Supplementary Information for

Predicting Ebola virus disease risk and the role of African bat birthing

C. Reed Hranac[1], Jonathan C. Marshall[2], Ara Monadjem[3,4] and David T.S. Hayman[1]

August 15, 2019

Corresponding Author

C. Reed Hranac c.r.hranac@massey.ac.nz David T.S. Hayman d.t.s.hayman@massey.ac.nz

Contents

List of Figures

List of Tables

1 SI Methods

1.1 Chiropteran parturition data mining

Bat species that have been implicated in filovirus transmission either through RNA or antibody detection methods [1, 2] were systematically queried through Walker's Bats of the World [3], Scopus, Web of Science, and Google Scholar. Generalized search terms including: "Birth*"; "Breed*"; "Reproduc*"; "Partur*" along with the Latin binomial and common species names. Bat species that had undergone taxonomic reassignment were queried under all names. Species that had been implicated, but did not reside in Africa, were queried at the genus level to identify representative sister species. Preliminary results suggested insufficient sample sizes to model parturition on a consistent per species, or per genus basis. Species were then aggregated into three taxonomic clusters: African fruit bats (family: *Pteropodidae*), molossid bats (family: *Molossidae*, and non-molossid microbats, according to Cumming and Bernard [4]. Publications were accessed by hand and the location and month of parturition events were extracted. Data points were restricted to those within mainland Africa. Studies that reported suckling neonates, lactating females, or attached pups were excluded as they did not provide explicate indication of the date, or location of parturition. Additional points for non-implicated species were added opportunistically as discovered and an African bat specialist (AM) was consulted to help fill holes in the dataset and to expand the data set to all mainland African bats. All gathered data was then compiled into a single, recirculating year for further analysis.

1.2 Covariate data

Covariate data was assembled for both the bat birthing models and EVD spillover models and is summarized in Table 2. Covariate layers were blocked into static variables and temporally dynamic variables depending on the data availability and hypotheses being tested. The static covariate layers used included those describing mammalian species biodiversity (both volant and non-volant) [5], land cover [6], and four of the 19 Bioclimatic variables representing 30 year average for precipitation seasonality, mean diurnal range, temperature seasonality, and temperature annual range [7]. Temporally dynamic covariate layers were used to describe mean monthly temperature, average monthly precipitation, potential evapo-transpiration [8] and an enhanced vegetative index [9].

Considering the vast size of Africa the study extent was restricted to locations in Africa receiving more than 500mL of precipitation annually as suggested by Schmidt *et al.* 2017 [10]. All covariate layers were cropped and masked to the precipitation layer, resolution was aggregated to 25km raster blocks and temporally dynamic covariates were normalized (mean zero and standard deviation of 1). All spatial handling was preformed within R [11], using tools in the `sp` [12], `raster` [13], and `rgdal` [14] packages.

1.2.1 Mammalian diversity layers

Covariate layers describing non-volant mammalian, African fruit bat, molossid, and non-molossid microbats diversity were created using the IUCN red list terrestrial mammals distribution database [5]. Classification by taxonomic rank was performed by `taxize` package [15] and manually checked by hand (see `DiversityRasters.R`) and the number of overlapping distributions for each cell within the study area were counted to create the diversity raster layers.

1.2.2 Land cover

The global land cover database [6] was obtained for the year 2009 and custom aggregation was used to reduce the number of classes from 23 to five as described by Table 3.

1.2.3 Fragmentation index

A binary mask of the aggregated 'forest' class (as described above) from the Globcover 2009 dataset [6] was used to define forest patches using 4-connectivity. A fragmentation index was then calculated for each pixel by counting the number of unique patches within a 20x20 sliding window using tools in the `EBImage` package [16].

1.3 African bat birth pulse modeling

The birth pulses for each of the taxonomic clusters were modeled though a modified ecological niche modeling (ENM) procedure devised for this analysis. Standard ENMs use occurrence (or occurrence/absence) and covariate data to create regressive correlations between observed environmental phenomena and observations. In this instance, we re-purposed these models to correlate phenological environmental signals with bat birthing events within a temporally dynamic framework.

Birthing events identified through the data mining were split by taxonomic grouping as described above and observation/absence matrices were generated to a sliding two month window. Records of a birth within the window were recorded as an occurrence within the 25x25km cell in which it was observed. All locations for which there was a recorded birth for within the taxon group, but no births were observed in those months were deemed "absence points". The two month sliding window was chosen to reflect the non-discrete nature of birthing within wild animals and to help account for deficiencies in the source data. An additional ten, randomly generated, down-weighted (0.001) points (five occurrence and five absence points) were added to all models. This measure was taken to ensure the representation of all land cover categories in all models, and provide necessary pseudo-absence points in a small number of cases in which and insufficient number of absence points existed, while having minimal impact on the model outcomes.

Temporal covariate data was selected using a wider six month sliding window centered on the same two month window used for the occurrence/absences and included the two preceding, and two following months. Due to the inherent correlation of the covariate layers (especially the temporally dynamic covariate layers) and general non-independence of all selected environmental metrics, a raster based principal components analysis (PCA) method was used to reduce the dimensionality of all continuous predictors into six orthogonal principal components using the `rasterPCA` function of the package RStoobox [17]. The categorical land cover variable was then added to the other dimensionally reduced co-variates and occurrence/absence data were fed into the `biomod2` [18] framework.

ENMs were procedurally generated for all taxonomic clusters and all pairs of consecutive months where the number of combined observations was greater than 7. Ten iterations of the potential eight preliminary models (generalized linear model, generalized boosted model, classification tree analysis, artificial neural network, surface range envelope, flexible discriminate analysis, random forest and maximum entropy) were computed using a standard 70:30 training:test ratio. Ensemble models were then compiled based on the weighted mean of the receiver operating characteristic (ROC score) to create a single consensus layer with the probability of event occurrence between 0 and 1.

1.4 qAIC

Models with and without bat associated terms were compared using a quasi-Akaike information criteria (qAIC) scheme of the form:

$$\text{qAIC} = -2\text{logLik}/\hat{C} + 2k,$$

where $\hat{C}$ is the overdispersion, and k represents the number of terms in the model.

2 Tables

Table 1: African bat birth pulse data mining results

Species	Annual Births	Locations	References
Pteropodidae			
Casinycteris ophiodon	1	1	[19]
Eidolon helvum	1	3	[20, 21, 22, 23]
Epomophorus gambianus	1-2	3	[24, 25, 26]
Epomophorus labiatus	2	1	[27]
Epomophorus wahlbergi	1-2	2	[28, 29]
Epomopos buettikoferi	2	2	[26, 30]
Epomopos franqueti	2	3	[31, 32, 27]
Hypsignathus monstrosus	2	3	[33, 34, 19]
Micropteropus pusillus	1-2	6	[35, 36, 37, 25, 38, 26]
Myonycteris angolensis	1	2	[24, 19]
Myonycteris leptodon	1-2	3	[21, 19]
Myonycteris torquata	2	1	[35]
Nanonycteris veldkampi	1	2	[19, 25]
Rousettus aegyptiacus	1-2	12	[19, 25, 39, 40, 41, 34, 36, 24, 42, 43]
Molossidae			
Chaerephon pumilas	2-3	4	[44, 45, 46, 47]
Chaerephon pumilus	1	1	[48]
Mops condylurus	2	5	[49, 45, 50, 46]
Mops midas	1	1	[51]
Otomops harrisoni	1	2	[46]
Tadarida aegyptiaca	1	1	[52]
Tadarida fulminans	2	1	[53]
Non-*Molossidae* Microbats			
Cardioderma cor	2	1	[54]
Coleura afra	2	1	[47]
Eptesicus hottentotus	1	1	[55]
Hipposideros abae	1	1	[37]
Hipposideros beatus	1	1	[56]
Hipposideros caffer	1	3	[57, 58, 59]
Hipposideros caffer rubber	1	2	[37, 19]
Hipposideros cyclops	1	1	[37]
Hipposideros gigas	1	2	[60, 61]
Hipposideros rubber	1	1	[62]
Hipposideros vittatus	1	1	[63]
Lavia frons	1	2	[37, 64]
Miniopterus fraterculus	1	1	[65]
Miniopterus inflatus	1	1	[61]
Miniopterus minor	1	1	[66]
Miniopterus natalensis	1	4	[67, 65, 68, 69]
Myotis bocageii	2	1	[56]
Myotis tricolor	1	1	[70]
Neoromicia capensis	1	1	[71]
Neoromicia nanus	1	4	[72, 73, 74, 50]
Neoromicia somalicus	1	1	[50]
Neoromicia zuluensis	1	1	[75]
Nycteris grandis	1	1	[76]
Nycteris hispidar	2	1	[37]
Nycteris nana	1	1	[37]
Nycteris thebaica	1	1	[57]
Nycticeinops schlieffeni	1	3	[77, 50, 75]
Pipistellus rusticus	1	1	[78]

Continued on next page

Table 1 – continued from previous page

Species	Annual Births	Locations	References
Rhinolophus basii	1	1	[75]
Rhinolophus capensis	1	1	[79]
Rhinolophus clivossis	1	1	[79]
Rhinolophus darlingi	1	1	[80]
Rhinolophus fumigatus	1	1	[75]
Rhinolophus landeri	1	1	[59]
Rhinolophus mossambicus	1	1	[81]
Rhinolophus simulator	1	2	[81, 50]
Scotoecus hirundo	1	1	[50]
Scroptophilus borbonicus	1	1	[77]
Scroptophilus dinganii	1-2	3	[50, 72, 36]
Scroptophilus leucigaster	1	1	[82]
Scroptophilus vividis	1	1	[77]
Taphozous hildegardeae	2	1	[66]
Taphozous mauritianus	2	2	[75, 50]

Table 2: Covariate layers for modelling

Description	Analysis	Variable Type	References
Non-volant mammalian biodiversity	Both	Static	[5]
Land cover (modified)	Both	Static	[6]
Precipitation seasonality	ENM	Static	[7]
Mean diurnal range	ENM	Static	[7]
Temperature seasonality	ENM	Static	[7]
Temperature annual range	ENM	Static	[7]
Mean monthly temperature	ENM	Temporal	[7]
Mean monthly precipitation	ENM	Temporal	[7]
Potential evapo-transpiration	ENM	Temporal	[8]
Enhanced vegetative index	ENM	Temporal	[9]
Vegetation fragmentation index	spatGLM	Static	This study
Human population density	spatGLM	Static	[83]

Table 3: Reclassification of land cover variables

Value	Label	Class
11	Post-flooding or irrigated croplands (or aquatic)	crop
14	Rainfed croplands	crop
20	Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)	crop
30	Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)	grass
40	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)	forest
50	Closed (>40%) broadleaved deciduous forest (>5m)	forest
60	Open (15-40%) broadleaved deciduous forest/woodland (>5m)	forest
70	Closed (>40%) needleleaved evergreen forest (>5m)	forest
90	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)	forest
100	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)	forest
110	Mosaic forest or shrubland (50-70%) / grassland (20-50%)	forest
120	Mosaic grassland (50-70%) / forest or shrubland (20-50%)	grass
130	Closed to open (>15%) (broadleaved or needleleaved; evergreen or deciduous) shrubland (<5m)	grass
140	Closed to open (>15%) herbaceous vegetation (grassland; savannas or lichens/mosses)	grass
150	Sparse (<15%) vegetation	grass
160	Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily)	forest
170	Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water	forest
180	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soi	grass
190	Artificial surfaces and associated areas (Urban areas >50%)	urban
200	Bare areas	other
210	Water bodies	other
220	Permanent snow and ice	other
230	No data (burnt areas; clouds;...)	NA

Table 4: The abbreviations abr, mic, and mol, represent African fruit bats, non-molossid microbats and molissid bats respectively. The numbers included within the model names are the calender months over which the model was produced. No models were created for January-February, and July-August for the non-molossid microbats.

Model	ROC	Sensitivity	Specificity
mic2.mic3	0.986	96.296	96.97
mic3.mic4	0.979	97.959	87.013
mic4.mic5	0.985	97.561	89.412
mic5.mic6	0.993	97.222	98.889
mic6.mic7	0.995	100	98.131
mic8.mic9	0.997	100	97.368
mic10.mic11	0.994	96.154	100
mic11.mic12	0.993	92.683	100
mic12.mic1	0.985	98.551	91.228
mol1.mol2	0.969	100	82.222
mol2.mol3	0.993	100	90.625
mol3.mol4	0.993	100	93.75
mol4.mol5	0.983	96.296	93.939
mol5.mol6	0.952	95.238	84.615
mol6.mol7	0.96	95.238	84.615
mol7.mol8	0.962	90.476	89.744
mol8.mol9	0.976	84.211	100
mol9.mol10	0.972	84.211	100
mol10.mol11	0.952	92.308	88.235
mol11.mol12	0.961	90.244	100
mol12.mol1	0.969	93.478	92.857
ptr1.ptr2	0.987	97.015	91.589
ptr2.ptr3	0.988	99.01	93.151
ptr3.ptr4	0.991	96.124	95.556
ptr4.ptr5	0.994	97.248	95.385
ptr5.ptr6	0.992	94.643	96.61
ptr6.ptr7	0.988	96.364	94.958
ptr7.ptr8	0.983	94.444	94.118
ptr8.ptr9	0.982	92.553	96.25
ptr9.ptr10	0.991	93.75	100
ptr10.ptr11	0.994	95.918	100
ptr11.ptr12	0.991	94	98.387
ptr12.ptr1	0.989	95.349	96.183

Table 5: Model for all alternative animal spatGLM models. Terms not included in that model are denoted by "-"

Model:	Null		D_{tot}		D_{tax}		P_{tot}		$D_{tot} + P_{tot}$		$D_{tot} \times P_{tot}$		$D_{tax} + P_{tax}$		$D_{tax} \times B_{tax}$	
	Estimate	P value	Estimate	P value	Estimate	P value	Estimate	P value	Estimate	P value	Estimate	P value	Estimate	P value	Estimate	P value
Intercept)	-32.81	<0.001	-30.02	<0.001	-27.56	<0.001	-38.2	0	-36.39	<0.001	-29.63	<0.001	-30.61	<0.001	-31.34	<0.001
P_{afb}	-	-	-	-	-	-	-	-	-	-	-	-	2	0.07	-	-
λ_{afb}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.08	0.01
P_{mic}	-	-	-	-	-	-	-	-	-	-	-	-	-0.03	0.98	-	-
λ_{mic}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.06	0.79
P_{mol}	-	-	-	-	-	-	-	-	-	-	-	-	-0.28	0.81	-	-
λ_{mol}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.18	0.64
P_{total}	-	-	-	-	-	-	2.11	0.24	1.74	0.31	-	-	-	-	-	-
λ_{total}	-	-	-	-	-	-	-	-	-	-	0.23	0.67	-	-	-	-
P_{afb_2}	-	-	-	-	-	-	-	-	-	-	-	-	1.27	0.25	-	-
λ_{afb_2}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.79	0.04
P_{mic_2}	-	-	-	-	-	-	-	-	-	-	-	-	1.67	0.08	-	-
λ_{mic_2}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.3
P_{mol_2}	-	-	-	-	-	-	-	-	-	-	-	-	0.75	0.56	-	-
λ_{mol_2}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.47	0.31
P_{total_2}	-	-	-	-	-	-	6.17	0.02	5.65	0.02	-	-	-	-	-	-
$\lambda_{\mathrm{total}_2}$	-	-	-	-	-	-	-	-	-	-	1.51	0.03	-	-	-	-
P_{afb_4}	-	-	-	-	-	-	-	-	-	-	-	-	-0.72	0.49	-	-
λ_{afb_4}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.46	0.19
P_{mic_4}	-	-	-	-	-	-	-	-	-	-	-	-	-1.09	0.28	-	-
λ_{mic_4}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.32	0.09
P_{mol_4}	-	-	-	-	-	-	-	-	-	-	-	-	-0.69	0.55	-	-
λ_{mol_4}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	0.95
P_{total_4}	-	-	-	-	-	-	0.96	0.54	0.57	0.71	-	-	-	-	-	-
$\lambda_{\mathrm{total}_4}$	-	-	-	-	-	-	-	-	-	-	0	1	-	-	-	-
P_{afb_6}	-	-	-	-	-	-	-	-	-	-	-	-	0.9	0.42	-	-
λ_{afb_6}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	0.16
P_{mic_6}	-	-	-	-	-	-	-	-	-	-	-	-	-1.69	0.09	-	-
λ_{mic_6}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.31	0.12
P_{mol_6}	-	-	-	-	-	-	-	-	-	-	-	-	-1.15	0.31	-	-
λ_{mol}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.3	0.44
P_{total_6}	-	-	-	-	-	-	2.45	0.17	2.08	0.24	-	-	-	-	-	-
$\lambda_{\mathrm{total}_6}$	-	-	-	-	-	-	-	-	-	-	0.46	0.4	-	-	-	-
D_{afb}	-	-	-	-	5.52	<0.001	-	-	-	-	-	-	5.93	<0.001	-	-
D_{mic}	-	-	-	-	-2	0.34	-	-	-	-	-	-	-1.54	0.33	-	-
D_{mol}	-	-	-	-	1.5	0.26	-	-	-	-	-	-	1.47	0.13	-	-
D_{bat}	-	-	2.21	0.01	-	-	-	-	0.91	0.36	-	-	-	-	-	-
PopDen	-1.7	<0.001	-1.79	<0.001	-2.03	<0.001	-1.84	<0.001	-1.84	<0.001	-1.84	<0.001	-2.01	<0.001	-1.87	<0.001
fragIndex	0.54	0.15	0.53	0.15	0.03	0.97	0.44	0.34	0.44	0.31	0.46	0.25	0.1	0.84	0.32	0.48
BVD	4.96	<0.001	4.73	<0.001	4.27	<0.001	4.62	<0.001	4.57	<0.001	4.55	<0.001	4.06	<0.001	4.13	<0.001
D_{MNB}	6.34	<0.001	3.97	<0.001	3.74	0.09	6.08	<0.001	5.16	<0.001	4.05	<0.001	3.67	0.04	5.36	<0.001
qAIC	325.99		271.56		481.71		358.26		320.38		272.43		280.96		340.56	
$\hat{c}$	0.82		0.69		1.32		0.92		0.81		0.69		0.71		0.87	

Table 6: Model for all alternative animal spatGLM models with modified African birth pulse terms. Terms not included in that model are denoted by “-”

Model:	P_{tot*}		$D_{tot} + P_{tot*}$		$D_{tot} \times P_{tot*}$		$D_{tax} + P_{tax*}$		$D_{tax} \times P_{tax*}$	
	Estimate	P value	Estimate	P value	Estimate	P value	Estimate	P value	Estimate	P value
Intercept)	-25.46	<0.001	-27.81	<0.001	-31.44	<0.001	-29.16	<0.001	-33.39	<0.001
$P_{\mathrm{afb}*}$	-	-	-	-	-	-	2.2	0.05	-	-
$\lambda_{\mathrm{afb}*}$	-	-	-	-	-	-	-	-	2.32	0.06
P_{mic}	-	-	-	-	-	-	-0.13	0.89	-	-
λ_{mic}	-	-	-	-	-	-	-	-	0	1
P_{mol}	-	-	-	-	-	-	-0.79	0.5	-	-
λ_{mol}	-	-	-	-	-	-	-	-	0.13	0.78
$P_{\mathrm{total}*}$	2.41	0.42	3.78	0.17	-	-	-	-	-	-
$\lambda_{\mathrm{total}*}$	-	-	-	-	2.8	0.04	-	-	-	-
$P_{\mathrm{afb}*_2}$	-	-	-	-	-	-	0.99	0.38	-	-
$\lambda_{\mathrm{afb}*_2}$	-	-	-	-	-	-	-	-	1.7	0.17
P_{mic_2}	-	-	-	-	-	-	1.58	0.12	-	-
λ_{mic_2}	-	-	-	-	-	-	-	-	0.19	0.41
P_{mol_2}	-	-	-	-	-	-	0.34	0.8	-	-
λ_{mol_2}	-	-	-	-	-	-	-	-	0.49	0.36
$P_{\mathrm{total}*_2}$	-6.27	0.13	-5.04	0.18	-	-	-	-	-	-
$\lambda_{\mathrm{total}*_2}$	-	-	-	-	-1.6	0.32	-	-	-	-
$P_{\mathrm{afb}*_4}$	-	-	-	-	-	-	-1.57	0.2	-	-
$\lambda_{\mathrm{afb}*_4}$	-	-	-	-	-	-	-	-	-0.79	0.51
P_{mic_4}	-	-	-	-	-	-	-0.94	0.38	-	-
λ_{mic_4}	-	-	-	-	-	-	-	-	-0.41	0.07
P_{mol_4}	-	-	-	-	-	-	-0.59	0.63	-	-
λ_{mol_4}	-	-			-	-	-	-	-0.12	0.81
$P_{\mathrm{total}*_4}$	-6.03	0.15	-4.81	0.2	-	-	-	-	-	-
$\lambda_{\mathrm{total}*_4}$	-	-	-	-	-1.55	0.35	-	-	-	-
$P_{\mathrm{afb}*_6}$	-	-	-	-	-	-	0.78	0.51	-	-
$\lambda_{\mathrm{afb}*_6}$	-	-	-	-	-	-	-	-	1.44	0.28
P_{mic_6}	-	-	-	-	-	-	-1.38	0.18	-	-
λ_{mic_6}	-	-	-	-	-	-	-	-	-0.3	0.16
P_{mol_6}	-	-	-	-	-	-	-1.07	0.36	-	-
λ_{mol}	-	-	-	-	-	-	-	-	-0.25	0.58
$P_{\mathrm{total}*_6}$	2.18	0.48	3.49	0.22	-	-	-	-	-	-
$\lambda_{\mathrm{total}*_6}$	-	-	-	-	2.68	0.05	-	-	-	-
D_{afb}	-	-	-	-	-	-	5.97	<0.001	-	-
D_{mic}	-	-	-	-	-	-	-1.65	0.31	-	-
D_{mol}	-	-	-	-	-	-	1.6	0.1	-	-
D_{bat}	-	-	2.21	0.01	-	-	-	-	-	-
PopDen	-1.72	<0.001	-1.79	<0.001	-1.78	<0.001	-2.01	<0.001	-1.91	<0.001
fragIndex	0.54	0.15	0.54	0.13	0.54	0.11	0.07	0.88	0.13	0.82
BVD	4.93	<0.001	4.75	<0.001	4.79	<0.001	3.96	<0.001	3.8	<0.001
D_{MNB}	5.97	<0.001	3.89	<0.001	4.1	<0.001	3.54	0.05	4.26	0.02
qAIC	315.64		253.83		252.21		295.64		390.43	
$\hat{c}$	0.79		0.63		0.63		0.75		1.05	

Table 7: Model for all alternative human spatGLM models. Terms not included in that model are denoted by "-"

Model:	Null		D_{tot}		D_{tax}		B_{tot}		$D+B_{tot}$		$D\times B_{tot}$		$D+B_{tax}$		$D\times B_{tax}$	
	Estimate	P value	Estimate	P value	Estimate	P value	Estimate	P value	Estimate	P value	Estimate	P value	Estimate	P value	Estimate	P value
Intercept)	-29.82	<0.001	-29.03	<0.001	-29.66	<0.001	-28.73	<0.001	-32.76	<0.001	-28.73	<0.001	-31.62	<0.001	-28.62	<0.001
P_{afb}	-	-	-	-	-	-	-	-	-	-	-	-	-1.49	0.14	-	-
λ_{afb}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.25	0.53
P_{mic}	-	-	-	-	-	-	-	-	-	-	-	-	1.48	0.06	-	-
λ_{mic}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.23	0.22
P_{mol}	-	-	-	-	-	-	-	-	-	-	-	-	-0.45	0.66	-	-
λ_{mol}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.31	0.43
P_{total}	-	-	-	-	-	-	0.79	0.22	1.88	0.27	-	-	-	-	-	-
λ_{total}	-	-	-	-	-	-	-	-	-		0.79	0.22	-	-	-	-
P_{afb_2}	-	-	-	-	-	-	-	-	-	-	-	-	1.39	0.15	-	-
λ_{afb_2}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.98	0.01
P_{mic_2}	-	-	-	-	-	-	-	-	-	-	-	-	-0.37	0.63		
λ_{mic_2}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.2	0.23
P_{mol_2}	-	-	-	-	-	-	-	-	-	-	-	-	0.11	0.92		
λ_{mol_2}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.08	0.85
P_{total_2}	-	-	-	-	-	-	1.94	0.01	4.5	0.04	-	-	-	-	-	-
$\lambda_{\mathrm{total}_2}$	-	-	-	-	-	-	-	-	-	-	1.94	0.01	-	-	-	-
P_{afb_4}	-	-	-	-	-	-	-	-	-	-	-	-	-0.02	0.98	-	-
λ_{afb_4}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	0.14
P_{mic_4}	-	-	-	-	-	-	-	-	-	-	-	-	-0.95	0.3	-	-
λ_{mic_4}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.17	0.37
P_{mol_4}	-	-	-	-	-	-	-	-	-	-	-	-	0.38	0.73	-	-
λ_{mol_4}	-	-	-	-	-	-					-	-	-	-	0.41	0.35
P_{total_4}	-	-	-	-	-	-	-0.13	0.78	-0.5	0.71	-	-	-	-	-	-
$\lambda_{\mathrm{total}_4}$	-	-	-	-	-	-	-	-	-	-	-0.13	0.78	-	-	-	-
P_{afb_6}	-	-	-	-	-	-	-	-	-	-	-	-	1.29	0.19	-	-
λ_{afb_6}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.68	0.08
P_{mic_6}	-	-	-	-	-	-	-	-	-	-	-	-	-0.23	0.78	-	-
λ_{mic_6}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	0.86
P_{mol_6}	-	-	-	-	-	-	-	-			-	-	1.48	0.13	-	-
λ_{mol}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.53	0.17
P_{total_6}	-	-	-	-	-	-	0.09	0.87	0.29	0.85	-	-	-	-	-	-
$\lambda_{\mathrm{total}_6}$	-	-	-	-	-		-	-	-	-	0.09	0.87	-	-	-	-
D_{afb}	-	-	-	-	3.16	<0.001	-	-	-	-	-	-	2.88	<0.001	-	-
D_{mic}	-	-	-	-	1.99	0.18	-	-	-	-	-	-	1.92	0.18	-	-
D_{mol}	-	-	-	-	-0.43	0.61	-	-	-	-	-	-	-0.63	0.43	-	-
D_{bat}	-	-	3.21	<0.001	-	-	-	-	2.64	0.01	-	-	-	-	-	-
PopDen	-0.23	0.24	-0.29	0.05	-0.25	0.07	-0.28	0.04	-0.28	0.05	-0.28	0.04	-0.23	0.08	-0.27	0.08
fragIndex	-0.21	0.54	-0.26	0.34	-0.38	0.17	-0.31	0.25	-0.3	0.26	-0.31	0.25	-0.4	0.12	-0.36	0.22
BVD	-11.04	0.99	-11.29	0.98	-11.21	0.98	-10.94	0.98	-11.01	0.98	-10.94	0.98	-11.43	0.98	-11.37	0.98
D_{MNB}	5.61	<0.001	2.88	0.02	2.92	0.01	3.37	<0.001	3.36	0.01	3.37	<0.001	3.36	<0.001	4.72	<0.001
OB_{an}	5.17	<0.001	4.96	<0.001	4.47	<0.001	4.74	<0.001	4.74	<0.001	4.74	<0.001	4.5	<0.001	4.73	<0.001
$OB_{\mathrm{an}_{l-1}}$	2.02	0.28	1.92	0.17	2.03	0.1	1.91	0.14	1.93	0.14	1.91	0.14	2.71	0.02	2.62	0.06
qAIC		1076.48		613.37		512.88		677.95		533.35		522.57		457.58		630.23
$\hat{c}$		1.87	1.08			0.91		1.18		0.93		0.92		0.79		1.10

Table 8: Model for all alternative human spatGLM models with modified African birth terms. Terms not included in that model are denoted by "-"

Model:	P_{tot*}		$D_{tot} + P_{tot*}$		$D_{tot} \times P_{tot*}$		$D_{tax} + P_{tax*}$		$D_{tax} \times P_{tax*}$	
	Estimate	P value	Estimate	P value	Estimate	P value	Estimate	P value	Estimate	P value
Intercept)	-3.81	<0.001	-9.4	0.29	-29.74	<0.001	-30.63	<0.001	-29.93	<0.001
$P_{\text{afb}*}$	-	-	-	-	-	-	-2.41	0.05	-	-
$\lambda_{\text{afb}*}$	-	-	-	-	-	-	-	-	-1.83	0.06
P_{mic}	-	-	-	-	-	-	1.83	0.89	-	-
λ_{mic}	-	-	-	-	-	-	-	-	0.26	1
P_{mol}	-	-	-	-	-	-	-0.19	0.5	-	-
λ_{mol}	-	-	-	-	-	-	-	-	-0.15	0.78
$P_{\text{total}*}$	-17.59	0.42	-15.29	0.01	-	-	-	-	-	-
$\lambda_{\text{total}*}$	-	-	-	-	-2.23	0.21	-	-	-	-
P_{afb_2*}	-	-	-	-	-	-	0.91	0.38	-	-
$\lambda_{\text{afb}*_2}$	-	-	-	-	-	-	-	-	1.89	0.17
P_{mic_2}	-	-	-	-	-	-	-0.06	0.12	-	-
λ_{mic_2}	-	-	-	-	-	-	-	-	-0.18	0.41
P_{mol_2}	-	-	-	-	-	-	0.29	0.8	-	-
λ_{mol_2}	-	-	-	-	-	-	-	-	-0.09	0.36
$P_{\text{total}*_2}$	-0.29	0.13	0.71	0.84	-	-	-	-	-	-
$\lambda_{\text{total}*_2}$	-	-	-	-	2.65	0.09	-	-	-	-
$P_{\text{afb}*_4}$	-	-	-	-	-	-	-0.39	0.2	-	-
$\lambda_{\text{afb}*_4}$	-	-	-	-	-	-	-	-	0.53	0.51
P_{mic_4}	-	-	-	-	-	-	-0.78	0.38	-	-
λ_{mic_4}	-	-	-	-	-	-	-	-	-0.24	0.07
P_{mol_4}	-	-	-	-	-	-	0.2	0.63	-	-
λ_{mol_4}	-	-	-	-	-	-	-	-	0.25	0.81
$P_{\text{total}*_4}$	-2.46	0.15	-0.91	0.8	-	-	-	-	-	-
$\lambda_{\text{total}*_4}$	-	-	-	-	2.14	0.17	-	-	-	-
$P_{\text{afb}*_6}$	-	-	-	-	-	-	1.6	0.51	-	-
$\lambda_{\text{afb}*_6}$	-	-	-	-	-	-	-	-	2.34	0.28
P_{mic_6}	-	-	-	-	-	-	-0.27	0.18	-	-
λ_{mic_6}	-	-	-	-	-	-	-	-	-0.04	0.16
P_{mol_6}	-	-	-	-	-	-	1.34	0.36	-	-
λ_{mol}	-	-	-	-	-	-	-	-	0.44	0.58
$P_{\text{total}*_6}$	-9.41	0.48	-7.28	0.09	-	-	-	-	-	-
$\lambda_{\text{total}*_6}$	-	-	-	-	0.07	0.96	-	-	-	-
D_{afb}	-	-	-	-	-	-	2.87	<0.001	-	-
D_{mic}	-	-	-	-	-	-	1.86	0.19	-	-
D_{mol}	-	-	-	-	-	-	-0.59	0.46	-	-
D_{bat}	-	-	2.1	0.04	-	-	-	-	-	-
PopDen	-0.21	0.2	-0.25	0.09	-0.29	0.07	-2.01	0.07	-0.25	0.08
fragIndex	-0.25	0.43	-0.28	0.33	-0.23	0.41	0.07	0.12	-0.38	0.17
BVD	-11.93	0.98	-11.88	0.98	-11.22	0.98	3.96	0.98	-11.53	0.98
D_{MNB}	4.73	<0.001	3.15	0.01	3.42	0.01	3.54	0.01	4.09	<0.001
OB_{an}	5.14	<0.001	5	<0.001	5.09	<0.001	4.56	<0.001	4.58	<0.001
$OB_{\text{an}_{l-1}}$	2.25	0.14	2.19	0.1	2.1	0.15	2.89	0.01	2.89	0.02
qAIC	757.58		595.88		664.63		454.93		542.84	
$\hat{c}$	1.35		1.06		1.16		0.78		0.96	

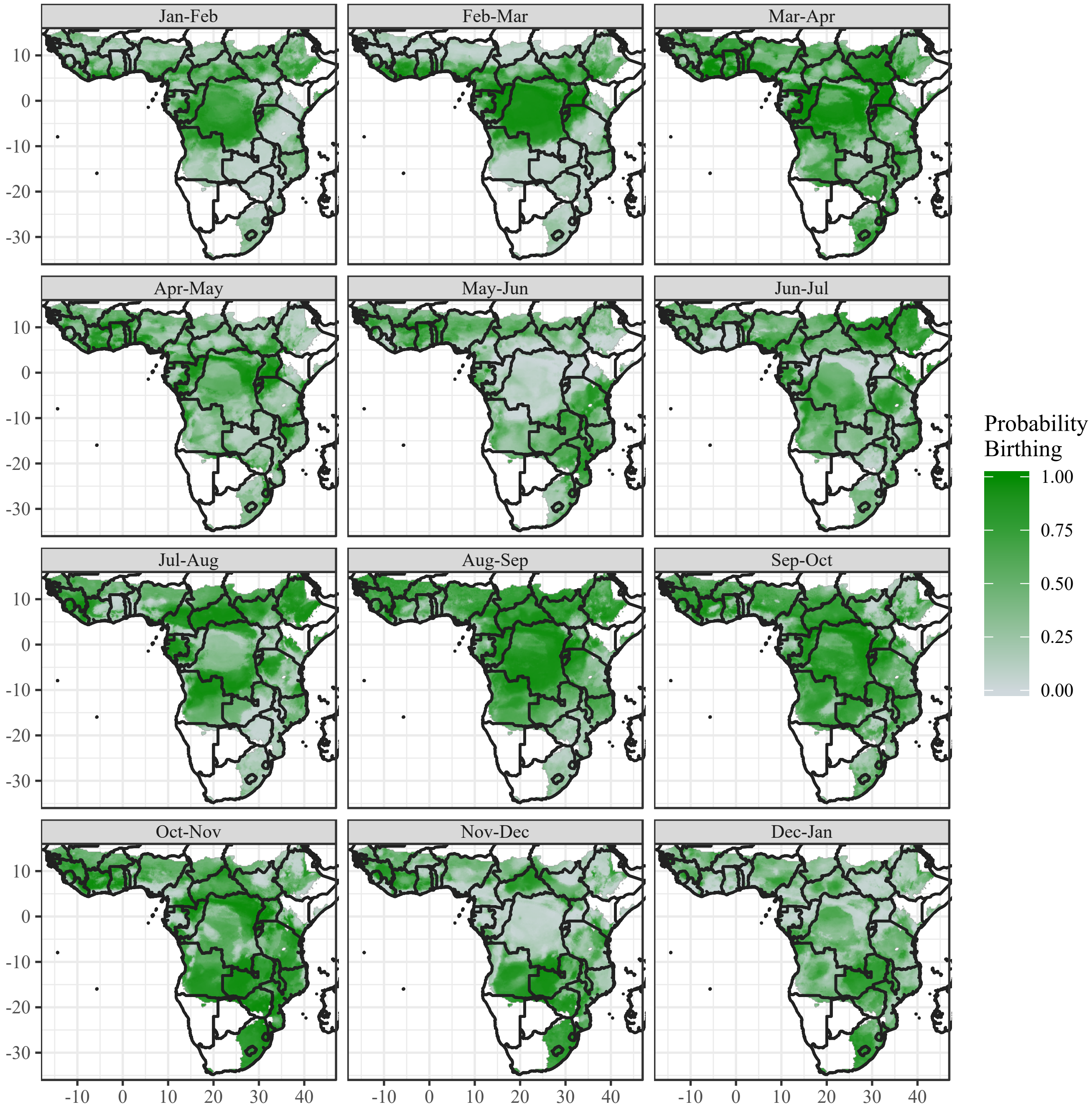

Figure 1: Monthly probability of birthing for African fruit bats

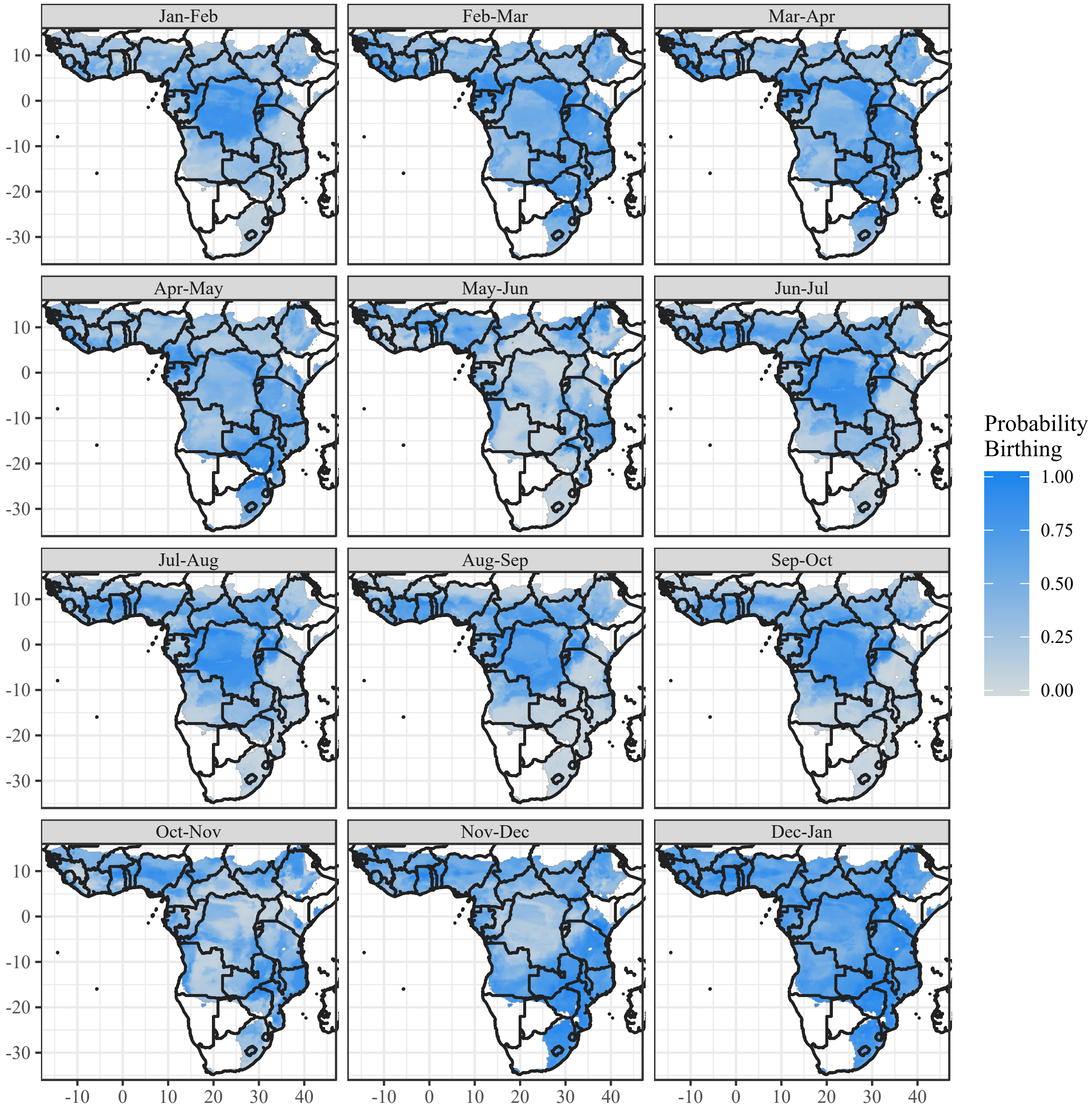

Figure 2: Monthly probability of birthing for molossid bats

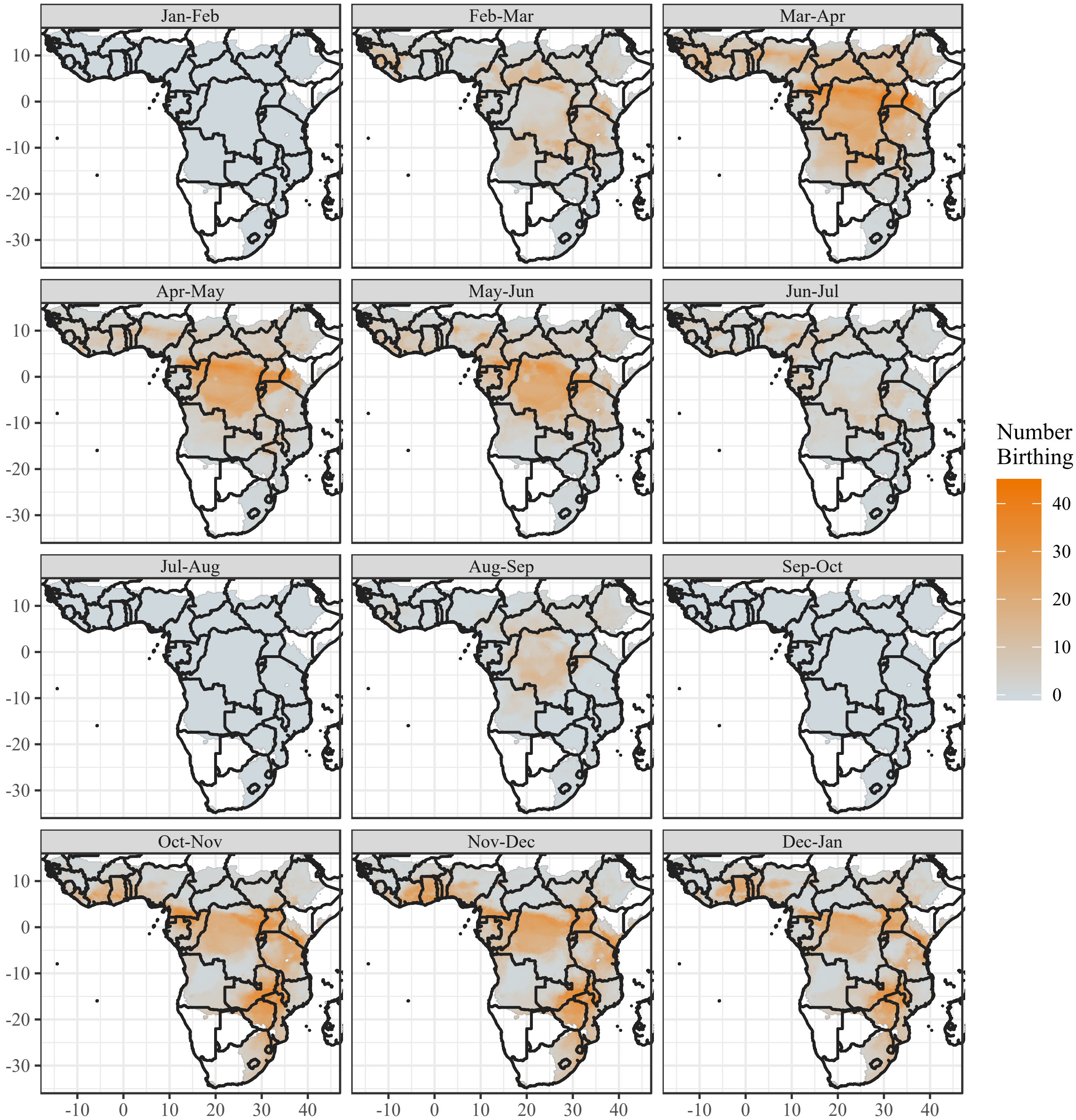

Figure 3: Monthly probability of birthing for non-molossid microbats

No models were generated for January-February or July-August.

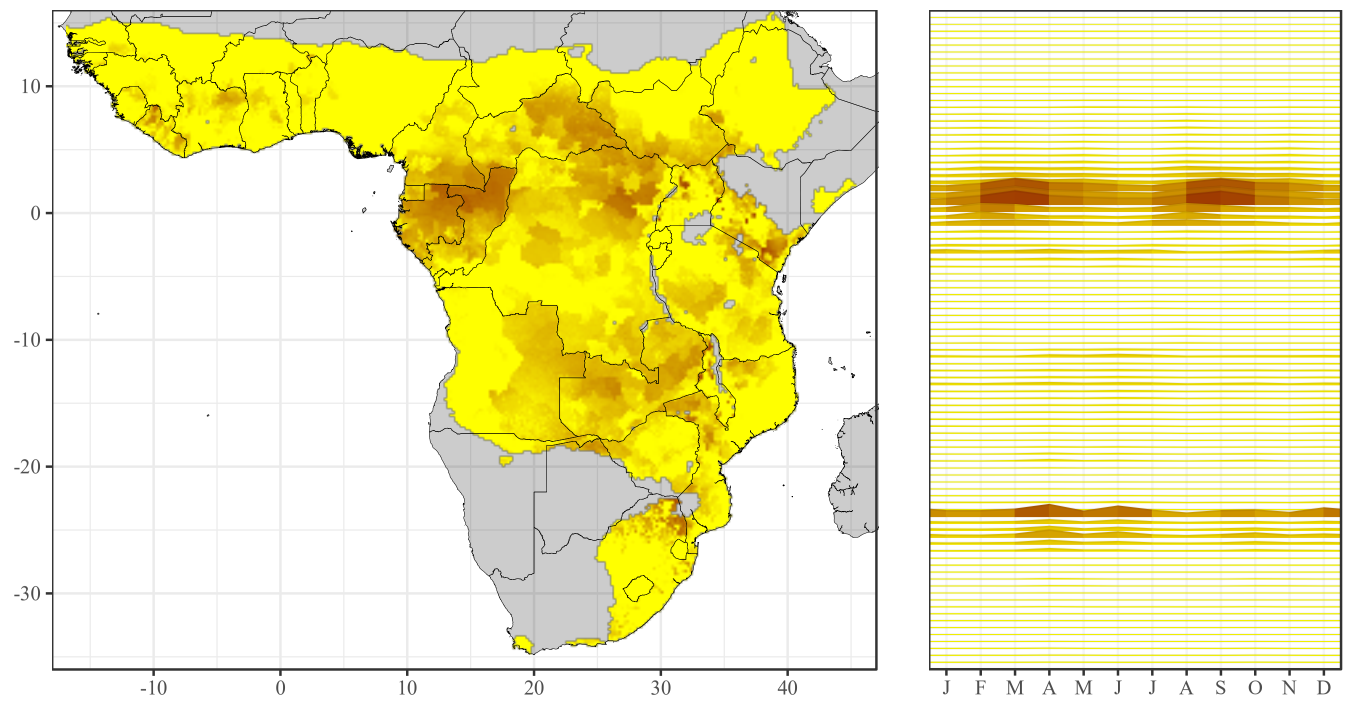

Figure 4: *Left:* Mean risk of EVD spillover to non-human reservoir hosts. *Right:* Risk of EVD spillover aggregated by latitude and month.

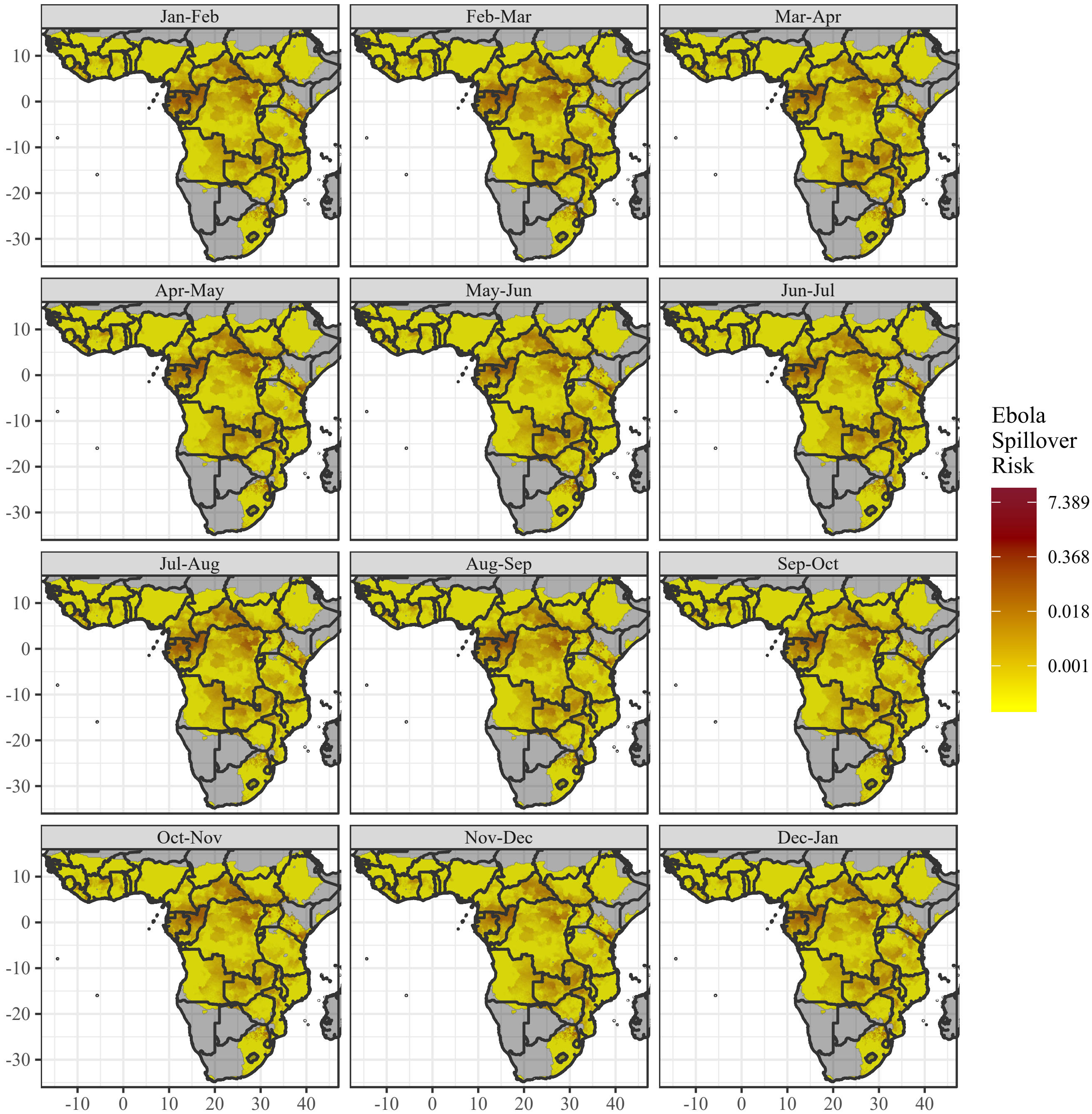

Figure 5: Monthly risk of ebolavirus spillover to non-human spillover hosts

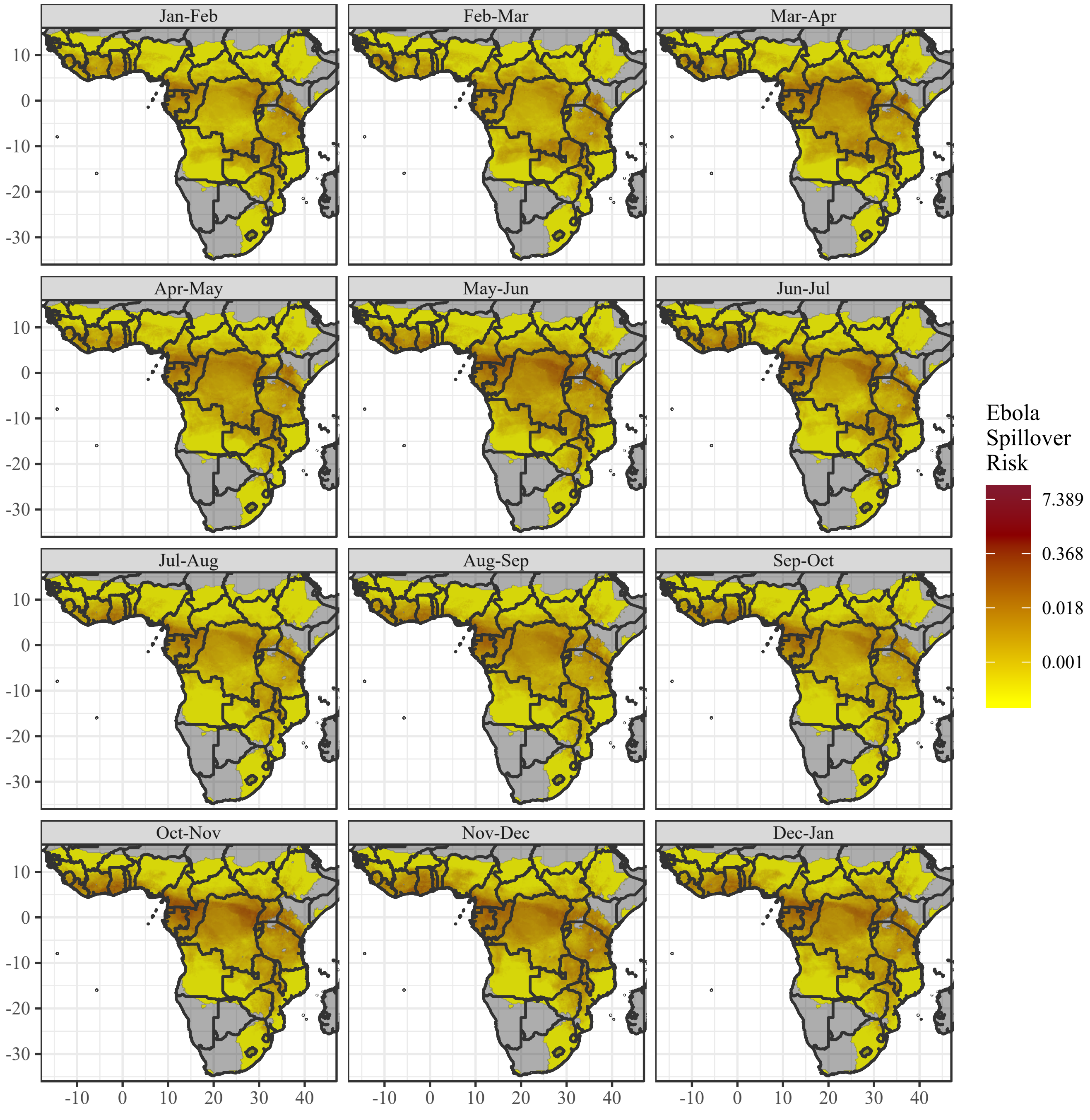

Figure 6: Monthly risk ebolavirus spillover into humans

References

[1] Han BA, Schmidt JP, Alexander LW, Bowden SE, Hayman DTS, Drake JM. Undiscovered Bat Hosts of Filoviruses. PLoS Neglected Tropical Diseases. 2016;10(7):1–10.

[2] Walsh PD, Biek R, Real LA. Wave-like spread of Ebola Zaire. PLoS Biology. 2005;3(11):1946–1953.

[3] Nowak RM. Walker's Bats of the World. Baltimore: John's Hopkins Iniversity Press; 1994.

[4] Cumming GS, Bernard RTF. Rainfall, Food Abundance and Timing of Parturition in African Bats. Oecologia. 1997;111(3):309–317.

[5] IUCN. Terrestrial Mammals Red List Spatial Data. The IUCN Red List of Threatened Species. 2016;Available from: http://www.iucnredlist.org.

[6] Olivier A, Ramos Perez JJ, Kalogirou V, Bontemps S, Defourny P, Van Bogaert E. Global Land Cover Map for 2009 (GlobCover 2009); 2012. Available from: https://doi.org/10.1594/PANGAEA.787668.

[7] Frick SE, Hijmans RJ. Worldclim 2: New 1-km spatial resolution climate surfaces for global land arease. Internation Journal of Climatology. 2017;.

[8] Trabucco A, Zomer RJ. Global Aridity Index (Global-Aridity) and Global Potential Evapo-Transpiration (Global-PET) Geospatial Database. CGIAR Consortium for Spatial Information. 2009;Available from: http://www.csi.cgiar.org.

[9] Huete A, Didan K, Miura T, Rodriguez E, Gao X, Ferreira L. Overview of the radiometric and biophysical performance of the MODIS vegetation indices. Remote Sensing of the Environment. 2002;83(1-2):195–213.

[10] Schmidt JP, Park AW, Kramer AM, Han BA, Alexander LW, Drake JM. Spatiotemporal fluctuations and triggers of ebola virus spillover. Emerging Infectious Diseases. 2017;23(3):415–422.

[11] Team RC. R: A Language and Environment for Statistical Computing. Vienna, Austria; 2017. Available from: https://www.r-project.org/.

[12] Pebesma E, Bivand R. Classes and methods for spatial data in R. R News. 2005;5(2):9–13. Available from: https://cran.r-project.org/doc/Rnews/.

[13] Hijmans RJ. raster: Geographic Data Analysis and Modeling. R package version 25-8. 2016;Available from: https://cran.r-project.org/package=raster.

[14] Bivand R, Keitt T, Rowlinson B. rgdal: Bindings for the Geospatial Data Abstraction Library; 2017. Available from: https://cran.r-project.org/package=rgdal.

[15] Chamberlain SA, Szöcs E. taxize: taxonomic search and retrieval in R. F1000Research. 2013 oct;191:1–28. Available from: http://f1000research.com/articles/2-191/v2.

[16] Pau G, Fuchs F, Skylar O, Boutros M, Huber W. EBImage—an R package for image processing with applications to cellular phenotypes. Bioinformatics. 2010;26(7):979–981.

[17] Leutner B, Horning N. RStoolbox: Tools for Remote Sensing Data Analysis; 2017. Available from: https://cran.r-project.org/package=RStoolbox.

[18] Thuiller CW. biomod2: Ensemble Platform for Species Distribution Modeling; 2017. Available from: https://r-forge.r-project.org/projects/biomod/.

[19] Wolton RJ, ARAK PA, Godfray HCJ, Wilson RP. Ecological and behavioural studies of the Megachiroptera at Mount Nimba, Liberia, with notes on Microchiroptera. Mammalia. 1982;46(4):419–448. Available from: http://www.degruyter.com/view/j/mamm.1982.46.issue-4/mamm.1982.46.4.419/mamm.1982.46.4.419.xmlhttps://www.degruyter.com/view/j/mamm.1982.46.issue-4/mamm.1982.46.4.419/mamm.1982.46.4.419.xml.

[20] Mutere FA. The breeding biology of equatorial vertebrates: reproduction in the fruit bat, Eidolon helvum, at latitude 0.20N. Journal of Zoology. 1967;153(2):153–161. Available from: http://doi.wiley.com/10.1111/j.1469-7998.1967.tb04058.x.

[21] Thomas DW. The annual migrations of three species of West African fruit bats (Chiroptera: Pteropodidae). Canadian Journal of Zoology. 1983 oct;61(10):2266–2272. Available from: http://www.nrcresearchpress.com/doi/abs/10.1139/z83-299.

[22] Funmilayo O. Ecology of the Straw-colored fruit bat Eidolon helvum in Nigeria. Revue de Zoologie Africaine. 1979;93(3):589–600.

[23] Fayenuwo JO, Halstead LB. Breeding Cycle of Straw-Colored Fruit Bat, Eidolon helvum, at Ile-Ife, Nigeria. Journal of Mammalogy. 1974;55(2):453–454. Available from: http://jmammal.oxfordjournals.org/cgi/doi/10.2307/1379016.

[24] Coe M. Mammalian ecological studies on Mount Nimbia, Liberia. Mammalia. 1975;39(4). Available from: https://www.degruyter.com/view/j/mamm.1975.39.issue-4/mamm.1975.39.4.523/mamm.1975.39.4.523.xml.

[25] Marshall AG, McWilliam AN. Ecological observations on epomorphorine fruit-bats (Megachiroptera) in West African savanna woodland. Journal of Zoology. 1982;198(1):53–67. Available from: http://doi.wiley.com/10.1111/j.1469-7998.1982.tb02060.x.

[26] Thomas DW, Marshall AG. Reproduction and growth in three species of West African fruit bats. Journal of Zoology. 1984;202(2):265–281. Available from: http://doi.wiley.com/10.1111/j.1469-7998.1984.tb05954.x.

[27] Okia NO. The breeding pattern of the eastern epauletted bat, Epomophorus anurus Heuglin, in Uganda. Journal of reproduction and fertility. 1974;37(1):27–31. Available from: http://www.ncbi.nlm.nih.gov/pubmed/4816945.

[28] Monadjem A, Reside AE. Breeding Season of Epomophorus walhbergi in the Lowveld of Swaziland. African Zoology. 2012 oct;47(2):321–325. Available from: http://www.bioone.org/doi/abs/10.3377/004.047.0217.

[29] Wickler W, Seibt U. Field studies on the African fruit bat Epomophorus wahlbergi (Sundevall), with special reference to male calling. Zeitschrift für Tierpsychologie. 1976;40(4):345–376. Available from: http://eutils.ncbi.nlm.nih.gov/entrez/eutils/elink.fcgi?dbfrom=pubmed{&}id=936788{&}retmode=ref{&}cmd=prlinks{%}5Cnpapers3://publication/uuid/1F2488D4-D27A-4B8C-8351-9A5299D0DBD3.

[30] Kofron CP, Champan A. Reproduction and sexual dimorphism of the West African fruit bat, Epomops buettikoferi, in Liberia. African Journal of Ecology. 1994;32(4):308–316.

[31] Bergmans W. Taxonomy and Zoogeography of the fruit bats of the peoples republic of Congo, with Notes on their reporductive biology. Bijdragen tot de Dierkunde. 1979;48:161–186.

[32] King T, Dallimer M. The fruit bats (Chiroptera: Pteropodidae) of the Lesio-Louna Reserve, Bateke Plateau, Republic of Congo. Mammalia. 2010;74(1):63–69.

[33] Bradbury JW. Lek Mating Behavior in the Hammer-headed Bat. Zeitschrift für Tierpsychologie. 2010 apr;45(3):225–255. Available from: http://doi.wiley.com/10.1111/j.1439-0310.1977.tb02120.x.

[34] Kingdon J. East African mammals IIA. Insectivores and bats. London: Academic Press; 1974.

[35] Bergmans W. A revision of the African genus Myonycteris Matschie, 1899 (Mammalia, Megachiroptera). Beaufortia. 1976;24(317):189–216. Available from: http://www.repository.naturalis.nl/record/504729{%}5Cnhttp://www.repository.naturalis.nl/document/548386.

[36] Okia NO. Reproductive Cycles of East African Bats. Journal of Mammalogy. 1987;68(1):138–141.

[37] Verschuren J. Ecologie, biologie, et systématique des Chiroptères. Journal of Mammalogy1. 1957;58:469–478.

[38] Hill JE, Morris P. Bats from Ethiopoa collected by the great Abbai Expedition. Zoology. 1971;21(2):27–49.

[39] Herzig-Straschil B, Robinson GA. On the ecology of the fruit bat, rousettus aegyptiacus leachi (A. Smith, 1829) in the Tsitsikama Coastal National Park. Koedoe. 1978;21(1):101–110. Available from: http://www.koedoe.co.za/index.php/koedoe/article/view/965.

[40] Jacobsen NHG, Du Plessis E. Observations on the ecology and biology of the Cape Fruit Bat Rousettus aegyptiacus Leachi in the Eastern Transvaal. South African Journal of Science. 1976;72:270–273.

[41] Adam JP, Le Pont F. Les chiroptères cavernicoles de la République Populaire du Congo : notes bioécologiques et parasitologiques. Annales de Spéléologie. 1974;29(1):143–154.

[42] Anderson J, De Winton WE. Zoology of Egypt: Mammalia; 1902.

[43] Mutere FA. The breeding biology of the fruit bat Rosettuus aegyptiacus living at 0 degrees 22 minutes South. Acta Tropica1. 1968;25(2):97–108.

[44] van der Merwe M, Rautenbach IL. Reproduction in Schlieffen's bat, Nycticeius schlieffenii, in the eastern Transvaal lowveld, South Africa. Journal of Reproduction & Fertility. 1987;81(September):41–50.

[45] Happold DC, Happold M. Reproduction of Angola free-tailed bats (Tadarida condylura) and little free-tailed bats (Tadarida pumila) in Malawi (Central Africa) and elsewhere in Africa. Journal of reproduction and fertility. 1989;85(1):133–149.

[46] Mutere FA. Reproduction in two species of equatorial free-tailed bats (Molossidae). African Journal of Ecology. 1973 dec;11(3-4):271–280. Available from: http://doi.wiley.com/10.1111/j.1365-2028.1973.tb00092.x.

[47] Mcwilliam AN. Polyoestry and postpartum oestrus in Tadarida (Chaerephon) pumila (Chiroptera: Molossidae) in northern Ghana, West Africa. Journal of Zoology. 1987 dec;213(4):735–739. Available from: http://doi.wiley.com/10.1111/j.1469-7998.1987.tb03738.x.

[48] Monadjem A, Monadjem L, Putnam J. Notes and Records. African Journal of Ecology. 1998 sep;36(3):280–285. Available from: http://doi.wiley.com/10.1046/j.1365-2028.1998.00136.x.

[49] Vivier L, van der Merwe M. Aspects of the histology of reproduction in the female Angolan free-tailed bat Mops condylurus (Microchiroptera: Molossidae) in Mpumalanga, South Africa. Journal of Zoology. 2001;254(4):495–504. Available from: http://doi.wiley.com/10.1017/S0952836901000991.

[50] O'Shea TJ, Vaughan TA, O'SHEA TJ, Vaughan TA. Ecological observations on an East African bat community. Mammalia. 1980;44(4):485–496. Available from: https://www.degruyter.com/view/j/mamm.1980.44.issue-4/mamm.1980.44.4.485/mamm.1980.44.4.485.xmlhttp://www.degruyter.com/view/j/mamm.1980.44.issue-4/mamm.1980.44.4.485/mamm.1980.44.4.485.xml.

[51] Smithers RHN. The mammals of Botswana. Trustees of the National Museums of Rhodesia; 1971.

[52] Bernard RTF, Tsita JN. Seasonally monoestrous reproduction in the molossid bat, Tadarida aegyptiaca from low temperate... South African Journal of Zoology. 1995;30(1):18. Available from: http://ezproxy.stir.ac.uk/login?url=http://search.ebscohost.com/login.aspx?direct=true{&}db=asx{&}AN=9609194475{&}site=eds-live.

[53] Cotterill FPD, Fergusson RA. Seasonally Polyestrous Reproduction in a Free-Tailed Bat Tadarida fulminans (Microchiroptera: Molossidae) in Zimbabwe. Biotropica VO - 25. 1993;25(4):487. Available from: http://ezproxy.stir.ac.uk/login?url=http://search.ebscohost.com/login.aspx?direct=true{&}db=edsjsr{&}AN=edsjsr.10.2307.2388875{&}site=eds-live.

[54] Vaughan TA. Nocturnal Behavior of the African False Vampire Bat (Cardioderma cor). Journal of Mammalogy. 1976 may;57(2):227–248. Available from: https://academic.oup.com/jmammal/article-lookup/doi/10.2307/1379685.

[55] Happold M, Happold DCD. Mammals of Africa Volume IV - Hedgehogs, Shrews and Bats. London: Bloomsbury; 2013.

[56] Brosset A. La biologie des chiropteres. Paris: Masson and Company; 1966.

[57] Bernard RTF, Meester JAJ. Female reproduction an dthe female reproductive cycle of Hipposideros caffer caffer in Natal, South Africa. Annals of the Transvaal Museum. 1982;33(8):131–144.

[58] Ansell WFH. Some Chiroptera from south-central Africa. Mammalia. 1986;50(4):507–520. Available from: http://www.degruyter.com/view/j/mamm.1986.50.issue-4/mamm.1986.50.4.507/mamm.1986.50.4.507.xml.

[59] Menzies JI. A Study of Leaf-Nosed Bats (Hipposideros caffer and Rhinolophus landeri) in a Cave in Northern Nigeria. Journal of Mammalogy. 1973 dec;54(4):930–945. Available from: https://academic.oup.com/jmammal/article-lookup/doi/10.2307/1379087http://jmammal.oxfordjournals.org/cgi/doi/10.2307/1379087.

[60] Mcwilliam AN. Adaptive responses to seasonality in four species of insectivorous bats in costal Kenya. University of Aberdeen; 1982.

[61] Brosset A. La vie sociale des oiseaux dans une foret equitoriale du Gabon; 1969.

[62] Howell K. An ecological study of three species of insectivorous bats near Kisarawe, Tanzania. University of Dar es Salaam; 1976.

[63] Cotterill FPD, Fergusson RA. Reproductive ecology of Commerson's leaf-nosed bats Hipposidores commersoni (Chiroptera: Hipposideridae) in South-Central Africa: interactions between seasonality and large body size; and implications for conservation. South African Journal of Zoology. 1999;34(2):53–63. Available from: http://content.ajarchive.org/cgi-bin/showfile.exe?CISOROOT=/00445096{&}CISOPTR=1371{%}5Cnhttp://hdl.handle.net/10499/AJ20407.

[64] Vaughan TA, Vaughan RP, Bat Yw, Vaughan TA, Vaughan RP. Seasonality and the Behavior of the African Yellow-Winged. Journal of Mammalogy. 1986;67(1):91–102.

[65] Bernard RTF. Reproductive cycles of Miniopterus schreibersi natalensis (Kuhl, 1819) and Miniopterus fraterculus Thomas and Swann, 1906. Annals of the Transvaal Museum. 1980;32(3):55–64. Available from: http://journals.co.za/content/nfi{_}annalstm/32/3/AJA00411752{_}185.

[66] McWilliam AN. The reproductive cycle of male tomb bats, Taphozous hildegardeae (Chiroptera: Emballonuridae), in a seasonal environment of the African tropics. Journal of Zoology. 1988 jul;215(3):433–442. Available from: http://doi.wiley.com/10.1111/j.1469-7998.1988.tb02850.x.

[67] Bernard RTF, Cotterill FPD, Fergusson RA. On the occurance of a short period of delayed implantation in Schreibers' long-fingered bat (Miniopterus schreibersii) from a tropical latitude in Zimbabwe. Journal of Zoology, London. 1996;238:13–22.

[68] Bernard RT, Bojarski C. Effects of prolactin and hCG treatment on luteal activity and the conceptus during delayed implantation in Schreibers' long-fingered bat (Miniopterus schreibersii). Journal of reproduction and fertility. 1994 mar;100(2):359–65. Available from: http://www.ncbi.nlm.nih.gov/pubmed/8021852.

[69] Van derMerwe M. Foetal Growth Curves and Seasonal Breeding in the Natal Clinging Bat Miniopterus Schreibersi Natalensis. South African Journal of Zoology. 1979 jan;14(1):17–21. Available from: http://www.tandfonline.com/doi/full/10.1080/02541858.1979.11447643.

[70] Bernard RTFTF. Monthly changes in the female reproductive organs and the reproductive cycle of Myotis tricolor (Vespertilionidae : Chiroptera). South African Journal of Zoology. 1981 jan;17(2):79–84. Available from: http://www.tandfonline.com/doi/full/10.1080/02541858.1982.11447784.

[71] van der Merwe M. Reproductive biology of the cape serotine bat, Eptesicus capensis in the Transvaal, South Africa. South African Journal of Zoology. 1994 jan;29(1):36–39. Available from: http://www.tandfonline.com/doi/full/10.1080/02541858.1994.11448324.

[72] van der Merwe M, van der Merwe NJ, Penzhorn BL. Aspects of reproduction in the seasonally breeding African yellow bat, Scotophilus dinganii (A. Smith, 1833). African Zoology. 2006;41(1):67–74. Available from: http://dx.doi.org/10.3377/1562-7020(2006)41[67:AORITS]2.0.CO;2.

[73] LaVal RK, LaVal ML. Reproduction and behaviour of the African Banana Bat, Pipistrellus nanus. Journal of Mammalogy. 1977 aug;58(3):403–410. Available from: http://jmammal.oxfordjournals.org/cgi/doi/10.2307/1379339.

[74] Bernard RTF, Cumming GS. African Bats: Evolution of Reproductive Patterns and Delays. The Quarterly Review of Biology. 1997;72(3):253–274.

[75] Happold DCD, Happold M. Reproductive strategies of bats in Africa. Journal of Zoology. 1990 dec;222(1990):557–583. Available from: http://doi.wiley.com/10.1111/j.1469-7998.1990.tb06014.xhttp://dx.doi.org/10.1111/j.1469-7998.1990.tb06014.x{%}5Cnhttp://onlinelibrary.wiley.com/store/10.1111/j.1469-7998.1990.tb06014.x/asset/j.1469-7998.1990.tb06014.x.pdf?v=1{&}t=gtxht5qx{&}s=35af88ad592eaed55.

[76] Fenton MB, Cumming DHM, Hutton JM, Swanepoel CM. Foraging and habitat use by Nycteris grandis (Chiroptera: Nycteridae) in Zimbabwe. Journal of Zoology. 1987 apr;211(4):709–716. Available from: http://doi.wiley.com/10.1111/j.1469-7998.1987.tb04481.x.

[77] Van der Merwe, N J Rautenbach IL, Penzhorn B. A new pattern of early embryonic development in the seasonally breeding non-hibernating lesser yellow house bat, Scotophilus borbonicus (E. Geoffroy, 1803) (Chiroptera: Vespertilionidae). Annals of the Transvaal Museum. 1988;34(24):551–556.

[78] van der Merwe M, Rautenbach IL. Reproduction in the rusty bat, Pipistrellus rusticus, in the northern Transvaal bushveld, South Africa. Journal of reproduction and fertility. 1990;89:537–542.

[79] Bernard RTF. Reproduction of Rhinolophus clivosus (Microchiroptera) in Natal, South Africa. Z Saugetierkunde. 1983;48(6):321–329.

[80] Smithers RHN, Wilson V. Check list and atlas of the mammals of Zimbabwe Rhodesia. Trustees of the National Museums and Monuments; 1979.

[81] Cotterill FPD. Female Reproduction in Two Species of Tropical Horseshoe Bats (Rhinolophidae) in Zimbabwe. Journal of Mammalogy. 1998 dec;79(4):1306–1316. Available from: https://academic.oup.com/jmammal/article-lookup/doi/10.2307/1383022.

[82] Barclay RM. No Titl Foraging behaviour of the African insectivorous bat, Scotophilus leucogastere. Biotropica. 1985;17:65–70.

[83] (CIESIN) CfIESIN, University C, FAO UNF, Programme A, (CIAT) CIdAT. Gridded Population of the World, Version 3 (GPWv3): Population Count Grid. Palisades, NY; 2005.