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Avian Behavior, Ecology, and Evolution

Diurnal and nocturnal movements of Kori Bustards in the Serengeti ecosystem

Movimientos diurnos y nocturnos de *Ardeotus kori* en el ecosistema del Serengeti

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ABSTRACT. Although Kori Bustards (*Ardeotis kori*) are reported as diurnal, the species' activity patterns have not been assessed to date. We report on the movement during different parts of the day of eight GPS-tagged individuals in the Serengeti ecosystem, Tanzania. Overall, mean distance moved was 206.2 m per hour. The shortest movements were recorded during the night (18.7 m per hour). Our results show strong support for Kori Bustards remaining mostly stationary during the nighttime compared with higher levels of movement during the day.

RESUMEN. Aunque *Ardeotis kori* es considerada una especie diurna, hasta ahora no se han evaluado los patrones de actividad de la especie. Reportamos los movimientos durante diferentes partes del día de ocho individuos marcados con GPS en el ecosistema del Serengeti, Tanzania. En general, la distancia media recorrida fue de 206.2 m por hora. Los movimientos más cortos se registraron durante la noche (18.7 m por hora). Nuestros resultados muestran un fuerte apoyo a la idea de que *A. kori* permanece mayormente estacionario durante la noche, en comparación con los mayores niveles de movimiento durante el día.

Key Words: *activity patterns, Kori Bustard, movement, time, Serengeti ecosystem*

INTRODUCTION

Animals adjust their activity patterns to fulfil their social-ecological requirements at different times of the day (Rave and Baldassarre 1989). Knowledge about activity patterns and what might affect such patterns use provides insights into individual environmental conditions as well as social aggregates of a species in question (Paulus 1988, Aissaoui et al. 2011, Abrha et al. 2018). An individual's activity patterns are related to resource needs, seasonality of resource availability, predation risk, temperature variations, and social interactions (Jacquet and Launay 1997, Mmassy et al. 2019). Movement variations have been observed in other species of Bustards including Houbara Bustards (*Chlamydotis undulata*; Abril-Colón et al. 2022) and Little Bustards (*Tetrax tetrax*; Villers et al. 2010), where short movements were performed during the night. Though some Bustards perform night movements, they are prone to deaths because of powerline collisions and other infrastructures compared to Bustards that perform daytime movements. Deaths by collisions with powerlines are recorded among many different species (Bevanger 1994, Allan 2005, Marques et al. 2021, Silva et al. 2022). Therefore, a better understanding about the extent of nocturnal movements in large flying birds is particularly valuable in developing mitigation measures for when Bustards are more prone to such collisions. Although the Kori Bustard (*Ardeotis kori*) species is reported as diurnal, there have been no efforts conducted to investigate diurnal and nocturnal movements of the species. We report results of daily movement patterns of radio-collared Kori Bustards in the Serengeti National Park, Tanzania, and assess the extent to which movement occurs at different times of day and night.

METHODS

Study area

The study was carried out in the Serengeti ecosystem, in northern Tanzania. The Serengeti ecosystem consists of Serengeti National Park, Ngorongoro Conservation Area, the Ikorongo, Maswa, and Grumeti Game Reserves, the Loliondo Game Controlled Area, and Wildlife Management areas (Fig. 1). The average annual temperature ranges from 15 °C to 27 °C and the average rainfall ranges from 550 to 1500 mm (Sinclair et al. 2000). The long rain season is from March to May and the short rain season from November to December (Sinclair 1979, Schaller 2009).

Data collection

Data on movements were collected for four individuals (three females and a male) June–September 2013, and another four individuals (three males and a female) from February to October 2014 (Appendix 1). Bird captures were performed either after the long rain season, which ends in June, or in February close to the start of the long rain season. Kori Bustards were captured during the cool morning hours (0700 to 1000). Immediately after a bird was observed, the bird was approached by vehicle at a low speed, i.e., 10 to 20 km/hour. When approximately 3–5 meters from the bird, two people jumped out of the vehicle to capture the bird by hand. This was possible because prior to the breeding season birds tend to accumulate a lot of fat, thus limiting their flight abilities (Mmassy et al. 2018). Captured individuals were fitted with GPS satellite collar transmitters (four males and four females; Appendix 1). Transmitters were attached/fixed on the back of the Kori Bustard using Teflon™ ribbon material (African Wildlife Tracking, Pretoria, South Africa). Harnessing materials were passed at the base of the neck at the back side going down and

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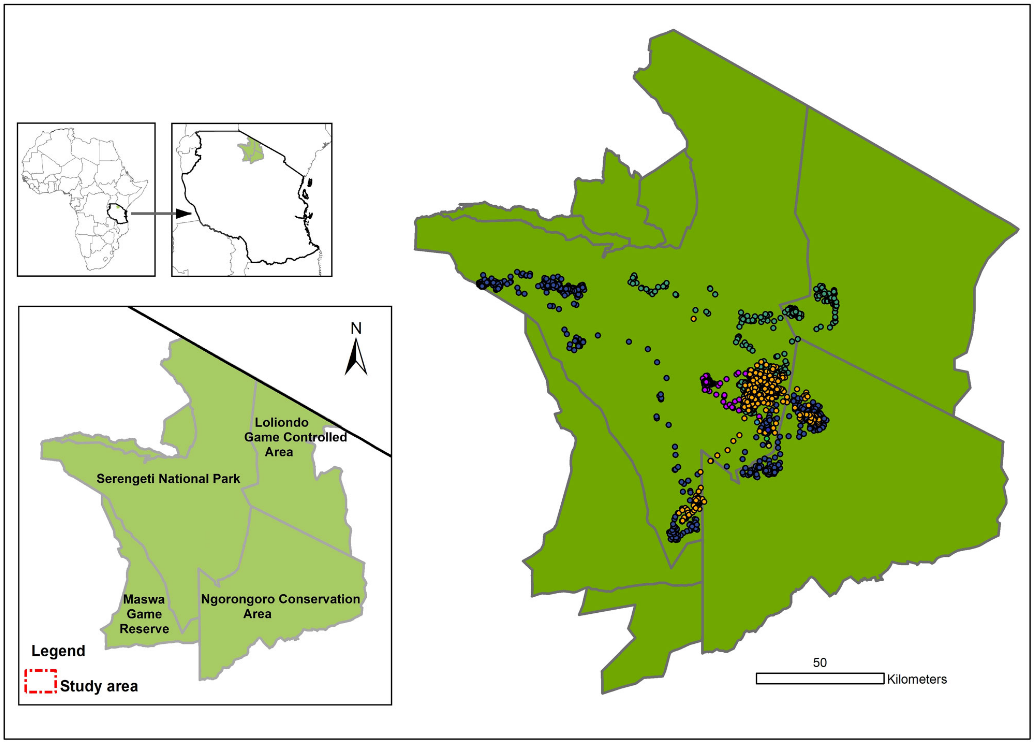
Fig. 1. Map showing diurnal movement of Kori Bustard (*Ardeotis kori*) in Serengeti ecosystem. Circles at the bottom right represent individual readings and colors indicate different collared individuals.



tied under the thorax, leaving feathers free without being touched by the Teflon ribbon. Based on this attachment method, courtship displaying male Kori Bustards could inflate their neck feathers without interfering in courtship displays. Captured Kori Bustards were not aged because long-time handling of the bird could lead to stress, which again could result in death. There was no unusual behavior or myopathy observed immediately after release or a few days after capture. We gathered data on distance moved per hour (meters), by measuring the distance between the location at time *t* and time *t*-1. The median time between readings was six hours, thus, because of the large time span between readings, we chose to group readings into three categories during the day: morning category between 0500 and 1100 (n = 254), afternoon category between 1100 and 1900 (n = 920), and night category between 2100 and 0500 hours (n = 248). All readings exceeding eight hours apart were excluded from the analysis.

Statistical methods

We assessed movement data using a generalized mixed-effects model with the R package *glmmTMB* (Brooks et al. 2015, R Core Team 2020) with a negative binomial error distribution and a log-link. As a response, we used the distance moved per hour, and as a fixed effect we added the period of the day (categorical with four levels; Table 1). To account for the effect of sex and seasonal variation, we also included sex and the month as a fixed effect, respectively (Appendix 2 and 3). Individual (i.e., collar) identity was added as a random factor to account for non-independence within individuals. In all analyses, we used R version 3.6.3 (R Core Team 2020). DHARMa diagnostics (Hartig and Hartig 2017) revealed slight deviations from assumptions in all models.

Table 1. Model output from a generalized linear mixed-effects model, using the distance moved per hour (m hr^-1) as response, in Kori Bustard (*Ardeotis kori*; n = 8) located in Greater Serengeti-Mara ecosystem in 2013 and 2014. The model contained one fixed effect (Time-of-day; 3 levels: Morning, Afternoon, and Night), and a random effect (individual identity). Morning was selected as reference level.

	Estimate	SE	*Z*	*P*
Intercept	5.85	0.16	36.70	< 0.001 ***
Time-of-day (Afternoon)	-0.42	0.04	-9.58	< 0.001 ***
Time-of-day (Night)	-2.36	0.08	-28.71	< 0.001 ***

RESULTS

For eight individuals (four males and four females) we recorded an average of 312 readings (± 190 SD) per individual. The overall mean distance moved per hour between readings was 206.2 m (± 256.1 SD). We found the shortest movements during the night period (mean = 18.7 m per hour [± 41.2 SD]; Fig. 2). The morning period showed a small but significant effect for longer movements in the morning hours compared to the afternoon (Table 2). Thus, these analyses revealed that Kori Bustards remain mostly stationary during the nighttime (Appendix 2) and perform movements primarily during daytime. There was some monthly variation in movement, which we needed to account for in our model (Table 2).

Fig. 2. Predicted mean values for movement in Kori Bustard (*Ardeotis kori*) during the day in Serengeti National Park 2013–2014. Whiskers depict 95% confidence interval.

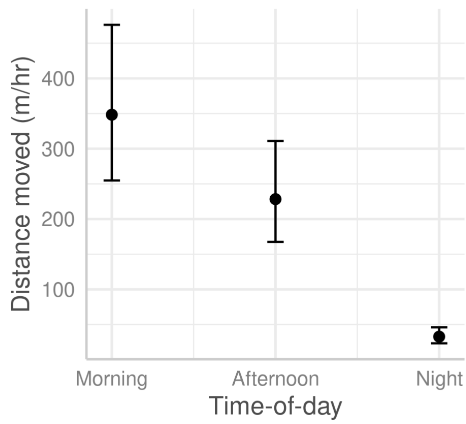


Table 2. Differences in log-transformed distance moved per hour, among periods of the day accounting for monthly variation, in Kori Bustard (*Ardeotis kori*), in the Serengeti ecosystem between 2013 and 2014. We report untransformed model outputs from a negative binomial mixed-effect model, using the distance moved per hour as response, and as fixed effects, a categorical variable containing three periods of the day and a categorical variable month (March–October). Individual identity was added as random intercept, thus accounting for non-independence among individuals. Morning and March were set as reference categories, and each category depicts the difference in distance moved from the reference.

	Estimate	SE	*z*	*P*
Intercept	5.46	0.19	28.37	< 0.001
Ref: Morning				
Afternoon	-0.16	0.07	-2.13	0.033
Night	-2.39	0.09	-27.37	< 0.001
Ref: March				
April	0.20	0.15	1.27	0.204
May	0.16	0.16	1.04	0.299
June	0.35	0.15	2.37	0.018
July	0.33	0.14	2.38	0.017
August	0.56	0.14	4.13	< 0.001
September	0.46	0.14	3.15	0.002
October	0.94	0.24	3.88	< 0.001

DISCUSSION AND CONCLUSION

The results indicated activity patterns of Kori Bustards depended on the time of day (Mmassy et al. 2019). Distances moved per hour were shortest during the night (Fig. 2; Table 2). Variations in movement during the day were most likely influenced by the Kori Bustard's feeding activity, peaking during morning hours when it was still cool and most insects were not active enough to fly far when disturbed by Kori Bustards (Mmassy et al. 2017). As observed during the field work, Kori Bustards capture more insects during the morning hours. This observation was also supported by studies that indicated insects are the main food source for Kori Bustards (Bailey and Hallager 2003, Collar and Morales 2022). Decreasing movement toward mid-day might be caused by increased heat, leading to less activity in the open grass plains (Judaset al. 2006, Mmassy et al. 2019, Collar and Morales 2022). This reduced movement might additionally be because during that hot time of the day less food was available to the birds as flying insects became more active, and creeping insects, such as beetles, buried themselves in the ground to avoid the heat (Alonso et al. 2012). Kori Bustard movements became shorter during the night, which might either be a strategy to avoid predation, or because birds were sleeping and therefore remained in a stationary state (Bailey and Hallager 2003). Feeding has been explained as the main cause affecting diurnal activities/movements in birds including Kori Bustards, though other factors such as heat and predation could be considered (Judas et al. 2006, Morales et al. 2008, Ali and Asokan 2015, Mmassy et al. 2018, Mmassy et al. 2019).

The distances moved by the Kori Bustards were shortest in May, which can be attributed to the breeding season, when most mothers have young chicks. Furthermore, the distance was longest in July (dry month), which reflects seasonal movements in Kori Bustards (Jiguet et al. 2000, Moreira et al. 2004, Mmassy et al. 2018). Meanwhile, the longer distance movements in July were driven by drought; the grass plain became drier and the species was forced to move to other habitats with better and conducive environments (Judas et al. 2006, Mmassy et al. 2018, Mmassy et al. 2019). These factors affect diurnal activities and seasonal movement inconsistences of birds including Kori Bustards (Morales et al. 2008, Ali and Asokan 2015).

We demonstrated that Kori Bustard movement was lowest during the night, and highest during the day. Though the movement rates reported were most likely much lower than actual distances moved because only undirectional movement was captured during the time between GPS readings (median 6 hours). Because the species is categorized as "Near Threatened" on the IUCN Red List, and with the continuing reduction in its range, more movement studies of the Kori Bustard over the entire Serengeti ecosystem are important to acquire better knowledge and understanding of the timing of day accounting for seasonal variation of this little studied species. As the Serengeti ecosystem is surrounded by different communities that may hunt the species, management authorities need to create awareness of the importance of the species for this iconic ecosystem and for tourism attractions.

Author Contributions:

Dr. Emmanuel Mmassy: Genesis of the study, conceptualization, data collection, original manuscript draft Dr. Peter S. Ranke: Software, analysis, and results Dr. Nicephor P. Lesio: Manuscript editing Dr. Craig Jackson: Review and editing Dr. Roel May: Manuscript editing Prof. Eivin Røskaft. Funding requisition, advice, concept proposal review, and editing of the manuscript

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Data Availability:

The data that support the findings of this study are available in this resubmission and they are attached as an appendix. RScrip.R.

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Appendix 1. Movements for four individuals (three females and a male) June – September 2013, and another four individuals (three males and a female) from February to October 2014:

Collar ID	**Sex**	**n - readings**	**Mean (m/h)**	**SD (m/h)**	**Max (m/h)**	**Deployment_start**	**Deployment_end**
631	F	293	284.1	291.2	1561.8	2013-06-13	2013-09-10
632	F	171	184.7	433.9	5170.7	2013-07-16	2013-09-02
633	F	105	208.5	208.7	1027.7	2013-07-18	2013-08-22
634	M	77	159.2	175.6	805.2	2013-07-17	2013-08-15
1279	F	703	83.9	116.5	1085.3	2014-02-26	2014-10-07
1280	M	714	178.3	214.1	2088.7	2014-02-22	2014-10-07
1281	M	706	254.1	260.0	3094.0	2014-02-26	2014-10-07
1282	M	429	234.2	185.5	1158.1	2014-02-27	2014-07-12*
*died?							

Appendix 2. Model output from a generalized linear mixed-effects model, using the distance moved per hour (m hr^-1) as response, in Kori bustard (n=8) located in Greater Serengeti-Mara Ecosystem in 2013 and 2014. The model contained "Time-of-day" (3 levels: Morning, Afternoon and Night) and Sex (2 levels: Female and Male) as fixed effects, and a random effect (individual identity). Morning and Female were selected as reference levels.

	Estimate	**SE**	***Z***	***P***
Intercept	5.75	0.20	28.62	<**0.001** ***
Time-of-day (Afternoon)	**-0.42**	**0.04**	**-9.61**	**<0.001 *** **
Time-of-day (Night)	**-2.36**	**0.08**	**-28.70**	**<0.001 *** **
Sex (Male)	0.24	0.30	0.79	0.433

Appendix 3. Model output from a generalized linear mixed-effects model, using the distance moved per hour (m hr^-1) as response, in Kori bustard (n=8) located in Greater Serengeti-Mara Ecosystem in 2013 and 2014. The model contained “Time-of-day” (3 levels: Morning, Afternoon and Night) and Month (8 levels: March-October) as fixed effects, and a random effect (individual identity). Morning and March were selected as reference levels.

	Estimate	**SE**	***Z***	***P***
Intercept	5.59	0.16	35.16	<**0.001** ***
Time-of-day(Afternoon)	**-0.42**	**0.04**	**-9.65**	<**0.001 *****
Time-of-day(Night)	**-2.41**	**0.08**	**-29.27**	<**0.001 *****
Month(Apr)	0.15	0.08	1.92	0.056 .
Month(May)	-0.02	0.08	-0.30	0.764
Month(Jun)	**0.31**	**0.08**	**4.09**	**<0.001 *****
Month(Jul)	**0.27**	**0.08**	**3.55**	**<0.001 *****
Month(Aug)	**0.42**	**0.08**	**5.51**	**<0.001 *****
Month(Sep)	**0.24**	**0.08**	**2.87**	**0.004 ****
Month(Oct)	**0.47**	**0.14**	**3.38**	**<0.001 *****

Appendix 4. Data Scripts attached as per editor's request

Please click here to download file 'appendix4.r'.