Table S1. The number of offspring included in each analysis, and estimates of species-specific ages that correspond to the end of the pre-dispersal, immature period (analysis #2).

Species	Offspring Included in Analysis #1 (# excluded due to uncertainty in dates) [number of offspring deaths recorded]	Offspring Included in Analysis #2 (# excluded due to uncertainty in dates) [number of offspring deaths recorded]	Age corresponding to the end of the pre-dispersal, immature period (years)	Rationale for pre-dispersal, immature period estimate
Northern Muriquis	402 (11) [69]	176 (0) [71]	6.5	Approximate median age of dispersal (females)[1]
Yellow Baboons	1104 (1) [278]	1123 (0) [392]	4.5	Median age of menarche (females) and approximate earliest age at dispersal for males[2]
Blue Monkeys	534 (30) [157]	446 (1) [172]	6	Median age at first birth minus 1 standard deviation (females)(65, 74) and earliest age at dispersal (males)[3,4]
Chimpanzees	222 (2) [59]	71 (0) [27]	11	Median age sexual maturity for females[5]
Mountain Gorillas	222 (1) [61]	134 (0) [50]	8	Median age at first birth for females minus two years of "adolescent sterility"[6]
Verreaux's Sifaka	541 (53) [293]	250 (22) [153]	5	Median age at first birth for females minus 1 standard deviation[7]
White-Faced Capuchins Two populations: Lomas Barbudal (LB) and Santa Rosa (SR)	LB: 281 (11) [85] SR: 186 (2) [63]	LB: 352 (11) [129] SR: 126 (9) [53]	6	Median age at first birth for females minus 1 standard deviation[8]

[1] Strier, K. B. & Mendes, S. L. in *Long-Term Field Studies of Primates*, 125–140 (Springer-Verlag Berlin Heidelberg, 2012).

[2] Charpentier, M. J. E., Tung, J., Altmann, J. & Alberts, S. C. *Mol. Ecol.* 17, 2026–2040 (2008).

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[6] Watts, D. P. *Am. J. Primatol.* 24, 211–225 (1991).

[7] Richard, A. F., Dewar, R. E., Schwartz, M. & Ratsirarson, J. *J. Zool.* 256, 421–436 (2002).

[8] Perry, S. in *Advances in the Study of Behavior* 44, 135–181 (Academic Press Inc., 2012).

Table S2: Results from mixed effects Cox proportional hazards models of offspring survival to age 2 as predicted by impending maternal death that included an additional term of maternal age, standardized across species. Bold indicates a statistically significant effect (p < 0.05), italics indicate estimates where 0.05< p <0.10.

Species	Parameter	Estimate	Hazard Ratio [95% Confidence Interval]	p value
All 7 Species	Impending maternal Death	0.32	1.38 [1.19,1.60]	**< 0.0001**
	Maternal Age (z score)	0.03	1.03 [0.97,1.10]	0.36
Yellow Baboons	Impending maternal Death	0.30	1.35 [1.03,1.78]	**0.03**
	Maternal Age (z score)	-0.015	0.98 [0.88,1.11]	0.85
Chimpanzees	Impending maternal Death	0.80	2.22 [1.89,4.17]	**0.01**
	Maternal Age (z score)	-0.03	0.97 [0.75,1.25]	0.82
Northern Muriquis	Impending maternal Death	0.72	2.05 [0.99,4.22]	*0.051*
	Maternal Age (z score)	0.15	1.16 [0.91,1.48]	0.23
Verreaux's Sifaka	Impending maternal Death	0.26	1.29 [0.96,1.72]	*0.08*
	Maternal Age (z score)	0.04	1.04 [0.92,1.18]	0.46
White-Faced Capuchins (Combined)	Impending maternal Death	0.53	1.70 [1.17,2.47]	**0.006**
	Maternal Age (z score)	-0.07	0.94 [0.79,1.11]	0.44

Table S3. Results of mixed effects Cox proportional hazards models that predict offspring survival in years 0-2 as a function of impending maternal death. These model results are distinguished from those in Table 1 in the main text by the difference in random effects structure. The models in Table 1 contain study site-specific random effects of birth year, while these models contain social-group specific random effects of birth year. All models in Table 1 and here contain random effects of maternal ID. Bold values refer to a statistically significant effect ('p value' < 0.05) or an estimate in the expected direction ('In expected direction?' is 'Yes'). Italics indicate 0.05 < 'p value' < 0.10.

Species	Coef. Estimate	Std. Error	z value	p value	Hazard Ratio Est. [95% Conf. Int.]	In expected direction?
All Species Combined^	0.34	0.08	4.11	**<0.0001**	1.40 [1.20,1.64]	**Yes**
All Species, Except Baboons^	0.39	0.10	3.77	**0.0002**	1.47 [1.21,1.80]	**Yes**
Northern Muriquis	0.80	0.36	2.21	**0.03**	2.22 [1.09,4.52]	**Yes**
Chimpanzees	0.82	0.33	2.52	**0.01**	2.27 [1.20,4.28]	**Yes**
White-Faced Capuchins (Santa Rosa)	0.45	0.32	1.44	0.15	1.57 [0.85,2.91]	**Yes**
White-Faced Capuchins (Lomas Barbudal)	0.69	0.27	2.52	**0.01**	2.00 [1.17,3.38]	**Yes**
White-Faced Capuchins (Combined)^	0.59	0.20	2.89	**0.004**	1.80 [1.21,2.67]	**Yes**
Baboons	0.28	0.14	2.04	**0.04**	1.32 [1.01,1.72]	**Yes**
Sifaka	0.29	0.15	1.96	*0.051*	1.34 [1.00,1.80]	**Yes**
Gorillas	0.25	0.55	0.45	0.66	1.28 [0.43,3.79]	**Yes**
Blue Monkeys	0.03	0.24	0.12	0.90	1.03 [0.64,1.64]	**Yes**

Supplementary tables, figures, and materials for "Maternal Death and Offspring Fitness," Zipple et al., PNAS, 2020.
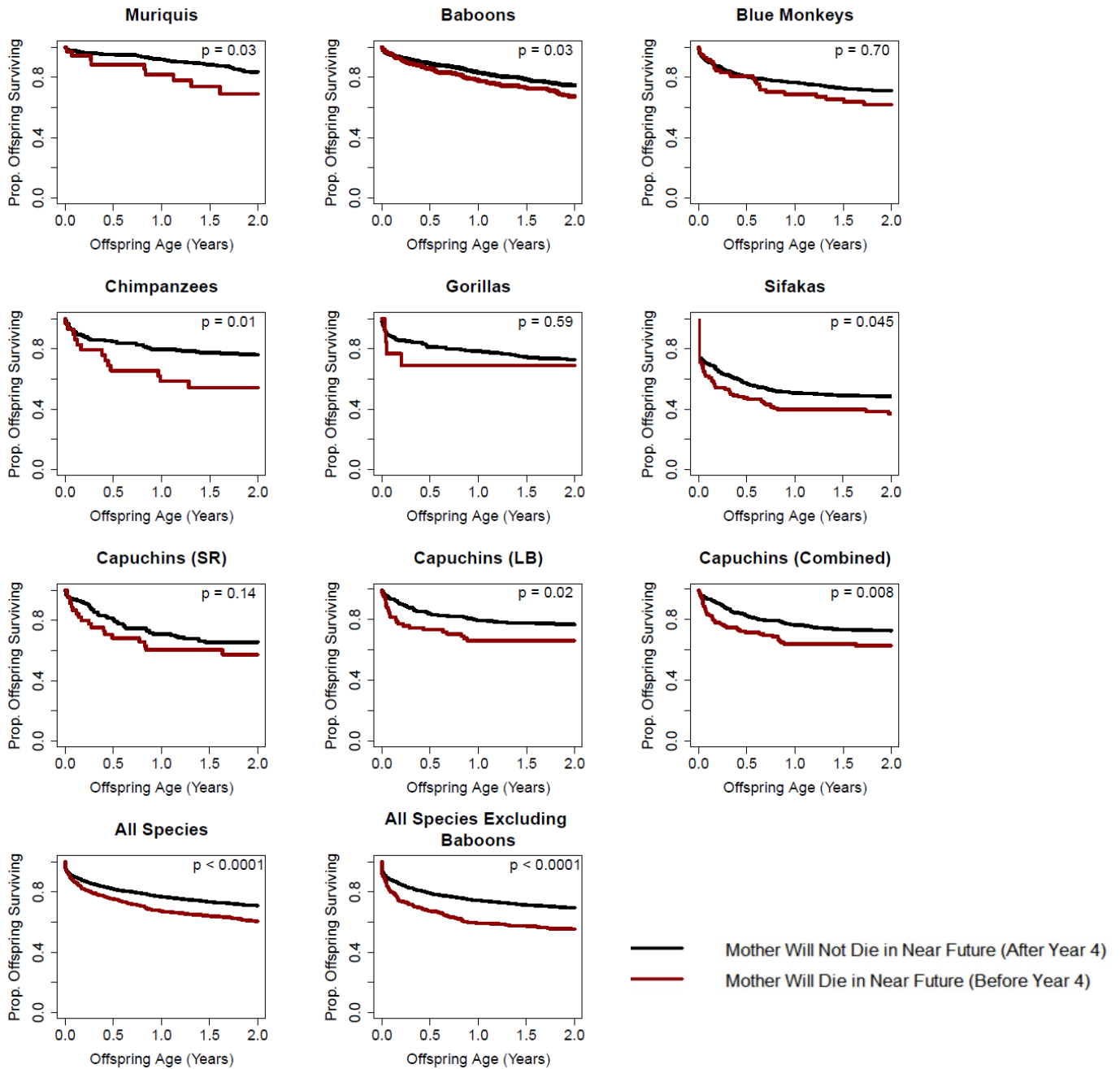
4

Figure S1. Offspring survival as a function of age and impending maternal death for each of the seven species as well as for all species combined and all species except for baboons. P values refer to the output of a mixed effects cox proportional hazards model of offspring survival through the first two years of life that includes random effects of maternal ID and site-specific birth year. Note that the he combined species models and the combined capuchin models additionally include a random effect of study site ID.
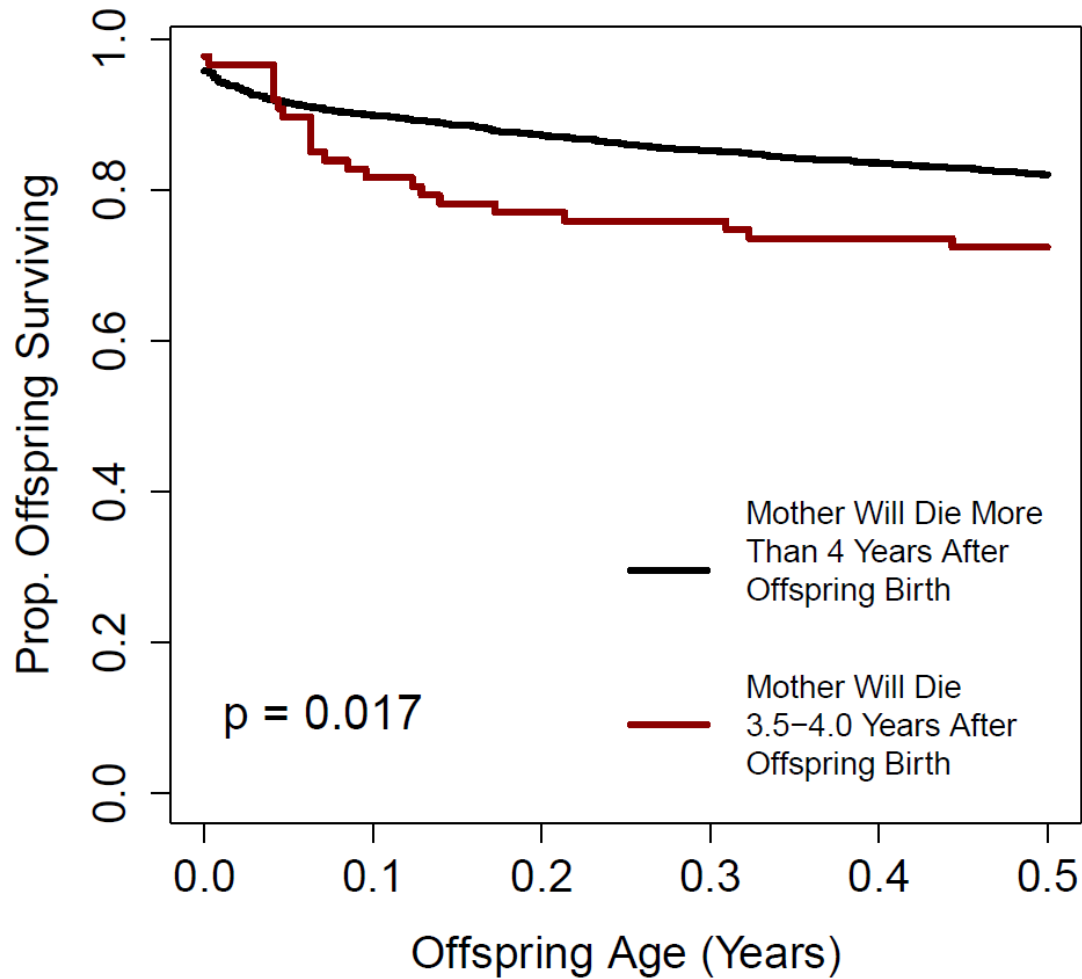
Figure S2. Offspring are more likely to die in the first half year of their life if their mother is going to die in years 3.5-4.0 after the offspring's birth. This figure contains data from all 7 species, including 84 total offspring whose mothers died 3.5-4.0 years after offspring birth. The displayed p value refers to the output of a mixed effects Cox proportional hazards model of offspring survival during the first six months of life that includes random effects of Maternal ID, study site ID, and site-specific birth year.
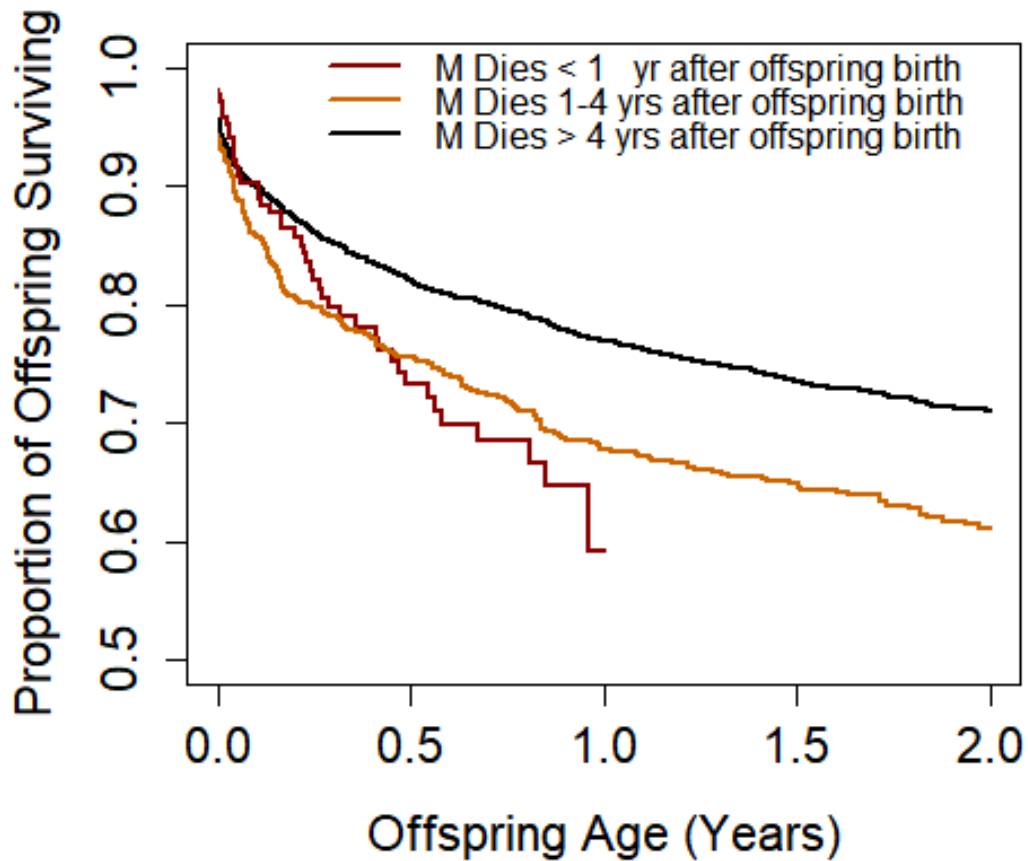
Supplementary tables, figures, and materials for "Maternal Death and Offspring Fitness," Zipple et al., PNAS, 2020.

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Figure S3. Offspring are more likely to die if they are born near the end of their mothers' lives, but they are not at increased risk if they are born particularly closer to the time of maternal death. This figure illustrates a mixed effects Cox proportional hazard model that predicts offspring survival during the first two years of life according to the time to maternal death following offspring birth (measured continuously in years). That model showed no significant effect of the time between offspring birth and maternal death, given that maternal death occurred within 4 years of offspring birth (Hazard Ratio for each year between offspring birth and maternal death = 0.97, 95% CI = 0.86-1.1, p = 0.63).
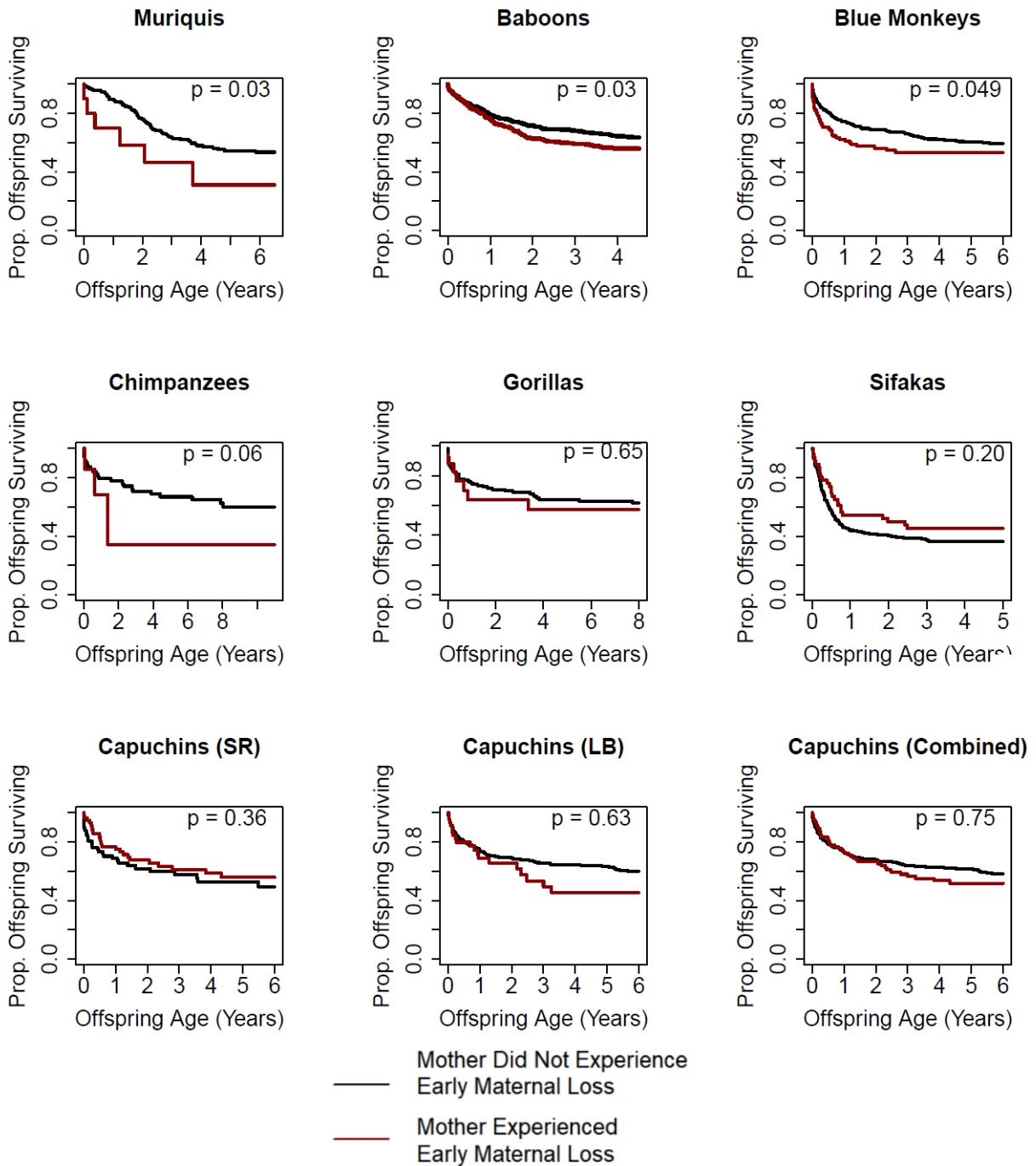
Figure S4. Survival curves for offspring of each species depending on whether the mother of the offspring experienced early maternal loss. P values refer to the output of a mixed effects Cox proportional hazards model of offspring survival throughout the immature period that includes random effects of maternal ID and site-specific birth year. Note that the combined capuchin model also includes a random effect of study site ID.

Supplemental analysis: intergenerational effects are not explained by loss of direct grandmaternal care

We examined the possibility that the observed intergenerational effect of early maternal death occurs because F2 individuals lack the direct grandmaternal care that they would have received if F1 had not experienced early maternal loss. Of the four species that display a significant, or near-significant, intergenerational effect of maternal loss (muriquis, chimpanzees, blue monkeys, and baboons), two are species with female dispersal (muriquis and chimpanzees). In these species we expect it to be quite unlikely that the loss of direct grandmaternal care could affect offspring outcomes.

To explore the potential role of grandmaternal care in blue monkeys, and baboons we added to our intergenerational survival models a binary indicator of whether the grandmother of the offspring was alive at the time of the offspring's birth. We find no evidence that grandmothers being alive at the time of their grandoffspring's birth affects grandoffspring survival in baboons (HR = 1.00, p = 0.97) or blue monkeys (HR = 1.21, p = 0.32). The results were qualitatively unchanged if we considered the proportion of the first two years of offspring life for which a grandmother was alive, rather than a binary indicator of presence at birth (baboons: HR = 0.95, p = 0.71; blue monkeys: HR = 1.42, p = 0.09). We therefore find no evidence that the intergenerational effects of maternal loss in any of the species can be explained by the loss of direct grandmaternal care. Importantly, none of these species display menopause (Alberts et al 2013), and grandmothers have their own young offspring to care for throughout their lives (Hawkes 2003).

Supplemental analysis: intergenerational effects are not explained by F2 experience of maternal (F1) death

It is possible that the observed intergenerational effect of early maternal death operates exclusively by increasing the likelihood that F1 will die while F2 is young, followed by F2 death thereafter. We tested this possibility in the three species that displayed intergenerational effects of early maternal loss on offspring survival.

First, in blue monkeys and baboons, we added a day-by-day time-varying binary indicator of the F1 female's presence to our survival model of the F2 offspring's survival throughout the immature period. This approach required that we exclude those cases in which F2 and F1 death dates were identical (N=58 F2 baboons and N=3 F2 blue monkeys). For blue monkeys, the estimate of the magnitude of the intergenerational effect was nearly identical (0.396 vs 0.393), although the estimate no longer met the conventional threshold for statistical significance (p = 0.051). Still, the fact that the coefficient estimate was entirely unchanged suggests that the intergenerational effect in blue monkeys was not explained by an increase in the likelihood that F1 would die during F2's early life.

For baboons, the intergenerational effect that is independent of this F1 death parameter did not meet the threshold for statistical significance (p = 0.08) and the coefficient estimate was somewhat reduced in magnitude (0.21 vs 0.25) as compared to the total intergenerational effect presented in Table 2. This lack of a statistically significant, independent intergenerational effect is likely explained by the strong effect of maternal loss (the M generation) on the adult lifespan of F1 females (Tung & Archie *et al* 2016, Figure 1, red arrow), which in turn increases the chance that F2 offspring will directly experience early maternal loss. However, previous results from the same baboon population indicated a strong and significant intergenerational effect of maternal loss on offspring survival that was

independent of maternal death in the offspring generation (Zipple *et al* 2019; p = 0.009, coefficient = 0.34). This previous analysis used a more restricted dataset of offspring and identified 4 years of age as the end of the immature period (as compared to 4.5 years in this analysis, which was selected for consistency with criteria for the other species, see below for details).

For muriquis, a formal statistical approach was limited by the small sample size, as only six F2 offspring whose F1 mothers experienced early maternal loss died while they were immature. Of those six individuals, five died while their mothers were still alive, and those mothers did not die in the near future, indicating that any intergenerational effect of early maternal loss is independent of any effect on F1 death. In the sixth muriqui case, uncertainty in death dates creates uncertainty as to whether the F2 or F1 individual died first. Regardless of the order of events in this final case, the data from muriquis suggest that the intergenerational effect of maternal loss cannot be explained by an increased likelihood of death in the F1 generation.

Taking these results together we conclude that the intergenerational effects of early maternal loss on offspring survival in these three species are largely independent of the offspring's direct experience of maternal presence or absence, although the two are perhaps not completely independent in baboons.

Explanation of differences between baboon dataset in this study and a previous analysis of the intergenerational effect of early maternal loss.

A previous study (Zipple *et al* 2019) measured the intergenerational effect of early maternal loss in the Amboseli baboons and identified a strong intergenerational effect that was independent of maternal loss (i.e. death of the F_1 individual) experienced by the offspring (the F_2 individual) directly. Our baboon-specific results presented here are on the whole quite similar to those described by Zipple *et al* (2019), but are not identical because we used somewhat different datasets and a different assessment of the end of the baboon immature period in this study than did Zipple *et al* (2019).

Specifically, Zipple *et al* (2019) was a study of the intergenerational effect of multiple sources of early life adversity, not just early maternal loss. For an offspring to be included in that analysis, the authors needed to be able to measure five sources of early adversity, experienced both by offspring directly and by their mothers. For example, it was necessary to know whether the offspring was born to a low-ranking mother and if the offspring's *mother* had been born to a low-ranking mother. The analytical approach in the present study did not employ such a restriction. Furthermore, Zipple *et al* (2019) restricted their analysis to offspring who had no uncertainty at all about their birth date. We did not impose this stringent requirement in the present study, in part because such a restriction would greatly reduce the sample size in non-baboon species. The end result of these differences in inclusion criteria was that the present study included a larger number of offspring in the intergenerational analysis (n = 1123) than the analysis in Zipple *et al* (2019), which included 687 offspring.

Additionally, Zipple *et al* (2019) analyzed offspring survival in the first 4 years of baboon life, while the present study considers offspring survival to age 4.5. The former study used 4 years as the period of analysis to guarantee that only the immature periods of animals' lives were being considered (the earliest ages of menarche and natal dispersal is ~4 years in the Amboseli population). In the present study, our estimates of the age corresponding to end of the immature period are meant to represent

the median experience of animals in each species, so we used 4.5 years (the median age of menarche in Amboseli) as our estimate of the end of the immature period for baboons. Together, these differences between Zipple *et al* (2019) and the present study likely account for the minor differences in results presented in each study. Both studies are fully consistent with the hypothesis that maternal input is critical a critical determinant of offspring fitness, and that cessation of that input during early life has strong acute and chronic effects.

Assessing violations of the proportional hazards assumption

We assessed all models contained in Tables 1 and 2 (20 total models) for potential violations of the proportional hazards assumption using the cox.zph function in the *survival* package. Because cox.zph supports coxph objects (rather than coxme objects), we converted our models to coxph objects with frailty terms rather than random effects. Because the coxph function supports only one frailty term per model, we built alternate versions of each model that included each random effect in turn. Across our 20 models, we found evidence that the proportional hazards assumption was significantly violated in only a single case ($p < 0.03$ for the blue monkey intergenerational analysis; see Table 2).

If we assume that this single case represents a real age-related relationship rather than a type I error, how might it have affected our results? In this case the hazard ratio estimate for offspring whose mothers experienced maternal loss declined significantly as immature offspring aged (see Figure S2, as the separation between red and black lines was greatest during the first two years of life). Therefore, if any bias was introduced into our results by this violation of the proportional hazards assumption, it would have been in the direction of returning a *lower* hazard ratio estimate on average across the immature period as compared to the true effect during the earliest period of offspring life. This violation of assumptions is therefore unlikely to affect our qualitative results, and to the extent that it does, it does so in a *conservative* direction.

References:

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Hawkes K. 2003 Grandmothers and the evolution of human longevity. Am. J. Hum. Biol. 15, 380–400. (doi:10.1002/ajhb.10156)

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