Effects of tree removal on population of the globally-endangered Sokoke Pipit (*Anthus sokokensis* van Someren, 1921) in *Brachystegia* woodland, Arabuko-Sokoke forest, Kenya

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Abstract

Arabuko- Sokoke forest is the largest remaining patch of an earlier large contiguous mass of East African coastal forest. It forms part of the Eastern Arc Mountain and Coastal Forest biodiversity hotspots and is regarded as the one of the most important habitats for bird conservation in Africa, holding 9 globally-threatened and 4 regionally threatened species. However, the high-endemism forest is threatened by encroachment and degradation from a high population of adjacent human community that relies heavily on it for various resources. Sokoke Pipit (*Anthus sokokensis*) is one of the globally-endangered birds in the forest whose habitat is in danger of loss due to various processes of degradation. The study examined the effect of removal of trees in three blocks of *Brachystegia* woodland (Narasha, Kararacha and Jilore area) on the species' density and distribution. Over a period of 3 weeks, 6 transects totaling 6 km were used in surveying Sokoke Pipit population and sampling key vegetation structure, forest floor litter and main forms of human activity to test the relationships. Overall density of Sokoke Pipit was 0.72±0.15 birds/ha with an estimated population of 5,544 for the Brachystegia woodland. Logging showed a negative effect on Sokoke Pipit density, especially removal of small trees (R^2 = 0.663, ß = -0.814, p = 0.048) but the species seemed to select for deeply-littered habitat (R^2 = 0.769, ß = 0.877, p = 0.021) which partly resulted from removal of small trees, though it was in general randomly distributed ($\chi^2_{(2, 0.05)}$ = 2.061). Overall human activity intensity had little influence on the species' spatial occurrence despite selective logging constituting an important part of overall human activity. We conclude that human-driven logging is not the only cause of overall tree removal and suggest that elephant activity might be a significant contributor to this form of habitat degradation for Sokoke Pipit. Long term conservation strategy for the species will require continued control of illegal logging as well as regulation of elephant dispersal across the forest especially in the *Brachystegia* woodland

Introduction

Many natural habitats in the world are facing increasing threats of loss and modification to give way to other uses to provide for needs of a similarly increasing human population (Silver and Defries 1990). Such habitat effects inevitably affect biodiversity through fragmentation or loss of habitat with adverse consequences on dispersal and reproduction amongst wild communities or species (Wilson, 1992). Of all natural habitats, tropical forests are by far the riches in biodiversity since, although they cover no more that 6% of the global land surface, they host at least half of all terrestrial species on earth (Gardner *et al*., 2009). Yet they are among the most threatened habitats from human exploitation and degradation with an estimated rate of loss of c. 10 % every decade in absence of formal protection (Whitmore, 1997).

In Africa, exploitation and loss of the natural forest mainly takes the form of unsustainable or unregulated uptake of various products such as wood, fruits, vegetables, medicine, soils, water, direct hunting of animals or clearing for agriculture, settlement and other forms of development (Gardner *et al.,* 2009; Otieno and Analo, 2012). High intensities of such human activities may trigger various ecological and even genetic responses by species of forest biodiversity. Birds, for instance, are among the most threatened by forest destruction, particularly for species that are forest-dependent (Collar *et al.*, 1994; Stattersfield *et al.*, 1998). According to Bennun and Howell (2002), such sensitivity of birds to habitat perturbations might even be harnessed as a tool for monitor quality of such impacted habitats.

Sokoke Pipit (*Anthus sokokensis* van Someren, 1921) is a forest-floor dwelling Motacillid of the East African coastal forests of Kenya and Tanzania (Burgess *et al*., 1991; Dowsett and Forbes-Watson, 1993; BirdLife International, 2013). The globally-Endangered species is restricted in its range, mainly to non-closed canopy woodland habitat dominated by *Brachystegia* tree species (Leguminoceae) (Oyugi *et al*., 2007; BirdLife International, 2013) where it feeds on arthropods on the ground or in the under-storey (Fry *et al*., 1992Mlingwa *et al*., 1996; Musila *et al*., 2001; BirdLife International, 2013). It is also more commonly encountered in parts of the woodland with deep floor litter with fairly closed tree canopy (BirdLife International, 2013).

The species is more commonly sighted in the coastal forests of Kenya than in Tanzania though this might mainly be due to variations in intensities of effort. The most common sites in Kenya are Arabuko-Sokoke forest and Dakatcha Woodland. However, the main threat to the species, which influences its local distribution, is thought to be various degrees of modification of its habitat (Fry *et al.*, 1992; Musila *et al.*, 2001) especially removal of *Brachystegia* trees, a process to which it is very sensitive (Birdlife International, 2013) as it accelerates degradation of the species and might hamper its dispersal.

The study aimed to assess the role of tree removal and other anthropogenic impacts on density and distribution of Sokoke Pipit in the *Brachystegia* woodland sections of Arabuko-Sokoke forest, which is the largest single contiguum of indigenous forest of coastal East Africa (ASFMT, 2002; BirdLife International, 2013). Although there have been extensive previous studies on the forest's biodiversity in general (Waiyaki and Bennun, 1999; Bennun and Njoroge, 1999); on some forest-dependent bird species (Matiku *et al.*, 2000; Davis, 2005; Oyugi *et al.*, 2011) and one on forest disturbance (Oyugi *et al.*, 2007) no study has been conducted to directly investigate the link between Sokoke Pipit population or distribution to anthropogenic habitat impacts. Although Musila *et al.* (2001) looked at the specie's habitat requirements within the *Brachystegia* woodland, they did not specifically examine its response to tree removal. Our study thus aimed at filling these gaps as well as providing updates on the species current population estimate over the past decade.

Materials and methods

Study area: Arabuko-Sokoke forest is located between $39^0 40^' E$ - $39^0 50^' E$ longitude and $3^0 10^' S$ - $3^0 30^' S$ latitude, within Malindi and Kilifi Districts along Kenya's north coast (18 km south of Malindi) see Fig 1. Its altitude ranges from 60 to 200 m above sea level (Davis, 2005) where the mean annual rainfall ranges from 600 mm in the northwest part to 1100 mm in the northeast, long rains falling between late March and May and short rains occurring from November to December (Oyugi, *et al.,* 2007). Mean monthly temperatures range from 26 - 31^0 C. The forest is one of the few remaining indigenous forests in Kenya, and one of the largest fragments of an earlier, much larger coastal forest that once covered much of the East African coast (Burgess *et al.,* 2003). The forest covers 41, 600 ha (ASFMT, 2001) including 4,300 ha which is formally protected as a nature reserve (Davies, 2005; BirdLife International, 2012).

In terms of biodiversity, the forest forms part of the Eastern Arc Mountains and Coastal Forests biodiversity hot spots (Gordon *et al.*, 2003) and is one of the most key Important Bird Areas in Kenya according to BirdLife International protocols (Bennun and Njoroge, 1999; BirdLife International, 2013), hosting no fewer than 230 bird species including 5 globally-endangered (including Sokoke Pipit *Anthus sokokensis*, Spotted Ground Thrush *Zoothera guttata*, Sokoke Scops Owl *Otus ireneae*, Clarke's Weaver *Ploceus golandi* and Amani Sunbird *Anthreptes pallidigaster* (IUCN, 2013), 4 near-threatened (East Coast Akalat *Sheppardia gunningi,* Plain-backed Sunbird *Anthreptes reichenowi*, Fischer's Turaco *Tauraco fischeri* and Southern-banded Snake Eagle *Circaetus fasciolatus*) and 8 regionally-vulnerable species (ASFMT, 2002; BirdLife International, 2013). Among these are five species endemic to the East African Coastal Forests Endemic Bird Area (Waiyaki and Bennun, 1999; Musila *et al.*, 2001; BirdLife International, 2013). According to Collar and Stuart (1988) it is the second most important forest for bird conservation in mainland Africa. In addition there are three endangered mammals including the African elephant (*Loxodonta africana*); an amphibian *Mertensophryne micrannotis;* the rare lizard *Gastropholis prasina* at least 50 globally rare plant taxa (BirdLife International, 2013).

However, the forest is surrounded by an increasing population of adjacent communities who, due to high relative poverty levels (Fanshawe, 1992; Commission on Revenue Allocation, 2012) rely heavily on various forest products for their daily sustenance. According to a strategic forest management plant estimate, there are almost 60 villages scattered all around the forest in all directions that directly depend of the forest products (Fanshawe, 1995; ASFMT, 2002) although this might have increase over the years.

The forest comprises of three main forest plant community zones: *Brachystegia* woodland which runs in a central strip, relatively open habitat dominated by *Brachystegia spiciformis* growing on soil of white sands and covers some 7,700 ha; mixed forest with a diversity of relatively dense, tall and undifferentiated trees covering an area of about 7000 ha; and Cyanometra forest and thicket, which covers about 23,500 ha, occurs to the west on red Magarini sands and is dominated by *Cyanometra webberi*, *Manilkara sulcata Oldfieldia somalensis* and *Brachystegia huillensis (*Oyugi *et al.*, 2007; Ngala and Jackson, 2012; BirdLife International, 2013). The rest consists of plantation forest and open gaps (Fig 1).

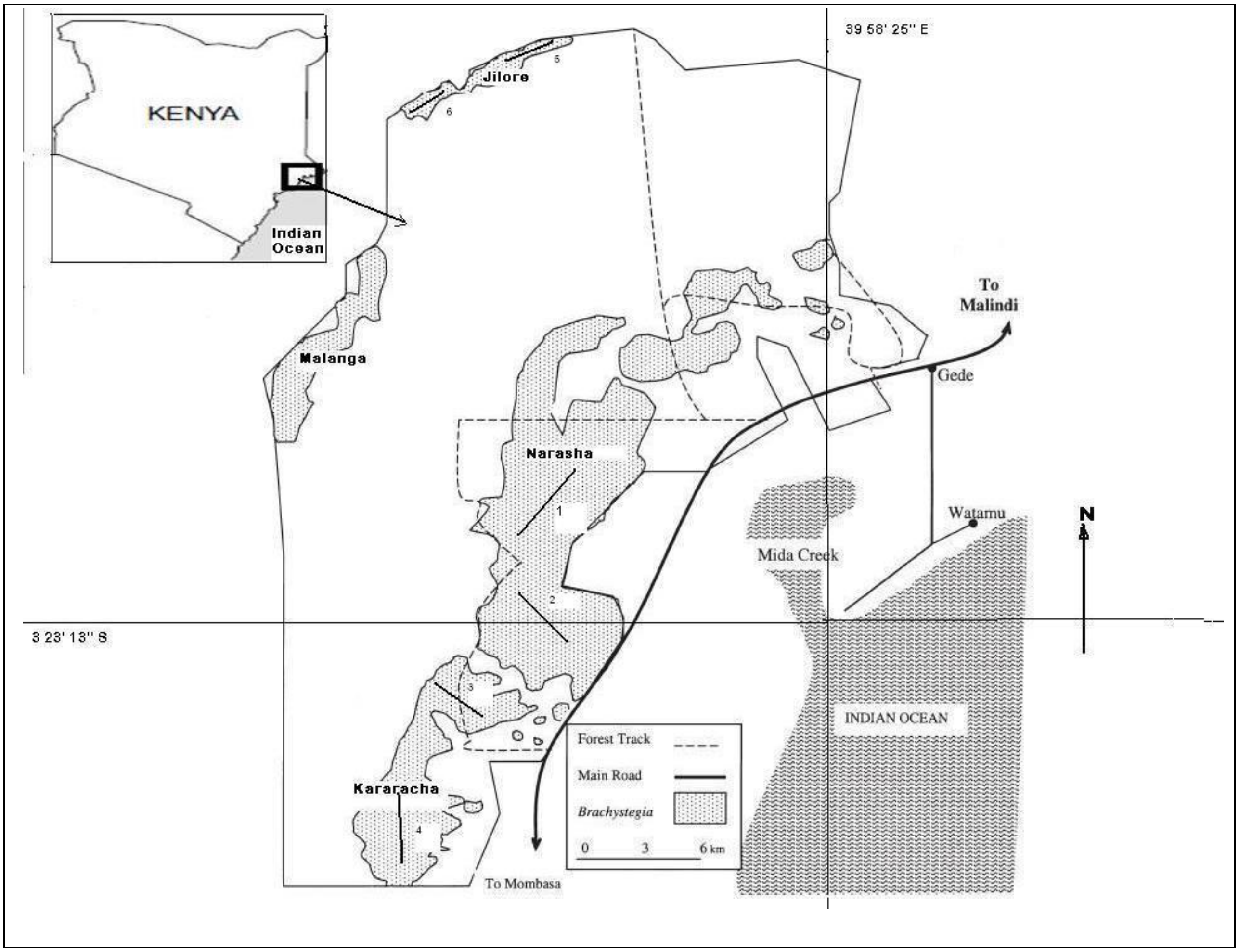

Figure 1: Map of Arabuko-Sokoke showing main blocks in *Brachystegia* woodland where surveys were conducted and the 6 transects used. Numbers 1, 2, 3…. Are transects numbers in the blocks (Adopted from Davis, 2005).

The key human activities impacting on the forest habitat include illegal logging, honey harvesting, game snaring, cattle grazing and numerous tracks used by tree poachers into and out of the forest (Ngala and Jackson, 2010). Nevertheless, much of the impact particularly on trees, resulting in removal and localised habitat fragmentation, forest cover is also caused by the African elephant which is present in populations estimated at between 126-172 in the forest in 1999 (Muoria, 2001) and 180-223 in 2008 (Omondi *et al*., 2012). This is compounded by the fact that a considerable proportion of the forest is now bounded by an electric fence, following earlier complaints of elephant crop damage on adjacent farms.

The study was conducted in the *Brachystegia* forest zone to examine responses of Sokoke Pipit to removal of trees and other key impacts on its habitat originating from or related human activities in that part of the forest. Response to such variables were assessed in term of the specie's density, encounter and distribution. Our main expectation was that anthropogenic impacts had adverse effects on the specie's occurrence and distribution across the *Brachystegia* forest habitat

Sampling strategy

All surveys and sampling took place over 2 two-week periods, one in November 2011 and the other in February 2012. The surveys were conducted within three blocks of the *Brachystegia* woodland zone of the forest which is characterized mainly by dominance of large *Brachystegia* vegetation in low density with largely open under-storey with little or no undergrowth, and heavily leached infertile whitish sandy soils that have very low moisture or water retention/content (UESCO, 2013). The study sites were stratified thus: the main forest reserve block covering the northern central part of *Brachystegia* woodland or north-eastern part of the forest, centered around Narasha (generally regarded as disturbed); the lower block of the forest reserve (regarded as less disturbed) in Kararacha area; and the smaller strip on the outer north-western part of the forest around the Jilore village (Fig 1). This classification is based on the methodology of Oyugi *et al.* (2007). A total of 6 one-kilometre transects were laid randomly in across the three forest blocks, two in each, with 100 m separating them. Bird surveys, vegetation sampling and habitat assessment for human activities, were assessed on separate days. Bird surveys were conducted twice along each of the transects, once on each sampling week.

Bird survey

Sokoke Pipit and other birds were surveyed using Distance protocol, as described by Buckland *et al*. (1993) starting from 6.00 am to 9.00 am along the randomly selected 1-km transects in each forest block. Transect widths were fixed at 60 metres and birds were counted by moving slowly and recording all sightings and calls (Bibby *et al.*, 1998; Bennun and Howell, 2002). Two surveyors worked in pairs, one observing with a pair of binoculars and listening and the other recording encounters. Perpendicular distance of each encounter from the transect centre was also determined, using a range finder, and recorded, including cluster sizes Buckland *et al.*, (1993; Fewster *et al.*, 2009). To reduce biases associated with double counting, birds flying from behind were ignored and a distance of no less than 100m was maintained between transects (Bibby *et al.*, 1998).

Vegetation sampling

Vegetation parameters were assessed within ten 10 x 10 m quadrats along the same transects used for birds. The quadrats were established on alternate sides of the transects at 100-m intervals and within them estimates of canopy height, using range finder, and canopy cover from three different points along a diagonal line down the quadrat, were scored. Canopy cover was scored as either ranging from 0 - 33 %; 34 - 66 %; or > 66 %). Live woody stems were also counted in each quadrat to gauge the under-storey woody vegetation density. These were scored in three size classes of small (10 – 30 cm); medium sized (31 – 60); cm and large (above 60 cm) measured using a standard tape measure at breast height. In addition, selective logging rate was assessed in each of the quadrats by counting all cut stems of trees of similar diameter size classes as above (Oyugi, 1996).

Human activities

Along stretches of 100 m stretch sections on each transects, observations and assessment were made and recorded of signs of human activities including such as foot tracks, paths or roads; wood collection; cattle grazing; charcoal burning; logging, pole cutting or vegetation clearing; grass or leave harvesting; hunting or game snaring; settlement; or agriculture. These were eventually consolidated and evaluated for each block to quantify disturbance indices. Assessment along 100-m sections was a more efficient way of ultimately gauging relative prominence of each activity on the habitat.

Floor litter sampling

In each of the quadrats along transects used for vegetation sampling, forest floor litter depth was assessed at three points along a diagonal running from one corner to another through the quadrat centre (Sutherland, 1996) see Fig 2. The depth of litter was determined using a straight, stiff thin metallic rod driven vertically and gently downward till it touched the forest floor beneath the litter, and then read off against a standard 30 cm ruler.

Litter cover was assessed by dividing the 10 x 10 m quadrats into 25 smaller grids of 2 x 2 m qaudrats by use of standard metre rule and tape measure, then counting the total number of these that was covered by litter to 30 % or less; 31- 66 % and > 66 % before scoring accordingly on a proportion out of a total of 25 squares.

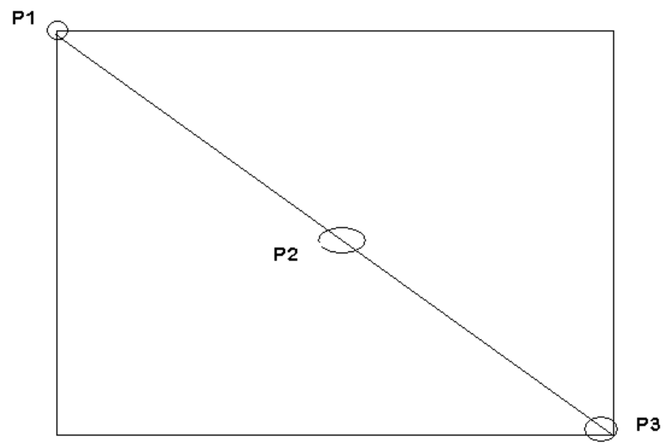

Figure 2. Diagram showing systematic sampling of forest floor litter

Data analyses

Because of the relatively small number of replicates in the study (two transect runs for birds and one set of habitat variable samples) there was need to make deliberate effort to improve normal distribution of the data (Bibby *et al.*, 1998; Zar, 1999). Consequently, all count data such as for birds, live stems and cut tree stumps, were transformed by logarithm while ratios and scale data such as canopy cover score and activity intensity were transformed by arc-sine (Zar, 1999). Sokoke Pipit densities per hectare were determined using DISTANCE v 6 software (Buckland *et al.*, 1993) while their encounter rates were also determined using the relationship $R_E = n / L_t$ where R_E = encounter rate; n = mean abundance of Sokoke Pipits along transect; and L_t = total length in kilometers, of transect. Species richness for all birds was evaluated as the total cumulative number of different species recorded in each transect during all the bird sampling sessions. Bird diversity was worked out using the reciprocal of Simpson's index of the form: $1/S = 1/[(\Sigma n(n-1)/N(N-1)]$ where n = the total number of organisms of a particular species and N = the total number of organisms of all species. Simpson's index of diversity was chosen as it is suitably robust for non-numerous replicate sampling such as was the case in the study (Bibby *et al.,* 1998).

Mean number of live stems and tree stumps/cut stems were derived from all stems counted in the three size classes in all quadrats in transects and transformed into densities per hectare. Percent canopy cover scores were coded such that open canopy, moderately open canopy and closed canopy scored 1, 2 and 3, respectively. These were then scaled up to rations, with '3' as the maximum. Canopy height, floor litter cover and litter depth measurements were worked into means from all quadrats in all transects. Overall human impacts on habitat for each forest block were expressed as indices determined as mean frequencies obtained from percent scores of encounter rates of each form of activity within all 100-m stretches along transects. Overall activity intensity index was calculated from: $D_I = [\Sigma(a_f*10)/A_f)]T_t*100$ where D_I = overall habitat disturbance index; a_f = the sum of encounter rates of a particular activity in a 100-m stretch of transect; A_f = the sum of all encounters of all forms of activity in all transects; T_t = the sum of all transects in a forest block and *10* = the number of 100-m stretches in each transect (Otieno *et al*., in press).

A preliminary multiple correlation test between habitat variables (fixed) and Sokoke bird variables showed considerable covariance amongst the various size classes of live stems and tree stump counts. Therefore, the size classes were pooled together into 'total live stems' and 'total stems cut' for purposes of subsequent analyses. For habitat variables that showed particularly strong correlations o bird variables, simple linear regression was performed to test the actual correlations and relative strengths of predictability. Differences of means of the key habitat and activity variables were compared on the spatial scale by one-way Analysis of Variance (ANOVA) using the forest blocks as the categorical treatment effects. Finally, Chi test of homogeneity was employed to test the departure from random dispersion of Sokoke Pipit across the blocks surveyed.

Results

In all surveys, a total of 308 birds were encountered, distributed across 55 species belonging to 25 families. This included three of the globally-endangered species Sokoke Pipit, Clarke's Weaver and Amani Sunbird; two globally near-threatened species East Coast Akalat and Plain-backed Sunbird*;* and one regionally-vulnerable species Little Yellow Flycatcher *Erythrocercus holochlorus* (Appendix 1). There were 15 encounters of Sokoke Pipit with an overall abundance of 27 individuals. Sokoke Pipit occurred at an overall density of 0.72 birds/ha across the blocks surveyed, with a projected overall population estimate of 5,544 individuals (Table 1). The density was highest in the Jilore block than in Narasha and Kararacha. Thus the mean density for the relatively less disturbed zone is 0.89 birds km^{-1} compared to 0.71 birds km^{-1} in the more disturbed zone. Nevertheless, there was no significant departure from random distribution of the species across the blocks ($\chi^2_{(2, 0.05)} = 2.061$).

Table 1. Density per hectare of Sokoke Pipit in the three blocks surveyed in *Brachystegia* woodland of Arabuko-Sokoke forest. AIC = Akaike Information Criterion with right-truncated distances and cosine adjustment function.

Forest block/area	Area (ha)	Disturbance level	Density/ha	AIC	Estimated population	Standard error
Kararacha	2700	Undisturbed	0.79	27.3	2133	184
Jilore	400	Moderately disturbed	0.99	59.7	396.8	100
Narasha	4600	Disturbed	0.71	14.9	3266	104
Overall	7700	General	0.72	98.6	5544	826

Similarly, the species had the highest encounter rate in Jilore (5.2 birds km^{-1}) while Kararacha had 2.5 birds km^{-1} and Narasha 1.9 birds km^{-1}. On the other hand, for the all birds, Kararacha recorded the highest species diversity ($1/S = 0.69$) followed by Narasha ($1/S = 0.721$) then Jilore area ($1/S = 0.724$). Note that S is the reciprocal of Simpson's diversity index. Jilore was most bird species rich (38±2.8), followed by Narasha (35±3.3) and then Kararacha (34±3.1).

Floor litter deepest in the Kararacha block (2.52±0.83) followed by Jilore block (2.21±0.73) and Narasha (1.75±0.58), $F = 6.839$, $p = 0.002$ see Fig 3. Mean litter cover was generally within the second scale (33 – 66 %) in Kararacha and Jilore blocks and below the second scale (0 – 33 %) in the Narasha block ($F = 9.937$, $p = < 0.001$).

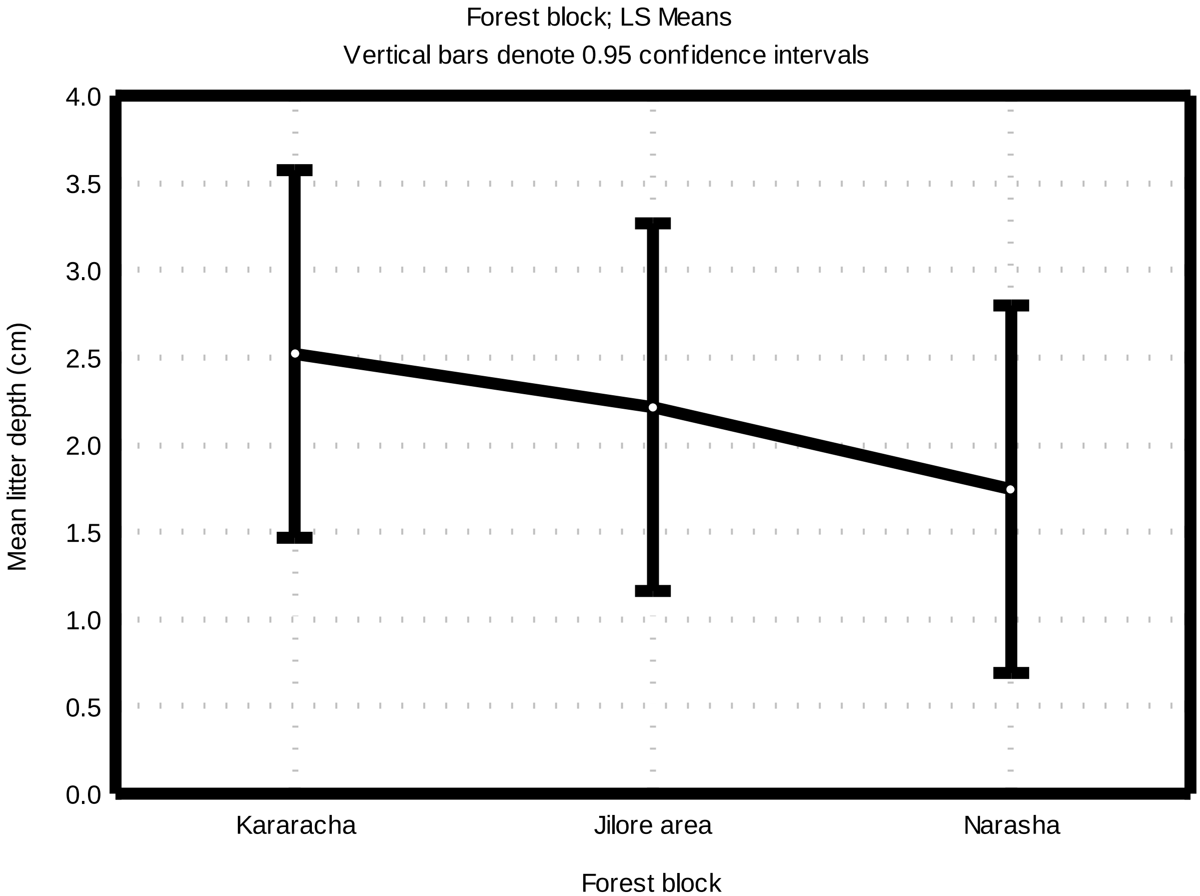

Figure 3. Error plot of differences in litter depth across the three forest blocks

Other significant spatial variations in means of habitat variables were observed in litter cover, overall tree removal (total cut stems), human activity intensity, removal of small poles (small-sized trees), density of live mid-sized trees and removal of mid-sized trees (Table 2). Thus overall tree removal rate was highest in Kararacha block and lowest in Narasha whether for small poles or large mature trees. The same pattern was observed for density of mid-sized live woody vegetation. Despite this, most impact from human activity was felt in Jilore area and least in Narasha.

Table 2. One-way ANOVA results for significant variations in means of key habitat parameters amongst the forest blocks surveyed. Tree removal and live tree figures are given in densities per hectare. Activity intensity is an index derived from overall intensity of activity forms.

Parameter	Forest block	N	Mean (ha^{-1})	Standard error	F statistic	Probability (at 95 % confidence)
Overall tree removal	Kararacha	20	140.0	1.40	10.62	< 0.001
	Jilore area		35.0	0.07		
	Narasha		10.0	0.01		
Small-sized tree removal	Kararacha	20	105	0.84	6.18	0.004
	Jilore area		35.0	0.11		
	Narasha		11.0	0.01		
Mid-sized tree removal	Kararacha	20	25.0	0.03	4.48	0.016
	Jilore area		20.0	0.04		
	Narasha		20.5	0.01		
Mid-sized live trees	Kararacha	20	200.5	4.01	6.28	< 0.001
	Jilore area		65.0	0.52		
	Narasha		175.4	03.33		
Activity intensity	Kararacha	20	0.97	0.16	3.23	0.047
	Jilore area		1.01	0.17		
	Narasha		0.92	0.14		

In overall, the *Brachystegia* forest was dominated by small-sized tree of dbh 30 cm or less especially in Jilore area (Table 3). These were also the most intensely logged tree sizes with most of them cut in Kararacha block (Table 2).

Table 3. Mean number of live woody stems and cut stems per hectare across the *Brachystegia* woodland.

Block	Live woody stem			Total	Cut stems			Total
	0-30 cm	31-60 cm	> 60 cm		0-30 cm	31-61 cm	>60 cm	
Kararacha	750	200	180	1130	105	25	10	140
Jilore area	980	65	180	1225	35	20	0	35
Narasha	785	175	150	1110	0	20.5	10	10
Total	2515	440	510	3465	140	65.5	20	185

Sokoke Pipit abundance was strongly correlated to forest floor litter depth (R^2 = 0.719, ß = 0.848, p = 0.033) and floor litter cover (R^2 = 0.769, ß = 0.877, p = 0.021) but litter depth was the better predictor of the species' abundance (Fig 4), with a predictive equation:

*Sokoke Pipit Abundance = 0.727 + 0.485 * Mean Litter Dept*

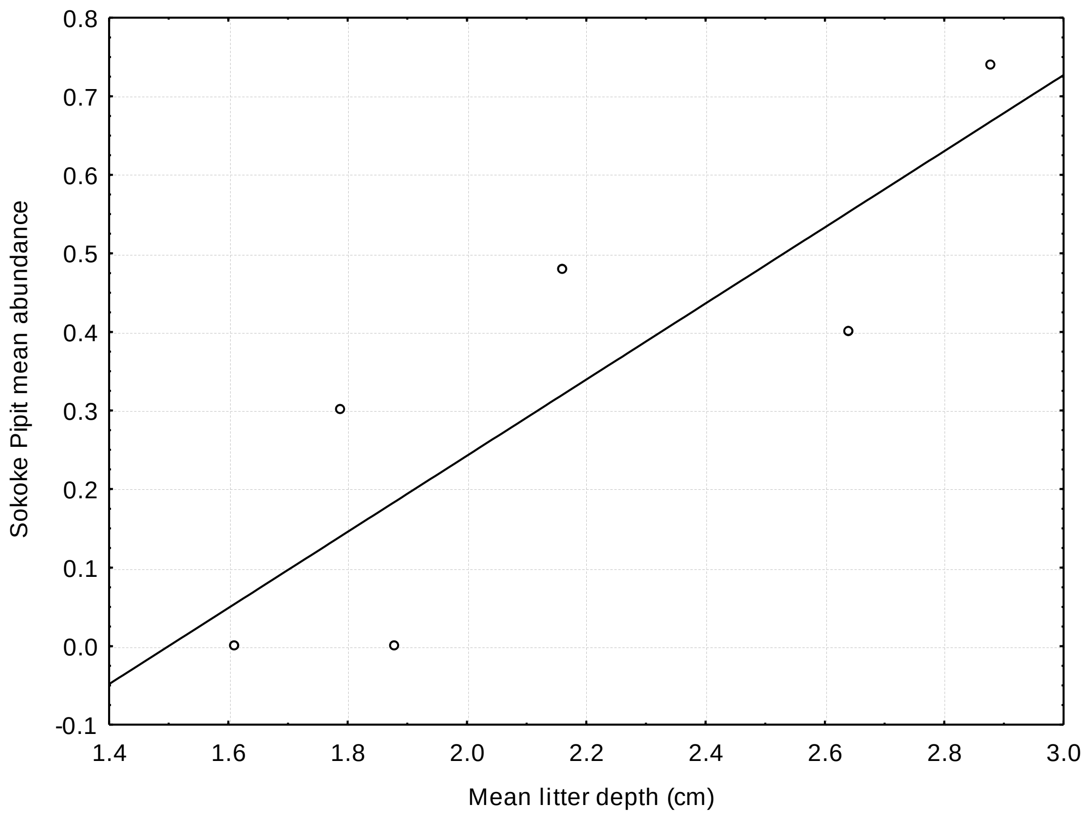

Figure 4. Scatter-plot of litter forest floor litter depth and mean abundance of Sokoke Pipit across the forest blocks surveyed.

Further, litter depth appeared slightly correlated to the rate of logging of small trees (R = 0.787, p = 0.063). Conversely, Sokoke Pipit density appeared adversely affected by overall rate of tree removal ($R^2 = 0.663$, ß = -0.814, p = 0.048) see Fig 5. However, there was no significant effect of overall habitat disturbance, depicted by total human activity intensity ($R^2 = 0.028$, ß = 0.114, p = 0.753) on Sokoke Pipit density. Nor did the species seem to be seriously affected by variations in forest canopy cover (R = 0.5798, p = 0.228) or canopy height (R = 0.174, p = 0.742). Presence of paths and tracks in general was the most prominent form of human activity (R = 0.613, p = 0.031) followed by logging especially illegal removal of small-sized trees/poles (R = 0.883, p =

0.019). An average of 6 paths/tracks were observed per hectare in Narasha and Jilore area blocks and 4 in Kararacha block.

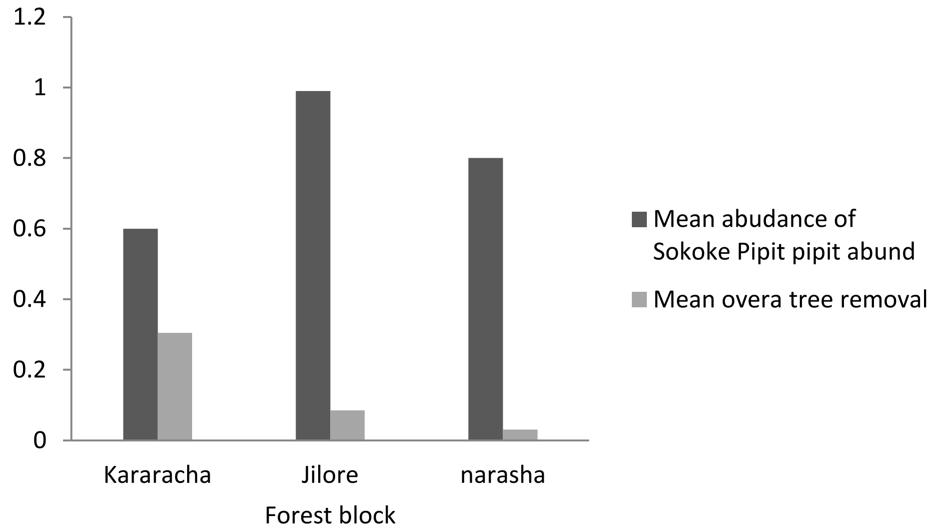

Figure 5. Relationship between Sokoke Pipit density and overall tree removal in the *Brachystegia* woodland surveyed across the blocks.

Discussion

The density of Sokoke Pipit here are lower than those from the studies by in the same habitat about a decade ago in which the undisturbed *Brachystegia* forest had 2.8 birds ha^{-1} while disturbed zone had 0.9 birds ha^{-1} (Musila *et al.,* 2001). The same applies for the same authors' estimated total population of 13,000 birds. The most plausible explanation for this is the continued modification and degradation of the species' *Brachystegia* woodland habitat in the forest, through disturbance especially loss of tree cover, that continuously opens up the forest as observed by Bennun and Njoroge (1999), Matiku *et al.* (2000), ASFMT (2002), Davis, (2005), Oyugi, *et al.* (2007), Oyugi *et al*. (2011) and BirdLife International (2013). Human activity and related encroachment effects are strongly presumed by all these workers as the sole and direct source of such disturbance. However, from this study, while encroachment-related human activity certainly plays a preeminent role in modifying the forest, it might not be the only factor that currently drives degradation of the forest habitat.

To give perspective to this perception, it is important to point out that the current general categorization of the area around Narasha towards the middle section of *Brachystegia* woodland as “disturbed” and Kararacha area to the south eastern part as “undisturbed” (Davis, 2006; Oyugi *et al.*, 2007 and 2011) is mainly on the basis of the comparative intensities of decades of massive selective logging which was spurred by high demand for valuable timber species, thus accelerating loss of much of primary indigenous stands of *Brachystegia* trees in the forest’s pre-protection era (ASFMT, 2002; Oyugi *et al.*, 2007). The effect of that thrust impacted the *Brachystegia* forest so heavily that it is yet to recover its primary stand density even with the advent of current formal forest protection. Thus the scar of differential “disturbance” of the woodland still persists and this spatial characterization continues to largely influence habitat stratification in most scientific studies in Arabuko-Sokoke. The main guideline for habitat stratification to these scientists is the existing historical ecological evidence, such as patchiness of distribution of dominant tree species, comparative densities of woody vegetation or sparseness of undergrowth (Fanshawe, 1995; Davis, 2005; Oyugi *et al.*, 2997) rather than the more consequential and current processes like forest management regimes, climate change and or demographic dynamics of keystone species.

For instance, while it is a fact that the impact of the earlier massive deforestation is still reflected in the structure and function of much the forest and its biodiversity, and that human encroachment and associated illegal activities still affect forest in general the Kenya Forest Service and Kenya Wildlife Service has greatly reduced these anthropogenic effects over the past one-and-a-half decades. This has been through increased surveillance and enforcement supported by establishment of more stations and patrol outposts particularly in the “disturbed” Narasha area (ASFMT, 2002); Ngala and Jackson (2010) as a result of which tree logging is now much less in scale than what it was in those earlier years. As an illustration, in this study, although logging was the second greatest contributor to overall human activity intensity, it was selectively skewed towards the smallest logs mainly in Kararacha block. Small-size trees are easy targeted by illegal loggers not only because they are most numerous as the forest attempts to regenerate but also for the fact that they are easier to cut down and carry away with minimum time and risk of being apprehended by forest authorities. But though poaching of small logs has negative long term implications for forest regeneration, it does not have as profound impacts on tree canopy or other aspects of the forest habitat as did those earlier decades of massive logging of large trees.

Nevertheless, tree removal still has a strong negative effect on densities of such forest specialist bird species as Sokoke Pipit though its effects are either mitigated or superimposed on by other habitat variables. For instance, degradation of habitat dues to massive removal of small sized tree appeared be countered by the commandingly positive role of forest litter depth and cover for the species. Floor litter harbours much of the arthropod and other invertebrate biomass on which many insectivorous birds such as Sokoke Pipit depend (Bennun and Njoroge, 1999; Lange *et al.*, 2011). Secondly, the process of removal of small trees seemed to be a significant source of floor litter even though there was no evidence that such removal of small trees favoured Sokoke Pipit abundance to an extent that the species selected for areas with high rates of small tree logging. The likely explanation for this is that much of the litter associated with small tree removal was mainly of recently shed and still unprocessed thus not very useful in attracting Sokoke Pipit as it harboured little arthropod biomass. This is partly because of low decomposition rate of floor litter typical of many eastern African coastal forests due to generally low But litter supply from logging or other forms of tree removal cannot be a sustainable incentive for Sokoke Pipit because as more trees are removed and their litter decompose, no matter how slowly, the habitat ultimately becomes intolerably open and bereft of the arthropod biomass rendering it resource-poor while exposing the individuals to predators.

Human versus elephant activity

Tree removal definitely had a negative effect on the population of Sokoke Pipit in the *Brachystegia* woodland and in fact, Kararacha block's predominance in overall human-induced tree removal (logging) over Jilore area and Narasha, conforms to patterns featured in findings by Ngala and Jackson (2010) from surveys carried out in 2009 and 2010. But since the heavily-logged Kararacha block recorded higher Sokoke Pipit density than the least-logged Narasha (Table 1), it follows that human-driven selective tree removal, is no longer the sole determinant of Sokoke Pipit population or distribution across the *Brachystegia* woodland. Secondly, the presence of paths and tracks, which constituted the most prominent form of overall human activity showed little deterrence on occurrence of Sokoke Pipit in its habitat. In fact, on several occasions, we sighted the species rich in the middle of the open tracks. This is why despite the highest overall intensity of human activity with high concentration of footpaths and tracks in the small narrow peripheral *Brachystegia* woodland block around Jilore area, most Sokoke Pipits and other bird species were encountered there compared to Narasha with the lowest overall human activity and logging rate yet lowest Sokoke Pipits encounter rates. Thirdly, litter depth that was a great incentive for Sokoke Pipit encounter rates, was lower in Narasha area compared to the other two blocks due to largely exposed forest canopy.

From the foregoing, it seems that there are other additional influences on habitat suitability for the species other than human activity *per se*. From Musila *et al*., (2001) Sokoke Pipit density was positively associated to forest tree canopy cover. Although there was no such association in the present study, the lowest values for the two parameters in Narasha block further point to non-suitability of the Narasha area habitat to the species as compared to the other two blocks. Such comparative inferiority of habitat due to lower canopy height, canopy cover which exposes the understory, can be associated to elephant activity which is highest in the Narasha block as observed in the management plan by ASFMT (2002) and later from field surveys conducted by FASF (Ngala, 2009). On the other hand, Kararacha block's comparative habitat suitability is also depicted by its superiority in overall bird species diversity.

There are three main reasons why elephants can be associated with current major cause of disturbance and habitat degradation in *Brachystegia* woodland of Arabuko-Sokoke forest. First, the forest is estimated to hold between 126 and 172 individuals of the large browser, giving a density of 0.43 km^{-1} (Mworia, 2001; Omondi *et al.*, 2012). This is very close to the threshold of the recommended maximum of 0.5 km^{-1} carrying capacity to ensure stability and sustainability of the integrity of vegetation in the habitat (Jachmann and Cores, 1989). Secondly, and to aggravate the elephant-driven habitat destruction and tree loss in Arabuko-Sokoke forest, the forest management has now erected an electric fence along a substantial portion of the forest boundary for the purpose of keeping the animals within the forest to reduce conflicts with forest adjacent farmers who previously incurred heavy crop losses to the elephants. Thirdly, the *Brachystegia* woodland in Arabuko-Sokoke forest has one of the lowest vegetation regeneration rates due to poor soil structure (UNESCO, 2013) low soil nutrient, low soil water content and limited micro-organic activity (Bacheus *et al.*, 2006; Oyugi, *et al.*, 2007). These factors combine to make elephants at least as profound a driver of overall habitat change in the *Brachystegia* woodland as are the adjacent human community. Although the study did not include collection and analysis of data on elephant-driven habitat destruction in the forest, we noticed throughout the fieldwork several small to medium-sized trees freshly or recently felled by the large mammals as they browse along or off their regular tracks. In some transects in Narasha area, the frequency of elephant-felled trees outnumbered those cut down by humans even on a 1-km stretch.

Without deliberate considerations to regulate population and movement of elephants in *Brachystegia* woodland concurrently with a halt in illegal logging in the forest, the rate of tree removal is likely to accelerate considerably in the medium term with serious ramifications for basic ecological needs of Sokoke Pipit.

Conclusion

In conclusion, Sokoke Pipit density and estimated population in *Brachystegia* woodland is a lot lower than it was a little more than a decade ago, mainly due to continuing degradation of its habitat. The main cause of habitat degradation for the species still remains removal of trees although this now appears to be driven as much by illegal logging pressure by humans as by elephant feeding activity especially in the northern end of the *Brachystegia* forest. Illegal selective loggers mainly target small trees/poles trees which are taken mainly from parts of the forest farthest away from patrol bases and are easily carried out of the forest. The species favoured habitat with open under-storey and deep litter cover but not necessarily with dense vegetation or purely no disturbance. Thus, despite numerous paths and tracks used by tree poachers, the species was encountered in appreciable numbers even in the heavily disturbed Jilore area and the heavily-logged Narasha block. A sound long-term conservation strategy for the species should incorporate both stricter enforcement against logging, exploration of habitat restoration options as well as management of elephant populations or movement in the pipit's *Brachystegia* woodland stronghold that would otherwise be rapidly lost.

Other project milestones

- The project has yielded results that now contribute to a comprehensive understanding of the effect on Sokoke Pipit of tree removal and related human activities in the *Brachystegia* woodland of Arabuko-Sokoke *forest*
- The results are ready for use in updating the bird checklist fro Arabuko-Sokoke forest and Kenya's national bird atlas database
- Results made available to Nature Kenya for use in compiling the annual Kenya IBA status and Trends report. In this regard, ultimately, the results of the proposed study are intended to enrich the methodology that forms a basis for the ongoing long-term community-based monitoring activity for Arabuko-Sokoke forest with Sokoke Pipit as one of the flag-ship species.
- The results will also form part of the periodical IBA Status and Trends Report for Kenya that is published by Nature Kenya. This is one of the widest circulated bird-related publications in Kenya.
- This project report is designed in away to a manuscript produced for possible publication in *Bulletin of ABC*. In addition, copies of the report have been handed to the Kenya Wildlife Service Coastal Region Coordinator and Kenya Forest Service Regional Conservator, both based in Arabuko-Sokoke Forest, Gede Station, and to the local

conservation groups, Arabuko-Sokoke Forest Guides Association (ASFGA) and Friends of Arabuko Sokoke Forest (FASF). This is to contribute information towards better management of Arabuko-Sokoke forest.

- Mr. Alex Mwalimu and Mr. David Ngala both of the ASFGA and FASF were fully involved in the actual execution of the project and authorship of the results. They received training in simple forest bird survey design, habitat monitoring, assessment of human impacts and forest litter characteristics. They also acquired additional skills in use of GPS to map forest tracks. This represents a significant capacity building achievement not only for themselves as individuals but also for the local conservation groups of which they are members to which the benefits shall be multiplied. They shall be better skilled in carrying out the periodical monitoring of Arabuko-Sokoke forest habitat and flagship birds, which forms part of Nature Kenya's Critical IBA monitoring scheme in Kenya.
- One colour-plated bird field guide book and 1 pair of binoculars was purchased from project finances and donated to the Arabuko-Sokoke Forest Guised Association to support their regular monitoring activity.

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Appendices

Appendix 1: Checklist of all birds observed across the *Brachystegia* woodland blocks of forest surveyed in Arabuko-Sokoke forest. Checklist is in phylogenetic order following Bird Committee, EANHS (2009)

No.	**Family**	**Scientific Name**	**Common Name**
1	Accipitridae	*Accipiter tachiro*	African Goshawk
		Polyboroides typus	African Harrier Hawk
		Accipiter minullus	Little Sparrowhawk
2	Columbidae	*Turtur chalcospilos*	Emerald-spotted Wood Dove
		Streptopelia semitorquata	Red-eyed Dove
		Turtur tympanistria	Tambourine Dove
3	Cuculidae	*Chrysococcyx klaas*	Klaas Cuckoo
		Pachycoccyx audeberti	Thick-billed Cuckoo
		Centropus superciliosus	White-browed Coucal
4	Caprimulgidae	*Caprimulgus pectoralis*	Fiery-necked Nightjar
5	Phoeniculidae	*Rhinopomastus cyanomelas*	Common Scimmitarbill
		Phoeniculus purpureus	Green Wood Hoopoe
6	Bucerotidae	*Bycanistes bucinator*	Trumpeter Hornbill
7	Lybiidae	*Stactolaema olivacea*	Green Barbet
8	Indicatoridae	*Indicator variegatus*	Scaly-throated Honeyguide
9	Picidae	*Dendrocopos minor*	Little-spotted Woodpecker
		Campethera mombassica	Mombasa Woodpecker

10	Platysteridae	*Batis mixta*	Forest Batis
		Batis soror	Pale Batis
11	Malaconotidae	*Dryoscopus cubla*	Black-backed Puffback
		Telophorus viridis	Four-coloured Bush-shrike
		Laniarius aethiopicus	Tropical Boubou
12	Prionopidae	*Prionops retzii*	Retz Helmetshrike
			Chestnut-fronted
13	Timaliidae	*Prionops scopifrons*	Helmetshrike
14	Oriolidae	*Oriolus larvatus*	Black-headed Oriole
		Oriolus oriolus	Eastern Golden Oriole
		Oriolus oriolus	Eurasian Golden Oriole
15	Dicruridae	*Dicrurus adsimilis*	Common Drongo
			Blue-mantled Crested
16	Monarchidae	*Trochocercus cyanomelas*	Flycatcher
		Erythrocercus	
		holochlorus	Little Yellow Flycatcher
17	Cisticolidae	*Apalis melanocephala*	Black-headed Apalis
		Camaroptera	
		brevicaudata	Grey-backed Camaroptera
		Prinia subflava	Tawny-flanked Prinia
18	Pycnonotidae	*Nicator gularis*	Eastern Nicator
		Phyllastrephus fischeri	Fischer's Greenbul
		Phyllastrephus strepitans	Northern Brownbul

		Phyllastrephus debilis	Tiny Greenbul
		Chlorocichla flaviventris	Yellow-bellied Greenbul
		Andropadus importunus	Zanzibar (Sombre) Greenbul
19	Sturnidae	*Lamprotornis corruscus*	Black-bellied starling
20	Turdidae	*Cercotrichas quadrivirgata*	Eastern Bearded Scrub Robin
		Neocossyphus rufus	Red-tailed Ant Thrush
21	Muscicapidae	*Muscicapa caerulescens*	Ashy Flycatcher
		Sheppardia gunningi	East Coast Akalat
		Bradornis pallidus	Pale Flycatcher
22	Musophagidae	*Tauraco fischeri*	Fischer's Turaco
23	Nectariniidae	*Anthreptes pallidigaster*	Amani Sunbird
		Hedydipna collaris	Collared Sunbird
		Cyanomitra olivacea	Olive Sunbird
		Anthreptes reichenowi	Plain-backed Sunbird
24	Ploceidae	*Ploceus golandi*	Clarke's Weaver
		Ploceus bicolor	Dark-backed Weaver
25	Motacillidae	*Anthus sokokensis*	Sokoke Pipit

Appendix 2: Some images from the project site



Inside typical *Brachystegia* woodland; Bird survey; Measuring floor litter depth



Electric perimeter fence around the forest; Small poles logged out inside the forest; Large tree felled by elephant



Small tree felled by elephant; Bags of charcoal awaiting transportation from forest; The survey and logistics team