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RESEARCH ARTICLE

REVISED Spatial response of the globally-endangered Sokoke Pipit (*Anthus sokokensis* van Someren, 1921) to habitat degradation in an Eastern Arc Coastal forest [version 2; peer review: 1 approved, 1 approved with reservations]

Previously titled: Spatial response of the globally-endangered Sokoke Pipit (*Anthus sokokensis* van Someren, 1921) to habitat modification in an Eastern Arc Coastal Forest

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Abstract

The Arabuko-Sokoke forest is the largest relic of a formerly larger contiguous East African coastal forest. It forms part of the Eastern Arc Mountains and Coastal forest ecoregion which is a global biodiversity hotspot with considerable species endemism. Despite such conservation significance, the forest is undergoing rapid modification and habitat loss mainly from anthropogenic pressures, with negative impacts on sensitive species such as the Sokoke Pipit (*Anthus sokokensis*), one of the globally-endangered birds. The study examined impacts of habitat degradation on the species' population and spatial occurrence within three blocks of *Brachystegia* woodland in this forest. Over a three week period, six 1km transects were used to estimate the species' population in relation to major habitat quality variables. Sokoke Pipits occurred at an overall mean density of 0.72 ± 0.15 birds/ha with an estimated population of 5,544 in the *Brachystegia* woodland. Tree logging intensity was the key cause of the degradation of the Sokoke Pipit's critical habitat, which affected its density ($R^2 = 0.663$, $\beta = -0.814$, $p = 0.048$). The species also preferred sites covered with deep floor litter ($R^2 = 0.769$, $\beta = 0.877$, $p = 0.021$) even in areas with low tree canopy height, but showed no clumped distribution ($\chi^2_{(2, 0.05)} = 2.061$). The species generally occurred at very low densities in sites with intensive elephant activity that accelerated habitat modification by felling trees and opening the understorey. We conclude that although human-driven tree removal is a major driver of overall degradation of the Sokoke Pipit's critical habitat, elephant

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Any reports and responses or comments on the article can be found at the end of the article.

activity may be an important additional catalytic factor in this process. Long term conservation strategies for the species will require stricter control of logging. Management of the population and dispersal of the elephants across the forest, especially in the *Brachystegia* woodland, may also be helpful.

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REVISED Amendments from Version 1

Many changes have been made in the main body of text in response to the first reviewer's comments, the text and structure of Table 1 has been modified and multiples changes have been made regarding the figures including:

- A new figure has been added, which is now Figure 2 to show the detection histograms for the distance sampling results of Sokoke Pipit density estimates.
- The old Figure 2 therefore now becomes Figure 3 but has been redrawn and is now in the form of box and whisker plots, which should replace the old format.
- The earlier Figure 3 now becomes Figure 4. The figure itself is the same but have substituted "block" for "quadrat" in the legend.
- The earlier Figure 4 now becomes Figure 5, and it has a few changes (including additions in the legend text and transfer of regression equation from text to figure caption).
- All the figures legends have therefore all been renumbered and revised in text, except the old Figure 2 (new Figure 3).
- The stem diameter and canopy cover categories have been corrected.

See referee reports

Introduction

Tropical forests are the most important habitats for biodiversity because although they cover less than 7% of the global land surface, they host at least half of all terrestrial species¹. These habitats also face the greatest threat from human exploitation, destruction or modification with an estimated loss rate of c. 10% every decade particularly in areas without formal protection^{1,2}. Forest-dependent birds are among the most affected by forest destruction and habitat loss^{3,4} and may respond to such perturbations in such spatially wide patterns as to make them suitable for monitoring the quality of the forest habitat and its suitability for other taxa⁵.

The Sokoke Pipit⁶ is a forest-floor insectivore of the East African Coastal forests of Kenya and Tanzania^{7,8}. This globally-endangered species¹⁰ is generally restricted to near-closed canopy woodland habitat dominated by *Brachystegia* tree species (Leguminosae)¹¹, where it feeds on arthropods on the ground or in the lower understorey^{12–14}, in parts of the woodland with deep floor litter cover¹⁴.

Despite its regional coastal distribution, the species has been more frequently encountered in the coastal forests of Kenya than those of Tanzania, with the most common sites in the Arabuko-Sokoke forest (hereafter ASF), and the Dakatcha Woodland. The main threat to the species is the degradation and reduction of its suitable habitat^{12,14}, especially the removal of *Brachystegia* trees, a process to which it is very sensitive¹⁴. Although the species has been reported to occasionally venture to the forest edge including observations while it fed on termites and sparse grass in open areas⁵⁰, it is essentially restricted to the interior of the *Brachystegia* forest. Musila *et al.* observed that the Sokoke Pipit prefers the thicker areas of the understorey, with most of the time spent less than 2 m above ground when not feeding, quickly flushing to upper branches when threatened before returning to forage on the forest floor. The specialist attributes described above suffice to qualify the Sokoke Pipit

as a potentially good candidate indicator species for monitoring disturbance trends of the lower understorey of the *Brachystegia* forest in the same way as the East Coast Akalat *Sheppardia gunningi* has been identified as a good flagship species for monitoring the understorey of the thicket forest in the ASF^{17,38}.

This study aimed to assess the Sokoke Pipit's response to the general degradation of its habitat by comparing its estimated densities across three zones of its *Brachystegia* woodland stronghold in the ASF. Although there have been extensive previous studies on the ASF's biodiversity in general^{15,16}; on other forest-dependent bird species^{17,19,20} and one on forest disturbance¹¹ no study has been conducted to directly investigate the link between Sokoke Pipit population or distribution and degradation of its habitat. Musila *et al.* examined¹⁴ the species' general habitat requirements within *Brachystegia* woodland, but did not specifically examine its demographic response to spatial variations in structural habitat quality. Other specific studies on the birds of the *Brachystegia* zone of the forest explored their demographic relationship to habitat change^{16,19,20} but the species studied were those of the mid to upper canopy rather than of the forest floor such as the Sokoke Pipit. Our study thus aimed at filling these gaps as well as providing updates on the species' current population estimate over the past decade since the study by Musila *et al.*¹⁴ when species density was estimated at 2.8 ha⁻¹ and 0.7 ha⁻¹, respectively in the undisturbed and disturbed areas of the *Brachystegia* forest, with an overall population projection of 13,000 for the whole forest.

Materials and methods

Study area

The ASF is located between 39°40'E–39°50'E longitude and 3°10'S–3°30'S latitude, within the Malindi and Kilifi Districts along Kenya's north coast (18 km south of Malindi) see Figure 1. Its altitude ranges from 60 to 200 m above sea level²⁰, and mean annual rainfall ranges from 600 mm in the northwest to 1100 mm in the northeast, with the rainy season falling between late March and May, the short rains occurring from November to December and dry season from June to October and December to February¹¹. Mean monthly temperatures range from 26 to 31°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 coast²¹. The forest covers 41,600 ha¹⁸ including 4,300 ha which is formally protected as a nature reserve²⁰.

The ASF constitutes one of the Eastern Arc Mountains and Coastal forest ecoregion biodiversity hot spots²² and is one of the most significant Important Bird Areas in Kenya based on BirdLife International criteria^{9,15}. It hosts at least 230 bird species including 5 globally-endangered species (Sokoke Pipit *Anthus sokokensis*; Spotted Ground Thrush *Zoothera guttata*, Sokoke Scops Owl *Otus ireneae*, Clarke's Weaver *Ploceus golangi* and Amani Sunbird *Anthreptes pallidigaster*). In addition there are 4 near-threatened and 8 regionally-vulnerable species^{10,18}. Five of the species namely the Sokoke Pipit, Clarke's Weaver, Amani Sunbird, Fischer's Turaco and Sokoke Scops Owl¹⁶ are endemic to the Eastern African Coastal forest biome¹⁴. These features make ASF the second most important forest for bird conservation in mainland Africa¹⁴.

The ASF consists of three main forest plant communities: *Brachystegia* woodland which runs in a central strip and is a relatively open habitat dominated by *Brachystegia spiciformis* trees growing in low density mainly on whitish-leached sandy soils and covers some 7,700 ha of largely open understorey with little or no undergrowth²⁴; mixed forest zone with denser stands of many undifferentiated trees covering an area of about 7,000 ha; and a thicket forest zone with a variegated thicket covering about 23,500 ha in the western part of the forest dominated by *Cyanometra webberi* trees^{11,25}. The rest consists of plantation forest and open gaps (Figure 1).

The forest is surrounded by small-scale agricultural land and settlement by a growing population of adjacent communities whose relatively low income levels are partly responsible for their high dependence on forest products for many of their needs^{26,27}. There is hardly any forest fragment left within this agricultural and settlement zone. According to current strategic forest management plan estimates, there are almost 60 villages scattered around the forest that utilize natural products directly derived from the forest^{18,25}.

The main forms of human activities that impact on the forest habitat include illegal logging, honey harvesting, game snaring, cattle grazing and the creation of numerous tracks used by tree poachers²⁵.

Further impact on the habitat is caused by the foraging behaviour of the resident population of African elephants, which has increased from an estimated mean value of 141 individuals in 1996^{28,29} to 180–227 during the period from 2002–2006^{29,30}. Official figures since 2006 were not readily available.

This study was conducted in the *Brachystegia* woodland zone to examine the response of the Sokoke Pipit population to human-induced habitat degradation, particularly the removal of trees. The Sokoke Pipits' response to such effects was assessed in terms of its density, encounter rates and distribution. Accordingly, we expected the species' density and distribution to reflect corresponding spatial patterns in logging intensity.

Sampling strategy

The survey was carried out over 28 days between November 2011 and February 2012 within three blocks in the *Brachystegia* woodland stratified as follows: the main forest reserve block in the north-east, centred around Narasha (generally regarded as the most highly disturbed area from earlier intensive lumbering which was officially sanctioned and continued until the early 1980s); the southern block of regenerating forest (a reserve regarded as less disturbed) in the Kararacha area; and the smaller strip on the outer

Figure 1. Map of study area. The figure shows the map of the Arabuko-Sokoke forest indicating the main blocks in *Brachystegia* woodland where surveys were conducted (Jilore, Narasha and Kararacha) and the six transects used (two in each block). Numbers 1, 2, 3.... are transects numbers in the blocks (Map adapted from Davis, 2005)²⁰. Transect lines shown indicate the start and end points of the actual transect routes, which were not necessarily straight.

north-western part of the forest around the Jilore village, which is considered more disturbed than Kararacha but slightly less so than Narasha (Figure 1). This classification is based on the methodology of Oyugi *et al.*¹¹. Two 1-km transects were laid randomly in each block. Randomization was achieved by selecting the third track that branched to the left of the main forest track each time^{31,32}. When such a track was too short to cover one whole kilometre of forest as was in the case in the Jilore zone, a track was selected to run parallel to the main forest track but maintaining at least 250 m from the main track and the forest edge. In Figure 1, the transect lines represent the distance between the start and end points of each transect, which were not necessarily straight. In addition, bird surveys were conducted by starting from a different end of the transect each successive time³¹. Sampling independence for bird detection was ensured by maintaining at least 1 km from neighbouring transects. Bird surveys, vegetation sampling and habitat assessment for tree logging intensity were assessed on separate days.

Bird survey

Sokoke Pipit survey was the main objective of the study but we also recorded other birds encountered along the transects. The survey was conducted using a distance protocol, as described by Buckland *et al.*³³ starting from 6.00 am to 9.00 am along the randomly selected 1-km transects in each forest block. Transect widths were variable but truncated to a maximum of 60 meters and birds were counted by moving slowly and recording all sightings and calls^{5,31}. Surveyors worked in pairs, one observing with a pair of Bushnell XLT binoculars with 8 × 32 magnification and the other recording any encounters as they walked along the transect. Only positively identified Sokoke Pipit individuals or clusters were recorded. Perpendicular distance of each encounter from the transect centre was also determined, using a Nikon NKU 8371 range-finder and recorded [see Buckland *et al.*³³ and Fewster *et al.*³⁴]. To reduce biases associated with double counting, birds flying from behind the surveyors were ignored and a distance of no less than 1 km was maintained between transects³¹. For clusters of birds, the perpendicular distance measured was to the centre of the point where the individual cluster was originally detected^{31,33}. Each transect was surveyed twice, on two separate days.

Vegetation sampling

Vegetation parameters were assessed within ten 10 × 10 m quadrats along the same transects used for birds. The quadrats were established on alternate sides of the transects at 100-m intervals. Estimates of percent canopy height were measured using a Nikon laser rangefinder 8371 at these positions. Specifically, canopy height was estimated by first identifying a tree or group of trees constituting the highest crown within a quadrat. While standing at a pre-determined distance (about 10–15 m) from the base of the tree or group of trees, the laser of the range finder was beamed to the stem crown to read off the angular height before finally using triangulation to calculate the tree height, making sure to take into account the observer eye-level height. Canopy cover was estimated from three different points along a diagonal line down the quadrat (each corner and the centre) and expressed as 100-x percent of open space then averaged for each quadrat. Subsequently, canopy cover percent were categorized into three range classes (≤33%; 34–65%; or ≥66%).

Live woody stems were also counted in each quadrat to gauge the woody vegetation density of the understorey. These were scored in three circumference size classes of small (under 34 cm); medium (34–66 cm); and large (above 66 cm) measured using a standard tape measure at breast height. In addition, logging intensity was assessed in each of the quadrats by counting all cut stems of trees in the same circumference size categories above¹¹.

Floor litter sampling

In each of the quadrats used for vegetation sampling along transects, forest floor litter depth was assessed at three points along a diagonal running from one corner to another through the quadrat centre³². The depth of litter was determined using a straight, stiff thin metallic rod driven vertically and gently downward until it touched the firm forest floor beneath the litter, and then read off against a standard 30 cm ruler. Litter cover was assessed by dividing the 10 × 10 m quadrats into 25 smaller grids of 2 × 2 m quadrats by use of a standard metre rule and tape measure, then counting the total number of these that was covered by litter to ≤33%; 34–65%; or ≥66% before scoring accordingly on a proportion out of a total of 25 squares. The predominant cover score category (category observed in 15 or more of the 2 × 2 m squares) was taken as the overall cover score for each 10 × 10 m quadrat. Ranking these cover scores as 3 (≥66%), 2 (34–65%) and 1 (≤33%), each score was then divided by “3” to derive a cover score that was finally arcsine transformed towards normalization of distribution.

Data analyses

Due to the relatively small number of replicates in the study (two transect runs for birds and one set of habitat variable samples) preliminary data exploration showed departure from normal distribution. As such, all count data such as for live stems and cut tree stumps were transformed by logarithm and ratio or scale data such as by arc-sine before proceeding with analyses^{31,35}. This was also for the purpose of rationalising units of independent and response variables for graphical analyses. Sokoke Pipit densities were determined per hectare using DISTANCE v 6 software³³, while the encounter rates were calculated from the relationship $R_E = n/L_t$, where R_E = encounter rate; n = total number of detections of Sokoke Pipits along the transect; and L_t = total length of transect in kilometres. Due to high variance in detection of Sokoke Pipit in the Jilore block compared to Kararacha and Narasha (Table 1), which was likely a result of differences in understorey structural characteristics, Multiple Covariate Distance Sampling (MCDS) was preferable to Conventional Distance Sampling in estimating Sokoke Pipit density even with the relatively small sample size as the mean cluster sizes were quite constant at two individuals per sighting^{36,37}.

Thus we used forest block disturbance level as a random factor (covariates) in the MCDS to reduce the variance in the density estimation. We also truncated perpendicular distances to the right as recommended by Buckland *et al.*, by a general value of 5 m to reduce the likelihood of incorrect distance measurements that could increase variance in the estimate of density (Figure 2).

The half-normal key function model with cosine adjustment is the one that fitted all detection functions for the three blocks and we

Table 1. Density per hectare of Sokoke Pipit in the three blocks surveyed in the *Brachystegia* woodland of the Arabuko-Sokoke forest. AIC = Akaike Information Criterion with right-truncated distances (by 5 m) and cosine adjustment function; LCI = Lower 95% confidence interval; UCI = Upper 95% confidence interval. Mean cluster: 1.7 SE 0.16.

Forest block/area	Area (ha)	Disturbance level	Density/ha	95% CI LCI - UCI	Estimated population
Kararacha	2700	Undisturbed	0.79	-	-
Jilore	400	Moderate	0.99	-	-
Narasha	4600	High	0.71	-	-
Overall	7700	N/A	0.72	0.422–1.181	3249–9094

Figure 2. A histogram of distance versus detection probabilities of Sokoke Pipit across the forest blocks surveyed. The horizontal dropping line denotes declining probability of detection of Sokoke Pipit with increasing distance from the transect. Distances were truncated by 5 metres to reduce variance in measurements of distances farthest from the transect.

selected the model with the lowest Akaike Information Criterion (AIC) value (98.93) in the density estimations³⁷ rather than a second model with AIC of 100.41. The model chosen was also the one offering the greater probability strength of realizing expected detections and cluster sizes from the observed ones, based on a chi square goodness of fit (i. e. $p = 0.057$ compared to 0.063). 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: $1/S = 1/[(\sum n(n-1)/N(N-1)]$ where S = Simpson's Index, 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^{32,35}. A chi square test was performed to test clumpedness of Sokoke Pipit distribution across the blocks.

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 expressed as densities per hectare. Percent canopy cover scores were ranked such that open canopy, moderately open canopy and closed canopy scored 1 ($\leq 33\%$), 2 (34–65%) and 3 ($\geq 66\%$), respectively. These were then transformed to ratios scaled with '3' as the maximum before further transformation using arcsine function. Canopy height, floor litter cover and litter depth measurements were worked into means from all quadrats in all transects.

Due to high preliminary-test covariance amongst the various size classes of live tree stems and tree stump counts, the size classes were pooled together into 'total live stems' and 'total stems cut' for subsequent analyses. For habitat variables that showed particularly strong correlations to bird variables, simple linear regression was performed to test the actual correlations and relative strengths of

predictability. Means of habitat variables were compared across the blocks using one-way Analyses of Variance (ANOVA). The relationships between the independent and response variables (ANOVA and regressions) were analyzed in SPSS version 18.

Results

In all surveys, a total of 308 birds were encountered, distributed across 55 species belonging to 25 families (Supplementary Table 1). There were 17 encounters of Sokoke Pipits during which a total of 30 individuals were detected, with the most frequent cluster size being 2 birds. The pipit occurred at a mean overall density of 0.72 birds/ha across the blocks surveyed, with a projected overall population estimated at 5,544 individuals (Table 1). The density was higher in the relatively less disturbed *Brachystegia* forest zone represented by Jilore and Kararacha blocks (0.89 birds ha⁻¹) compared to the more disturbed zone comprising Narasha block (0.71 birds ha⁻¹), as can be seen on Table 1 in conjunction with Table 2. Nevertheless, there was no significant evidence of clumped distribution of the species across the blocks ($\chi^2_{(2, 0.05)} = 2.061$).

Similarly, the species had the highest encounter rate in Jilore (2.3 birds km⁻¹) while Kararacha had 1.3 birds km⁻¹ and Narasha 0.8 birds km⁻¹. For all birds, Kararacha had the highest species diversity ($1/S = 0.69$) followed by Narasha ($1/S = 0.721$) then the Jilore area ($1/S = 0.724$), S being the reciprocal of Simpson's diversity index. Jilore was the most bird species-rich (38 species) followed by Narasha (35 species) and then Kararacha (34 species).

Floor litter was deepest in the Kararacha block (2.52 ± 0.83 cm) followed by the Jilore block (2.21 ± 0.73 cm) and Narasha (1.75 ± 0.58), $F = 6.839$, $p = 0.002$ (see Figure 3) though a Tukey honest significant difference post hoc test revealed the main difference to be between Kararacha and Narasha blocks (mean difference, 0.776, $SD = 0.211$, $p = 0.002$) rather than between Kararacha and Jilore (mean difference 0.302, $p = 0.335$) or between Jilore and Narasha

Figure 3. Comparison of litter depths across the forest blocks.

The figure shows the comparative depths of forest floor litter across the three forest blocks with the deepest litter in Kararacha and the shallowest in Narasha. The bottom and top of the boxes represent the second and third quartiles, respectively) while the horizontal band represents the median of litter depth for each block. The region between the error bar whiskers represents the data spread or dispersion.

(mean difference 0.475, $SD = 0.211$, $p = 0.073$). Mean litter cover was generally within the middle category (33–65%) in the Kararacha and Jilore blocks and below the lower category (0–33%) in the Narasha block ($F = 9.937$, $p = <0.001$).

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.

Parameter	Forest block	N	Mean (ha ⁻¹)	Standard error	F statistic	p (p<0.05)
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		

Other significant spatial variations in means of habitat variables were observed in overall tree removal (total cut stems), removal of small poles (small-sized trees), and density of live mid-sized trees and removal of mid-sized trees (Table 2). Thus overall tree removal rate was highest in the Kararacha block and lowest in Narasha both for small poles and large mature trees. The same pattern was observed for the density of mid-sized live woody vegetation.

Overall, the *Brachystegia* habitat was dominated by small-sized trees of 30 cm diameter at breast height (dbh) or less especially in

the Jilore area (Table 3). These were also the most intensely logged tree sizes with most of them cut in the Kararacha block (Table 2).

Sokoke Pipit abundance was strongly correlated to forest floor litter depth ($R^2 = 0.769$, $\beta = 0.877$, $p = 0.021$) and floor litter cover ($R^2 = 0.719$, $\beta = 0.848$, $p = 0.033$) but litter depth was the better predictor of the species' abundance (Figure 4).

Furthermore, litter depth was positively correlated to logging intensity of small trees ($R = 0.787$, $p = 0.063$) suggesting that pruning

Table 3. A comparison of vegetation density and logging intensity per hectare across the *Brachystegia* woodland habitat. Vegetation density is expressed as mean number of live woody stems and logging intensity as mean number of cut stems.

Block	Live woody stem			Total	Cut stems			Total
	≤33 cm	34–66 cm	≥67 cm		≤33 cm	34–66 cm	≥67 cm	
Kararacha	750	200	180	1130	105	25	10	140
Jilore	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

$$\text{Sokoke Pipit abundance} = 0.727 + 0.485 * \text{Mean litter depth}$$

Figure 4. Partial regression plots of relationship between Sokoke Pipit density and (A) litter depth (cm) and (B) litter cover percent. The regression plot illustrates an overall greater positive influence of litter depth on abundance and distribution of the Sokoke Pipit across the three forest blocks. Litter cover is expressed as arcsine (ASIN) of the percent cover index scores.

of small trees in the forest by tree poachers might be a significant source of forest floor litter. Sokoke Pipit density appeared adversely affected by overall logging intensity ($R^2 = 0.663$, $\beta = -0.814$, $p = 0.048$) see [Figure 5](#). However, there was no significant effect of percent canopy cover ($R = 0.5798$, $p = 0.228$) or canopy height ($R = 0.174$, $p = 0.742$) on Sokoke Pipit density.

Arabuko-Sokoke forest ecological data: Sokoke Pipit abundance, vegetation survey results, floor litter measures and elephant damage in three forest blocks

4 Data Files

<http://dx.doi.org/10.6084/m9.figshare.924690>

Discussion

The densities of the Sokoke Pipit from this study are lower than the values from studies in the same habitat about a decade ago in which the undisturbed *Brachystegia* forest had 2.8 birds ha^{-1} and disturbed zones had 0.9 birds ha^{-1} ¹¹⁴. The same applies for the previous estimated total population of 13,000 birds. This is attributable to the continued degradation of the species' habitat in the *Brachystegia spiciformis* zone through disturbance, especially in the form of tree cover loss, which has continued over the past decade as observed by many investigators^{11,15,17–20,38}. Human activity and related encroachment effects are strongly presumed by all these investigators as the sole and direct source of the disturbance. The results of the present study confirm this but suggest that in addition complementary causes could be responsible for this habitat degradation processes.

For instance, not only is earlier intensive deforestation still discernible in the structure of much of the forest, but also adjacent human

populations have grown steadily and rapidly over the years^{9,18} with even higher dependence on forest products, resulting in considerable negative effects on forest habitat^{9,14,17,20}. In addition, certain intervention measures such as increased forest surveillance led to a thriving population of elephants whose feeding habits have had adverse effects on the forest habitat. Increased forest surveillance may have also led to tree poachers predominantly targeting smaller trees or poles that are easier to cut and remove from the forest.

In this study, the main driver of Sokoke Pipit habitat degradation was tree removal that results in opening up the understorey, a process that may expose individuals to the risk of predation through increased edge^{39,40}, reduction in patch substrate^{14,26}, reduction of forest floor litter or change in micro-climate³⁹. One of the main reasons for lower logging rates in Narasha is that it is closest to the KWS and KFS stations and thus enjoys higher levels of surveillance against tree poaching compared to Kararacha and Jilore where logging rates were higher. These patterns conform to patterns observed by Ngala and Jackson from surveys carried out in 2009 and 2010^{25,41}. Secondly, it is the region with the highest elephant activity³⁸ which is a further deterrent to illegal loggers.

The comparatively lower logging pressure and high surveillance in Narasha did not however translate to higher Sokoke Pipit abundance in this block. This may be because the low litter depth coupled with lower percent canopy cover and low overall tree density due to poor regeneration, all contributed to the block's relative non-suitability for the Sokoke Pipit.

However, the effect of tree removal on Sokoke Pipit abundance was offset by the positive influence of forest floor litter cover and depth. Floor litter harbours much of the arthropod and other invertebrate

Figure 5. Impact of logging pressure on Sokoke Pipit abundance. The figure shows the net impact of tree removal intensity per hectare on the Sokoke Pipit with the species being encountered less in areas with high tree loss pressure. The logging pressure depicted by the figure excludes the proportion due to elephant habitat damage. For actual values of logging rates see [Table 2](#).

biomass on which many insectivorous birds such as Sokoke Pipit depend^{15,42}. Secondly, the process of removing small trees appeared to be a significant additional source of floor litter, due to cumulative layers of discarded leaves and twigs left behind by tree poachers during pole harvesting, in addition to the slow rate of decomposition of organic matter typical of many forests along the eastern coast of Africa^{43,44}. Thus the addition of pruned leaves of poached trees to the floor litter may be a trade-off against Sokoke Pipit habitat degeneration. For this reason, Jilore recorded the higher Sokoke Pipit abundance compared to the other blocks since small pole removal pressure was highest there.

Nevertheless, far from prescribing pruning of understory trees, it is more sound to suggest stricter restrictions against removal of dead wood, which also harbours invertebrates, and control against forest fires to preserve already fallen litter, as ways to ameliorate degradation impacts on the species' habitat¹⁷. This is because understorey pruning as a prescriptive intervention measure would lead to more rapid degradation between 0–4 m, the height range that the Sokoke Pipit uses exclusively for foraging, perching, predator escape and possibly social contact¹⁴.

The Jilore block's predominance in Sokoke Pipit encounter rates, in spite of its proximity to human settlements and farmland, may also be due to its unattractiveness to elephants owing to its comparatively small size and low canopy with an understorey dominated by small regenerating trees (Table 3). The electric fence, construction of which began in 2006 to reduce animal conflicts with the adjacent farmers and which now almost encloses the forest, might also provide an additional layer of protection against direct regular human disturbance in the Jilore block.

On the other hand, despite the higher logging pressure compared to the Narasha block, Kararacha had a higher abundance of Sokoke Pipit as well as a higher overall bird species richness (Table 1). This suggests that human-driven selective tree removal is not the sole determinant of Sokoke Pipit population abundance or distribution across the *Brachystegia* habitat, and implies additional impacts related to elephant feeding activity.

Evidence of the role of elephants in degrading the forest habitat is borne by our numerous direct, incidental observations across the study area, particularly in the Narasha block during which we made frequent sightings of trees felled or broken and the ground dug up by elephants. Along some transects in the Narasha block, the frequency of elephant-felled trees outnumbered those cut down by humans. Analyses of data (see Data File) from these incidental observations was not attempted since counts were made only for the Narasha and Kararacha blocks. However, the spatial distribution of elephant damage noted here is consistent with similar earlier studies and observations conducted by ASFMT¹⁸, Ngala⁴¹ and Banks *et al.*³⁸, all of which recorded the highest elephant activity intensity in Narasha. Such intensive activity results in more open canopy, exposed understorey and increased area of edge habitat that may limit dispersal distance of species that avoid crossing gaps, or may result in increased nest predation rate^{45,46}.

Two main reasons support the contribution of elephants to habitat destruction in the ASF's *Brachystegia* woodland. First, the forest

is estimated to hold between 126 and 184 individuals, giving a density of 0.44 animals km^{-129,30}. Not only does this make the ASF the 7th highest elephant density site of all 30 elephant habitats across Kenya²⁹ but this density is also fast approaching the 0.5 km⁻¹ recommended maximum carrying capacity, to ensure stability and sustainability of the vegetation in the habitat⁴⁷. This density is a conservative estimate as it represents a projection for the whole forest; considering that the elephants seem to favour the *Brachystegia* forest zone³⁸, the carrying capacity will likely be exceeded much sooner than for the ASF overall, with negative consequences for the Sokoke pipit for which this is a critical habitat.

Secondly, the electric fence which already covers a substantial portion of the forest boundary, forms a physical barrier to elephant dispersal outside the forest. This barrier has had the effect of nearly doubling elephant density in the forest, further stretching the carrying capacity and worsening the habitat degradation process⁴⁷. The pressure is particularly high in the ASF due to its small size in comparison to other elephant sites in Kenya³⁰ and given the peri-urban nature of the forest with its adjacent agricultural land and human settlements¹⁸. In addition, the *Brachystegia* vegetation zone of the ASF has the lowest vegetation regeneration rates along the entire eastern coast of Africa due to soil with a functionally poor structure²⁴, low nutrient content, low moisture level and limited micro-organism activity that is necessary for nutrient cycling^{11,44}. Thus, in addition to human-driven tree removal, the high elephant density and the restrictive nature of the electric fence are compounded by the slow forest regeneration rate, which amplifies the impact of elephant activity on overall habitat degradation in the *Brachystegia* woodland.

Many sustainable management options for ASF have also been suggested by earlier investigators. Oyugi and Brown¹⁹ recommended preservation and restoration of tall *Brachystegia* trees to conserve the Amani Sunbird's (*Hedydipna pallidigaster*) high canopy habitat; Davies²⁰ prescribed community involvement in efforts to reduce illegal logging of the trees, also to conserve the Amani Sunbird; Musila¹⁴ recommended up scaling the reforestation of degraded areas, while Matiku *et al.*¹⁷, who did not focus on *Brachystegia* woodland, recommended preservation of dead wood and other forest understorey debris that would help conserve the East Coast Akalat. A multi-pronged approach incorporating these recommendations to conserve various vertical strata and microhabitats for the respective species that utilize them has been proposed by Banks *et al.*³⁸ to be suitable for overall management of the ASF for the benefit of flagship bird species. The results of the present study indicate that this multi-pronged conservation strategy should also include pragmatic measures to regulate populations and movement of elephants across the forest complimented with measures to halt illegal logging.

Conclusions

The Sokoke Pipit's favored habitat is an open understorey with deep litter cover, often but not always with dense vegetation. Its density and estimated population in *Brachystegia* woodland in the ASF is lower than it was a little more than a decade ago, suggesting increased pressure on the species through increased loss or continued modification of its habitat. Tree loss and opening up of the forest canopy may be the main cause of this habitat degradation, which may be further exacerbated by elephant damage of habitat

through tree felling, though more in-depth studies are needed to ascertain its scale and impact patterns on the Sokoke Pipit and other forest specialist birds^{25,41}. Tree poachers target small trees/poles taken from areas farthest from patrol bases with minimal elephant numbers. Reduced tree poaching in areas close to the KWS and KFS stations and patrol bases indicates the potential benefits of increased surveillance as an immediate check on human-mediated habitat destruction in the *Brachystegia* woodland zone. This would feasibly boost Sokoke Pipit densities across the AFS and benefit the conservation biodiversity in general. A sound long-term conservation strategy would involve significantly reducing tree logging, effectively managing the population and movement of elephants, and stepping up restorative reforestation. These efforts should focus especially on heavily degraded areas, determined by monitoring flagship-species data.

Data availability

figshare: Arabuko-Sokoke forest ecological data: Sokoke Pipit abundance, vegetation survey results, floor litter measures and elephant damage in three forest blocks, <http://dx.doi.org/10.6084/m9.figshare.924690>⁴⁸.

Author contributions

NO conceived the study and designed the experiments, NO prepared the first draft of the manuscript while NO, DN and AM were

all involved in the process of project planning, logistical arrangements, data collation, data summary and revision of the initial project report. They all agreed to the final content of the manuscript.

Competing interests

No competing interests were disclosed.

Grant information

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The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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Supplementary material

Supplementary Table 1. Checklist of all birds observed across the *Brachystegia* woodland blocks of forest surveyed in Arabuko-Sokoke forest. The checklist is in phylogenetic order grouping birds by family, scientific and common name following Bird Committee of the east African Natural History Society⁴⁹.

No.	Family	Scientific name	Common name
1	Accipitridae	<i>Accipiter tachiro</i>	African Goshawk
		<i>Polyboroides typus</i>	African Harrier Hawk
		<i>Accipiter minullus</i>	Little Sparrowhawk
2	Columbidae	<i>Turtur chalcospilos</i>	Emerald-spotted Wood Dove
		<i>Streptopelia semitorquata</i>	Red-eyed Dove
		<i>Turtur tympanistria</i>	Tambourine Dove
3	Cuculidae	<i>Chrysococcyx klaas</i>	Klaas Cuckoo
		<i>Pachycoccyx audeberti</i>	Thick-billed Cuckoo
		<i>Centropus superciliosus</i>	White-browed Coucal
4	Caprimulgidae	<i>Caprimulgus pectoralis</i>	Fiery-necked Nightjar
5	Phoeniculidae	<i>Rhinopomastus cyanomelas</i>	Common Scimitarbill
		<i>Phoeniculus purpureus</i>	Green Wood Hoopoe
6	Bucerotidae	<i>Bycanistes bucinator</i>	Trumpeter Hornbill
7	Lybiidae	<i>Stactolaema olivacea</i>	Green Barbet

No.	Family	Scientific name	Common name
8	Indicatoridae	<i>Indicator variegatus</i>	Scaly-throated Honeyguide
9	Picidae	<i>Dendrocopos minor</i>	Little-spotted Woodpecker
		<i>Campethera mombassica</i>	Mombasa Woodpecker
10	Platysteridae	<i>Batis mixta</i>	Forest Batis
		<i>Batis soror</i>	Pale Batis
11	Malaconotidae	<i>Dryoscopus cubla</i>	Black-backed Puffback
		<i>Telophorus viridis</i>	Four-coloured Bush-shrike
		<i>Laniarius aethiopicus</i>	Tropical Boubou
12	Prionopidae	<i>Prionops retzii</i>	Retz Helmetshrike
13	Timaliidae	<i>Prionops scopifrons</i>	Chestnut-fronted Helmetshrike
14	Oriolidae	<i>Oriolus larvatus</i>	Black-headed Oriole
		<i>Oriolus oriolus</i>	Eastern Golden Oriole
		<i>Oriolus oriolus</i>	Eurasian Golden Oriole
15	Dicruridae	<i>Dicrurus adsimilis</i>	Common Drongo
16	Monarchidae	<i>Trochocercus cyanomelas</i>	Blue-mantled Crested Flycatcher
		<i>Erythrocercus holochlorus</i>	Little Yellow Flycatcher
17	Cisticolidae	<i>Apalis melanocephala</i>	Black-headed Apalis
		<i>Camaroptera brevicaudata</i>	Grey-backed Camaroptera
		<i>Prinia subflava</i>	Tawny-flanked Prinia
18	Pycnonotidae	<i>Nicator gularis</i>	Eastern Nicator
		<i>Phyllastrephus fischeri</i>	Fischer's Greenbul
		<i>Phyllastrephus strepitans</i>	Northern Brownbul
		<i>Phyllastrephus debilis</i>	Tiny Greenbul
		<i>Chlorocichla flaviventris</i>	Yellow-bellied Greenbul
		<i>Andropadus importunus</i>	Zanzibar (Sombre) Greenbul
19	Sturnidae	<i>Lamprotornis corruscus</i>	Black-bellied starling
20	Turdidae	<i>Cercotrichas quadrivirgata</i>	Eastern Bearded Scrub Robin
		<i>Neocossyphus rufus</i>	Red-tailed Ant Thrush
21	Muscicapidae	<i>Muscicapa caerulescens</i>	Ashy Flycatcher
		<i>Sheppardia gunningi</i>	East Coast Akalat
		<i>Bradornis pallidus</i>	Pale Flycatcher
22	Musophagidae	<i>Tauraco fischeri</i>	Fischer's Turaco
23	Nectariniidae	<i>Anthreptes pallidigaster</i>	Amani Sunbird
		<i>Hedydipna collaris</i>	Collared Sunbird
		<i>Cyanomitra olivacea</i>	Olive Sunbird
		<i>Anthreptes reichenowi</i>	Plain-backed Sunbird
24	Ploceidae	<i>Ploceus golangi</i>	Clarke's Weaver
		<i>Ploceus bicolor</i>	Dark-backed Weaver
25	Motacillidae	<i>Anthus sokokensis</i>	Sokoke Pipit

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The revised manuscript is much improved, and the authors have satisfactorily addressed all issues of concern. I especially appreciate their thoughtful analysis of the implications of their findings regarding the effects of pruning/tree poaching, highlighting the complexity of the tradeoffs involved. Likewise, the revised discussion of the role elephant disturbance likely plays in the species interactions is nicely balanced and compelling.

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 22 July 2014

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Jeremy Lindsell

A Rocha International, Cambridge, UK

Overall comments:

The authors have addressed many of the comments that were made on the first submission and

as a result the paper is much improved. However there remain significant problems in some areas – some that were overlooked in the first review, and others that the authors appear not to have taken on board. These really need to be addressed if the paper is to meet a good standard. It still requires a good edit throughout.

Introduction:

- Change “**flagship**” to “**indicator**”. A flagship is a species whose high profile conservation ensures other lesser known species are conserved along with it.

Materials and methods:

- It's still not clear how honey harvesting affects the forest habitat as stated.

Sampling strategy:

- The positioning of transects is still unclear. You have provided some clarification in your response but have not put this clarification into the text. It needs to be stated in the text. In your response you say that you did not use existing paths but in your text you say “**When such a track was too short to cover one whole kilometre of forest ...**, a track was selected to run parallel to the main forest track...” which sounds a lot like you did use existing tracks as long as they were long enough.
- Are you using track and transect interchangeably here? This might not help with clarity.
- I don't think you can refer to the transect selection as randomised. It more closely resembles a systematic selection.
- In your response you say why you don't think the transect selection is biased by using the 3rd track method. This justification needs to be added to the text as many readers will still suspect that the selection using the 3rd track would be biased.
- You still don't say how you ensured at least 1 km separation between transects. Please add this.

Bird Survey:

- You do say you recorded distance to clusters – please just add that you recorded cluster size too!

Vegetation sampling:

- You clarified a lot in this section.
- Please add a word to say where you measured the circumference of cut stems – at the base, at the place where the stem was cut, somewhere in between?

Floor Litter Sampling:

- I still find this section baffling...

“Litter cover was assessed by dividing the 10 × 10 m quadrats into 25 smaller grids of 2 × 2 m

quadrats by use of a standard metre rule and tape measure, then counting the total number of these that was covered by litter to $\leq 33\%$; 34–65%; or $\geq 66\%$ before scoring accordingly on a proportion out of a total of 25 squares. The predominant cover score category (category observed in 15 or more of the 2×2 m squares) was taken as the overall cover score for each 10×10 m quadrat. Ranking these cover scores as 3 ($\geq 66\%$), 2 (34–65%) and 1 ($\leq 33\%$), each score was then divided by “3” to derive a cover score that was finally arcsine transformed towards normalization of distribution.”

I think this is what you did...

“Litter cover in each 2×2 m square was scored as 1, 2 or 3 (category 1 = $< 33\%$, 2 = 34–65% and 3 = $> 65\%$ cover) and the number of squares of each category was summed and expressed as a proportion. The category occurring in more than 60% of the squares (15 out of 25) was selected as representative of the whole 10×10 m plot. This overall category was converted to a proportion for further analysis.”

- What happened if none of the categories had as many as 15 squares? Which score was chosen then? The mode?
- Since you have 25 measures of cover in each plot why not just take the mean of the 25 scores rather than the mode? Then you'd have a more continuous distribution of cover values rather than just your three original categories.

Data analyses:

- There are still a few significant issues here that need addressing some of which will entail re-analysis, not just rewording. Some of your clarifications appear in the response but have not been transferred into the article where they need to be for all to see.
- Firstly, you seem to be confusing truncation and pooling (or binning) distances in Distance analysis. Several places – including table/figure captions - refer to “truncation by 5 metres” when I think you mean that distances were pooled into 5 m interval classes? (e.g. figure 2 caption and elsewhere).
- You do state clearly that distances were truncated at 60m. Truncation can be done in the field where you ignore distant detections, and can also be done at the analysis stage to deal with outlying points. Can you state more clearly what you did?
- I think the results of the Distance analysis model selection should appear in Results, not Methods. Restrict the methods to describing how you selected the preferred model.
- You state that models were selected using AIC but still don't say what alternative models were considered.
- You still refer to “densities per hectare”. This doesn't make sense unless you mean that you worked out density for each hectare, which I don't think you do.

- You do really need to take on board my point about log transformation of count data. It is not the right way to analyse count data for many reasons. Have a look at O'Hara, R., & Kotze, D. (2010). Do not log-transform count data *Methods in Ecology and Evolution*, 1 (2), 118-122 DOI: [10.1111/j.2041-210X.2010.00021.x](https://doi.org/10.1111/j.2041-210X.2010.00021.x) If you don't have access to this paper then email me offline and I will send you a pdf. The way to do this is to use a generalized linear model which allows to you compare values which are not normally distributed. I would expect the distribution to be poisson.
- "[S]imple linear regression" - In your response you say you use multivariate tests but don't mention this in the article. You say "Multivariates was the method, through which for instance were selected litter depth as a better predictor of pipit abundance than litter cover as we had stated in the results section". I'm not sure you used a multivariate test as opposed to multiple univariate tests. (By the way, I should have said multiple regression as multivariate usually means something else).
- The species richness data still don't add to the paper. They are barely mentioned in the discussion so presumably of little consequence to your conclusions about the pipit. I suggest you omit those.

Results:

- "*There were 17 encounters of Sokoke Pipit*" - I overlooked this in the first submission but 17 is a very low number to derive a decent detection function from. You need to discuss this as it could have an impact on your density estimate. Can any other species be used to pool with the pipit to improve the detection function? Is there another species that is detected in a similar way? The plot of the function looks worrying with that big dip around 10 metres. It looks like you need to try pooling the distances up to 12 or 15 metres as the model looks a very poor fit at present. You can specify your own cut points in Distance to do this. I'd find it hard to believe you'd get a non-significant chi sq test of that model.
- You now say in the methods you did a chi sq test of clumpedness but don't explain what you mean or reference this test.
- Table 1 caption still refers to AIC
- Table 2 still refers to density per hectare.
- It's still the case that having said stems size classes were pooled due to low numbers, table 2 reports results of analysing them unpooled.
- In your response to my comment on "Why can't Fig 4 be shown as scatter plot like Fig 3?" you say that **"In the discussion, we clearly showed that impact on Sokoke pipit due to habitat degradation was both a function of stem cutting as well as elephant tree removal."** This needs to be clearly shown in the results not the discussion. As you haven't collected or analysed data on elephant damage your comments about this need to be more circumspect. Incidentally I thought Banks *et al* 2010 dealt very specifically with elephant impacts on birds in ASF via habitat modification?

- Figure 5 has a typo “pipir”
- For richness you report a value of $1/S$ and say that S is the reciprocal of the Simpson index. Which would mean that $1/S$ is the Simpson's index. Presumably S is the Simpson index value, not $1/S$.

Discussion:

- Musila densities in the intro are 0.7 for disturbed but 0.9 for disturbed in the discussion. Which is it? The 0.7 figure is remarkably similar to your overall figure which is very interesting.
- Restate your population estimate relative to Musila's.

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Version 1

Reviewer Report 24 March 2014

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John Banks

Environmental Science, Interdisciplinary Arts and Science, University of Washington, Tacoma, WA, USA

This article addresses the links between habitat condition and an endangered bird species in an important forest reserve (ASF) in eastern Kenya. It addresses an important topic, especially given ongoing anthropogenic pressures on this and similar types of forest reserves in eastern Kenya and throughout the tropics. Despite the rather small temporal and spatial extent of the study, it should make an important contribution to bird and forest conservation. There are a number of issues with the methods and analysis that need to be clarified/addressed however; furthermore, some of the conclusions overreach the data collected, while other important results are given less emphasis that they warrant. Below are more specific comments by section:

Abstract:

The conclusion that human-driven tree removal is an important contributor to the degradation of

ASF is reasonable given the data reported in the article. Elephant damage, while clearly likely a very big contributor to habitat modification in ASF, was not the focus of the study (the authors state clearly in the Discussion that elephant damage was not systematically quantified, and thus no data were analyzed) – and thus should only be mentioned in passing here – if at all.

Introduction:

More information about the life history ecology of *A. sokokensis* would provide welcome context here. A bit more detail about breeding sites as well as dispersal behavior etc. would be helpful – and especially why these and other aspects render the Pipit a good indicator species/proxy for habitat condition. This could be revisited in the Discussion as links are made between habitat conditions and occurrence of the bird (where you discuss the underlying mechanisms for why it thrives in some parts of ASF and not others, and why its abundance correlate strongly with some types of disturbance and not others). Again, you reference other studies that have explored other species in ASF and forest disturbance, but do not really explicitly state why the Pipit is a particularly important indicator of forest condition.

Methods:

- Bird Survey: As described, all sightings and calls were recorded and incorporated into distance analysis – but it is not clear here whether or not distances to both auditory and visual encounters were measured the same way (i.e., with the rangefinder). Please clarify.
- Floor litter sampling: Not clear here whether or not litter cover was recorded as a continuous or categorical variable (percentage). If not, please describe percentage “categories” used.

Results:

- Mean litter depth graph (Figure 2) and accompanying text reports the means and sd but no post-hoc comparison test (e.g. Tukey HSD) – need to report the stats on which differences were/were not significant.
- Figure 3 – you indicate litter depth was better predictor of bird abundance than litter cover, but r-squared is higher for litter cover. Need to clarify (and also indicate why you chose only to shown depth values in Figure 3).
- The linear equation can be put in Figure 3 caption (not necessary to include in text).
- Figure 4 – stats aren’t presented here; also, the caption states that tree loss and leaf litter are inversely correlated – this might be taken to mean, given discussion (below) about pruning, that there could be a poaching threshold below which poaching may pay dividends to Pipits (and above which Pipits are negatively affected). This warrants further exploration/elaboration.
- The pruning result is arguably the most important one here – this suggests an intriguing trade-off between poaching and bird conservation (in particular, the suggestion that pruning by poachers may bolster Pipit populations – or at the very least mitigate against other aspects of habitat degradation). Worth highlighting this more in Discussion.

Discussion :

- Last sentence on p. 7 suggests causality ("That is because...") – but your data only support correlation (one can imagine that there may have been other extrinsic or intrinsic drivers of population decline).
- P. 8: discussion of classification of habitat types in ASF is certainly interesting, but could be made much more succinct in keeping with focus of this paper.
- P. 9, top: first paragraph could be expanded – as noted before, tradeoff between poaching/pruning and Pipit abundance is worth exploring in more depth. Could your results be taken as a prescription for understory pruning as a conservation tool for the Sokoke Pipit or other threatened species? More detail here would be welcome (and also in Conclusion); in subsequent paragraph about Pipit foraging behavior and specific relationship to understory vegetation at varying heights could be incorporated into this discussion. Is there any info about optimal perch height for foraging or for flying through the understory? Linking to results of other studies in ASF, is there potential for positive correlations with optimal habitat conditions for the other important bird species in ASF in order to make more general conclusions about management?

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 12 Apr 2014

Nickson Otieno, National Museums of Kenya, Kenya

Dear Dr. John Banks,

Thank you for your useful comments on our manuscript. We have attempted to address your concerns about the manuscript in the following ways:

Introduction:

- We have now added more information about the habits of the Sokoke Pipit, although we have also indicated that no comprehensive previous studies are known of the species' life history traits, especially breeding records. We have also added that the specialist attributes of the species, especially as the key forest-floor specialist of the interior Brachystegia forest, make it a good candidate for monitoring habitat quality of the Brachystegia understory.

Methods:

- Only once was an encounter of the Pipit based on a call only, and in this case the abundance was assumed to be that of 1 bird and perpendicular distance determined for its approximate location as for the other cases.
- Litter cover was recorded as percentages of cover in three main categories: fully covered (67-100%); moderately covered (34-66%) and not little or no cover (0-33%).

Scoring these respectively as 3, 2 and 1 on a scale of 1 to 3, each was then divided by "3" to derive a cover score that were finally arcsined transformed towards normality of distribution.

Results:

- We have now reported the post hoc Tukey test results statistics for the significant difference in forest floor litter depth across the three blocks.
- For figure 3 (now figure 4) we have now presented the figure with fresh partial regressions of both the mean litter depth and the arcsines of mean litter cover percent against Sokoke pipit densities per transect. Accordingly, we have revised the legend of this figure to reflect these changes. We have also made the correction in the text of the results section, in which the regression stats for how Sokoke Pipit density varied with litter depth and litter cover were initially written in reversed order.
- The regression equation between Sokoke Pipit density and litter depth is now transferred from results text body to the caption of figure 4 (formerly figure 3).
- Actual figures and statistics on logging rate were presented already in Table 2.

Discussion:

- We have now revised the statement that the lower density of the S. Pipit recorded in the study, in comparison to the earlier survey, was "*because of*" continued habitat to read "*attributable to*" instead.
- The part of the discussion which details the ASF zonation and characterization is now cut down to the essential facts directly relevant to the study.
- We have expounded from discussion through to conclusion on the issue of the apparent tradeoff between leaf litter from trees pruned by poachers and the quality of Sokoke Pipit habitat, stressing that while such compensatory effects may be beneficial, it might be unwise to recommend understory pruning of young trees, as this might further degrade habitat for S. Pipit and other understory species. Instead, work should be stepped up towards preserving dead wood and controlling forest fires that would reduce forest litter. We have also put recommended conservation measures for the species' habitat in perspective of recommendations from previous studies in ASF.

Competing Interests: No competing interests to declare

Reviewer Report 14 March 2014

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Jeremy Lindsell

A Rocha International, Cambridge, UK

Overall comments:

This is an important survey, and I support the collection of these results, but not the way they are currently presented and interpreted. The presentation has been compromised by poor attention to methods. This raises concerns about errors in the analysis and that conclusions are not assured. The small sample size involved also raises concerns about the robustness of the conclusions. Given the very large population decline being described it is important to ensure that the conclusions are supported by the data. As it stands a lot more caution needs to be attached to this work - results might be suggestive of a decline that needs more serious investigation rather than this being proven.

Furthermore, explanation of the declines is not always clear – the overall tone of the discussion is that disturbance has harmed the pipit even though some evidence suggests the pipits benefit from disturbance. No data are presented to demonstrate that disturbance has increased over the course of the decline.

I think the authors could do with a good session with a qualified statistician to first straighten out the analyses, and then review their conclusions. And I would urge them to do this as the conclusions could be important for the conservation of this species.

Abstract:

- 5 globally threatened and 4 near-threatened, not 9 threatened. The Methods section states it correctly.

Introduction:

- Birds in general are not most sensitive to forest change, but certain groups are good indicator species.
- Avoid reference to BirdLife factsheets if possible, good as they are - the original source is preferable.
- The title of the article by [Musila et al. \(2001\)](#) certainly implies they studied response to habitat change. Make clear that you are not studying change – it is not a before and after study. You are substituting space for time. The title also implies you have studied change over time (modification).

Materials and methods:

- Change “BirdLife protocols” to “BirdLife criteria”.
- The second paragraph is largely not needed as it is unrelated to the pipits, and can be referenced elsewhere.

- Third paragraph, change “community zones” to “communities”.
- Paragraph four – insert a quick statement about the amount of forest in the surrounding landscape (i.e. almost none!)
- How do honey harvesting and game snaring affect the habitat? Do they cut trees to harvest honey? But what about snaring?

Sampling strategy:

- You use the term “lumbering”. If this is to denote commercial logging as opposed to illegal logging might be better to make this clear.
- The positioning of transects is very unclear. Are you saying that you used existing paths as transects? Or were the paths only used to locate a starting point?
- You also need to say why you used existing paths as transects when you have already said that the habitat has a relatively open understory and is therefore presumably easy to move through.
- Looking at the map, the transect look very straight which suggests they were not on existing tracks.
- Do you think the 3rd track on the left really is unbiased since more heavily disturbed areas are likely to have a higher density of tracks, which means your sample in more disturbed areas will always tend to be nearer your point of entry and likely therefore to be the more disturbed parts of the patch. I think you need to be clear about this.
- You say you ensured at least 1 km separation between transects but don't say how you actually did this given that the transect selection is described as random.

Bird Survey:

- Distance sampling (as cited) does not specify a fixed width to the transect. It is called “variable distance” sampling. You may specify a cut off beyond which you don't bother recording observations. Is that what you mean?
- Doubling counting of birds on different transects is only a problem if the movement of the bird between the two was caused by the observers.
- Presumably you recorded cluster size? It isn't mentioned.
- Did you walk transects more than once? This is implied in the paragraph on sampling strategy but no information is given about how many times here or there.

Vegetation sampling:

- How did you measure % canopy height with rangefinder? How many readings did you take and how do you express this as a percentage? Percentage of plot covered by different height classes? If you measured straight up this tends to underestimate height because of the number of occasions that the laser hits lower branches and because you only read from the underside of the canopy. If you measured from the distance then you needed to

measured angle too?

- Was the stem size you measured the circumference or the DBH. You say you used an ordinary tape measure. Why do you say this - you can still use this to record diameter. Are the size classes given circumferences or diameters?
- You say you recorded cut stems in “similar” size classes to the live stems. What do you mean? The same? If not the same say why and how the classes differed. Obviously you can’t usually measure a cut stem at breast height so need to say so and how you dealt with this. In that sentence about cut stems you also refer to diameter – so does that mean the other measurement earlier were diameters?

Floor Litter Sampling:

- *“Litter cover was assessed by dividing the 10 × 10 m quadrats into 25 smaller grids of 2 × 2 m quadrats by use of a standard meter rule and tape measure then ascertaining the percentage category in each 2 × 2 square before averaging the total out of 25”* This is an awkward sentence. Did you ascertain the percentage cover in each 2x2 square and then record the average value for all 25 squares?

Data analyses:

- Try to avoid starting section/paragraph/sentence with “because”.
- OK, so here you state the number of visits – this is in the wrong section.
- You shouldn’t be expecting normal distribution in bird count data or counts of trees in stem size classes, regardless of samples sizes. Counts are discrete integers whereas a normal distribution assumes all possible values could be observed (i.e. fractional values). This means that log-transforming the count data to cope with the apparent skew in the data is incorrect. Count data in natural populations are nearly always heavily skewed – for birds there are always lots of low counts (and often many zero counts) and for trees there are (nearly) always lots of small trees compared to big trees. Bird count data often follow a poisson distribution. Having said all that there shouldn’t be any transformations undertaken of the bird data (the distances) prior to analysis in Distance. You are not analysing the counts but the distances and in this case you certainly won’t have a normal distribution – at best a half normal.
- The distribution of predictor variables like stem density is not important and don’t need transforming for a regression. But if you are analysing stem density by forest block then stem density becomes the response variable and you do need to worry about its distribution.
- When you analyse using regression the densities arising from the Distance analysis *then* you need to worry about the distribution. And in this case you may need to transform the densities to approximate normality.
- For calculation of the encounter rate, “n” is not “mean abundance”, it is the “number of detections”. You are using the number of detection to try and work out the abundance.

- Explanation of choosing MCDS isn't clear. If cluster size was entered as a covariate because cluster size affected detectability then that makes sense, but you state that cluster size varied little implying it wasn't an issue. But you do seem to say that encounter rate varied a lot from one site to another. But you've not made it clear why MCDS would help cope with this (actually I don't think it would).
- *"We selected the cosine adjusted half-normal detection functional model with the lowest value based on Akaike Information Criterion in the density estimations"* would read better as: "We selected the cosine adjusted half-normal detection function based on it having the lowest AIC value". However, you ought to assess model fit on more than just AIC. Did you have to pool data? Or truncate data? What other models did you consider?
- *"Bird diversity was worked out using the reciprocal of Simpson's..."* better worded as "Bird diversity was estimated using the reciprocal of Simpson's..."
- It is not clear the level at which stem densities were calculated – for each transect? Same goes for the other veg measurements.
- It is not clear what you did to canopy cover: converted the values to ordinal scale then converted this to a ratio. Ratio of what to what? Doesn't this imply a closer numeric relationship between the classes than you really measured?
- Presumably the high variance in stem densities was because of the very small plot size relative to mean stem density – 0.1 ha is quite a small area to sample for trees in any forest.
- *"simple linear regression"* - It is not clear what this means. Do you mean univariate tests where you only consider one predictor variable at a time? If so, then you really ought to consider multivariate tests.
- *"Differences of means of the key habitat (independent) variables were compared on the spatial scale by one-way Analysis of Variance (ANOVA) using the forest blocks as the categorical treatment effects on the bird (response) variables."* I don't understand this sentence so please rephrase. Are you saying you used ANOVA to test for differences in the habitat variables between the different forest blocks? Not sure how the "bird (response) variables" also fit in here.

Results:

- No need to report on other birds species. The paper is about the pipit. You can mention that pipits surveyed as part of survey of all species but the other species data are few and add little.
- *"There were 17 encounters of Sokoke Pipit with an overall abundance of 30 individuals"* Confusing. You encountered pipits on 17 occasions comprising 30 individuals. Abundance is what you are trying to estimate from these encounters. You could put mean group size in brackets here to clarify further).
- Jilore and Kararacha are described as "moderate to highly disturbed" in contrast to Narasha which is "more disturbed". Not clear which is actually the more disturbed. Table suggests

the former are less disturbed.

- You report results of a chi sq test of clumpedness but don't explain this in methods.
- Can you report 95% confidence intervals instead of standard errors in table 1. Makes it much easier to interpret the results.
- Table 1 says you right-truncated the data – presumably you mean in Distance. This is not mentioned in Methods. Perhaps relates to earlier confusion about appearing to use fixed width transects at 60m.
- Table 1 AIC presumably refers to the value returned by distance. This serves no purpose in this table as you cannot compare AIC values for the different forest blocks as they are computed from different data. AIC values can only be compared where the data are the same.
- Is degradation confounded with edge effect (Jilore)?
- Figure 2 - there should be no line connecting the three sites because there are no intermediate locations to be represented by positions along the line. They are discrete sites. Would be better to have a box and whisker plot for this figure.
- Fig 2 - it is hard to believe from this plot that litter depth does vary significantly between the blocks despite the reported very low p value!
- Table 2 should say stems per hectare, not densities per hectare.
- Having said stems size classes were pooled earlier on, table 2 reports results of them unpooled.
- Why can't Fig 4 be shown as scatter plot like Fig 3? There appears to be no relationship in Fig 4 between logging and pipits. Two unlogged sites have both high and low pipit density and the logged site had intermediate pipit density.
- Good to include the raw Distance data – that's commendable. Would be also good to have a plot showing the Distance histogram and selected model to demonstrate how suitable the selected model was.
- The analysis really lacks a coherent conclusion as there was no attempt to combine the predictor variables in a single analysis. Admittedly this may not be possible with so few replicates but there may be other ways to cut the data to improve this.

Discussion:

- A good edit for language is required, in the discussion especially.
- There are long sections about forest disturbance and history that do not arise from the results of the survey. These should be moved to the introduction by way of describing the

site and why the survey might be needed or removed.

- Not sure that the impact of logging on the pipits is proven from the presentation given. Fig 4 is not convincing as it stands. In fact the opposite seems to be argued for in places – logging leads to more litter which is good for pipits.
- The article needs a good reference to back up the idea that leaf litter from felled trees persists for any length of time. Usually if a tree is felled the leaves dry up attached to the branches and don't fall off as they would naturally. Logging may lead to there being more dead wood rotting on the forest floor though.
- The elephant issue is important as fenced population must be having an impact. My understanding was that the fence was now complete.
- There is no real discussion of comparison with former surveys. Decline is rather simply attributed to habitat degradation without comparing the habitat in current survey with the habitat before.

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Author Response 01 Apr 2014

Nickson Otieno, National Museums of Kenya, Kenya

Dear Dr. Lindsell,

We highly appreciate your review comments on our article, particularly the accompanying detailed suggestions for revision. We have now gone through the comments and revised the article accordingly by addressing the concerns as outlined below, and hope that our treatment meets with your expectations.

Thanks,

Nickson E. Otieno (for the co-authors)

Revisions by the authors in detail:

Abstract

- We have now corrected the proportion of globally threatened and near-threatened species.

Introduction

- We have clearly specified that the group of birds useful for monitoring forest health are the forest-dependent ones.

- We have now minimized repeat references to BirdLife Fact sheets.
- We have clarified that our study, in contrast to that of Musila *et al.* which examined species' response to habitat change, dealt also with spatial variations in habitat structural quality, and that the results provide an update in the spatial and temporal dimensions of the habitat effects on the species.

Materials and methods:

- We have changed *BirdLife protocols* to *BirdLife criteria* as suggested.
- We have retained paragraph two, as we feel it presents a suitable background the forest as a significant national and global habitat for many forest-dependent species of which SP is one. But we have eliminated the part outlining other taxa found in the forest.
- We have changes *community zones* to *communities* as suggested.
- We have included a statement about the absence of any forest fragment within the agricultural zone outside the main forest blocks.
- We have clarified that honey harvesters and game hunters damage the forest habitat by clearing vegetation to make paths, burning vegetation to access hives. Creation of such openings further accelerated anthropogenic impacts on the forest habitat, which affects forest-interior species like SP.

Sampling strategy

- Lumbering: we have clarified that this was officially sanctioned commercial logging, in the era before forest protection was actively enforced.

Transect positioning

- We did not use existing paths, as you rightly point out, the habitat was penetrable enough for survey walking, and the paths were only use for purposes of location the starting points of transects.
- On the map the transects look straight but in actual fact they were not necessarily so. The illustrations representing the transects on the map show only the straight lines joining the starting and ending points of transects. We have included this clarification in the main text.
- Using the 3rd track to select the start of transects was considered sound enough as a way of randomizing transects across the blocks because despite there being differences in disturbance levels across the blocks, presence of the paths did not differ significantly across them (see results, final paragraph) in frequency and thus was unlikely to be a significant source of bias. The "3rd track" tool was thus just a way of systematizing transect randomization to minimize spatial bias. It is this systematization scheme that ensured that if we could not maintain at least 1 km between adjacent transects, we continued searching till we found a transect starting

point that fulfilled both conditions. So the abundance of tracks in the forest indeed assisted in some way.

Bird survey

- We have specified that we used Distance sampling but “fixed” our maximum transect width to 60m, beyond which, even in a forest that is not exactly too thick, it makes it subjective to accurately detect all individuals or clusters of a species as sensitive, silent and camouflaged as the SP. For this reason we also made truncation of our distance values on the programme itself by a general value of 5m.
- It is also clearly mentioned that we recorded SP individuals “and clusters” because there were incidents in which only single individuals were detected/encountered.
- We have added that bird transects were run twice each on different days.

Vegetation sampling

- It is canopy cover that was determined into % and not canopy heights. The canopy heights were determined using a range finder not from the within each transect quadrat but from an open area, either on a track or a deforested area, and using the range finder to obtain the observer distance from the tallest crown tree and then measuring to the crown height then using triangulation to determine crown height and adding eye-level height.
- We have clarified that live stems and cut tree stumps were measured in terms of circumference (not diameter) size classes. Only live stems were measured at breast height.

Floor litter sampling

- The sampling description is now made clearer.

Data analysis

- The count data that was log transformed initially were those of other counted things as only live stems and logged-out tree stumps. Bird data was only transformed from encounter rates (abundance) for purposes of regression against litter depth.
- By “transformed into densities per hectare” with regard to stem densities, we actually means “expressed as densities per hectare”. We have now reflected this in the data analysis section text. The initial transformation by logarithm was for the purpose of comparing these variables between blocks.
- We have clarified that SP encounter rates were worked out from total number of detections divided by survey effort, which was 2 km of transect in each forest block, surveyed twice each. Accordingly, we have reworked the encounter rates and corrected the values.
- It was our feeling that the rather small sample size of pipit detections was related to disturbance effects on the Pipit habitat within the *brachysetgia* forest. Having shown

that disturbance as a parameter itself varies across the three segments of Brachystegia forest, we felt that it would significantly influence detection of the pipits. One evidence of the variant disturbance across the blocks was the mean sighting/detection distance, which also ended up corresponding to the forest disturbance levels of the blocks. Therefore MCDS was employed by using disturbance levels as factor covariates thus reducing the variance (and possible low confidence) in the density estimates that would be expected if CDS were to be used.

- In determining the densities using Distance, data were pooled for the various blocks into a global analysis, factoring in the block factor covariates. But the densities were also worked for the individual blocks. For the global analyses, we have also replaced the standard errors of density estimate on table 1 with 95% confidence intervals.
- We have also included a description of how the model of fit was selected for distance estimation, and how data was truncated for analysis.
- Vegetation assessment variables analysis were treated at the transect and block levels.
- 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 transformed to ratios scaled with '3' as the maximum. So the ratio was cover score:3. Transformation of the ratios using ArcSine ensured that there would be no close relationship between the rations representing the cover scores than was actually measured.
- By simple linear regression, we mean "neither logistic nor loglinear". Multivariates was the method, through which for instance were selected litter depth as a better predictor of pipit abundance than litter cover as we had stated in the results section.
- Although 10 x 10 m quadrats could be small for sampling forest trees, our analyses of vegetation measurements were done at the transect level which integrated 10 of the qudrats of each transect thereby reporting results per ha rather than 0.1 ha.
- The statement on ANOVA means that means were compared across the blocks. We have revised the statement to read: "Means of habitat variables were compared across the blocks using one-way ANOVA"

Results

- The section mentioning other bird species has been removed in the revised version of results.
- Jilore and Narasha blocks are described as less disturbed as compared to the more disturbed Narasha block.
- We have included in the data analysis section the use of the chi test for S Pipit distribution.

- It is possible that edge effects could be linked to effects of degradation in Jilore block. However, as we did not investigate extent or effects of edge effect, our main view about the high detection of S Pipit in that block is related to lack of massive destruction by elephants and comparatively reduced human traffic over the past few years due to the enclosing electric fence barrier.
- AIC values have been removed from Table 1.
- Figure 2 is now reproduced in box and whisker form to more distinctly show variation in litter depth across the blocks.
- Table 2 actually presents the tree stem data pooled into size classes (small sized = >30cm, mid-sized = 31-60cm and large = >60cm)
- Figure 4 is not presented as a scatterplot because the logging data used to produce it are those of total trees stems cut, as the figure shows (human removal) without inclusion of trees removed or felled by elephants. In the discussion, we clearly showed that impact on Sokoke pipit due to habitat degradation was both a function of stem cutting as well as elephant tree removal. Furthermore, the figure as presented is intended to demonstrate that a slight increase in tree cutting/removal can correspond to a drastic impact on the Pipit abundance. Accordingly Narasha with low logging rate also had low pipit encounter rates, because the habitat degradation in that block is due to the numerous elephants rather than from human-mediated logging (stem cutting). We have updated the legend for Fig 4 to reflect this clarification.

Discussion

- It is our view that the section that deals with description of many authors' characterization of Arabuko Sokoke forest as a way of delineating it in terms of disturbance zones, provides a good setting in which we present our own characterization based on actual observed attributes which are in addition to, rather than restricted to, spatial variations in tree logging patterns. For instance, no other researcher has ever appeared to notice the possible relationship between the elephant feeding habits and forest habitat impacts. Putting this section in the introduction would imply that it is common documented knowledge, which it is not. We have however removed the first paragraph of that section, which might have been the more redundant of earlier descriptions under "Materials and methods".
- We were not able to find any study linking Sokoke Pipit needs with habitat variables ever since Musila *et al* did so in 2000, which is why we did not have much such discussion in our paper. We mentioned however that since the Musila *et al* study, there has been a decline in Pipit density, presumably due to habitat degradation that has continued since then. This is clearly outlined in the first paragraph of discussion. Oyugi, Fanshawe, Banks, Davis *et al*. all studied habitat of the Brachystegia forest, but in reference to other species mostly of the forest canopy and thus not directly comparable to the Sokoke Pipit.

- The impact of tree loss is proven as the main cause of Sokoke Pipit habitat in terms of abundance and distribution and as we argue in the discussion, trees are lost not only through logging by human (fig 4) but also by elephant tree damage. Augmentation of leaf litter (important for pipit) from pruning poached poles in the forest was neither evident throughout the study area nor considered the main driver of Pipit abundance and distribution. It was only associated to areas where logging intensity targeted small trees (human-induced removal). Again, human-induced tree removal was not the only driver of S pipit demographics.

Competing Interests: No competing interests

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