

Responses of phenology, synchrony and fecundity of breeding by African ungulates to interannual variation in rainfall

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Fig. S1. The distribution of the observed number of newborns (solid vertical bars), from the onset of the birth season (July) per adult warthog of both sexes, and the fitted model (solid black curve) with 95% confidence bands (shaded region). The dashed black vertical line marks the location of the birth peak. The population-averaged model (dashed curve) and location of peak birth month (dashed vertical line) are shown in gray.

Fig. S2. The distribution of the observed number of newborns (solid vertical bars), from the onset of the birth season (July) per adult zebra of both sexes, and the fitted model (solid black curve) with 95% confidence bands (shaded region). The dashed black vertical line marks the location of the birth peak. The population-averaged model (dashed curve) and location of peak birth month (dashed vertical line) are shown in gray.

Fig. S3. The distribution of the observed number of newborns (solid vertical bars), from the onset of the birth season (July) per adult female hartebeest, and the fitted model (solid black curve) with 95% confidence bands (shaded region). The dashed black vertical line marks the location of the birth peak. The population-averaged model (dashed curve) and location of peak birth month (dashed vertical line) are shown in gray.

Fig. S4. The distribution of the observed number of newborns (solid vertical bars), from the onset of the birth season (July) per adult female impala, and the fitted model (solid black curve) with 95% confidence bands (shaded region). The dashed black vertical line marks the location of the birth peak. The population-averaged model (dashed curve) and location of peak birth month (dashed vertical line) are shown in gray.

Fig. S5. The distribution of the observed number of newborns (solid vertical bars), from the onset of the birth season (July) per adult female giraffe, and the fitted model (solid black curve) with 95% confidence bands (shaded region). The dashed black vertical line marks the location of the birth peak. The population-averaged model (dashed curve) and location of peak birth month (dashed vertical line) are shown in gray.

Table S1. Results of the linear regression of the estimated month of birth peak, birth synchrony and peak fecundity rate divided by their respective population-averaged values (arithmetic mean for peak fecundity) for 1989–2003 on the annual, seasonal and quarterly rainfall components in the preceding (Annual1, wet1, dry1, earlywet1, latewet1, earlydry1 and latedry1) or current (Annual, wet, dry, earlywet, latewet, earlydry, latedry) year. The wet season spans November–June, whereas the late-wet season spans March–June. The Akaike information criterion-selected best models are highlighted in bold face font. R^2 is the coefficient of determination.

SAS Code. SAS (version 9.3) code used to fit the random-coefficients regression model to estimate parameters needed to calculate the timing of peak births, birth synchrony and peak fecundity rate.

```
/*-----Sample SAS Code (SAS Version 9.3) used to fit the random coefficients regression model to estimate parameters needed to calculate the timing of peak births, birth synchrony and peak fecundity rate. Zebra is used as an example species-----*/
```

```
/*1.---Birthyear starts in July of the current year and ends in June of the following year*/
```

```
/*2.---The plots option generates plots of the studentized conditional (BLUP) and marginal residuals---*/;
```

```
/*3.---Newborn is the count total of the newborn calves in each birth month. Birth month is defined as 1 for July for the current year and 12 for June of the following year---*/
```

```
/*4.---m is the birth month whereas m2 is  $m \times m$ .
```

```
/*5.---logfemales is the natural logarithm of the count total of the adult male and female zebra in each month----*/.
```

```
/*6.---mu, lower and upper are the predicted number of newborn and its lower and upper pointwise 95% confidence limits on the original or inverse link scale--*/
```

```
/*7.---This model was used for all the species with two minor modifications for topi, warthog and impala. For topi and warthog the statement requesting for an overdispersion parameter for the negative binomial model:- Random _residual_ /subject=birthyear; was dropped since allowing for overdispersion brought no improvement compared to not doing so. For impala the overdispersion parameter was allowed to vary across four groups of birthyears defined as follows: Group1: Drought years (1993,1997, 1999,2000), Group 2: Average years (1989,1990,1991,1992,1995,1996,1994), Group 3: wet years (2001,2002,2003) and Group 4: Flood years (1998)-*/.
```

```
/*8.----Detailed documentation for the other glimmix procedure statements and options can be found in SAS user's guides freely available online ----*/
```

```
ods graphics on;
```

```
ods output tests3=conception_tests3
```

```
Parameterestimates=conception_sol(where=(Effect ^= 'Scale'))
```

```
covb=conception_covb
```



```

SolutionR=conception_solR estimates=estimates;
Proc glimmix data=Conception Noclprint Method=RSPL ic=pq initglm
plots=(studentpanel (BLUP Marginal));
where species in ('Zebra');
by species;
class birthyear ;
Model newborn= m m2 / dist=negbin link=log solution covb offset=logfemales cl;
Random int m m2/sub=birthyear type=un s;
Random _residual_ /subject=birthyear;
output out=Pred Pred(ilink)=mu LCL(ilink)=lower UCL(llink)=Upper;
nloptions tech=NMSIMP Maxiter=200000 maxfunc=200000 ;

```

```

/*9. ---Compute the variance of each random linear slope of month for each year---
*/

```

```

estimate '1989' | m 1/ subject 1 0;
estimate '1990' | m 1/ subject 0 1;
estimate '1991' | m 1/ subject 0 0 1;
estimate '1992' | m 1/ subject 0 0 0 1;
estimate '1993' | m 1/ subject 0 0 0 0 1;
estimate '1994' | m 1/ subject 0 0 0 0 0 1;
estimate '1995' | m 1/ subject 0 0 0 0 0 0 1;
estimate '1996' | m 1/ subject 0 0 0 0 0 0 0 1;
estimate '1997' | m 1/ subject 0 0 0 0 0 0 0 0 1;
estimate '1998' | m 1/ subject 0 0 0 0 0 0 0 0 0 1;
estimate '1999' | m 1/ subject 0 0 0 0 0 0 0 0 0 0 1;
estimate '2000' | m 1/ subject 0 0 0 0 0 0 0 0 0 0 0 1;
estimate '2001' | m 1/ subject 0 0 0 0 0 0 0 0 0 0 0 0 1;
estimate '2002' | m 1/ subject 0 0 0 0 0 0 0 0 0 0 0 0 0 1;

```

```

/*10.---Compute the variance of each random quadratic slope of month for each
birth year---*/

```

```

estimate '1989' | m2 1/ subject 1 0;
estimate '1990' | m2 1/ subject 0 1;
estimate '1991' | m2 1/ subject 0 0 1;
estimate '1992' | m2 1/ subject 0 0 0 1;
estimate '1993' | m2 1/ subject 0 0 0 0 1;
estimate '1994' | m2 1/ subject 0 0 0 0 0 1;
estimate '1995' | m2 1/ subject 0 0 0 0 0 0 1;
estimate '1996' | m2 1/ subject 0 0 0 0 0 0 0 1;
estimate '1997' | m2 1/ subject 0 0 0 0 0 0 0 0 1;
estimate '1998' | m2 1/ subject 0 0 0 0 0 0 0 0 0 1;
estimate '1999' | m2 1/ subject 0 0 0 0 0 0 0 0 0 0 1;
estimate '2000' | m2 1/ subject 0 0 0 0 0 0 0 0 0 0 0 1;
estimate '2001' | m2 1/ subject 0 0 0 0 0 0 0 0 0 0 0 0 1;
estimate '2002' | m2 1/ subject 0 0 0 0 0 0 0 0 0 0 0 0 0 1;

```

/*11.---Compute the variance of the sum of the linear and quadratic random slopes of month for each year---*/

```
estimate '1989' | m 1 m2 1 / subject 1 0;  
estimate '1990' | m 1 m2 1 / subject 0 1;  
estimate '1991' | m 1 m2 1 / subject 0 0 1;  
estimate '1992' | m 1 m2 1 / subject 0 0 0 1;  
estimate '1993' | m 1 m2 1 / subject 0 0 0 0 1;  
estimate '1994' | m 1 m2 1 / subject 0 0 0 0 0 1;  
estimate '1995' | m 1 m2 1 / subject 0 0 0 0 0 0 1;  
estimate '1996' | m 1 m2 1 / subject 0 0 0 0 0 0 0 1;  
estimate '1997' | m 1 m2 1 / subject 0 0 0 0 0 0 0 0 1;  
estimate '1998' | m 1 m2 1 / subject 0 0 0 0 0 0 0 0 0 1;  
estimate '1999' | m 1 m2 1 / subject 0 0 0 0 0 0 0 0 0 0 1;  
estimate '2000' | m 1 m2 1 / subject 0 0 0 0 0 0 0 0 0 0 0 1;  
estimate '2001' | m 1 m2 1 / subject 0 0 0 0 0 0 0 0 0 0 0 0 1;  
estimate '2002' | m 1 m2 1 / subject 0 0 0 0 0 0 0 0 0 0 0 0 0 1;
```

```
run;  
ods graphics off;
```

/*12.---Compute the covariance of the linear and quadratic random slopes of month for each birth year using the estimated parameters and the standard result:

$$\text{Cov}(X, Y) = \frac{1}{2}(\text{var}(X + Y) - \text{var}(X) - \text{var}(Y)).$$