

**STATUS AND BEHAVIOURAL ECOLOGY OF SENGIS IN THE
BONI-DODORI AND ARABUKO-SOKOKE FORESTS, KENYA,
DETERMINED BY CAMERA TRAPS**

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ABSTRACT

The biodiversity of northern coastal Kenya, east of the Tana River, is poorly understood because security problems and poor infrastructure have discouraged access to the area. However, the wooded areas in the region have great potential for harbouring endemic and rare species, including sengis or elephant-shrews (order Macroscelidea), especially giant sengis in the genus *Rhynchocyon*. Based on extensive camera-trap surveys of the Boni-Dodori forest, east of the Tana River near the Somalia border, and the Arabuko-Sokoke forest west of the Tana River, the golden-rumped sengi *Rhynchocyon chrysopygus* appears to be limited to the Arabuko-Sokoke area, while the giant sengi in the Boni-Dodori forest is different. The Boni-Dodori forest, the largest Kenyan coastal forest, with a potential forest and thicket area of at least 3000 km² is likely to hold a significant number of *Rhynchocyon*, making it very important to sengi conservation. The study generated over 2700 images of giant sengi and 32 000 camera-trap images of soft-furred sengi in a total surveyed area of approximately 300 km² providing the first detailed 24-hour behaviour data for the species. The circadian patterns have confirmed *R. chrysopygus* and Boni *Rhynchocyon* to be strictly diurnal while the soft-furred sengi were mostly nocturnal. Occupancy for *Rhynchocyon* was over 80 percent for both the Boni forest thicket and Arabuko-

Sokoke *Cynometra* forest thicket. Occupancy and trapping rates for the soft-furred sengi were significantly higher for the Arabuko-Sokoke forest than the Boni-Dodori forest. It was not possible in the camera trap images to reliably differentiate between the two soft-furred sengi species, four-toed sengi *Petrodromus tetradactylus* and rufous sengi *Elephantulus rufescens*, known to occur in the area.

Keywords: Macroscelidea, elephant-shrew, *Rhynchocyon*, abundance, distribution, activity pattern

INTRODUCTION

The sengis or elephant-shrews (order Macroscelidea) are endemic to Africa and are part of an ancient radiation of mammals, the Afrotheria, which also includes elephants, sea cows, hyraxes, aardvark, golden moles, and tenrecs (Springer *et al.*, 1997). There are 19 recognised species of extant sengis in the family Macroscelididae, with two well-defined sub-families: the soft-furred sengis (Macroscelidinae) with four genera (*Macroscelides*, *Elephantulus*, *Petrodromus*, and *Petrosaltator*) and 15 species, and the giant sengis (Rhynchocyoninae) with a single genus (*Rhynchocyon*) and four species (Rovero *et al.*, 2008; Dumbacher *et al.*, 2014; 2016).

The montane and coastal forests of Tanzania and Kenya are the centre of diversity for *Rhynchocyon* (Rathbun, 2009), with Kenya coastal forests harbouring two species: the black-and-rufous sengi *Rhynchocyon petersi* Bocage, 1880 and the endemic and endangered golden-rumped sengi *Rhynchocyon chrysopygus* Günther, 1881. Kenya coastal habitats also harbour two species of soft-furred sengis: the rufous sengi *Elephantulus rufescens* (Peters, 1878) occurs in bushlands and sparse woodlands, and the four-toed sengi *Petrodromus tetradactylus* Peters, 1846 occupies forests and dense thickets, and woodlands (Rathbun, 2009).

The status of the sengis in the Kenya coastal forests, especially east of the lower Tana River, is poorly known due to political insecurity and difficult logistical problems limiting access to the area. However, a survey in 2008 documented a *Rhynchocyon* form with a pelage pattern that was unexpectedly different from the nearby but allopatric *R. chrysopygus*. This finding was based on a single voucher specimen and several images from 10 opportunistically placed camera-traps (Andanje *et al.*, 2010).

In order to better understand the occurrence, relative abundance, and behavioural ecology of *Rhynchocyon* in the Kenya coastal forests, we used systematic camera-trap surveys to gather data from the Boni-Dodori forest east of the Tana River near the Somalia border, and the Arabuko-Sokoke forest near the town of Malindi. This study is part of a wider study of terrestrial mammalian diversity in these highly threatened Kenya coastal forests (Stokes *et al.*, 2016).

MATERIALS AND METHODS

Study area

The mosaic of wooded savannahs, thickets, and forests of coastal Kenya form part of the “Coastal Forests of Eastern Africa” biodiversity hotspot, known for globally significant levels of species richness and endemism (Burgess & Clarke, 2000; Mittermeier *et al.*, 2005). Although much of this habitat in Kenya has been greatly altered or destroyed by urban development and agriculture (Mittermeier *et al.*, 2005), several protected areas have been

established along the northern Kenya coast (figure 1). The Boni and Dodori National Reserves (NRs), in Ijara and Lamu East districts, respectively, were gazetted in 1976. However, the exact location of the gazetted boundaries remains uncertain. The two reserves are adjacent to the Boni forest and we refer to these three areas and its surroundings, as the 'Boni-Dodori forest' (figure 1).

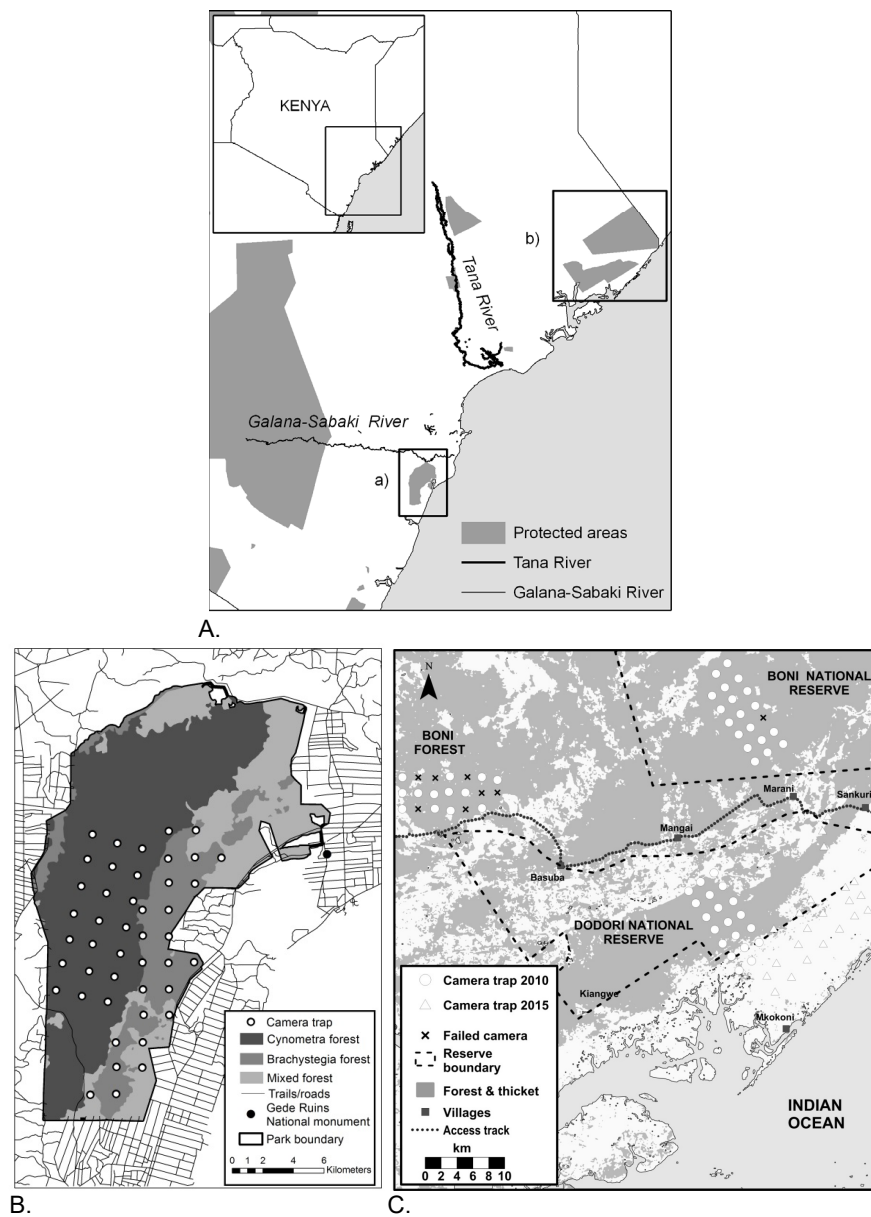


Figure 1.A. Map of the Kenya coastal forest showing the study areas a) Arabuko-Sokoke forest separated from b) the Boni-Dodori forest by two major intervening rivers, the Tana and Galana-Sabaki, and detailed maps showing camera trap grids relative to protected area boundaries at B) Arabuko-Sokoke forest and C) Boni-Dodori forest.

During the April and October–November wet seasons, roads often become impassable in Boni-Dodori area. This, along with poor infrastructure in the remote location and a history of border insecurity, have resulted in a comparatively low human population density and minimal development in the region. Only about 1800 Aweer people live in four principle villages that are located along a bush track running between the two reserves (Musina *et al.*, 2016). The people, traditionally hunter gatherers, now subsist mainly on small scale agriculture, much of it dominated by maize cultivation.

The Arabuko-Sokoke forest, gazetted in 1943, lies 250 km to the south of the Boni-Dodori forest in Kilifi County. It is separated from the Boni-Dodori forest by two major intervening rivers, the Tana and Galana-Sabaki. The Arabuko-Sokoke forest is completely encircled by dispersed settlements with an estimated human population greater than 100 000 (ASFMT, 2002). Between the two study areas relatively little suitable habitat for *Rhynchocyon* remains.

Illegal hunting and timber extraction occurs in both study areas, but it is likely to be at a higher intensity in the smaller Arabuko-Sokoke forest, as it is surrounded by a much larger human population (FitzGibbon *et al.*, 1995).

Habitat in the Boni–Dodori forest system consists of a mosaic of forest, thicket, and savannah (Kuchar & Mwendwa 1982). The Arabuko-Sokoke forest is composed of three main vegetation types: *Cynometra* forest and thicket (235 km²), *Brachystegia* woodland (77 km²), and mixed forest (70 km²) (ASFMT, 2002).

Field sampling methods

We set up four camera-trap grids with camera spacing of two km. In the Boni-Dodori forest, grids were placed in the Boni NR (1°32'13''S, 41°19'32''E) between March 2010 and June 2010, Dodori NR (1°49'19''S, 41°04'28''E) between January 2010 and March 2010, Boni forest (1°40'34''S, 40°52'32''E) between June 2010 and September 2010, and in the open coastal scrub habitat south of the Dodori NR (1°51'11''S, 41°19'09''E) between February 2015 and July 2015. In Arabuko-Sokoke forest, camera-trap grids were placed in the *Cynometra* forest (3°21'49''S, 39°50'37''E), and in the *Brachystegia* woodland (3°39'14''S, 39°87'19''E) between January 2015 and March 2015 (figure 1). We didn't survey the mixed forest due to the limited number of camera-traps we had for this study and the mixed forest was of lesser priority than the other two forests.

We used Global Positioning System (GPS) receivers in the field to locate camera-trap grid sampling points, and then, for optimal positioning in the habitat, we placed a single camera trap within 100 m of each grid point. We positioned the camera-traps 30–45 cm above ground, pointing to a likely target zone 4–8 m away (often perpendicular to game trails). The intention was to capture full body lateral images of mammals. We used Bushnell Trophy Cam (Bushnell Outdoor Products, Cody, Kansas, USA) and Reconyx RM45 (RECONYX, Inc., Holman, WI, USA) digital cameras. The two camera models were programmed similarly to ensure consistency in performance. They took three pictures per trigger with no delay (Reconyx) and 1 second delay (Bushnell). The cameras had a trigger delay of 0.1 sec. (Reconyx) and <1 sec. (Bushnell), with a detection range of 25+ m (depending on target characteristics). The cameras used an infrared flash, which minimised the risk of startling animals as would be the case with white flash.

Each grid was operational for sufficiently long time period to achieve at least 1000 camera-trap days of sampling effort (O'Brien *et al.*, 2003). Field personnel were trained and tested in their ability to deploy camera-traps to obtain a well-defined and consistent camera

field of view, and they triggered each camera while holding a white board with location ID, date, and time upon activation and deactivation.

Data analysis

We used Exiv2 software (Huggel, 2012) to extract the EXIF information (image label, date, time and temperature) that was then compiled in an EXCEL spreadsheet (Microsoft Office Professional Plus 2010). Animal images were identified to species when possible (see below), this information was added to the spreadsheet, and then the data were analysed with software developed by Amin *et al.* (2015).

We calculated the trapping rate for each species as the mean number of independent photographic “events” per trap day x 100. We defined an “event” as any sequence for a given species occurring after an interval of ≥ 60 min from the previous three-image sequence of that species (Tobler *et al.*, 2008). We also calculated standard error from the standard deviation of the daily trapping rate. We applied the “Wald” parametric statistical test to test for significant difference in trapping rates between surveyed areas for each species with $P < 0.05$ considered to be significant (Amin *et al.*, 2015). We also used the species trapping 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 per hour across each survey time period.

Single season occupancy analysis (MacKenzie *et al.*, 2006) was used to estimate the proportion of area occupied by a species, within each of the six grids. Occupancy estimates were corrected by detection probability (*i.e.* the likelihood that a species was detected when present) and are therefore a more rigorous index of abundance for both within and between species comparisons. This, however, is limited to surveys generating adequate data sets and where camera spacing is greater than the species home range, and occupancy is not confounded by changes in the home range (Efford & Dawson, 2012). Sengi home-ranges or territories are 1.7 – 4.1 ha for *R. chrysopygus* (Rathbun, 1979; FitzGibbon, 1994), 0.34 ha for *E. rufescens* (Rathbun, 1979) and approximately 1.2 ha for *P. tetradactylus* (FitzGibbon, 1995), thus home range sizes of the sengis were likely small relative to our camera spacing. We constructed detection / non-detection history, using a ten-day period as the sampling occasion, for each species and camera per survey grid. We tested for significant differences among occupancy using Wald test.

RESULTS

We obtained our target minimum survey effort of 1000 camera-trap days on all six survey grids. The total camera-trap days for the two camera-trap grids in the Arabuko-Sokoke forest was 2209 with a mean of 49 per camera. In the Boni-Dodori forest, the total camera-trap days for the four camera-trap grids was 7020 with a mean of 95 per camera, with one of the camera-trap grids (south of Dodori) retrieved after 3240 days due to political insecurity in the area.

All the giant sengis photographed in the Boni-Dodori forest lacked the golden rump of *R. chrysopygus* found in the Arabuko-Sokoke forest (figure 2). They were also more abundant in Boni NR and Boni forest camera trap grids than in the Dodori grids, with significant difference in occupancy ($P < 0.01$) and trapping rate ($P < 0.01$) (table 1). The habitat in the more inland Boni NR and Boni forest camera-trap grids was largely lowland dry forest, with tall trees forming an open upper canopy with dense understory of lower trees

and bushes; while the habitat in Dodori camera-trap grids was a mosaic of forest patches, dominated by *Manilkara*, *Azelia* and other trees, interspersed with wooded savannah and dry bushland.



a)



b)

Figure 2. a) Camera-trap image of a giant sengi (note lack of golden rump) taken east of the Tana River in the Boni-Dodori forest. b) Camera-trap image of *Rhynchocyon chrysopygus* taken in Arabuko-Sokoke forest in which the golden rump is clearly defined.

In the Arabuko-Sokoke forest, *Rhynchocyon* were recorded at higher trapping rate in both the *Cynometra* and *Brachystegia* habitats than in Boni-Dodori forest (table 1). Occupancy in Arabuko-Sokoke forest was 100% in the *Cynometra* forest thicket and over 70% in the more open *Brachystegia* forest. However, there was no significant difference in trapping rate between the two forest habitats.

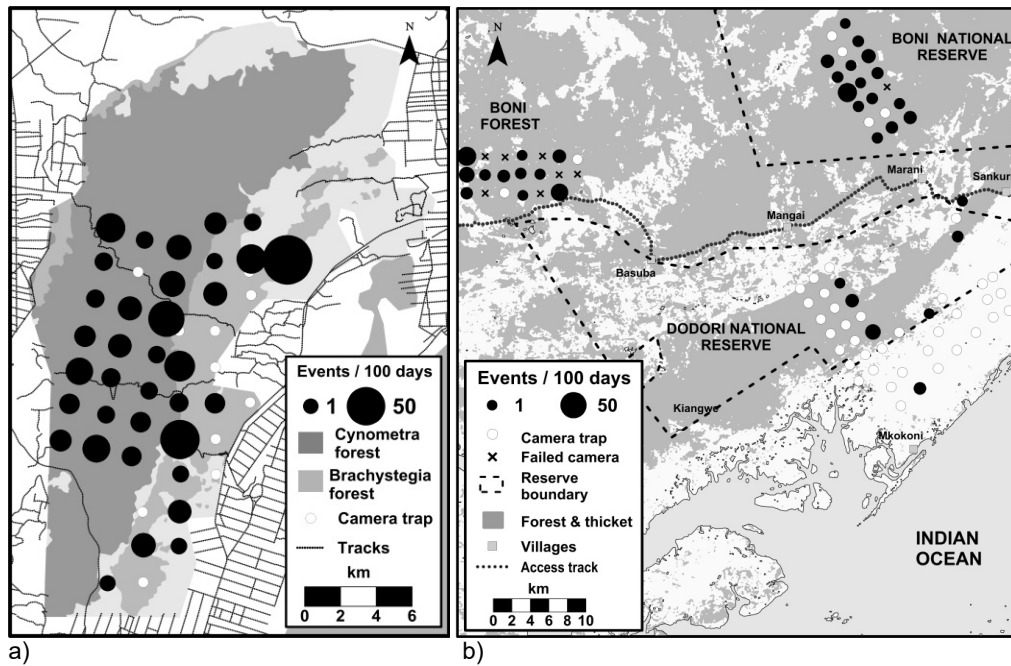


Figure 3. Distribution of giant sengis on camera-trap grids in a) the Arabuko-Sokoke forest and b) the Boni-Dodori forest. Size of solid circle is proportionally weighted by trapping rate: open circles represent no sengi captures, minimum trapping rate: 1.1 and maximum trapping rate: 71.2 events captured/100 days (see methods for definition of an event).

Table 1. Trapping rate, occupancy and detection probability estimates for the Boni-Dodori *Rhynchocyon* and Arabuko-Sokoke *Rhynchocyon chrysopygus*. Standard errors are presented in brackets. Trapping rate was calculated as the mean of the number of independent photographic events per trap day times 100.

| Site | Trapping rate / 100 days (SE) | Occupancy (SE) | Detection probability (SE) |
|---|-------------------------------|----------------|----------------------------|
| Arabuko-Sokoke Cynometra forest | 13.99 (1.29) | 1.00 (0.00) | 0.53 (0.04) |
| Arabuko-Sokoke Brachystegia woodland | 15.67 (1.36) | 0.74 (0.10) | 0.56 (0.05) |
| Dodori National Reserve | 1.46 (0.38) | 0.15 (0.08) | 0.34 (0.10) |
| Boni National Reserve | 5.38 (0.68) | 0.800 (0.10) | 0.38 (0.04) |
| Boni forest | 7.89 (0.80) | 0.852 (0.10) | 0.41 (0.05) |
| South of Dodori National Reserve | 0.72 (0.24) | 0.183 (0.08) | 0.42 (0.08) |

It was difficult to differentiate between the two soft furred sengis in many of the images, thus we combined the two species for our analyses. Combined, they were one of the most frequently recorded species in the surveys and trapping rate was significantly higher in Arabuko-Sokoke forest than in Boni-Dodori forest ($P < 0.01$) (table 2). The $>90\%$ occupancy for soft furred sengis in the Arabuko-Sokoke forest was significantly ($P < 0.01$) greater than the $<50\%$ occupancy in the Boni-Dodori forest (table 2, figure 4).

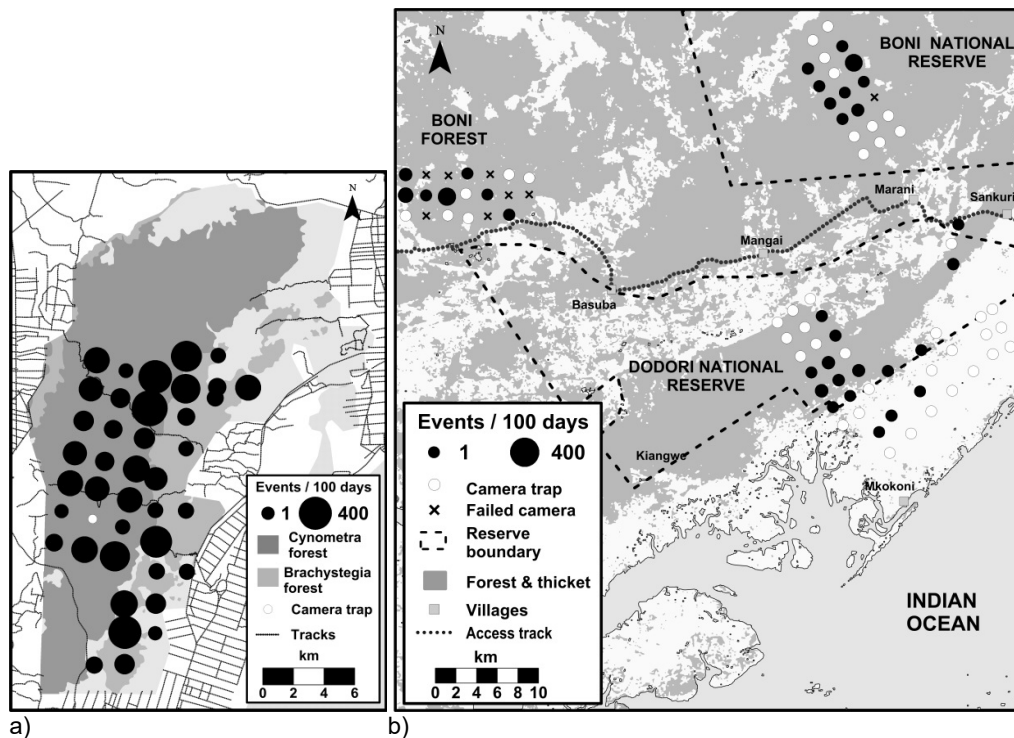


Figure 4. Distribution of soft-furred sengis on camera-trap grids in a) the Arabuko-Sokoke forest and b) the Boni-Dodori forest. Size of solid circle is proportionally weighted by trapping rate, open circles represent no sengi captures, minimum trapping rate: 0.7 and maximum trapping rate: 444.4 events captured/100 days (see methods for definition of an event).

Table 2. Soft-furred sengi trapping rate, occupancy and detection probability estimates in the Boni-Dodori and Arabuko-Sokoke camera-trap grids. Standard errors are presented in brackets. Trapping rate was calculated as the mean of the number of independent photographic events per trap day times 100.

| Site | Trapping rate / 100 days (SE) | Occupancy (SE) | Detection probability (SE) |
|---|-------------------------------|----------------|----------------------------|
| Arabuko-Sokoke Cynometra forest | 187.00 (4.85) | 0.95 (0.05) | 0.95 (0.02) |
| Arabuko-Sokoke Brachystegia woodland | 149.19 (7.22) | 0.91 (0.06) | 0.96 (0.02) |
| Dodori National Reserve | 6.64 (0.71) | 0.45 (0.11) | 0.46 (0.06) |
| Boni National Reserve | 10.72 (0.96) | 0.47 (0.12) | 0.43 (0.06) |
| Boni forest | 21.48 (1.89) | 0.46 (0.14) | 0.68 (0.06) |
| South of Dodori National Reserve | 1.49 (0.24) | 0.33 (0.10) | 0.33 (0.06) |

Giant sengis were almost entirely diurnal with >50% of their activity between 06:00–08:00 h (sunrise 05:54–06:25, sunset 18:06–18:37 h) (figure 5), with less activity in late afternoon and even less in the middle of the day at all the sites. The two soft-furred sengis were mainly nocturnal, with crepuscular activity peaks at dawn and dusk (figure 6). The soft-

furred sengis were also active over a longer period, 17 hours compared to 13 hours for the giant sengis.

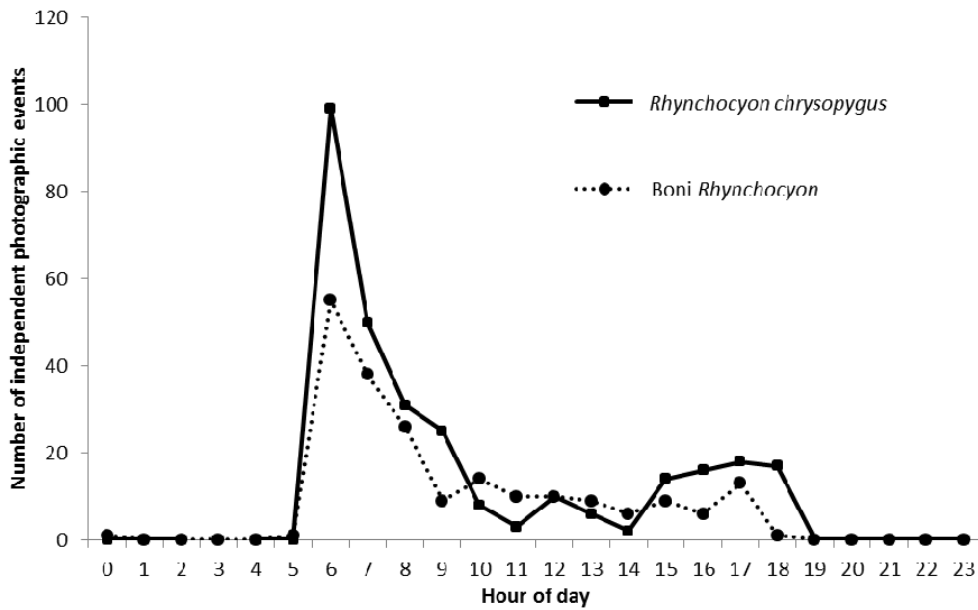


Figure 5. Giant sengi 24-hour activity patterns derived from the pooled data from camera-trap grids in the Arabuko-Sokoke forest (*Rhynchocyon chrysopygus*) and the Boni-Dodori forest (*Boni Rhynchocyon*).

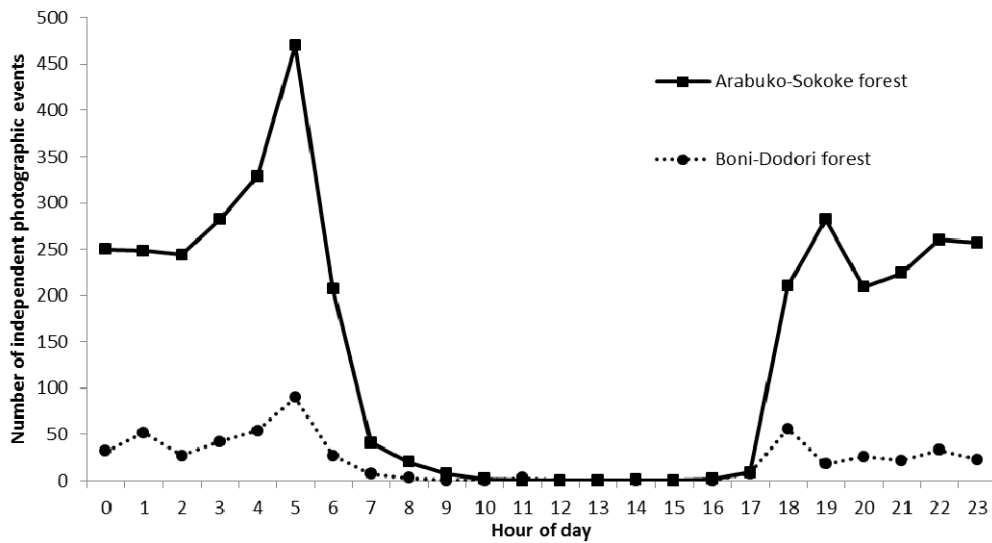


Figure 6. Soft-furred sengi 24-hour activity patterns derived from the pooled data from camera-trap grids in the Arabuko-Sokoke forest and the Boni-Dodori forest.

DISCUSSION

The taxonomy of *Rhynchocyon* has historically been based nearly exclusively on distinct colour patterns of the pelage and the allopatric distributions of the different forms (Corbet & Hanks, 1968; Rovero *et al.*, 2008; Coals & Rathbun, 2012). In this regard, the giant sengis of the Boni-Dodori forest conform to the traditional criteria used to designate unique taxa. However, because of the gross similarity in pelage pattern and colouration between the Boni *Rhynchocyon* and all the distant populations of *R. petersi* and the grey-faced sengi *Rhynchocyon udzungwensis* Rathbun and Rovero, 2008, a rigorous analyses of DNA for the different *Rhynchocyon* taxa will be needed to resolve the phylogenetics of the genus (Andanje *et al.*, 2010).

Rhynchocyon chrysopygus is classified as Endangered (IUCN, 2016). Unfortunately, until the phylogeny and taxonomic position of the Boni *Rhynchocyon* is established, an IUCN Red List assessment of this form is not possible. However, in preparation for its eventual evaluation, our camera trap data has revealed some interesting and useful information.

Based on the placement of our camera traps, the Boni *Rhynchocyon* and *R. chrysopygus* are associated with forest, woodland, and thicket habitats with a closed canopy and dense leaf litter – similar to other forms of giant sengis (Rathbun, 2009, Rovero *et al.*, 2008). This habitat association focuses conservation concerns on habitat condition and protection. For *R. chrysopygus*, most of the remaining small forests outside Arabuko-Sokoke forest are severely degraded by pole collection for house construction, and tree logging mainly for wood carving (FitzGibbon, 1994; Bauer, 1996). In the Arabuko-Sokoke forest, sengis are affected by the loss of hollow trunks used as refuges, and also probably a reduction in canopy cover and leaf litter, which may also impact other aspects of their life history (Rathbun & Kyalo, 2000). Hunting by loggers and subsistence trappers who capture a variety of wildlife for food is also a threat to sengis (FitzGibbon *et al.*, 1995). It was estimated in the early 1990s that about 3000 *R. chrysopygus* were being caught per year by hunters in the Arabuko-Sokoke forest (FitzGibbon *et al.*, 1995). Bauer (1996) and FitzGibbon (1994) also reported that the population of *R. chrysopygus* in the Arabuko-Sokoke forest decreased by *ca* 30% between 1993 and 1996, from an estimated 20 000 to 14 000 individuals. The small population at the nearby Gede Ruins National Monument (an area of 0.44 km²) declined significantly between the early 1970s (*ca* 70 individuals; Rathbun 1979) and the early 1990s (<15 individuals; FitzGibbon, 1994). Predation by domestic dogs was identified as a potential cause of the decline, and exclusion fencing was erected around the monument, but despite these efforts, the population in 2008 was estimated at only 20 individuals (Ngaruiya, 2009); no population estimates have been produced since then. There are no data on population trends in other areas and for other coastal sengi forms.

The Boni-Dodori forest is the largest coastal forest system in Kenya, with a potential forest and thicket area of at least 3000 km² measured from the habitat map produced as part of our terrestrial mammal diversity assessment in the region (figure 3, Amin *et al.*, 2015). Boni *Rhynchocyon*'s estimated occupancy was found to be over 80% in the Boni NR and forest, which have extensive forest cover and thicket covering approximately 1700 km² (figure 3); with approximately 10 percent of the area covered by the camera-trap grid. Arabuko-Sokoke forest, currently the largest remaining intact habitat for *R. chrysopygus*, has a total area of 420 km². The combination of occupancy and area of habitat at Boni-Dodori suggests that the Boni-Dodori forest holds significant number of *Rhynchocyon*, making it very important to sengi conservation in general. It also underlines the urgent need to establish

effective conservation measures, and characterise the phylogenetic relationship of *Rhynchocyon* from each area and resolve the taxonomic status of the Boni *Rhynchocyon*.

Our study has also provided further insights into soft furred sengis adding to a previous study which extended the range of *E. rufescens* and *P. tetradactylus* to Boni-Dodori forest (Andanje *et al.*, 2010). Our camera-trap data has provided the first detailed circadian patterns with over 32 000 images of soft-furred sengi and 2700 images of giant sengi. The results presented are for both soft-furred sengis combined as we were unable to reliably differentiate, in the images, between the two species. However, based on known habitat preference and general appearance of the images with a sample set of images confirmed by R. Rathbun (pers. comm.), it seems probable that most if not all represented the forest adapted *P. tetradactylus* at least in Arabuko-Sokoke forest. It is also likely that size differences between *E. rufescens* (58 g average adult body weight; Rathbun, 1979) and *P. tetradactylus* (196 g average adult body weight; Oxenham & Perrin, 2009) may have influenced camera detections with the larger *P. tetradactylus* more likely to be detected. FitzGibbon (1995) has reported *P. tetradactylus* to be active at all times of the day, mainly at dawn and dusk, with the level of activity at night uncertain but may continue to at least 22:25 h. Our camera-trap data provides a clearer pattern with consistent high activity levels throughout the night with crepuscular peaks at 05:00 and 19:00 h and almost no activity during daylight between 07:00 and 17:00 h.

Our study has provided much needed baseline data on the Endangered and endemic *R. chrysopygus* and the potentially new taxon of *Rhynchocyon* in the Boni-Dodori forest. We have also shown that camera-trapping can provide quantitative measures of the status of the sengis over time not easily obtained by any other methods. Such a standardised monitoring system would play an important role in conservation action and/or management plans for the species and their habitats.

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