Infanticide by females is a leading source of juvenile mortality in a large social carnivore

Ally K. Brown[1,4], Malit O. Pioon[4], Kay E. Holekamp[1,2,3,4], Eli D. Strauss[1,2,3,4,5]

[1]Department of Integrative Biology, Michigan State University, East Lansing, Michigan
[2]Program in Ecology, Evolutionary Biology, and Behavior, Michigan State University, East Lansing, Michigan
[3]BEACON Center for the Study of Evolution in Action, Michigan State University, East Lansing, Michigan
[4]Mara Hyena Project, Michigan State University, Masai Mara National Reserve, Kenya
[5]Department of Collective Behavior, Max Planck Institute of Animal Behavior, Konstanz, Germany

Supplemental Material for Brown et al. 2021, *The American Naturalist*

Correspondence: Eli D Strauss - straussed@gmail.com

1. Posthumous care by mother

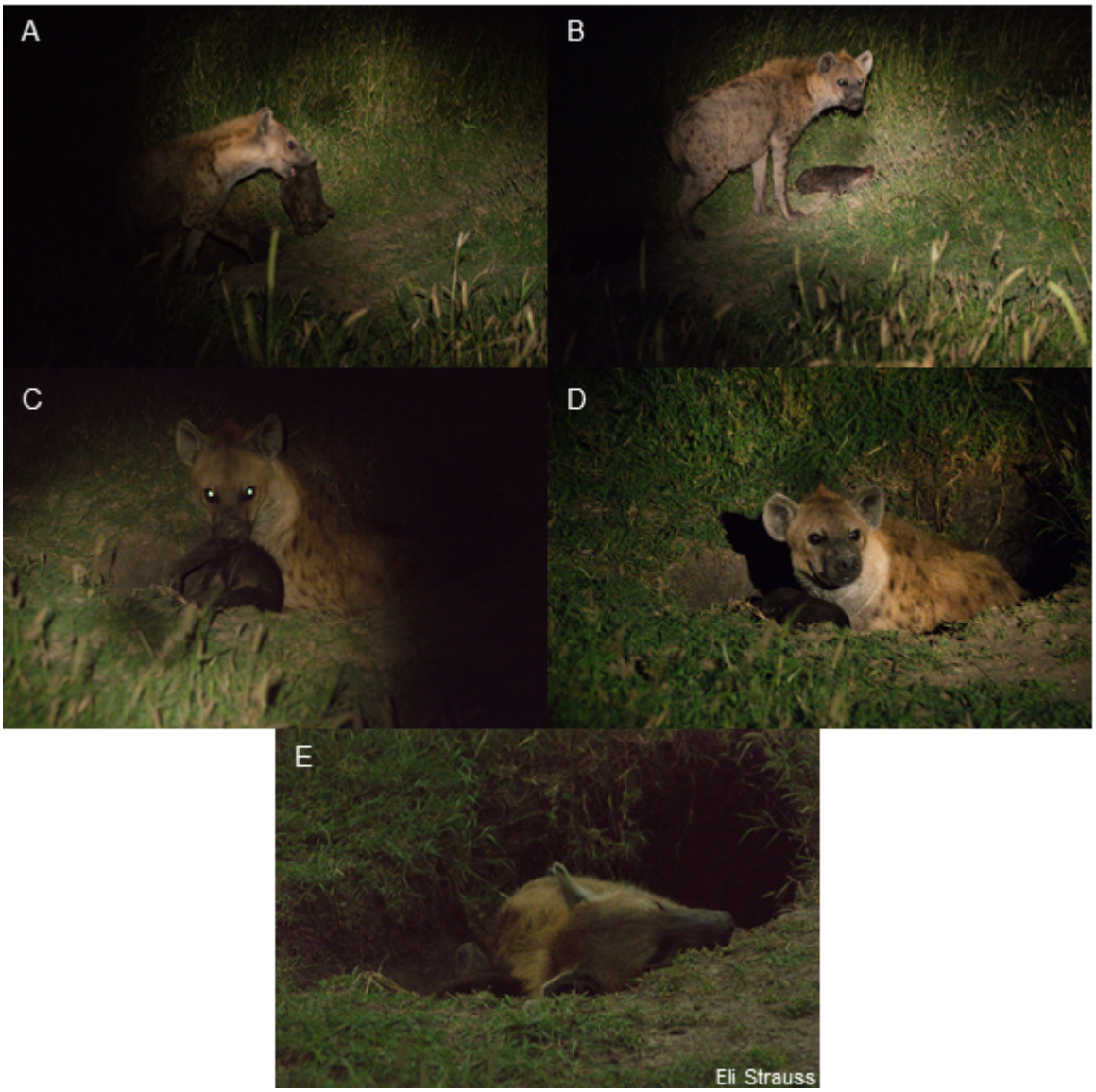

Figure S1. A mother showing posthumous care for her cub that had suffered infanticide. She defended it from others, moved it in and out of the den, and groomed it. Note the atypical way she is carrying her cub in panel A; cubs are typically carried by the head or the nape of the neck, as in other carnivores. When observers left her, she was sleeping next to the body of her dead cub (panel E).

2. Model detail for mortality ~ age at death

Here we used a multinomial model of mortality source as a function of age at death to understand the contribution of different mortality sources to overall juvenile mortality. This model was initialized with weak, uninformative priors, and four chains were run for 30000 iterations each (15000 warmup). To determine convergence, we visually examined rank plots of MCMC chains (not pictured) and confirmed that the potential scale reduction factor (R-hat) was less than 1.1 (in all cases R-hat < 1.001).

```
## MODEL SPECIFICATION:
##
## Family:  multinomial
## Formula:  y | trials(1) ~ 1 + age_at_death
## Number of observations:  66
## Samples:  4 chains, each with iter =  30000 ; warmup =  15000 ; thin =  1
##
## PRIORS:
##
## b_muhuman ~ (flat)
## b_muhuman_age_at_death ~ (flat)
## b_mulion ~ (flat)
## b_mulion_age_at_death ~ (flat)
## b_muother ~ (flat)
## b_muother_age_at_death ~ (flat)
## b_musiblicide ~ (flat)
## b_musiblicide_age_at_death ~ (flat)
## b_mustarvation ~ (flat)
## b_mustarvation_age_at_death ~ (flat)
## Intercept_muhuman ~ student_t(3, 0, 2.5)
## Intercept_mulion ~ student_t(3, 0, 2.5)
## Intercept_muother ~ student_t(3, 0, 2.5)
## Intercept_musiblicide ~ student_t(3, 0, 2.5)
## Intercept_mustarvation ~ student_t(3, 0, 2.5)
##
## MODEL OUTPUT:
##                          Estimate Est.Error l-95% CI u-95% CI
## starvation_Intercept      -2.8829    0.8981  -4.7875  -1.2587
## lion_Intercept            -4.0220    1.0425  -6.2429  -2.1704
## siblicide_Intercept       -0.1496    0.7128  -1.5644   1.2389
## human_Intercept           -5.1478    1.4012  -8.1956  -2.7240
## other_Intercept           -1.0379    0.6870  -2.4335   0.2622
## starvation_age_at_death    0.6362    0.2286   0.2187   1.1211
## lion_age_at_death          0.9475    0.2358   0.5308   1.4510
## siblicide_age_at_death    -0.4732    0.3763  -1.2767   0.1894
## human_age_at_death         0.9693    0.2672   0.4898   1.5368
## other_age_at_death         0.1158    0.2485  -0.3829   0.6001
##
## MODEL DIAGNOSTICS:
##                            Rhat Bulk_ESS Tail_ESS
## starvation_Intercept     1.0001    50801    39332
## lion_Intercept           1.0001    42895    37122
## siblicide_Intercept      1.0001    44791    47705
## human_Intercept          1.0001    40295    34513
## other_Intercept          1.0000    50117    44319
## starvation_age_at_death 1.0001    26098    29220
## lion_age_at_death        1.0000    25263    28857
## siblicide_age_at_death   1.0000    31527    31187
## human_age_at_death       1.0000    26122    28859
## other_age_at_death       1.0000    27555    33805
```

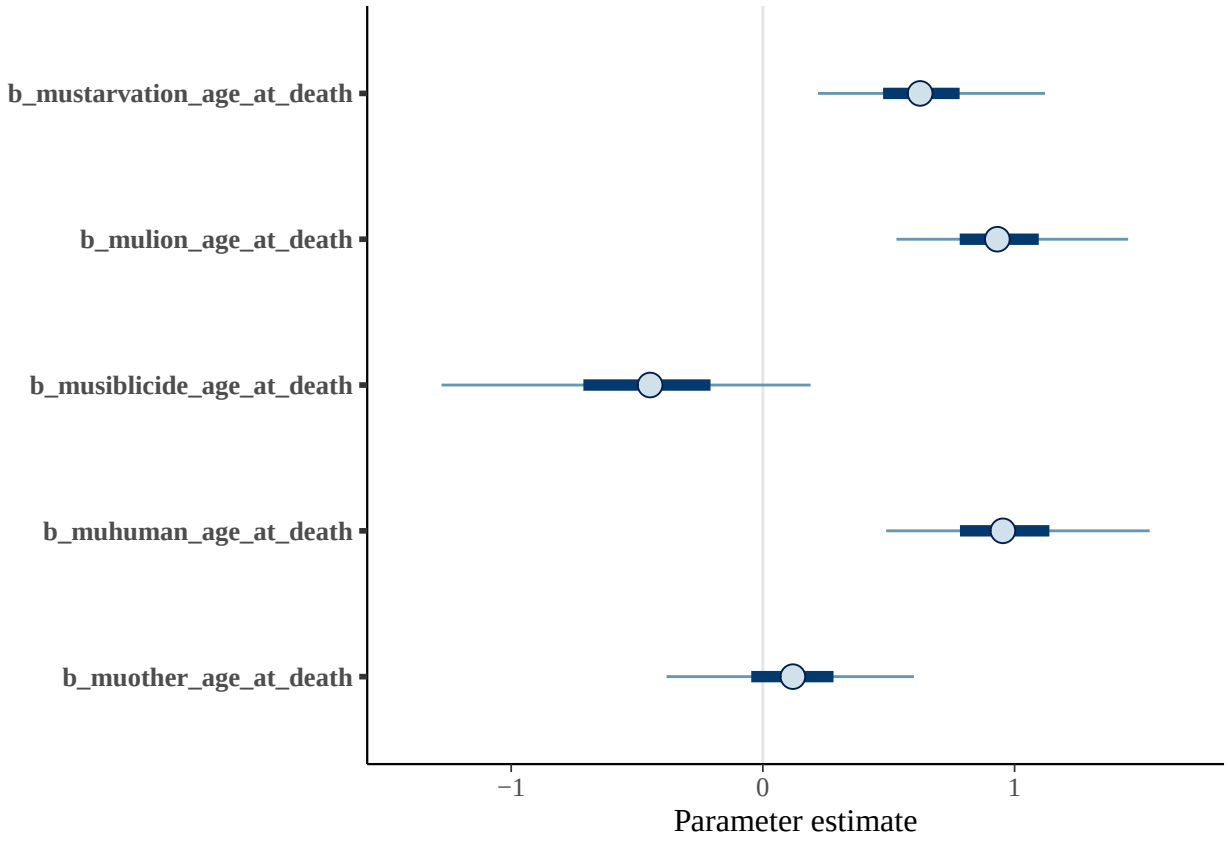

Figure S2. Interval plot showing parameter estimates and associated 50% and 95% credible intervals for the effect of age at death on the probability of different mortality sources. Infanticide is the reference level, so parameter estimates represent the log odds ratio of each mortality source relative to infanticide.

3. Model detail for mortality source ~ prey density

Here we used a multinomial model of mortality source as a function of prey density in the month before death. This model was initialized with weak, uninformative priors, and four chains were run for 30000 iterations each (15000 warmup). To determine convergence, we visually examined rank plots of MCMC chains (not pictured) and confirmed that the potential scale reduction factor (R-hat) was less than 1.1 (in all cases R-hat < 1.001).

```
## MODEL SPECIFICATION:
##
## Family:  multinomial
## Formula:  y | trials(1) ~ 1 + prey_density
## Number of observations:  85
## Samples:  4 chains, each with iter =  30000 ; warmup =  15000 ; thin =  1
##
## PRIORS:
##
## b_mudeathofmother ~ (flat)
## b_mudeathofmother_prey_density ~ (flat)
## b_muhuman ~ (flat)
```

```
## b_muhuman_prey_density ~ (flat)
## b_mulion ~ (flat)
## b_mulion_prey_density ~ (flat)
## b_muother ~ (flat)
## b_muother_prey_density ~ (flat)
## b_musiblicide ~ (flat)
## b_musiblicide_prey_density ~ (flat)
## b_mustarvation ~ (flat)
## b_mustarvation_prey_density ~ (flat)
## Intercept_mudeathofmother ~ student_t(3, 0, 2.5)
## Intercept_muhuman ~ student_t(3, 0, 2.5)
## Intercept_mulion ~ student_t(3, 0, 2.5)
## Intercept_muother ~ student_t(3, 0, 2.5)
## Intercept_musiblicide ~ student_t(3, 0, 2.5)
## Intercept_mustarvation ~ student_t(3, 0, 2.5)
##
## MODEL OUTPUT:
##                             Estimate Est.Error l-95% CI u-95% CI
## starvation_Intercept         -0.4076    0.7185  -1.8313   0.9738
## lion_Intercept               -1.0104    0.6744  -2.3649   0.2930
## siblicide_Intercept          -1.2770    0.7793  -2.8446   0.2077
## deathofmother_Intercept       0.4748    0.5222  -0.5440   1.5075
## human_Intercept              -1.4854    0.8284  -3.1754   0.0875
## other_Intercept              -1.5593    0.7111  -3.0135  -0.2205
## starvation_prey_density      -0.0014    0.0035  -0.0087   0.0052
## lion_prey_density             0.0031    0.0026  -0.0019   0.0082
## siblicide_prey_density        0.0018    0.0031  -0.0045   0.0077
## deathofmother_prey_density    0.0019    0.0023  -0.0023   0.0065
## human_prey_density            0.0019    0.0032  -0.0048   0.0080
## other_prey_density            0.0046    0.0025   0.0001   0.0098
##
## MODEL DIAGNOSTICS:
##                               Rhat Bulk_ESS Tail_ESS
## starvation_Intercept        1.0000    37804    44911
## lion_Intercept              1.0001    32598    40397
## siblicide_Intercept         1.0001    36408    39729
## deathofmother_Intercept     1.0002    28327    38545
## human_Intercept             1.0001    35138    40542
## other_Intercept             1.0000    31631    38417
## starvation_prey_density     1.0002    24060    34203
## lion_prey_density           1.0002    21374    27639
## siblicide_prey_density      1.0001    23843    33687
## deathofmother_prey_density 1.0003    19311    24819
## human_prey_density          1.0002    23521    32649
## other_prey_density          1.0002    20326    25653
```

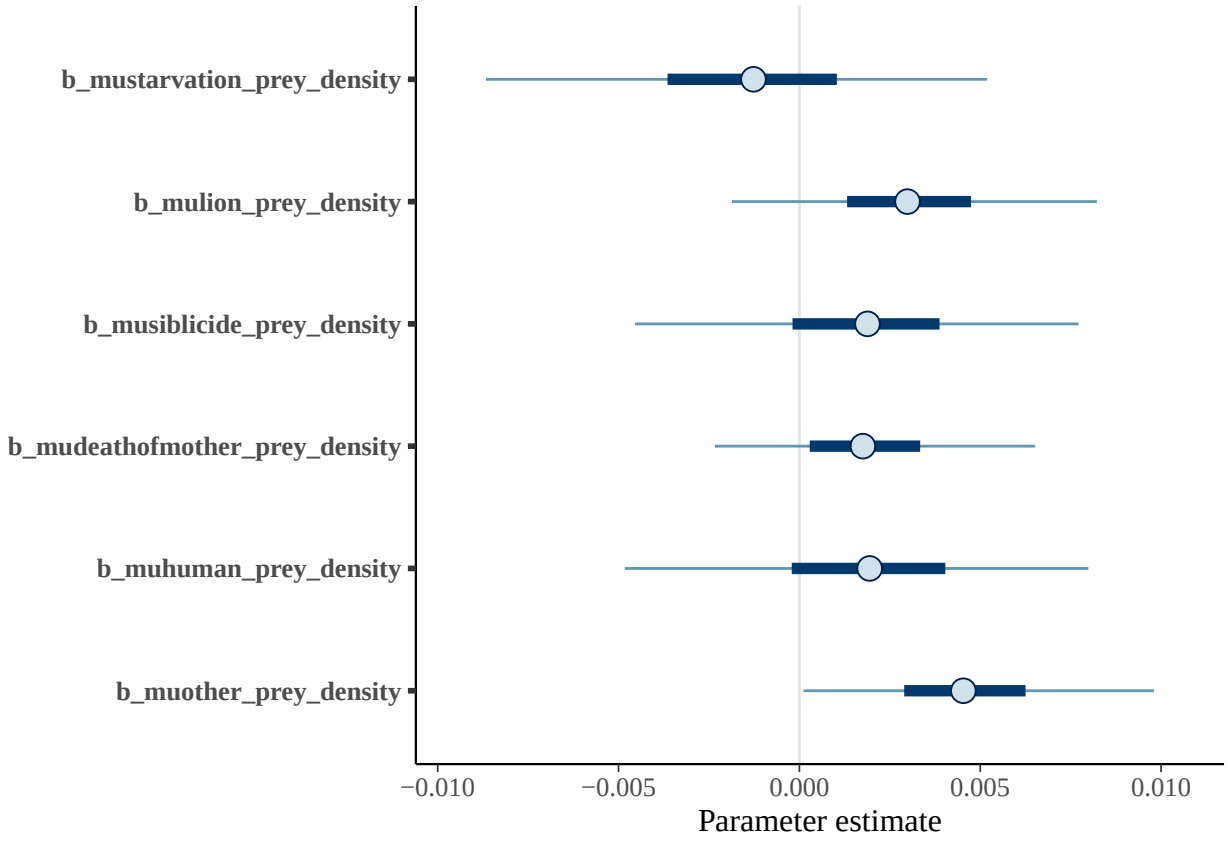

Figure S3. Interval plot showing parameter estimates and associated 50% and 95% credible intervals for the effect of prey density on the probability of different mortality sources. Infanticide is the reference level, so parameter estimates represent the log-odds ratio of each mortality source relative to infanticide.

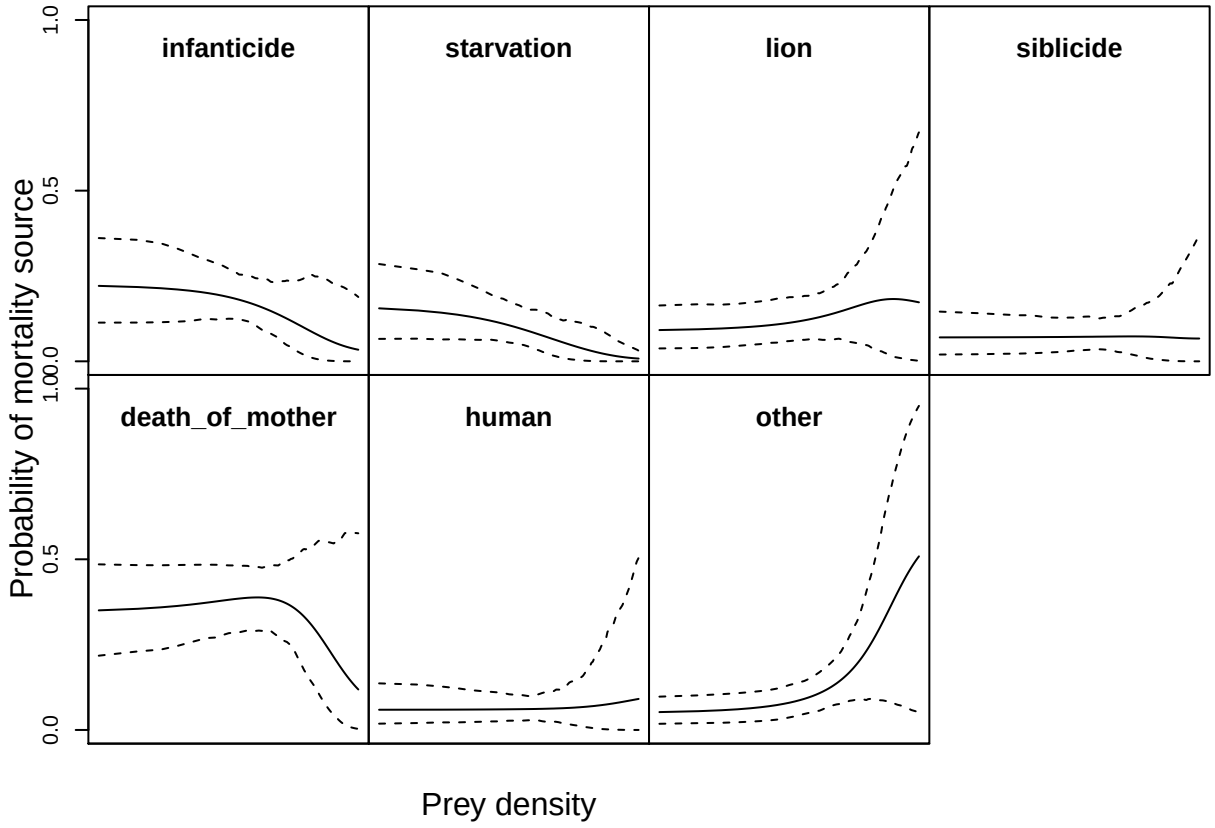

Figure S4. Predicted probability of mortality (with 95% prediction intervals) due to each mortality source as a function of prey density.

4. Model detail for mortality ~ cub density

Here we used a multinomial model of mortality source as a function of cub density at the communal den. This model was initialized with weak, uninformative priors, and four chains were run for 30000 iterations each (15000 warmup). To determine convergence, we visually examined traceplots of MCMC chains (not pictured) and confirmed that the potential scale reduction factor (R-hat) was less than 1.1 (in all cases R-hat < 1.001).

```
## MODEL SPECIFICATION:
##
## Family:  multinomial
## Formula:  y | trials(1) ~ 1 + cub_associates
## Number of observations:  80
## Samples:  4 chains, each with iter =  30000 ; warmup =  15000 ; thin =  1
##
## PRIORS:
##
## b_mudeathofmother ~ (flat)
## b_mudeathofmother_cub_associates ~ (flat)
## b_muhuman ~ (flat)
## b_muhuman_cub_associates ~ (flat)
```

```
## b_mulion ~ (flat)
## b_mulion_cub_associates ~ (flat)
## b_muother ~ (flat)
## b_muother_cub_associates ~ (flat)
## b_musiblicide ~ (flat)
## b_musiblicide_cub_associates ~ (flat)
## b_mustarvation ~ (flat)
## b_mustarvation_cub_associates ~ (flat)
## Intercept_mudeathofmother ~ student_t(3, 0, 2.5)
## Intercept_muhuman ~ student_t(3, 0, 2.5)
## Intercept_mulion ~ student_t(3, 0, 2.5)
## Intercept_muother ~ student_t(3, 0, 2.5)
## Intercept_musiblicide ~ student_t(3, 0, 2.5)
## Intercept_mustarvation ~ student_t(3, 0, 2.5)
##
## MODEL OUTPUT:
##                               Estimate Est.Error l-95% CI u-95% CI
## starvation_Intercept           -1.5318    1.0682  -3.7175   0.5000
## lion_Intercept                 -0.9073    0.9825  -2.8857   0.9842
## siblicide_Intercept            -1.2029    1.1414  -3.5104   0.9818
## deathofmother_Intercept        -1.0664    0.8347  -2.7194   0.5462
## human_Intercept                -1.7410    1.2329  -4.2693   0.5748
## other_Intercept                -0.9964    1.0836  -3.1835   1.0812
## starvation_cub_associates       0.2093    0.1898  -0.1612   0.5871
## lion_cub_associates             0.1372    0.1828  -0.2198   0.4994
## siblicide_cub_associates        0.0856    0.2161  -0.3451   0.5022
## deathofmother_cub_associates    0.3677    0.1511   0.0873   0.6797
## human_cub_associates            0.1529    0.2217  -0.2890   0.5829
## other_cub_associates            0.0775    0.2064  -0.3353   0.4775
##
## MODEL DIAGNOSTICS:
##                                 Rhat Bulk_ESS Tail_ESS
## starvation_Intercept          1.0001    36249    41304
## lion_Intercept                1.0000    35179    44034
## siblicide_Intercept           1.0001    37354    42779
## deathofmother_Intercept       1.0000    30108    40468
## human_Intercept               1.0001    41168    41901
## other_Intercept               1.0001    40039    45048
## starvation_cub_associates     1.0001    25021    33355
## lion_cub_associates           1.0000    23806    32515
## siblicide_cub_associates      1.0001    26009    36455
## deathofmother_cub_associates 1.0001    19926    25886
## human_cub_associates          1.0001    28946    34912
## other_cub_associates          1.0001    27125    36269
```

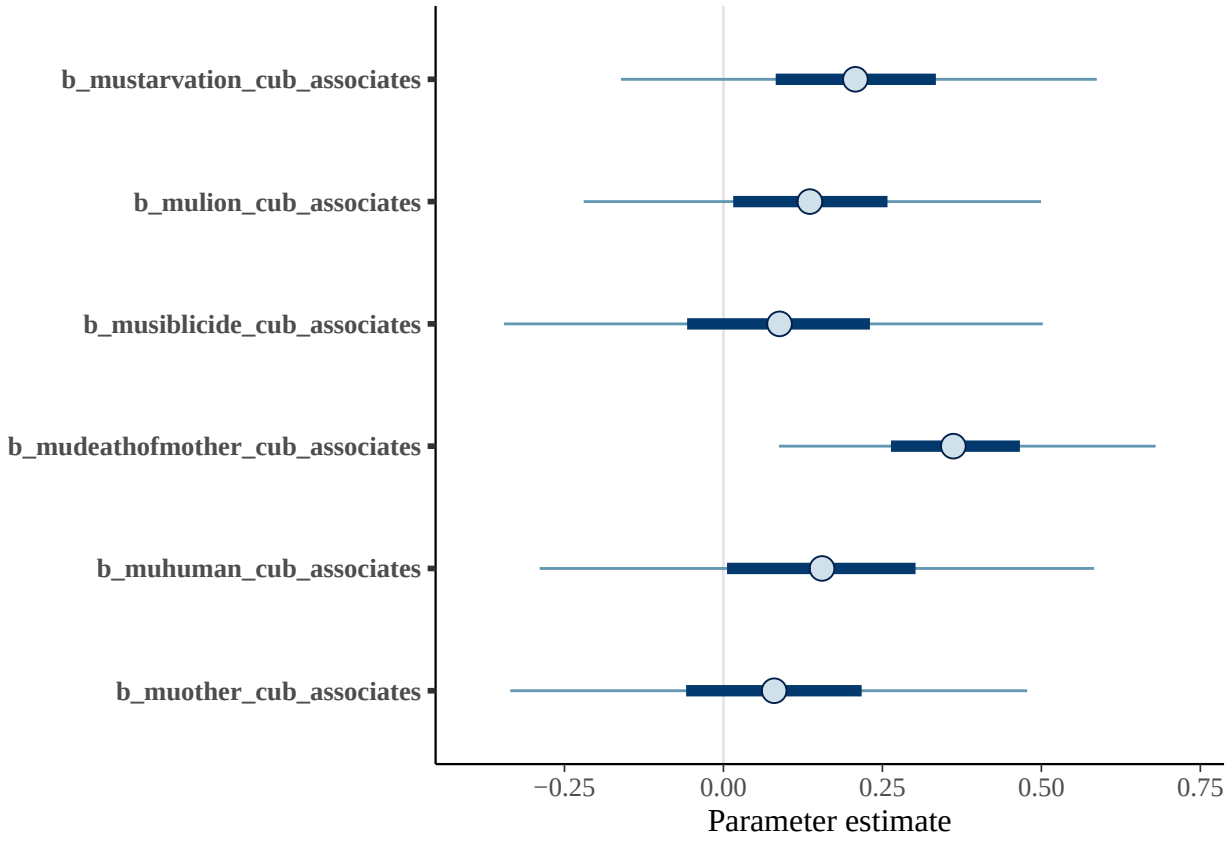

Figure S5. Interval plot showing parameter estimates and associated 50% and 95% credible intervals for the effect of cub density on the probability of different mortality sources. Infanticide is the reference level, so parameter estimates represent the log odds ratio of each mortality source relative to infanticide.

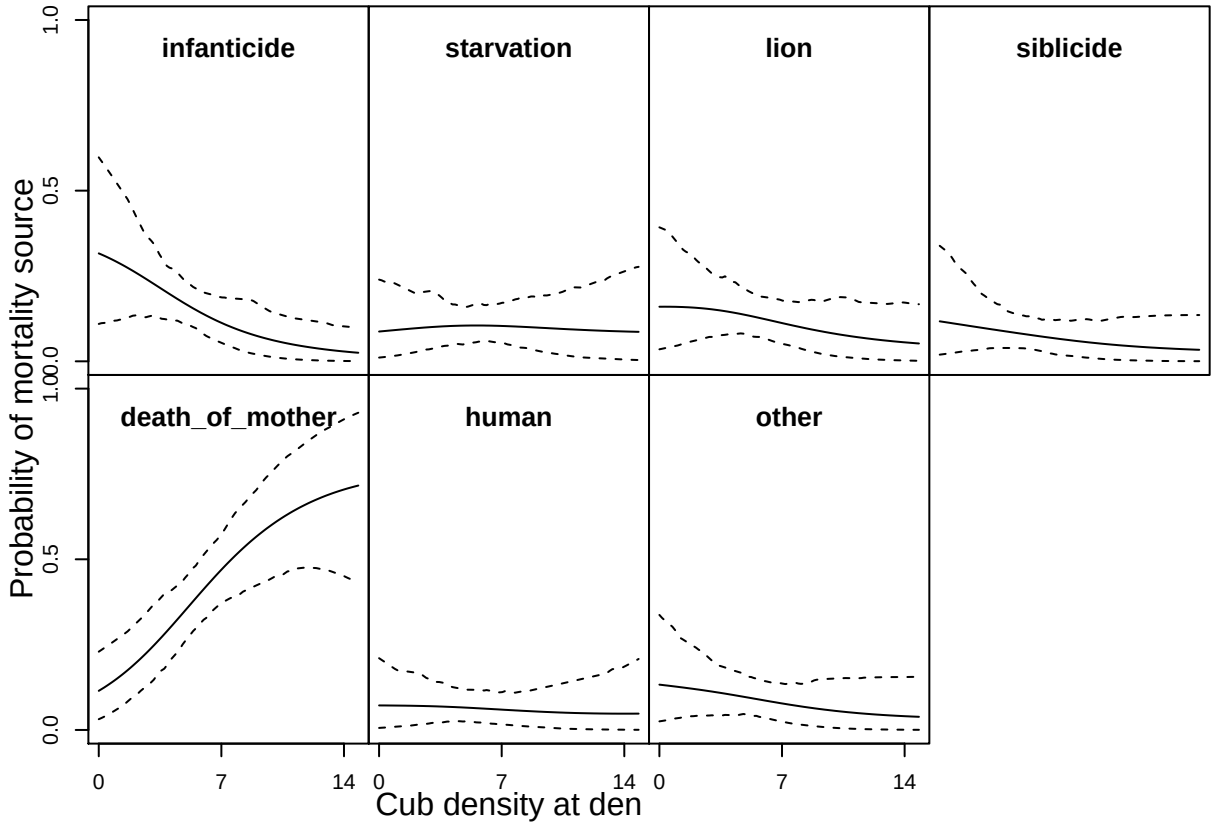

Figure S6. Predicted probability of mortality (with 95% prediction intervals) due to each source as a function of cub density.