Camera Trap Survey Report (2011)

Sapo National Park, Liberia



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Cover page images: Clockwise from top left: zebra duiker (*Cephalophus zebra*), giant pangolin (*Smutsia gigantea*), Jentink's duiker (*Cephalophus jentinki*), western chimpanzee (*Pan troglodytes verus*)

Acknowledgements

We thank Shadrach Kerwillain, Malavika Narayana, Constant Ndjassi and Mike Hoffmann for their very helpful comments. We also thank everyone who assisted in the fieldwork and data management.

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Summary

Sapo National Park (NP) is located in the Upper Guinean forest ecosystem, a biodiversity hotspot that has one of the highest mammal species diversity of any region in the world. The national park is Liberia's largest protected area of rainforest and contains the second-largest area of primary tropical rainforest in West Africa, second only to Taï National Park in neighbouring Côte d'Ivoire. However, the park faces many threats including hunting for the bushmeat trade, artisanal gold mining and agricultural expansion for commercial and subsistence farming. All these threats are linked to high level of poverty in park fringe communities.

This report summarises the results from the 2011 camera trap study conducted in Sapo NP. It was the first of its kind and provided baseline data for terrestrial medium-to-large sized mammals in the protected area although illegal settlements of armed artisanal gold miners in the central and southern parts prevented surveys in these areas.

A total of 32 mammal species were recorded including ten endemic species to West African Upper Guinean forest. Six species of duiker (small/medium forest antelopes) were detected including the endangered Jentink's duiker (*Cephalophus jentinki*), the vulnerable zebra duiker (*Cephalophus zebra*) and the near threatened Bay duiker (*Cephalophus dorsalis*). Maxwell's duiker (*Cephalophus maxwellii*) was locally the most abundant duiker based on trap rate and occurrence.

The endangered pygmy hippopotamus (*Choeropsis liberiensis*) was recorded in Sapo NP at only one site in the south-western sampling grid. Unique to West Africa, the total population size of pygmy hippopotamus remains unknown.

The western chimpanzee (*Pan troglodytes verus*) was more extensively encountered in the southwestern sampling grid; including a few groups with adult female and young. It is now endangered (2019) with total population loss estimated >80% over a three-generation period (i.e., ~70 years) (IUCN 2016). Increasing plantations of oil-palm is likely to exacerbate population declines in coming years and Sapo NP provides one of the last remaining protected habitat for the species.

The study also detected the endangered white-bellied pangolin (*Phataginus tricuspis*) and giant pangolin (*Smutsia gigantea*) at a few sites. Both species are threatened by illegal wildlife trade for its scales and meat and Sapo NP is one of the few remaining protected areas where both species still persist.

The endangered African forest elephant (*Loxodonta cyclotis*) was also recorded but only at four sites. The most recent population estimate is considered unreliable by the IUCN and there is an urgent need to carry out a suitable survey.

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Genets were also photographed but it wasn't possible to differentiate between the three species documented to exist in the park: Bourlon's genet (*Genetta bourloni*), pardine genet (*Genetta pardina*) and king genet (*Genetta poensis*). Bourlon's genet and pardine genet are also endemic to West Africa. West African oyan (*Poiana leightoni*) were also suspected but the associated images were of poor quality to confirm their presence.

The poorly documented small carnivore Liberian mongoose (*Liberiictis kuhni*) occurring in the Upper Guinean forest was not confirmed by the survey setup to detect medium-to-large mammals. It has been documented to occur in the park (Vogt et al. 2012). The endemic common cusimanse (*Crossarchus obscurus*) was detected in the dense forest undergrowth. Africa's only forestdependent felid golden cat (*Caracal aurata*) was recorded on six occasions in four camera sites.

1. Introduction

Sapo National Park (NP) is Liberia's oldest and largest protected area, comprising an area of 1804 km², and represents one of the most intact tropical forest ecosystems in Liberia (Figure 1). Established by a military decree in 1983 at a size of 1307 km², the boundaries of the park were expanded in 2003 after socio-economic and biological surveys demonstrated the importance of the bordering forested areas to the integrity of the park. Contained within one of the largest remaining blocks of the threatened Upper Guinean forest, Sapo NP consists entirely of lowland rainforest, including swampy areas, dryland and riparian forests. The terrain throughout the park is generally homogeneous, with lower (100–200 m) elevations and gently rolling hills in the south-western and central parts to higher elevations of approximately 400 m in the steeper ridges of the northeast. The park is bounded to the north by the Putu Mountains and to the southwest by the Sinoe River, which is the largest water body in the park. There are many smaller streams and rivers scattered across the park.



Figure 1. Protected areas of Liberia (source: FFI 2018).

Sapo NP harbours an exceptional biodiversity with high rates of endemism and provides one of the last strongholds for several globally endangered species including the pygmy hippopotamus (*Choeropsis liberiensis*), western chimpanzee (*Pan troglodytes verus*), Diana monkey (*Cercopithecus*)

diana), Jentink's duiker (*Cephalophus jentinki*), white-bellied pangolin (*Phataginus tricuspis*) and the giant pangolin (*Smutsia gigantea*). The park is also home to many endemic plant species including *Cercestis taiensis* (Arceae), *Sciaphila africana* (Triuridaceae) and *Cnestis bomiensis* (Connaraceae).

In 2001, Fauna & Flora International (FFI) in collaboration with the Liberian government's Forestry Development Authority (FDA) established a long-term faunal biomonitoring programme in Sapo NP, which was re-started in 2007 following the end of the civil war (Waitkuwait & Suter 2001, Waitkuwait 2003, Vogt 2011). In 2011, a revised biomonitoring programme was established with 90 line transects across the Sapo NP to carry out systematic biodiversity monitoring (Vogt 2012). Further, with the support of the Zoological Society of London (ZSL), the programme was complemented by systematic camera-trapping surveys. Surveys were designed to consistently detect terrestrial medium-to-large mammal species, especially for species that were difficult to monitor using traditional methods.

2. Methods

2.1 Survey design and camera deployment

Due to a history of illegal settlements of armed artisanal gold miners in the central and southern parts of the park, security restricted monitoring and field research in Sapo NP was only possible in the south-western and north-eastern parts.

A grid of 32 infrared heat- and motion- sensitive digital cameras, spaced at 2 km intervals and mounted 40 cm from the ground, was set for a minimum of 35 days and at 24-hour operation mode in the two areas of Sapo NP. The cameras were programmed to take three pictures per trigger with minimum delay.

The centre of each grid square was located using a GPS Garmin map 62s unit, and one camera was secured in an optimal location (e.g. next to a recently used animal trail), in a 100-m radius from the centre of the grid square. In the south-western part (Zone-1) of Sapo NP, the camera grid was established in October–December 2011. In the north-eastern part (Zone-2), the camera grid was established in June–July 2011 (Figure 2).



Figure 2. Map of camera-trap grids in Sapo National Park.

2.2 Data analysis

We used Exiv2 software (Huggel 2012) to extract EXIF information from each photograph (image name, date and time). Animals in the photographs were identified to species (or to lowest taxonomic level discernable in unclear images). These data were compiled in an Excel spreadsheet

(Microsoft Office Professional Plus 2010) and analysed with software developed specifically for camera-trap data analysis (Amin & Wacher 2017).

We calculated species sample-based rarefaction curves and estimated the medium-to-large (>0.5 kg) terrestrial mammal species richness using the non-parametric incidence-based estimator Jackknife with order one (Bunge & Fitzpatrick 1993). Smaller mammals induce sampling error through reduced likelihood of detection by the camera-trap thermal sensor and accurate identification of small mammals to species level is often not possible from camera-traps set up for medium-to-large mammals (Tobler et al. 2008).

We calculated the trapping rate for each species and for each sampling grid as the total number of independent photographic "events" divided by the number of days cameras were operational x 100. We defined an "event" as any sequence of images for a given species occurring after an interval of =>60 min from the previous three-image sequence of that species (Amin et al. 2014).

We constructed circadian (24 hour) species activity patterns by tallying the number of events initiated in each hour across the survey time period.

We used single season occupancy analysis (MacKenzie et al. 2006) to estimate the proportion of area occupied (or habitat use, depending on assessment of home range size relative to camera spacing) by a species, within each survey grid. Occupancy estimates were corrected by detection probability (i.e. the likelihood that a species was detected when present). Detection / non-detection histories were constructed using a five-day period as the sampling occasion, for each species and camera per survey grid.

We used the species trapping rate at each camera site to generate distribution map on each camera-trap grid. The camera trapping rates were depicted as circular symbols at each camera site on the map. The symbol size was weighted linearly between the minimum and maximum figures depicted in the scaling displayed in the map legend.

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3. Results

3.1 Camera-trap survey effort

Both camera-trap surveys were deployed with the objective of achieving the recommended 1000 camera-trap days of survey effort (O'Brien et al. 2003). This was successful in Zone-1 but camera failures in Zone-2 resulted in c. 10% fewer sample days than planned.

Zone-1 grid

Survey duration: 26/10/2011 – 5/12/2011 Total number of camera stations: 32 (32 operational) Total number of days deployed: 1273 (1087 operational)

Zone-2 grid

Survey duration: 8/06/2011 – 21/07/2011 Total number of camera stations: 32 (26 operational) Total number of days deployed: 1242 (951 days operational)

3.2 Mammal diversity

A total of 32 mammal species were confirmed in the two camera-trap sampling zones in Sapo NP (27 species in Zone-1; 27 species in Zone-2) (Table 1). This includes the pygmy hippopotamus, the western chimpanzee, Jentink's duiker, white-bellied pangolin, giant pangolin and Diana monkey all 'endangered' species under the IUCN Red List criteria. African golden cat (*Caracal aurata*), zebra duiker (*Cephalophus zebra*) and the African elephant (*Loxodonta Africana*), all classified 'Vulnerable' were also recorded. Genets were also recorded, however, the image quality was too poor to differentiate reliably between the three species considered to be present in the park: Bourlon's genet (*Genetta bourloni*), pardine genet (*Genetta pardina*) and king genet (*Genetta poensis*). West African oyan (*Poiana leightoni*) was also suspected to be photographed, but the associated images were of very low quality for accurate identification of their presence. The area has high endemism with ten species endemic to West Africa recorded (not including the West African oyan, pardine genet and Bourlon's genet). We also excluded small murid species for reasons given above. The vulnerable Liberian mongoose (*Liberiictis kuhni*) was not detected during the survey although it is documented to occur in the study area (Vogt et al. 2012).

			Zone-1	Zone-2	IUCN Red
Family	Species	Common name			List status
Felidae	Caracal aurata	African Golden Cat	Y	Y	VU
Felidae	Panthera pardus	Leopard	N	Y	NT
Herpestidae	Atilax paludinosus	Marsh Mongoose	Y	Y	LC
Herpestidae	Crossarchus obscurus	Common Cusimanse	Y	Y	LC
Mustelidae	Mellivora capensis	Honey Badger	N	Y	LC
Nandiniidae	Nandinia binotata	African Palm Civet	Y	N	LC
Viverridae	Civettictis civetta	African Civet	Y	Y	LC
Viverridae	Genetta bourloni	Bourlon's Genet	?	?	NT
Viverridae	Genetta pardina	Pardine Genet	?	?	LC
Viverridae	Genetta poensis	King Genet	?	?	DD
Viverridae	Poiana leightoni	West African Oyan	?	?	VU
Bovidae	Cephalophus dorsalis	Bay Duiker	Y	Y	NT
Bovidae	Cephalophus jentinki	Jentink's Duiker	Y	Y	EN
Bovidae	Cephalophus niger	Black Duiker	Y	Y	LC
Bovidae	Cephalophus ogilbyi brookei	Ogilby's Duiker	Y	Y	LC
Bovidae	Cephalophus zebra	Zebra Duiker	Y	Y	VU
Bovidae	Philantomba maxwellii	Maxwell's Duiker	Y	Y	LC
Bovidae	Tragelaphus eurycerus	Bongo	Y	N	NT
Hippopotamidae	Choeropsis liberiensis	Pygmy Hippopotamus	Y	N	EN
Suidae	Hylochoerus meinertzhageni ivoriensis	Western Forest Hog	Y	N	LC
Suidae	Potamochoerus porcus	Red River Hog	Y	Y	LC
Tragulidae	Hyemoschus aquaticus	Water Chevrotain	Y	Y	LC
Elephantidae	Loxodonta africana	African Elephant	Y	Y	VU
Manidae	Phataginus tricuspis	White-bellied Pangolin	Y	Y	EN
Manidae	Smutsia gigantea	Giant Pangolin	Y	Y	EN
Cercopithecidae	Cercocebus atys	Sooty Mangabey	Y	Y	NT
Cercopithecidae	Cercopithecus campbelli	Campbell's Monkey	Y	Y	LC
Cercopithecidae	Cercopithecus diana	Diana Monkey	N	Y	EN
Hominidae	Pan troglodytes verus	Western Chimpanzee	Y	Y	EN
Hystricidae	Atherurus africanus	African Brush-tailed Porcupine	Y	Y	LC
Nesomyidae	Cricetomys emini	Forest Giant Pouched Rat	Y	Y	LC
Sciuridae	Funisciurus pyrropus	Fire-footed Rope Squirrel	Y	Y	LC
Sciuridae	Heliosciurus rufobrachium	Red-legged Sun Squirrel	Y	Y	LC
Sciuridae	Protoxerus aubinnii	Slender-tailed Squirrel	N	Y	DD
Sciuridae	Protoxerus stangeri	African Giant Squirrel	N	Y	LC
Thryonomyidae	Thryonomys swinderianus	Greater Cane Rat	Y	N	LC

 Table 1. Mammal species recorded in Sapo National Park, 2011.

The species accumulation curves for medium-to-large (> 0.5 kg) terrestrial mammal species, the main target group for camera-traps placed at ground level (Tobler et al. 2008), are shown in Figure 3. Zone-1 had higher estimated medium-to-large terrestrial mammal species richness (29) compared to Zone-2 (22). Fire-footed rope squirrel (*Funisciurus pyrropus*), red-legged sun squirrel (*Heliosciurus rufobrachium*) and the slender-tailed squirrel (*Protoxerus aubinnii*) were considered to have average adult body weight less than or equal to 0.5 kg and were therefore excluded from the analysis. Campbell's monkey (*Cercopithecus campbelli*), Diana monkey, sooty mangabey (*Cercocebus atys*) and the African giant squirrel (*Protoxerus stangeri*) were also not included in the species richness estimates (and Figure 3) as they were considered arboreal. The genets and West African oyan were also not included due to the poor quality of images preventing accurate species identification.



Figure 3. Species accumulation 'rarefaction' curves for medium-to-large terrestrial mammals in surveyed areas, Sapo National Park.

3.3 Species trapping rate, occupancy, distribution, and activity patterns

This section summarises the camera-trap survey results for each recorded species. The results are grouped by the major groups of carnivores, ungulates, elephant, pangolin, primates and rodents. The number of sites detected, number of events, trapping rate, naïve and modelled occupancy, activity pattern, and camera grid distribution depicted on maps are provided for each species and for each of the two surveyed zones. All species images are camera-trap images from the surveys.

1) AFRICAN GOLDEN CAT (Caracal aurata)

Global conservation status: Vulnerable (Bahaa-el-din et al. 2015)



Species notes:

- Africa's only forest-dependent felid recorded on six occasions in four camera sites.
- Published accounts report nocturnal crepuscular behaviour, but camera trapping studies elsewhere increasingly suggest activity day and night is normal in quiet areas.
- Golden cats are extremely elusive and have been thought to be very rare; camera-trap studies are proving to be one of the most effective ways to study them.

African golden cat	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	2 (32)	2 (26)
Number of events	3	3
Trapping rate / 100 days (±SE)	0.28	0.32
Naïve occupancy	0.06	0.08
Modelled occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



2) LEOPARD (Panthera pardus)

Global conservation status: Near Threatened (Stein et al. 2020)



Species notes:

- One of the least recorded carnivores with only two events of solitary adults at two sites in the north-eastern sampling grid (Zone-2).
- Both events occurred at night.

Leopard	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	0 (32)	2 (26)
Number of events	0	2
Trapping rate / 100 days (±SE)	0	0.21
Naïve occupancy	0	0.08
Modelled occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



3) MARSH MONGOOSE (Atilax paludinosus)

Global conservation status: Least Concern (Do Linh San et al. 2015)



Species notes:

- The most frequently recorded carnivore found consistently in both sampling grids.
- Activity pattern shows a mainly nocturnal crepuscular behaviour, however there was one record in the middle of the day.

Marsh mongoose	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	19 (32)	16 (26)
Number of events	39	59
Trapping rate / 100 days (±SE)	3.59	6.2
Naïve occupancy	0.59	0.62
Modelled occupancy (±SE)	0.82 (±0.14)	0.68 (±0.11)
Detection probability (±SE)	0.19 (±0.04)	0.3 (±0.05)



4) COMMON CUSIMANSE (Crossarchus obscurus)

Global conservation status: Least Concern (Angelici et al. 2015)



Species notes:

- Endemic to the Upper Guinean forest of West Africa, where it is the only cusimanse species present. Found primarily in dense undergrowth of rainforest.
- Infrequent encounters in both zones.
- Forages largely during the day in family parties (up to three individuals seen in some images) with timings of encounters showing a diurnal activity pattern.

Common cusimanse	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	1 (32)	4 (26)
Number of events	3	5
Trapping rate / 100 days (±SE)	0.28	0.53
Naïve occupancy	0.03	0.15
Modelled occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



5) HONEY BADGER (Mellivora capensis)

Global conservation status: Least Concern (Do Linh San et al. 2016)



Species notes:

- A rare encounter of this generally widespread small carnivore suggests a low preference for the sampled rainforest habitat.
- Essentially solitary with only a single individual recorded at night.

Honey badger	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	0 (32)	1 (26)
Number of events	0	1
Trapping rate / 100 days (±SE)	0	0.11
Naïve occupancy	0	0.04
Occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



6) AFRICAN PALM CIVET (Nandinia binotata)

Global conservation status: Least Concern (Gaubert et al. 2015a)



Species notes:

- Only recorded in the south-western camera grid (Zone-2).
- Only encountered twice.
- Nocturnal habits well known and only recorded at night in this survey.
- Partially arboreal habit probably reduces detection for ground level cameras.
- [Photo quality from Sapo very low image at left come from eastern Guinea].

African palm civet	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	2 (32)	0 (26)
Number of events	2	0
Trapping rate / 100 days (±SE)	0.18	0
Naïve occupancy	0.06	0
Occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



7) AFRICAN CIVET (Civettictis civetta)

Global conservation status: Least Concern (Do Linh San et al. 2019)



Species notes:

- Records dispersed in both sampling zones.
- Comparatively low trapping rate and naïve occupancy compared to other smaller carnivores such as genets and marsh mongoose.
- Timings of camera-trap encounters indicate fully nocturnal habits.

African civet	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	5 (32)	6 (26)
Number of events	8	9
Trapping rate / 100 days (±SE)	0.74	0.95
Naïve occupancy	0.16	0.23
Occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



8) GENETS (Genetta sps.)

Global conservation status: Bourlon's Genet: Near Threatened (Gaubert et al. 2015b); Pardine Genet: Least Concern (Gaubert et al. 2016); King Genet: Data Deficient (Gaubert et al. 2008)



Species notes:

- Regularly recorded but identity among three possible species of genets reported from the area (king genet *Genetta poensis*, pardine genet *Genetta pardina*, Bourlon's genet *Genetta bourloni*), uncertain due to low definition infra-red images.
- Global distribution of the latter two species is restricted to the Upper Guinean forest and the status of all three species is poorly known.
- Examples of recorded variation in tail and spot pattern at Sapo shown at left.
- [Note similar but small and largely arboreal West African oyan / linsang *Poiana leightoni* also considered, but no firm evidence obtained].

Genet sp.	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	21 (32)	11 (26)
Number of events (pictures)	40	21 (78)
Trapping rate / 100 days (±SE)	3.68	2.21
Naïve occupancy	0.66	0.42
Occupancy (±SE)	0.73 (±0.12)	0.65 (±0.19)
Detection probability (±SE)	0.23 (±0.05)	0.16 (±0.05)



9) BAY DUIKER (Cephalophus dorsalis)

Global conservation status: Near Threatened (IUCN SSC Antelope Specialist Group 2020)



Species notes:

- One of the three larger duiker species showing significantly lower trapping rate than the three smaller duikers.
- Similar abundance and distribution in the two surveyed zones.
- Timings of camera-trap encounters indicate a nocturnal crepuscular activity pattern.
- Distinguished from Brooke's duiker by darker body colour, angular head shape, dark stripe on back broadening over rump, and mainly nocturnal habits.

Bay duiker	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	10 (32)	8 (26)
Number of events	19	16
Trapping rate / 100 days (±SE)	1.75	1.68
Naïve occupancy	0.31	0.31
Occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



10) JENTINK'S DUIKER (Cephalophus jentinki)

Global conservation status: Endangered (IUCN SSC Antelope Specialist Group 2016a)



Species notes:

- Endemic to Upper Guinean forest found only from Sierra Leone through Liberia to W Cote d'Ivoire.
- Very shy and secretive, with few direct observations; presence in Sapo NP only first confirmed in 1997 (East 1999).
- Largest of the six sympatric duiker species recorded in Sapo NP.
- Nocturnal crepuscular activity pattern and perhaps locally occupies ecological role of Yellow-backed duiker which was not recorded in this survey.

Jentink's duiker	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	13 (32)	5 (26)
Number of events	24	7
Trapping rate / 100 days (±SE)	2.21	0.74
Naïve occupancy	0.41	0.19
Occupancy (±SE)	0.58 (±0.14)	N/A
Detection probability (±SE)	0.2 (±0.05)	N/A



11) BLACK DUIKER (*Cephalophus niger*)

Global conservation status: Least Concern (IUCN SSC Antelope Specialist Group 2016b)



Species notes:

- Least frequently recorded duiker species.
- Low occupancy in both surveyed zones.
- Activity predominantly diurnal with some indication of an activity peak in the early morning.

Black duiker	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	5 (32)	6 (26)
Number of events	6	10
Trapping rate / 100 days (±SE)	0.55	1.05
Naïve occupancy	0.16	0.23
Occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



12) OGILBY'S (BROOKE'S) DUIKER (Cephalophus ogilbyi brookei)

Global conservation status: Least Concern (IUCN SSC Antelope Specialist Group 2016c)



Species notes:

- Upper Guinean forest population.
- Recently treated as a full species *C. brookei*; here we follow the IUCN Red list which classifies as a subspecies of Ogilby's duiker.
- The second most frequently recorded forest antelope.
- Significantly higher trapping rate and occupancy in the north-eastern camera grid (Zone-2).
- Camera-trap records indicate this a diurnal duiker.
- Distinguished from nocturnal bay duiker by more orange toned body colour, crest, narrower face, muzzle and dorsal band narrowing to tail base.

Ogilby's duiker	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	14 (32)	20 (26)
Number of events	32	71
Trapping rate / 100 days (±SE)	2.94	7.47
Naïve occupancy	0.44	0.77
Occupancy (±SE)	0.57 (0.13)	0.87 (0.11)
Detection probability (±SE)	0.22 (±0.05)	0.27 (±0.05)



13) ZEBRA DUIKER (*Cephalophus zebra*)

Global conservation status: Vulnerable (IUCN SSC Antelope Specialist Group 2016d)



Species notes:

- Endemic to Upper Guinean forest with distribution centred in east-central Liberia.
- One of the smaller sympatric duikers and also one of the most frequently encountered duiker species.
- Widely distributed in the surveyed area especially across south-western grid (Zone-1).
- Timings of camera-trap encounters show a predominantly diurnal crepuscular activity pattern.

Zebra duiker	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	22 (32)	14 (26)
Number of events	44	51
Trapping rate / 100 days (±SE)	4.05	5.36
Naïve occupancy	0.69	0.54
Occupancy (±SE)	0.86 (±0.12)	0.58 (±0.11)
Detection probability (±SE)	0.2 (±0.17)	0.32 (±0.05)



14) MAXWELL'S DUIKER (Philantomba maxwellii)

Global conservation status: Least Concern (IUCN SSC Antelope Specialist Group 2016f)



Species notes:

- The smallest of the six sympatric duiker species in Sapo NP.
- It was the most frequently recorded duiker species.
- Occupancy across both sampling zones appears to be high at around 80%. The species is known to also inhabit secondary forests.
- Timings of camera-trap encounters show a predominantly diurnal crepuscular activity pattern.

Maxwell's duiker	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	20 (32)	19 (26)
Number of events	39	84
Trapping rate / 100 days (±SE)	3.59	8.83
Naïve occupancy	0.63	0.73
Occupancy (±SE)	0.8 (±0.15)	0.76 (±0.1)
Detection probability (±SE)	0.19 (±0.04)	0.35 (±0.05)



15) BONGO (*Tragelaphus eurycerus*)

Global conservation status: Near Threatened (IUCN SSC Antelope Specialist Group 2016g)



Species notes:

- Only one event recorded of the lowland bongo in the south-western edge of Zone-1 sampling grid.
- Known to have a nocturnal crepuscular activity pattern.
- The single adult record in this study was in the middle of the night.

Bongo	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	1 (32)	0 (26)
Number of events	1	0
Trapping rate / 100 days (±SE)	0.09	0
Naïve occupancy	0.03	0
Occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



16) PYGMY HIPPOPOTAMUS (Choeropsis liberiensis)

Global conservation status: Endangered (Ransom et al. 2015)



Species notes:

- Confined to the Upper Guinean lowland forests mainly in Liberia, but also found in Cote d'Ivoire, Guinea and Sierra Leone.
- Secretive, nocturnal and solitary with only one event (six photos) of an adult recorded near the river at the northern edge of Zone-1 in the middle of the night.
- Sapo NP is one of the last remaining protected areas for this endangered species, highlighting further its importance.
- [Note cameras placed at known pygmy hippo wallows and tracks provided further records outside the systematic sampling grids].

Pygmy hippopotamus	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	1 (32)	0 (26)
Number of events	1	0
Trapping rate / 100 days (±SE)	0.09	0
Naïve occupancy	0.03	0
Occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



17) WESTERN FOREST HOG (Hylochoerus meinertzhageni ivoriensis)

Global conservation status: Least Concern (d'Huart et al. 2016)



Western forest hog	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	1 (32)	0 (26)
Number of events	1	0
Trapping rate / 100 days (±SE)	0.09	0
Naïve occupancy	0.03	0
Occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



18) RED RIVER HOG (*Potamochoerus porcus*)

Global conservation status: Least Concern (Reyna et al. 2016)



Species notes:

- Recorded only on nine occasions at eight camera sites in both surveyed zones.
- Mostly individual adults but occasionally two individuals were also recorded in the camera-trap images. [Larger groups are more typical in other sites (Guinea, Cameroon)].
- Timings of camera-trap encounters show a predominantly nocturnal activity pattern in this forest.
- Lactating female recorded in Zone-1 in November.

Red river hog	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	6 (32)	2 (26)
Number of events	6	3
Trapping rate / 100 days (±SE)	0.55	0.32
Naïve occupancy	0.19	0.08
Occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



19) WATER CHEVROTAIN (Hyemoschus aquaticus)

Global conservation status: Least Concern (IUCN SSC Antelope Specialist Group 2016e)



Species notes:

- The only tragulid representative in Africa (with nine species in Asia).
- The water chevrotain is similar in overall body size to the six duiker species recorded in Sapo NP; and all share a primary frugivorous diet.
- Recorded much more in the south-western sampling grid (Zone-1) but with low capture rate and occupancy.
- Primarily solitary with only single adults captured on camera.
- A strictly nocturnal activity pattern observed.

Water chevrotain	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	8 (32)	2 (26)
Number of events	19	7
Trapping rate / 100 days (±SE)	1.75	0.74
Naïve occupancy	0.25	0.08
Occupancy (±SE)	0.24 (±0.09)	N/A
Detection probability (±SE)	0.24 (±0.08)	N/A



20) AFRICAN FOREST ELEPHANT (Loxodonta africana)

Global conservation status: Vulnerable (Blanc 2008)



Species notes:

- Single large adult in Zone-1 in October 2011. At least five individuals together in Zone-2 in July including young (see photo).
- Timings of images indicate activity across the 24-hour cycle.

African elephant	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	1 (32)	3 (26)
Number of events	1	3
Trapping rate / 100 days (±SE)	0.09	0.32
Naïve occupancy	0.03	0.12
Occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



21) WHITE-BELLIED PANGOLIN (Phataginus tricuspis)

Global conservation status: Endangered (Pietersen et al. 2019)



Species notes:

- An arboreal pangolin equally at home in trees and on the ground; recorded on seven occasions at seven camera sites.
- Commonly solitary with only single adults recorded in the camera-traps.
- Timings of camera-trap encounters show a nocturnal activity pattern.

White-bellied pangolin	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	4 (32)	3 (26)
Number of events	4	3
Trapping rate / 100 days (±SE)	0.37	0.32
Naïve occupancy	0.13	0.12
Occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



22) GIANT PANGOLIN (Smutsia gigantea)

Global conservation status: Endangered (Nixon et al. 2019)



Species notes:

- Seven encounters across six sites, in both sampling zones, of this normally solitary animal.
- Timings of camera-trap encounters confirm the species' nocturnal habits.
- Sapo NP is one of the few protected areas where the species still persists.

Giant pangolin	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	3 (32)	3 (26)
Number of events	4	3
Trapping rate / 100 days (±SE)	0.37	0.32
Naïve occupancy	0.09	0.12
Occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



23) SOOTY MANGABEY (Cercocebus atys)

Global conservation status: Near Threatened (Oates et al. 2016a)



Species notes:

- Recently raised to full monotypic species following full species recognition of *C. lunulatus* (IUCN 2016).
- Endemic to Upper Guinean forests and the most frequently recorded species across both sampling grids.
- Detected most extensively in north-eastern sampling grid (Zone-2) with over 95% occupancy; significantly fewer encounters in Zone-1.
- Diurnal and predominantly terrestrial species reflected in timing and frequency of camera-trap encounters.

Sooty mangabey	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	14 (32)	25 (26)
Number of events	21	158
Trapping rate / 100 days (±SE)	1.93	16.61
Naïve occupancy	0.44	0.96
Occupancy (±SE)	N/A	0.96 (±0.04)
Detection probability (±SE)	N/A	0.58 (±0.04)



24) CAMPBELL'S MONKEY (Cercopithecus campbelli)

Global conservation status: Least Concern (Oates et al. 2008)



Species notes:

- Endemic to West Africa rainforests.
- Very few encounters; the camera-trap survey was not designed to consistently capture arboreal species.
- Diurnal; all encounters occurred during the day.

Campbell's monkey	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	1 (32)	2 (26)
Number of events	1	4
Trapping rate / 100 days (±SE)	0.09	0.42
Naïve occupancy	0.03	0.08
Occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



25) DIANA MONKEY (Cercopithecus diana)

Global conservation status: Endangered (Oates et al. 2016b)



Species notes:

- Endemic to the Upper Guinean forest of Guinea, Sierra Leone, Liberia and Cote d'Ivoire.
- Diurnal and arboreal species recorded only once in the north-eastern sampling grid (Zone-2).
- Camera-trap survey not designed to consistently capture arboreal species.

Diana monkey	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	0 (32)	1 (26)
Number of events	0	1
Trapping rate / 100 days (±SE)	0	0.11
Naïve occupancy	0	0.04
Occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



26) WESTERN CHIMPANZEE (*Pan troglodytes verus*)

Global conservation status: Endangered (Humle et al. 2016)



Species notes:

- Largest populations of the western chimpanzee are found in the Upper Guinean rainforests (Cote d'Ivoire, Guinea, Sierra Leon and Liberia).
- More extensively encountered in the south-western sampling grid (Zone-1); including a few groups with adult female and young.
- Diurnal and semi-terrestrial.

Western chimpanzee	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	11 (32)	5 (26)
Number of events	19	5
Trapping rate / 100 days (±SE)	1.75	0.53
Naïve occupancy	0.34	0.19
Occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



27) AFRICAN BRUSH-TAILED PORCUPINE (Atherurus africanus)

Global conservation status: Least Concern (Hoffmann & Cox 2016)



Species notes:

- Most frequently recorded rodent.
- Much higher encounters in the southwestern sampling grid (Zone-1) with approximately 75% of sampling grid occupied.
- Timings of camera-trap encounters indicate a strictly nocturnal activity pattern with the animals resting during the day in dens.

African brush-tailed porcupine	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	23 (32)	7 (26)
Number of events	110	14
Trapping rate / 100 days (±SE)	10.12	1.47
Naïve occupancy	0.72	0.27
Occupancy (±SE)	0.75 (±0.09)	0.36 (±0.13)
Detection probability (±SE)	0.35 (±0.04)	0.21 (±0.07)



28) FOREST GIANT POUCHED RAT (Cricetomys emini)

Global conservation status: Least Concern (Cassola 2016a)



Species notes:

- Generally terrestrial but able to climb, preferring high forest habitat.
- Relatively frequently recorded in both sampling zones with higher trapping rate in Zone-1.
- Solitary with all encounters of single individuals.
- Timings of camera-trap encounters show a strictly nocturnal activity pattern.
- Identification based on habitat.

Forest giant pouched rat	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	18 (32)	11 (26)
Number of events	56	22
Trapping rate / 100 days (±SE)	5.15	2.31
Naïve occupancy	0.56	0.42
Occupancy (±SE)	0.65 (±0.1)	0.61 (±0.19)
Detection probability (±SE)	0.31 (±0.05)	0.15 (±0.05)



29) FIRE-FOOTED ROPE SQUIRREL (Funisciurus pyrropus)

Global conservation status: Least Concern (Cassola 2016b)



Species notes:

- Terrestrial mainly solitary species with single individuals recorded.
- Most frequently recorded squirrel with higher trapping rate in the south-western sampling grid (Zone-1).
- Timings of camera-trap encounters show a strictly diurnal activity pattern.

Fire-footed rope squirrel	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	16 (32)	6 (26)
Number of events	48	19
Trapping rate / 100 days (±SE)	4.42	2
Naïve occupancy	0.5	0.23
Occupancy (±SE)	0.5 (±0.12)	0.28 (±0.1)
Detection probability (±SE)	0.25 (±0.06)	0.26 (±0.08)



30) RED-LEGGED SUN SQUIRREL (*Heliosciurus rufobrachium*)

Global conservation status: Least Concern (Cassola 2016c)



Species notes:

- Few encounters of an arboreal species inhabiting the canopy and middle level of the forests.
- Timings of camera-trap encounters show a strictly diurnal activity pattern. Red-legged sun squirrels leave their nests at dawn and often return well before dark as indicated in the activity pattern.

Red-legged sun squirrel	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	8 (32)	6 (26)
Number of events	8	7
Trapping rate / 100 days (±SE)	0.74	0.74
Naïve occupancy	0.25	0.23
Occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



31) SLENDER-TAILED SQUIRREL (Protoxerus aubinnii)

Global conservation status: Data Deficient (Decher & Grubb 2004)



Species notes:

- The subspecies *P.a. salae* is endemic to Liberia (and probably Sierra Leone) and poorly known.
- Only encountered once in the north-eastern sampling grid (Zone-2).
- An arboreal diurnal species with the single encounter in middle of the day.

Slender-tailed squirrel	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	0 (32)	1 (26)
Number of events	0	1
Trapping rate / 100 days (±SE)	0	0.11
Naïve occupancy	0	0.04
Occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



32) AFRICAN GIANT SQUIRREL (Protoxerus stangeri)

Global conservation status: Least Concern (Cassola 2016d)



Species notes:

- Only two events at one location. An arboreal species inhabiting the canopy and upper vegetation levels, only descending to the ground occasionally.
- A diurnal species with both events occurring during daylight.

African giant squirrel	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	0 (32)	1 (26)
Number of events	0	2
Trapping rate / 100 days (±SE)	0	0.21
Naïve occupancy	0	0.04
Occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



33) GREATER CANE RAT (*Thryonomys swinderianus*)

Global conservation status: Least Concern (Child 2016)



Greater cane rat	Zone-1 Oct-Dec 2011	Zone-2 Jun-Jul 2011
Number of sites detected (total sites)	1 (32)	0 (26)
Number of events	1	0
Trapping rate / 100 days (±SE)	0.09	0
Naïve occupancy	0.03	0
Occupancy (±SE)	N/A	N/A
Detection probability (±SE)	N/A	N/A



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