enhances awareness of the potential gains from forests, where they will be exposed to relevant information, including policy changes that directly affect forest management and use (Gaspert et al. 1998; Vedeld et al. 2007; Adhikari 2005). Globally forests play a role in poverty reduction through the diversification strategies adopted by households and through provision of important environmental services which benefit local, regional, national and global stakeholders (Vedeld et al. 2007; Paumgarten & Shackleton 2011; Tieguhong & Nkamgnia 2012).

Households also looked for projects that give returns at short intervals within one-two weeks, which could be explained by the need to meet daily and basic household needs. Projects that offer quick returns support the subsistence needs of the locals. For this reason, the Kipepeo project for bee keeping has been more popular than the tree nursery for native tree seedlings, while nurseries for commercially important *Casuarina sp*. have also attracted more interest. Although households apparently favour projects with conservation benefits, they will give priority to those that satisfy their basic needs both in the short term and sustainably. Forest-related employment has been highlighted as a major strategy for improvement of community gains and encouraging participation in conservation. I recommend active involvement of community working groups in conservation projects within the buffer zone, where on current evidence this happens only on a small scale. It is critical that conservation and eco-tourism projects address basic livelihood issues such as food security and water availability. In keeping with the objectives of the management plan, there is need to adjust the forests management policy to actively involve the forest adjacent communities in the joint forest management plan involving Kenya Forest Service, Kenya Wildlife Service, Kenya Forest Research Institute and National Museums of Kenya, in order actualize the recognition of their dependence on the forest as stated in the forest management plan. The need to fulfil the requirements of food, fodder, fuel wood, herbal medicine and small timber of local households informs the significance of their active participation in forest management and conservation. Creating a massive people's movement for protection and development of on-farm forests, could effectively supplement the demand for resources from the forest. A change of forest policy to favor active involvement of village communities in forest management contributed significantly towards regeneration of degraded forests in West Bengal, India (Ghosal 2014).

5.4.6 Relationship between household variables and benefits from the forest

Household income and farm size were positively and significantly correlated with benefits from the forest. This means that the ability of the households to exploit forest resources could be dependent on household wealth, here expressed as household income and farm size. This is in agreement with Kabubo-Mariara (2013), where similar result was found for many parts of Kenya. Households better endowed with land are expected to benefit more from forests, because forests are an important source of intermediate products such as agricultural compost that serve as inputs in the farming system (Fischer & Lindenmayer 2002; Adhikari 2005; Kabubo-Mariara 2013). Household wealth endowment is expected to affect benefits from forests directly, as productive wealth creates more opportunities for better-off households to use biomass resources (Tesfaye et al. 2011; Uberhuaga et al. 2012). While Forest income is relatively more important for the poor than the non-poor, the non-poor households have the productive income that enables them to exploit the forest resources. Three possible beneficial roles of forests in the lives of the rural poor: support of current consumption, safety nets in the face of misfortune and gap filling during seasonal shortfalls, as well as pathways out of poverty through participation in high-return forest activities (Vedeld et al. 2007; Rayamajhi et al. 2012; Kabubo-Mariara 2013).

CONCLUSION AND RECOMMENDATIONS

Conclusion

The findings suggest that land use type affects the distribution and composition of the bird community and those feeding guilds that offer important ecosystem services. Mixed forests with high vegetation heterogeneity and habitats with a high number of fruiting trees and large trees are shown to support a diverse bird guild community. Overall, the results show that Arabuko Sokoke Forest has a bird community distinct from the neighbouring plantation forest and farmlands, suggesting the need for structural improvement of plantations and farmlands to increase utilization by many bird guilds and to sustain the rich bird diversity in the forest.

The socio-economic results indicate that Arabuko Sokoke Forest plays an important role in supplementing the livelihood needs of the local community. To meet conservation and livelihood objectives of the forest, management plan requires increased support for community-based projects. However, the results of the survey also show a lack of knowledge by the local community of the forest management plan and of local birdlife, which could limit their capacity to participate in forest conservation. The findings suggest that the drivers for local community participation in conservation projects are sustainable income and fulfillment of basic household needs.

Recommendations

Habitat structure in both plantation forest and farmland can be improved by increasing vertical vegetation heterogeneity, which would involve maintenance of both large emergent trees and an understorey. Tree density in plantation forest could be increased by planting high value and fast growing trees and limiting clear-fell harvesting methods that lead to large open gaps, which would improve connectivity with primary forest. Improvement of the habitat quality in farmlands could be achieved by maintaining stands of large trees and increasing the number of fruiting trees, which would enhance utilization of by many bird species. There is a clear need to initiate programs to promote knowledge of local birds and their ecological significance. Promoting local avian tourism initiatives e.g. training in bird guiding, bird monitoring, translation of field guides into the local Giriama and Kiswahili languages, bird awareness workshops, and organized school field exercises could be significant. Community conservation education on Arabuko Sokoke Forest and its management plan would involve the local community in the conservation and sustainable use of forest resources. Support is needed for funding and training in community based projects and ecotourism. Sustainable community based tourism related to the rich local culture could also complement ecotourism. The basic needs of households such as access to a clean water supply need to be met and a sustainable framework must be developed for equitable sharing of tourism benefits from the forest with the local community, including the regulation of firewood collection permits and support of community based projects.

Further research

There are still significant gaps that need to be filled to inform an integrated conservation plan for forest biodiversity, bird populations and benefits to the community.

1. Nectarivore and frugivore plant association networks and the effectiveness of birds and other animal groups for pollination and seed dispersal of keystone species in Arabuko Sokoke Forest.

2. Local movement patterns of bird populations and current connectivity between the coastal forest patches.
3. Community based tourism which will benefit local people, and thus ensure conservation of Arabuko Sokoke Forest.
4. Impacts of forest elephant on the structure of Arabuko Sokoke Forest.

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Appendix I: Bird count and habitat dataset

Survey point	Landuse type	Vegetation type	No. of large trees	No. of fruiting trees	Proximity to settlement (km)	Proximity to forest (Km)	Vertical vegetation heterogeneity	overall bird diversity	Frugivore diversity	Nectarivore diversity	Insectivore diversity	Granivore diversity	Carnivore diversity
BRACPC1	PF	Brachystegia	12	3	12	0	6	3.060	1.932	0.637	2.623	0.562	0.000
BRACPC2	PF	Brachystegia	5	7	11.9	0	6	3.027	2.274	0.662	2.028	0.000	1.213
BRACPC3	PF	Brachystegia	9	5	11.8	0	6	3.062	2.115	0.673	2.663	0.000	0.000
BRACPC4	PF	Brachystegia	10	4	11.7	0	6	3.104	2.047	0.868	2.398	0.000	0.000
BRACPC5	PF	Brachystegia	7	6	9	0	6	3.015	2.163	0.000	2.427	0.305	0.000
BRACPC6	PF	Brachystegia	8	5	8.9	0	6	2.968	1.909	0.000	2.488	0.000	0.000
BRACPC7	PF	Brachystegia	13	7	8.8	0	6	2.839	1.778	0.000	2.425	0.000	0.000
BRACPC8	PF	Brachystegia	11	5	8.7	0	6	2.773	1.609	0.000	2.404	0.000	0.000
BRACPC9	PF	Brachystegia	9	8	8.6	0	6	2.902	1.735	1.040	2.212	0.000	0.000
CYNPC1	PF	Cynometra	0	5	13	0	5	2.589	1.677	1.055	1.983	0.000	0.000
CYNPC2	PF	Cynometra	0	4	13.1	0	5	1.946	1.550	0.000	1.561	0.000	0.000
CYNPC3	PF	Cynometra	0	7	13.2	0	5	2.726	2.025	0.637	2.212	0.000	0.000
CYNPC4	PF	Cynometra	0	6	13.3	0	5	2.736	1.733	1.040	1.922	0.000	0.000
CYNPC5	PF	Cynometra	0	3	13.4	0	5	2.164	1.386	0.000	1.802	0.000	0.000
CYNPC6	PF	Cynometra	0	7	13.5	0	5	2.272	1.696	0.693	1.643	0.000	0.000
CYNPC7	PF	Cynometra	0	6	13	0	5	2.245	1.649	0.000	1.773	0.000	0.000
CYNPC8	PF	Cynometra	0	4	12.9	0	5	2.352	1.733	0.000	1.561	0.530	0.000
CYNPC9	PF	Cynometra	0	4	12.8	0	5	2.505	1.692	0.693	1.987	0.000	0.000
FMPC1	FM	N/A	19	3	0.01	0.1	5	1.946	1.213	0.000	0.637	0.451	0.000
FMPC2	FM	N/A	7	7	0.1	0.2	5	1.242	1.074	0.000	0.000	0.000	0.000
FMPC4	FM	N/A	8	5	0.05	1	5	1.906	0.752	0.000	0.518	0.693	0.000
FMPC6	FM	N/A	7	2	0.01	1.5	5	2.079	1.792	0.000	1.561	0.000	0.000
FMPC7	FM	N/A	3	1	0.01	1.4	5	2.164	1.561	0.000	1.277	0.000	0.000
FMT1PC1	FM	N/A	5	5	0.05	0.5	5	2.864	2.414	0.693	1.894	1.004	0.000
FMT1PC5	FM	N/A	12	3	0.05	1.2	5	2.079	1.359	0.000	1.242	0.000	0.693
FMT1PC7	FM	N/A	11	2	0.01	1.4	5	2.670	1.760	0.687	1.311	0.598	0.000
FMT1PC8	FM	N/A	10	3	0.02	1.5	5	2.540	2.025	0.562	1.677	0.000	0.000
FMT2PC2	FM	N/A	4	3	0.01	0.4	5	2.831	2.211	0.000	2.025	0.721	0.693
FMT2PC3	FM	N/A	9	3	0.005	0.6	5	2.458	1.677	0.000	1.386	0.796	0.500
FMT2PC4	FM	N/A	2	4	0.01	0.8	5	2.338	1.295	0.693	0.974	0.652	0.000
FMT2PC5	FM	N/A	8	2	0.02	1	5	2.138	1.820	0.000	1.330	0.000	0.000
FMT2PC7	FM	N/A	7	5	0.02	1.2	4	1.099	0.637	0.000	0.000	0.000	0.000
FMT2PC8	FM	N/A	18	5	0.01	1.4	5	1.099	0.500	0.000	0.000	0.000	0.000
FMT2PC9	FM	N/A	5	5	0.01	1.6	5	2.670	1.985	0.000	1.560	1.055	0.000
FMT3PC1	FM	N/A	3	3	0.05	1.6	5	2.599	1.889	0.000	1.277	0.950	0.000
FMT3PC2	FM	N/A	4	2	0.05	1.5	4	2.369	1.303	0.000	1.792	0.000	0.637
FMT3PC3	FM	N/A	3	3	0.05	1.4	4	2.831	1.494	0.637	1.359	0.868	0.000
FMT3PC4	FM	N/A	4	3	0.05	1.5	4	2.523	1.685	0.000	1.561	0.000	0.000
FMT3PC5	FM	N/A	0	5	0.06	1.3	4	2.398	1.581	0.637	1.099	0.500	0.637
FMT3PC7	FM	N/A	0	1	0.05	0.5	4	2.210	1.330	0.000	1.234	0.000	0.000
FMT3PC9	FM	N/A	9	1	0.04	0.7	2	2.540	2.095	0.000	1.667	0.000	0.000
FMT5PC5	FM	N/A	5	5	0.02	1.2	5	2.480	1.418	0.693	1.358	0.000	0.637
FMT6PC6	FM	N/A	13	2	0.005	1.1	5	2.708	1.154	1.040	1.581	0.562	0.000
FMT7PC7	FM	N/A	2	4	0.005	1	5	2.342	1.273	0.000	1.011	1.386	0.693
FMT8PC8	FM	N/A	1	3	0.005	0.8	4	2.254	1.427	0.000	1.154	0.500	0.000
MXDPC1	PF	mixed_forest	11	5	12	0	6	2.565	1.332	1.055	1.581	0.000	0.000
MXDPC2	PF	mixed_forest	16	3	12.1	0	6	2.558	1.792	1.004	2.164	0.000	0.000
MXDPC3	PF	mixed_forest	7	5	12.2	0	6	2.245	0.956	0.693	1.162	0.000	0.000
MXDPC4	PF	mixed_forest	9	3	12.3	0	6	2.751	1.673	0.598	2.112	0.000	0.000
MXDPC5	PF	mixed_forest	10	7	12.4	0	6	2.967	1.822	1.040	2.137	0.000	0.000
MXDPC6	PF	mixed_forest	17	4	12.5	0	6	3.113	2.262	1.275	2.487	0.000	0.000
MXDPC7	PF	mixed_forest	12	7	12.6	0	6	2.985	2.138	0.937	2.323	0.000	0.693
MXDPC8	PF	mixed_forest	8	9	12.7	0	6	2.756	1.908	0.377	2.150	0.000	0.000
MXDPC9	PF	mixed_forest	14	6	12.8	0	6	2.875	1.978	0.693	2.231	0.693	0.000
PLT1PC1	PL	N/A	1	2	0.05	1	5	2.523	1.836	0.000	1.583	0.000	0.000
PLT1PC2	PL	N/A	4	4	0.1	0.5	5	2.965	2.272	0.637	1.906	0.673	1.099
PLT2PC1	PL	N/A	1	3	0.2	0.9	5	1.889	1.199	0.500	0.950	0.637	0.000

PLT2PC2	PL	N/A	2	3	0.1	0.8	5	1.792	1.040	0.000	1.154	0.000	0.000
PLT2PC3	PL	N/A	1	8	0.02	0.6	5	2.871	2.097	0.500	1.996	0.000	0.000
PLT2PC4	PL	N/A	0	9	0.1	0.4	5	2.871	1.748	0.693	1.748	0.000	1.332
PLT2PC5	PL	N/A	0	5	1	0.3	5	2.510	1.951	0.451	1.517	0.637	0.000
PLT2PC7	PL	N/A	0	3	0.6	0.1	5	0.000	0.000	0.000	0.000	0.683	0.000
PLT2PC8	PL	N/A	0	4	0.5	0.5	5	0.000	0.000	0.000	0.000	0.000	0.000
PLT3PC1	PL	N/A	1	6	1.4	0.4	5	2.369	1.494	0.000	1.679	0.000	0.000
PLT3PC3	PL	N/A	1	5	1.5	0.5	5	2.441	1.845	0.000	0.637	0.000	0.000
PLT3PC5	PL	N/A	0	3	1.7	0.6	5	1.946	1.427	0.000	1.427	0.637	0.000
PLT3PC6	PL	N/A	0	4	1.8	0.1	5	1.609	0.937	0.000	0.000	0.000	0.000
PLT4PC1	PL	N/A	0	3	1.5	0.05	4	3.020	2.095	0.956	2.339	0.000	0.000
PLT4PC2	PL	N/A	0	4	1.4	0.15	5	3.088	2.362	0.683	2.197	0.693	0.693
PLT4PC3	PL	N/A	0	5	1.3	0.25	5	2.485	1.386	0.000	2.254	1.149	0.000
PLT4PC4	PL	N/A	0	4	1.1	0.5	5	2.799	2.164	0.562	2.168	0.000	0.000
PLT4PC5	PL	N/A	0	3	1	0.6	5	2.565	1.386	1.040	1.581	0.693	0.000
PLT4PC6	PL	N/A	2	3	0.8	0.8	5	2.788	1.946	0.637	2.206	0.693	0.000
PLT4PC8	PL	N/A	14	2	0.7	1	5	2.303	1.494	0.000	1.332	0.000	0.000
PLT4PC9	PL	N/A	3	2	0.6	1.1	5	2.398	1.498	0.000	1.840	0.000	0.000
PLT5PC1	PL	N/A	0	2	0.3	1.2	5	1.946	1.352	0.000	0.451	0.000	0.000
PLT5PC2	PL	N/A	0	2	0.4	1.1	5	2.303	1.609	0.693	1.303	0.000	0.000
PLT5PC3	PL	N/A	0	2	0.5	1	5	2.342	1.332	0.000	1.977	0.000	0.000
PLT5PC4	PL	N/A	0	2	0.8	1.2	5	2.926	2.144	0.000	2.032	0.693	0.693
PLT5PC6	PL	N/A	0	3	0.1	1.1	5	2.813	1.748	0.000	2.023	0.637	1.040
PLT5PC7	PL	N/A	4	7	0.05	1	5	2.726	1.889	0.637	1.834	0.796	0.000

Appendix II: Questionnaire for ethno-ornithology and socio-economic data

Assessment of socio-economic value of Arabuko Sokoke Forest to local community and knowledge on local birds

Interviewer: David Chiawo	Email address: Chiawo2006@gmail.com

Household location (GPS coordinates)……………………………Date of collection………………

Questionnaire No……………………………………..

Arabuko Sokoke Forest ethno-ornithology and socio-economic data

A. Personal information
   1. Gender
      - ☐ Male
      - ☐ Female

      ☐ Family size

      ☐ Farm size

   2. Occupation……………………………..

   3. Monthly income
      - ☐ < 3000 KES
      - ☐ 3000-10000 KES
      - ☐ 10000-20000 KES
      - ☐ 20000-30000 KES
      - ☐ >30000 KES

B. Ethno-ornithology
   1. Do often see birds in your farm?
      - ☐ Yes
      - ☐ No

   2. What do you often find the birds doing in your farm?
      - ☐ Feeding
      - ☐ Nesting
      - ☐ Breeding
      - ☐ Perching

3. Which parts of your farm do they like?

4. Do you have any problems with birds in your farm?

☐ Yes
☐ No

   a. If yes give reasons and which birds?

   ....

   ....

5. Rate your knowledge on local birds.

☐ Very good
☐ Good
☐ Average
☐ Poor
☐ Very poor

6. How do you pass this knowledge to young ones

   ………………………………………………………………………………………

7. Suggest ways in which local knowledge on birds can be promoted in this area.

   ………………………………………………………………………………………

   ………………………………………………………………………………………

C. Participation in conservation projects

1. Which community conservation projects do you participate in?

   ………………………………………………………………………………………

2. Which project do you prefer most?

   ………………………………………………………………………………………

Please give reasons to your preference.

………………………………………………………………………………………..

D. Local knowledge of forest conservation planning and management

1. Do you know about ASF management plan?
   - ☐ Yes
   - ☐ No

2. Which resources do you get from the forest?

……………………………………………………………………………………………

……………………………………………………………………………………………

3. Please quantify the benefits you get from Arabuko Sokoke Forest in a month in KES?
   - ☐ < 3000 KES
   - ☐ 3000-10000 KES
   - ☐ 10000-20000 KES
   - ☐ 20000-30000 KES
   - ☐ >30000 KES

4. Do you know about zonation of ASF?
   - ☐ Yes
   - ☐ No

5. In what ways do you contribute towards conservation of ASF?

   ……………………………………………………………………………………………

   ……………………………………………………………………………………………

6. Give three challenges to your participation in conservation of the forest.

   ……………………………………………………………………………………………

   ……………………………………………………………………………………………

   ……………………………………………………………………………………………

7. How can participation of local people be improved towards conservation of the forest?

   ……………………………………………………………………………………………

   ……………………………………………………………………………………………

   ……………………………………………………………………………………………