Journal of East African Natural History **108**(1): 37–48 (2019)

ABUNDANCE, DISTRIBUTION, HABITAT, ACTIVITY AND CONSERVATION OF SOKOKE BUSHY-TAILED MONGOOSE *BDEOGALE OMNIVORA* IN CENTRAL AND NORTH COAST FORESTS OF KENYA

Rajan Amin, Tim Wacher, Josef Clifford
Conservation Programmes, Zoological Society of London
Regent's Park, London NW1 4RY, UK
Raj.Amin@zsl.org; Tim.Wacher@zsl.org; Josef.Clifford@zsl.org

Bernard Ogwoka
Kenya Wildlife Service
P.O. Box 40241-00100, Nairobi, Kenya
bogwoka@kws.go.ke

Bernard Risky Agwanda
Section of Mammalogy, National Museums of Kenya
P.O. Box 40658-00100, Nairobi, Kenya
ben_risky@yahoo.co.uk

ABSTRACT

The Sokoke dog or bushy-tailed mongoose *Bdeogale omnivora* is poorly known and considered to be endemic to the East African coastal forests. Systematic camera trap surveys, comprising 9229 camera trap days on grids at six study sites, were used to determine the distribution and relative abundance of the Sokoke bushy-tailed mongoose in the two largest Kenyan coastal forests: Boni-Dodori Forest Complex (*ca*. 4000 km²); and Arabuko-Sokoke Forest Reserve (416 km²). This species was captured in all surveyed forests with significantly more detections in *Brachystegia* woodland habitat (*ca*. 71 km²) of Arabuko-Sokoke and the Boni forest sectors (*ca*. 2000 km²) of the Boni-Dodori Forest Complex. Boni-Dodori Forest Complex, with an estimated occupancy of over 60% for this species, holds a significant population. The study generated over 1000 images of the Sokoke bushy-tailed mongoose in a total surveyed area of approximately 500 km² providing the first 24-hour activity data for the species. The circadian patterns confirm this species to be strictly nocturnal. This study strongly recommends that its Red List status remains 'Vulnerable'. The few remaining coastal forests continue to face human pressure. Recent proposals to find and extract hydrocarbons from under the Arabuko-Sokoke Forest, and the planned major development close to Boni-Dodori Forest Complex, raise serious conservation concerns for this exceptionally biodiverse ecosystem.

Keywords: Arabuko-Sokoke forest, Boni forest, Dodori forest, camera trap, status, *Bdeogale omnivora*

INTRODUCTION

The Sokoke dog mongoose or Sokoke bushy-tailed mongoose *Bdeogale omnivora* Heller, 1913, synonymous with *Bdeogale crassicauda* ssp. *omnivora* Heller, 1913, is IUCN Red Listed as a 'Vulnerable' species (Foley & Do Linh San, 2016). The known distribution, albeit based on few data, is primarily limited to the coastal forests of Kenya and Tanzania. In Tanzania, *B. omnivora* is reported in the hinterland as far as the Usambara Mountains although possible confusion with bushy-tailed mongoose *B. crassicauda* at this location is suggested (Taylor, 2013). The type locality is Mazeras, west of Mombasa, Kenya (Engel & Van Rompaey, 1995; Engel, 1996; Taylor, 2013; Foley & Do Linh San, 2016). The taxonomic status of *B. omnivora* in relation to *B. crassicauda* is not fully resolved, but *B. omnivora* is currently treated as largely allopatric to *B. crassicauda* and is the only form in the study areas of coastal Kenya considered here (Foley & Do Linh San, 2016).

The habitats where Sokoke bushy-tailed mongoose is found are of exceptional biodiversity. This mongoose is one of an array of endemic species characteristic of the East African coastal forest zone, recognised as the 'Northern Zanzibar-Inhambane Coastal Forest Mosaic Ecoregion (Burgess & Clarke, 2000). These coastal forests and woodlands have recently been reduced by nearly 80% by humans (Habel *et al.*, 2017).

The objective of the study was to establish new baseline data on the Sokoke bushy-tailed mongoose in the two largest blocks of lowland forest of coastal Kenya: Boni-Dodori Forest Complex north of the Tana River, and Arabuko-Sokoke Forest south of the Galana/Sabaki River (figure 1). This baseline will contribute towards comprehensive conservation planning for the high value habitat in which this mongoose is found.

DESCRIPTION OF THE STUDY AREAS

Boni National Reserve (NR) (1339 km²), Dodori NR (877 km²), and Boni-Ijara Forest Reserve (FR) (*ca.* 1400 km²) are located on the extreme north coast of Kenya (figures 1 & 2). These three reserves, and their surroundings, comprise 'Boni-Dodori Forest Complex' (Oduori, 1990; Amin *et al.*, 2015; Musina *et al.,* 2016). 'Boni-Dodori Forest Complex' is hereafter, referred to as 'Boni-Dodori'.

Boni-Dodori experiences two annual wet seasons with the long wet season in April–June and the short wet season in October–November. Mean annual rainfall ranges from 500 mm in the northeast to 800 mm in the southwest. Boni–Dodori is mainly located on a flat plain with a braided drainage system separated by marine sands and clay ridges. Towards the coast, several parallel, fossilised, sand dunes run southwest–northeast, the highest reaching *ca.* 100 m on Sankuri Ridge (Musina *et al.,* 2016).

Boni-Dodori consists of a tight mosaic of habitats, including patches of 10–15 m high trees with closed forest canopy and a dense understory interspersed by grassland, extensive bushland, and shrubby thickets. Boni-Ijara FR and Boni NR include an extensive forest of scattered tall trees and dense understory that is bordered by acacia woodland and scrub towards the coast. Dodori NR features seasonally flooded grassland with doum palm *Hyphaene compressa* H.Wendl. and patches of forest and thicket. Forest trees in Boni-Dodori include mbamba-kofi *Afzelia quanzensis* Welw., tamarind *Tamarindus indica* L., *Croton megalocarpoides* Friis & M.G.Gilbert, *Asteranthe asterias* (S.Moore) Engl. & Diels, *Grewia plagiophylla* K.Schum., *Manilkara* spp., *Diospyros* spp., and *Acacia* spp., mainly on white or grey sandy soil. *Ochna* spp. shrubs and *Fernandoa magnifica* Seem. trees occur on the red sandy soil of Sankuri Ridge (Oduori, 1990; Musina *et al.,* 2016).

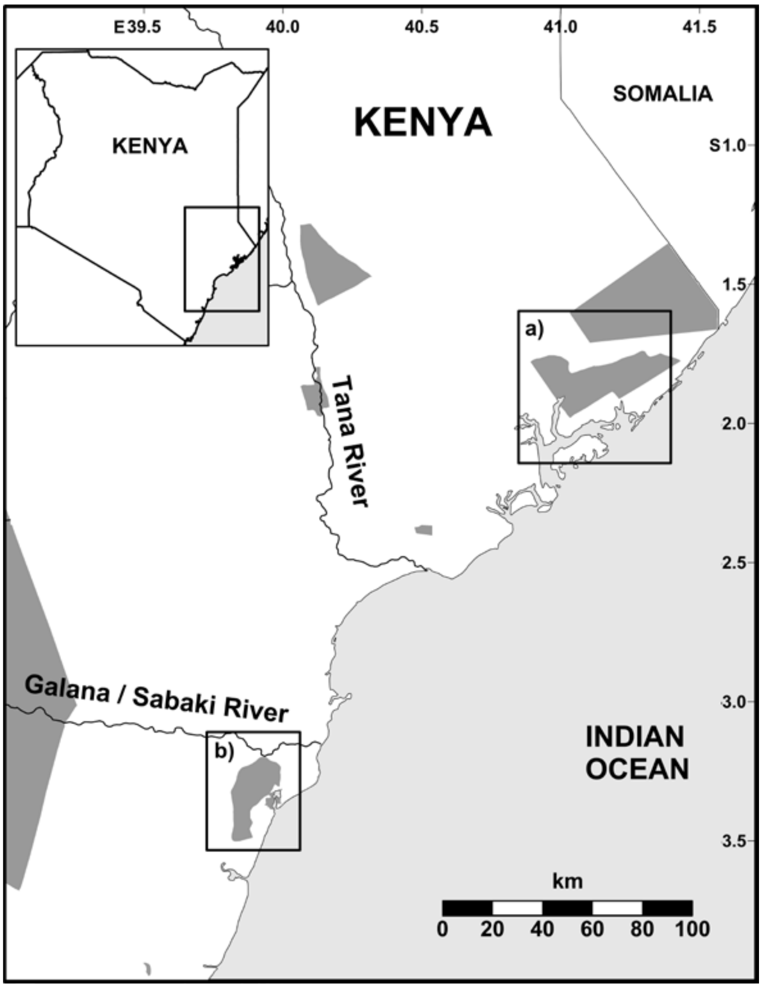

Figure 1. Location of Boni-Dodori Forest Complex Study Site (a), north coast of Kenya, and Arabuko-Sokoke Forest Study Site (b), central coast of Kenya. Terrestrial protected areas are in grey.

Human population density is low (< 3 people/km²) in this remote, politically insecure, region. Most of the *ca*. 1800 Aweer people live in four villages along a dirt track that is often impassable during the wet seasons. Traditionally hunter-gatherers, the people here now subsist mainly through small-scale agriculture, the primary crop being maize (Musina *et al.,* 2016).

The Arabuko-Sokoke Forest covers 416 km², altitude 0–210 m, and is the largest forest on the central coast of Kenya (figures 1 & 2; Bennun & Njoroge, 1999). It lies 250 km south of Boni-Dodori and is separated from it by two major rivers, the Tana and Galana-Sabaki. This area shares the same two annual wet seasons as Boni-Dodori, April–June and October–November, with the former being the wettest. Mean annual rainfall ranges from 900 mm in the north-west to 1100 mm in the east. Three main vegetation types occur: *Cynometra* thicket dominated by *Cynometra webberi* Bak.f. on red-coloured sandy soil; *Brachystegia* woodland dominated by *Brachystegia spiciformis* Benth. on white sandy soil; and Mixed forest dominated by several tree species, including *Afzelia quanzensis*, *Hymenaea verrucosa* Gaertn., *Manilkara sansibarensis* (Engl.) Dubard, *Manilkara sulcata* (Engl.) Dubard, *Combretum schumannii* Engl., and *Drypetes reticulata* Pax on grey sandy soil. The mixed forest has the highest diversity of trees, with 67 of the 87 species recorded in Arabuko-Sokoke Forest. Here, the abundance of *A. quanzensis*, once the most dominant tree, has been diminished through decades of logging (KIFCON, 1995; Bennun & Njoroge, 1999; ASFMT, 2002).

Arabuko-Sokoke Forest is encircled by settlements, agriculture, and a dense human population. As of 2002, about 100 000 people lived in the vicinity of Arabuko-Sokoke Forest (ASFMT, 2002).

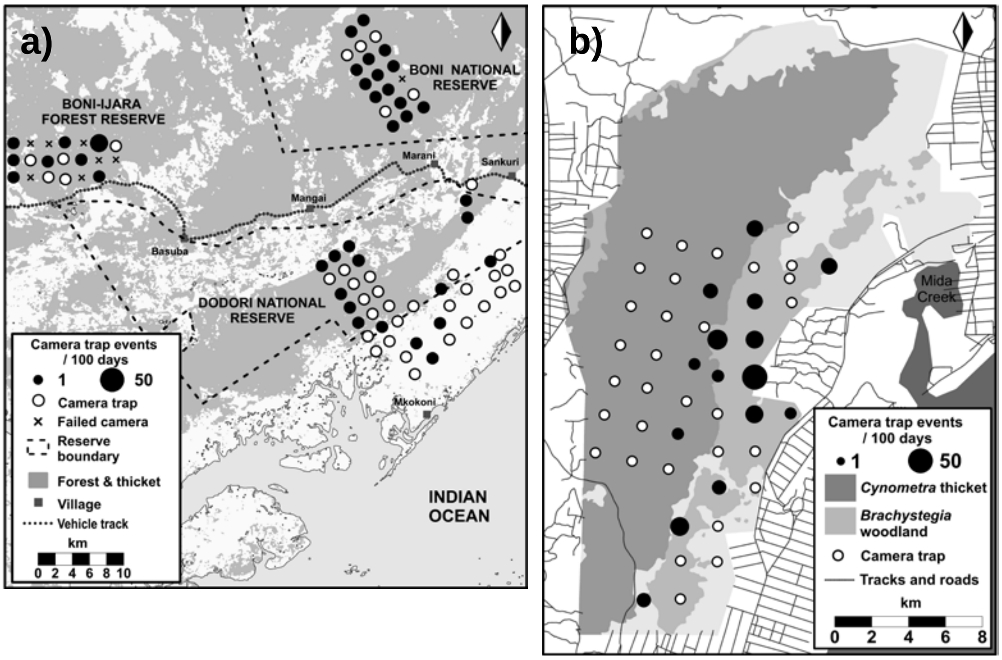

Figure 2. Forest cover map and distribution of Sokoke bushy-tailed mongoose on camera trap grids in Boni-Dodori Forest Complex (a) and Arabuko-Sokoke Forest (b). Size of solid circle is proportionally weighted by trap rate: open circles represent no captures (see Methods for definition of an event).

MATERIALS AND METHODS

Field materials and methods

To investigate habitat use by this species we created a forest cover map for Arabuko Sokoke Forest by classifying Landsat 8 satellite imagery in ERDAS IMAGINE software (Hexagon Geospatial, 2017). We selected Landsat 8 data from 12 January 2017 from USGS Earth Explorer (USGS, 2017), based on its low cloud cover percentage. Bands 1 to 7 of the data, all at 30 m resolution, were stacked using the Stack Bands tool in ERDAS IMAGINE software to produce a multispectral image. We used the ISODATA classification technique on the multispectral image, which produced 20 classes that were then merged and assigned values relating to one of the following land cover types: *Brachystegia* woodland, *Cynometra* thicket, mixed forest, agriculture, and other vegetation.

A common technique employed to enhance the accuracy of land cover maps created by automatic classification techniques is to use additional GIS products (Rozenstein & Karnieli, 2011; Rujoiu-Mare & Mihai, 2016). This was necessary in this case as the mixed forest had not been well represented by the unsupervised classification. We, therefore, manually created a land cover shapefile in QGIS 2.14 software (QGIS Development Team, 2017) based on the classified image, an earlier forest cover map from Kenya Wildlife Service (KWS), and an NDVI image and 15 m resolution panchromatic band (both derived from 12 January 2017 Landsat 8 data). To investigate habitat use at Boni-Dodori, we used a cover map from our previous work (Amin *et al.*, 2015).

We established camera grids in Boni NR (centred on 01°32'13"S, 41°19'32"E during March–June 2010), Dodori NR (01°49'19"S, 41°04'28"E during January–March 2010), Boni-Ijara FR (01°40'34"S, 40°52'32"E during June–September 2010), and in open coastal scrub south of Dodori NR (01°51'11"S, 41°19'09"E during February–July 2015; figure 2). Camera grids were set-up in Arabuko-Sokoke Forest, in *Cynometra* thicket (03°21'49"S, 39°50'37"E) and in a single grid across both *Brachystegia* woodland and mixed forest habitat (03°39'14"S, 39°87'19"E) during January–March 2015 (figure 2). Each camera grid was operational long enough to achieve at least 1000 camera trap days of sampling effort (O'Brien *et al.*, 2003).

We used Global Positioning System (GPS) receivers to locate the grid points, which were spaced at 2 km intervals. A single camera was positioned 30–45 cm above ground level within 100 m of each point, aimed at a clearing that provided sufficient field of view to capture lateral full-body images of small to medium-sized mammals.

The two camera models used (Bushnell Trophy Cam, Bushnell Outdoor Products, Cody, Kansas, USA, and Reconyx RM45, RECONYX Inc., Holman, Wisconsin, USA) were set-up to perform as similarly as possible. Detection range was at least 25 m with either no delay between triggers (Reconyx) or a 1 second delay (Bushnell). Three consecutive images were taken per trigger. Infrared flash lighting was used to minimise startling animals. All other settings were the defaults of each camera model. We trained and tested field personnel in camera trap deployment with the aim of obtaining high-quality images with consistent fields of view with respect to horizon line and detection zone. To record the duration of camera operation and to ensure images were easily associated with each camera location, the field teams triggered photos showing location, time, and date written on a white board at both completion of installation and on initiating recovery of each camera.

Data analysis

The metadata (*i.e.* image name, date and time) associated with all images were extracted with Exiv2 software (Huggel, 2012) and compiled in an Excel spreadsheet (Microsoft Office Professional Plus, 2010). We then added information indicating photo type (wildlife or other) and identified species for all images obtained. The subset of Sokoke bushy-tailed mongoose images were then analysed using the ZSL camera trap analysis package (Amin & Wacher, 2017). Based on body size and body shape, Sokoke bushy-tailed mongoose (figure 3) are unlikely to be confused with other species apart perhaps from the occasional poorly exposed infra-red images of marsh mongoose *Atilax paludinosus* (G. Cuvier, 1829). Although white-tailed mongoose *Ichneumia albicauda* (G. Cuvier, 1829) shows similar markings in dark legs and pale body, it is larger and even in dark-tailed morphs is much longer legged, characteristically holding the body higher off the ground. Also, the shape and carriage of the tail differ.

Figure 3. Camera trap photograph of a pair of Sokoke bushy-tailed mongoose Bdeogale omnivora *in Arabuko-Sokoke* Brachystegia *woodland.*

We calculated the species 'trap rate' for each grid as the number of independent photographic events per 100 trap days. We calculated a 95% confidence interval for species trap rate using non-parametric bootstrap with replacement (Efron & Tibshirani, 1994). We defined a camera trap 'independent photographic event' (or 'event') as any sequence of photographs of the Sokoke bushy-tailed mongoose occurring after an interval of >60 minutes from the previous photograph of the species (Amin *et al.*, 2015). Species trap rate provides an index of relative abundance with the assumption that species trigger cameras in relation to their density, all other factors being equal. Trap rate provides a comparative index within species when a standardised protocol is used for the surveys, including consistent positioning and management of cameras to help ensure similar detection probabilities.

We also used the species trap rate at each camera site to generate simple distribution maps for each camera trap grid. We constructed circadian (24-hour) species activity patterns by tallying the number of events initiated in each hour across each survey time-period.

We estimated the proportion of area occupied by the Sokoke bushy-tailed mongoose using a single-season occupancy model (MacKenzie *et al.*, 2006) with the assumption that mongoose home ranges are less than the trap density of 1 per 4 km^2 (Kingdon & Hoffmann 2013). We assessed the goodness-of-fit of the models using the MacKenzie and Bailey goodness-of-fit test (2004). We also modelled the effect of 'distance from forest edge' and 'forest habitat type' on species occurrence in Arabuko-Sokoke Forest with its distinct habitat zones. Forest type at each camera trap was derived using the Select by Location tool and field calculator in QGIS software (QGIS Development Team, 2017). We calculated the camera trap distance to forest edge in meters using the NNJoin plugin in QGIS. We treated detection probability as a constant and evaluated all covariate combinations: $\psi(.),p(.)$;

ψ(forest type),p(.); ψ(distance to forest edge),p(.); ψ(forest type, distance to forest edge),p(.). We ranked models by Akaike's information criteria (AIC). For Boni-Dodori, we tested for significant difference among occupancy for the four sites using the Wald test with $P < 0.05$ considered to be significant (Amin *et al.*, 2015, Amin, *et al.*, 2017).

RESULTS

We accumulated 2209 camera trap days (mean 49 days/camera) in Arabuko-Sokoke Forest, not including two cameras on the *Brachystegia* woodland grid that failed and thus were excluded from the analysis. In Boni-Dodori, total camera trap days for the four camera trap grids was 7020 with a mean of 95 days per camera, with one of the camera trap grids (south of Dodori) retrieved after 3240 trap days due to political insecurity in the area. One camera failed in the Boni NR grid and six cameras failed in the Boni-Ijara FR grid.

Sokoke bushy-tailed mongoose was captured in all camera grids. The most detections were recorded in the Arabuko-Sokoke *Brachystegia* woodland and in the Boni-forests (table 1). Overall, Sokoke bushy-tailed mongoose had the highest trap rate in the Arabuko-Sokoke *Brachystegia* woodland (table 2). The trap rate was significantly different, with non-overlapping 95% confidence intervals, compared to the other forest habitats in Arabuko-Sokoke Forest and compared to the two more open southern habitats in Boni-Dodori. The open coastal scrub habitat south of Dodori appears to be the least suitable habitat for this species (table 2, figure 2).

Sokoke bushy-tailed mongoose occurrence was most strongly associated with forest type in Arabuko-Sokoke Forest (table 3). *Brachystegia* woodland (70.2 km^2) had the highest mean occupancy for the species: 0.63 (SE=0.15). Mixed forest (72.5 km^2) had a mean occupancy of 0.33 (SE=0.35), and *Cynometra* thicket (252.7 km^2) had a mean occupancy of 0.25 (SE=0.1).

In Boni-Dodori, no statistically significant difference in Sokoke bushy-tailed mongoose occupancy was detected among the four sites (table 2). Occupancy values in all the northern forest grids were also higher than in the Arabuko-Sokoke *Cynometra* thicket and mixed forest, confirming the importance of this forest complex for this species.

This species was only photographed at night (sunrise 05:54–06:25 h, sunset 18:06–18:37 h) (figure 4). Sokoke bushy-tailed mongoose is generally described as solitary, and single individuals were represented in more than 90% of the 195 photographic events recorded. Two animals were present in the same image in 3.6% of events, and evidence of one animal following another at between 9 to 120 second intervals was present in another 3% of events. In one case, two individuals passed through and appeared to scent mark the same spot.

DISCUSSION

Our study provides baseline data on this vulnerable East African coastal endemic. Results show that the Sokoke bushy-tailed mongoose is widely distributed across all sampled woodland and thicket habitats of Boni-Dodori. At Arabuko-Sokoke, the species' distribution is concentrated in the *Brachystegia* woodland, which comprises only 17% of the 420 km^2 area.

Table 1. Summary of Sokoke bushy-tailed mongoose detections in the six camera trap grids in Boni-Dodori Forest Complex and Arabuko-Sokoke Forest.

Site	Total number of active camera sites	Total camera trap days	Number of sites detecting Sokoke bushy-tailed mongoose	Total number of Sokoke bushy-tailed mongoose photographs	Total number of Sokoke bushy-tailed mongoose independent photographic events
Arabuko-Sokoke *Cynometra* thicket	25	1339	6	155	15
Arabuko-Sokoke *Brachystegia* woodland	13	628	8	327	46
Arabuko-Sokoke mixed forest	5	242	1	17	3
Boni National Reserve Forest of tall trees and dense understory	19	1656	14	242	56
Boni-Ijara Forest Reserve Forest of tall trees and dense understory	13	1004	8	171	45
Dodori National Reserve Mosaic habitat of seasonally flooded grassland and patches of forest and thicket	20	1124	8	60	17
South of Dodori National Reserve Open coastal scrub	22	3236	7	49	13

Note: Arabuko-Sokoke Brachystegia woodland and mixed forest were surveyed as one camera trap grid.

Table 2. Trap rate, occupancy, and detection probability estimates for the Sokoke bushy-tailed mongoose. Standard errors are presented in brackets. Trap rate was calculated as the number of independent photographic events per 100 trap days. Occupancy is the proportion of area occupied or, alternatively, probability of a given site being occupied (1 means 100 percent probability of the site being occupied). Detection probability is probability of detecting the species if it is present.

Site	Trap rate (95% credible interval)	Occupancy (±SE)	Detection probability (±SE)
Arabuko-Sokoke *Cynometra* thicket	1.12 (0.21–2.41)	0.25±0.1	0.18±0.07
Arabuko-Sokoke *Brachystegia* woodland	7.62 (3.35–12.46)	0.63±0.15	0.36±0.06
Arabuko-Sokoke mixed forest	1.24 (0–3.24)	0.33±0.35	0.11±0.1
Boni National Reserve Forest of tall trees and dense understory	3.38 (2.01–4.81)	0.77±0.11	0.18±0.03
Boni forest Forest of tall trees and dense understory	4.48 (1.39–9.19)	0.63±0.14	0.22±0.04
Dodori National Reserve Mosiac habitat of seasonally flooded grassland and patches of forest and thicket	1.51 (0.53–2.78)	0.63±0.24	0.09±0.04
South of Dodori National Reserve Open coastal scrub	0.4 (0.15–0.71)	0.5±0.21	0.03±0.02

Table 3. Comparison of Sokoke bushy-tailed mongoose occupancy models based on different combinations of site covariates (forest type and distance to forest edge) in Arabuko-Sokoke Forest.

Occupancy model	AIC	Delta AIC	AIC weight
ψ(forest type),p(.)	214.546	0.000	0.515
ψ(.),p(.)	216.376	1.830	0.206
ψ(forest type+distance to forest edge),p(.)	216.538	1.991	0.190
ψ(distance to forest edge),p(.)	218.075	3.529	0.088

Boni-Dodori is the largest coastal forest system in Kenya, with a forest area of at least 3000 km^2 measured from the habitat map produced as part of our terrestrial mammal diversity assessment in the region (figure 2, Amin *et al.*, 2015). This species' estimated occupancy is over 60% (table 2); with approximately 10% of the area covered by the camera trap grids. This species was recorded more frequently in the northern (inland) forests of Boni NR and Boni-Ijara forest, an area *ca.* 2000 km^2.

Camera trapping also reveals the highly nocturnal behaviour of the Sokoke bushy-tailed mongoose, which goes some way towards explaining the lack of information about it. It also confirms that while this species does occasionally travel in pairs, or one following another at a short interval, the established description of 'mainly solitary' is supported.

This study also provides deeper insight into the species' habitat preferences, albeit only within the limitations of camera placement. Sokoke bushy-tailed mongoose was found associated with *Brachystegia* woodland, closed canopy forest habitat and, to a lesser extent, more open coastal forest rather than with dense thickets. Elsewhere this mongoose was recorded foraging on a road between a pine plantation (with a regenerating natural forest understorey) and grassland with bushes and small forest islands near Longomwagandi, Kenya, formerly a dense lowland forest with a closed canopy (Engel, 2000).

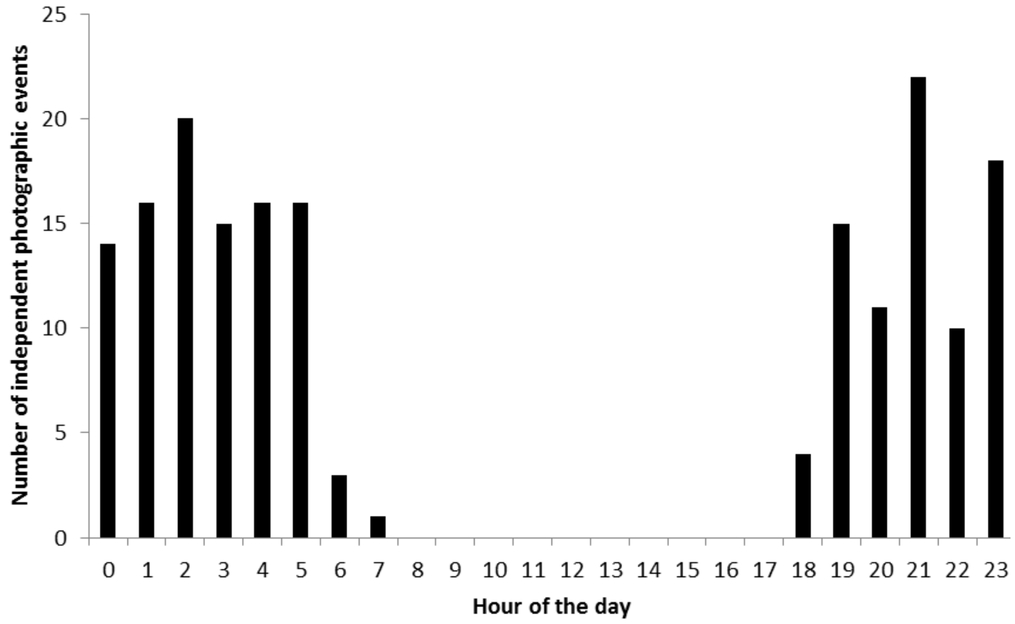

Figure 4. Sokoke bushy-tailed mongoose 24-hour activity patterns derived from the pooled data from camera trap grids in Arabuko-Sokoke Forest and Boni-Dodori Forest Complex (sunrise 05:54–06:25 h, sunset 18:06–18:37 h).

Although the camera trap results suggest that Sokoke bushy-tailed mongoose is more widely distributed within coastal forest habitat than previously indicated by the few known records, there are strong reasons to retain its Red List status as 'Vulnerable'. This species' known habitats, including those in gazetted protected areas, increasingly face human pressure. Most of the remaining small forests outside Arabuko-Sokoke Forest are severely degraded by pole collection for house construction, and logging mainly for wood carving (FitzGibbon, 1994; Bauer, 1996). Hunting by loggers and subsistence trappers who capture a variety of wildlife for food is also a threat to this species (Amin *et al.*, 2015). Recent proposals to find and extract hydrocarbons from under the Arabuko-Sokoke Forest (Gordon *et al.*, 2015) and the development of a major seaport at Lamu, along with development of a cross country pipeline (Morris & Amin, 2012), may become further major threats to this already vulnerable species. Continuous habitat degradation, loss and fragmentation, and indiscriminate hunting, raises serious conservation concerns and highlights the need for a conservation management plan and protective action.

ACKNOWLEDGMENTS

This study was funded and supported by the UK Department for International Development (DFID) through the UK DFID/DEFRA Darwin Initiative and through its Programme Partnership Agreement with WWF-UK, Kenya Wildlife Service, Mohamed bin Zayed Species Conservation Fund, Size of Wales, Whitley Wildlife Conservation Trust, WWF, and the Zoological Society of London. We thank everyone who assisted in the fieldwork and data management. We also thank Dr Thomas R. Engel for reviewing the manuscript prior to submission.

REFERENCES

Amin, R., S.A. Andanje, B. Ogwonka., A.H. Ali, A.E. Bowkett, M. Omar & T. Wacher (2015). The northern coastal forests of Kenya are nationally and globally important for the conservation of Aders' duiker *Cephalophus adersi* and other antelope species. *Biodiversity and Conservation* **24**(3): 641–658.

Amin, R. & T. Wacher (2017). A new comprehensive package for the management and analysis of camera trap data for monitoring antelopes and other wild species. *Gnusletter* **34**(2): 21–23.

Amin, R., T. Wacher, A. E. Bowkett, B. Ogwoka & B. R. Agwanda (2018). Africa's forgotten forests: the conservation value of Kenya's northern coastal forests for large mammals. *Journal of East African Natural History* **107**(2): 41–61.

ASFMT (2002). Arabuko-Sokoke Strategic Forest Management Plan 2002–2027. Arabuko-Sokoke Forest Management Team. Unpublished report by Forest Department, Kenya Wildlife Service, Kenya Forestry Research Institute, National Museums of Kenya, Nature Kenya, and Birdlife International, Nairobi.

Bauer, C.R. (1996). Impact of commercial and subsistence practices on the Arabuko-Sokoke Forest in coastal Kenya, using an endemic mammal as an indicator species. Unpublished MA Thesis, Eastern Kentucky University, USA.

Bennun, L.A. & P. Njoroge (1999). *Important Bird Areas in Kenya*. East Africa Natural History Society, Nairobi.

Burgess, N.D. & G.P. Clarke (2000). *Coastal Forests of Eastern Africa*. IUCN, Gland, Switzerland.

Efron, B. & R.J. Tibshirani (1994). *An Introduction to the Bootstrap*. CRC press, Florida, USA.

Engel, T. & H. Van Rompaey (1995). New records of the rare Sokoke bushy-tailed mongoose, *Bdeogale crassicauda omnivora* in the coastal Shimba Hills National Reserve and at Diani Beach, Kenya. *Small Carnivore Conservation* **12**: 12–13.

Engel, T.R. (1996). Update of the rare (Sokoke) bushy-tailed mongoose, *Bdeogale crassicauda cf omnivora* at the Shimba Hills, Diani Beach and Tiwi. *EAHNS Bulletin* **26**(2): 24–29.

Engel, T.R. (2000). *Seed Dispersal and Forest Regeneration in a Tropical Lowland Biocoenosis* (Shimba Hills, Kenya). Logos-Verlag, Berlin.

FitzGibbon, C.D. (1994). The distribution and abundance of the golden-rumped elephant shrew *Rhynchocyon chrysopygus* in Kenyan coastal forests. *Biological Conservation* **67**: 153–160.

Foley, C. & E. Do Linh San (2016). *Bdeogale omnivora*. The IUCN Red List of Threatened Species 2016: e.T136686A45221619. http://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T136686A45221619.en. [Accessed on 24 September 2018].

Gordon, I., J. Fanshawe & C. FitzGibbon (2015). An update on Arabuko-Sokoke Forest, Kenya. *Afrotherian Conservation - Newsletter of the IUCN-SCC Afrotheria Specialist Group* **11**: 11–12.

Habel, J.C., I.C.C. Casanova, C. Zamora, M. Teucher, B. Hornetz, H. Shauri, R.K. Mulwa & L. Lens (2017). East African coastal forest under pressure. *Biodiversity and Conservation* **26**(1): 237–241. DOI: 10.1007/s10531-017-1375-z.

Hexagon Geospatial, 2017. ERDAS IMAGINE. Version 2017. Hexagon Geospatial. www.hexagongeospatial.com.

Huggel, A. (2012). Exiv2 software tool. http://www.exiv2.org/index.html [accessed 20 August 2017].

KIFCON (1995). *Arabuko-Sokoke Forest: The Official Guide*. Kenya Indigenous Forest

Conservation Programme, Nairobi.

Kingdon, J. & M. Hoffmann (eds.) (2013). *Mammals of Africa. Volume V: Carnivores, Pangolins, Equids and Rhinoceroses*. Bloomsbury Publishing, London.

MacKenzie, D.I. & L.L. Bailey (2004). Assessing the fit of site-occupancy models. *Journal of Agricultural, Biological, and Environmental Statistics* **9**: 300–318.

MacKenzie, D.I., J.D. Nichols, J.A. Royle, K.H. Pollock, L.L. Bailey & J.E. Hines (2006). *Occupancy Estimation and Modelling*. Elsevier, Amsterdam.

Morris, M. & R. Amin (2012). An update on the threats to Afrotheria in northern coastal Kenya. *Afrotherian Conservation* Number 9. IUCN. http://afrotheria.net/newsletter.html. [Accessed 30 May 2018].

Musina, J., F. Ng'weno, M. Mwema, D. Ngala, M. Ngala, A. Baya, E. Mlamba, T. Mwinami, D. Chesire, M. Alale, A. Shizo, W. Sawii Ware, I. Mohamed, B. Binda, B. Mohamed, A. Mohamed, A. Hassan, M. Morris, J. Bett & R. Amin (2016). Bird Diversity Survey in the Boni-Dodori Forest System, Kenya (2015). Unpublished report to the Zoological Society of London, London. https://www.zsl.org/users/rajan-amin [accessed 20 August 2017].

Oduori, S.M. (1990). The Vegetation of Boni and Dodori Game Reserves and Adjoining Areas. Technical Report Number 139. Department of Resource Surveys and Remote Sensing, Nairobi.

O'Brien, T.G., M.F. Kinnaird & H.T. Wibisono (2003). Crouching tigers, hidden prey: Sumatran tiger and prey populations in a tropical forest landscape. *Animal Conservation* **6**: 131–139.

QGIS Development Team (2017). QGIS Geographic Information System. Version 2.14. Open Source Geospatial Foundation Project. http://www.qgis.org.

Rozenstein, O. & A. Karnieli (2011). Comparison of methods for land-use classification incorporating remote sensing and GIS inputs. *Applied Geography* **31**(2): 533–544.

Rujoiu-Mare, M. & B. Mihai (2016). Mapping land cover using remote sensing data and GIS techniques: a case study of Prahova Subcarpathians. *Procedia Environmental Sciences* **32**: 244–255.

USGS (2017). USGS Earth Explorer. Available at: https://earthexplorer.usgs.gov. [Accessed: 01/09/17].

Taylor M.E. (2013). *Bdeogale omnivora* Sokoke bushy-tailed mongoose. In J. Kingdon & M. Hoffman (eds.), *Mammals of Africa: volume V: Carnivores, Pangolins, Equids and Rhinoceroses*. Bloomsbury Publishing, London. Pp. 328–330.