



Supporting Online Material for

Compromised Survivorship in Zoo Elephants

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Methods

Survivorship analyses (Cox Proportional hazards) were run using ‘R’ (v. 1.9.1), where survival was the time between population-entry (birth; or importation/capture -- the latter being treated as left-censored) and an ‘event’ (death; or living/lost to follow-up -- the latter being treated as right-censored). Proportionality of hazards was tested using scaled Schoenfeld residuals; data were divided into age-classes (1-10: Juvenile; 10+: Adult) to ensure proportionality. Infant deaths were non-proportional and so compared using Fisher Exact tests (Table S1).

Human-caused deaths in reference populations were also treated as censored, in ‘Natural mortality’ analyses that conform closer to fully-protected populations and provide more valid benchmarks. In Amboseli, this affected 142 females (e.g. speared, shot or killed in accidents); these animals were treated as right-censored. In the M.T.E. population, this affected 42 elephants killed for ivory or by insurgents, plus all 1344 wild-born animals captured and ‘broken’, which elevates mortality (e.g. *SI*). To quantify these capture effects, all wild-caught M.T.E. elephants living longer than x years after capture, T , had their histories split at age $T+x$, where x was varied between one and 14 years. Comparing survivorship before and after x showed significantly elevated mortality for up to eight years post-capture ($z = 8.69$, $P < 0.0001$; *SI*). The first eight years of wild-caught histories were therefore left-censored in ‘Natural mortality’ analyses for this species.

‘Recency’ was investigated, by including year of entry into a zoo as a covariate, because zoo husbandry has changed since the 1960’s, and recency (plus dam parity) could account for apparent ‘birth origin’ effects.

Transfer effects were explored in Asian elephants experiencing one or two moves (sample size precluded investigating further moves) via the approach used to assess capture effects. In elephants transferred twice, only effects after the second transfer were investigated. Initial imports for wild-borns were included.

In Amboseli, females who lose a mother before nine years of age show reduced survivorship up to the age of first reproduction (*S2*). Effects of the age when zoo-born elephants were separated from their mothers were therefore investigated in Asians (whose sample size allowed this) by including as a covariate the age at which each calf was moved from her birth zoo and mother; calves still with their mothers, i.e. right-censored data, were included.

Supporting text

In Africans, recency markedly improved adult survivorship (see paper), but not juvenile (recency: $z = -0.83$, $P > 0.10$, birth origin: $z = -0.19$, $P > 0.10$) or zoo-born infant survivorship (recency: $z = -0.26$, $p > 0.10$; dam parity: $z = 0.002$, $P = 0.10$). In Asians, recency did not affect survivorship in adults (see paper), juveniles (recency: $z = 1.24$, $P > 0.10$; birth origin: $z = -0.94$, $P > 0.10$), nor zoo-born infants (recency: $z = 1.19$, $P > 0.10$, dam parity: $z = 1.27$, $P > 0.10$).

47 Compared to subsequent years, mortality hazards were 50% higher four years following
 48 transfer (see paper). Wild-borns experienced lower hazards; but birth origin and transfer
 49 number did not interact. Adding transfer age had no significant effect.

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52 **Table S1. Infant mortality data (for female calves) in the first year.** For Amboseli
 53 elephants, natural mortality ('natural') excludes human-caused deaths, 'All mortality' ('all')
 54 includes them. Censored infants were excluded from analyses. However, for illustration,
 55 proportions were re-calculated assuming they were all (A) dead or (B) alive by one year.

Liveborn infant mortality			
	Primiparous dams	Multiparous dams	Fisher's Exact Test Zoo cf. Reference
Africans, European zoos	6/26 = 23.1% A: 7/27 = 25.9%; B: 6/27 = 22.2%	0/7 = 0% A: 4/11 = 36.4%; B: 0/11 = 0%	<i>Natural mortality:</i> Primiparous: $P > 0.10$ Multiparous: $P > 0.10$
Africans, reference – natural	29/164 = 17.7%	41/604 = 6.8%	<i>All mortality:</i> Primiparous: $P > 0.10$ Multiparous: $P > 0.10$
Africans, reference – all	29/164 = 17.7% <i>(i.e. unchanged)</i>	50/604 = 8.3%	
Asians, European zoos	6/16 = 37.5% A: 7/17 = 41.2%; B: 6/17 = 35.3%	5/27 = 18.5% A: 6/28 = 21.4%; B: 5/28 = 17.9%	<i>Natural & all mortality:</i> Primiparous: $P < 0.05$ Multiparous: $P < 0.05$
Asians, reference	34/257 = 13.2%	30/430 = 7.0%	
Total infant mortality, i.e. premature and still-births included (NB. reference values are probably under-estimates due to inability to sex all neonates at birth)			
	Primiparous dams	Multiparous dams	Fisher's Exact Test Zoo cf. Reference
Africans, European zoos	7/27 = 25.9% A: 8/28 = 28.6%; B: 7/28 = 25.0%	0/7 = 0% A: 4/11 = 36.4%; B: 0/11 = 0%	<i>Natural mortality:</i> Primiparous: $P > 0.10$ Multiparous: $P > 0.10$
Africans reference - natural	31/166 = 18.7%	51/614 = 8.3%	<i>All mortality:</i> Primiparous: $P > 0.10$ Multiparous: $P > 0.10$
Africans, reference – all	31/166 = 18.7% <i>(ie. unchanged)</i>	60/614 = 9.8%	
Asians, European zoos	14/24 = 58.3% A: 15/25 = 60.0%; B: 14/25 = 56.0%	6/28 = 21.4% A: 7/29 = 24.1%; B: 6/29 = 20.7%	<i>Natural & all mortality:</i> Primiparous: $P < 0.0001$ Multiparous: $P < 0.10$
Asians, reference	47/270 = 17.4%	42/442 = 9.5%	

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58 **Table S2. Statistical analyses of survivorship data.**
 59 Cox Proportional Hazards regression analysis results from the data presented in Figure 1 are
 60 given here (Figure 1 sub-sections are referred to by letters A, B, C and D). For significant
 61 interactions, *post hoc* pairwise comparisons are also shown. ‘Environment’ refers to Zoo vs.
 62 Reference (Amboseli/M.T.E.); ‘Ref’ to Reference; and ‘Birth Origin’ to whether captive-
 63 born (CB) or wild-born (WB). For WB Ref populations, Natural mortality (‘natural’)
 64 excludes human-caused deaths, while All mortality (‘all’) includes them.
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A: African juveniles		Natural mortality: No significant Environment or Birth Origin effects ($z = 1.52, P > 0.10$) All mortality: No significant Environment or Birth Origin effects ($z = 0.417, P > 0.10$)		
B: African adults		Natural mortality: Significant Environment effect ($z = 10.9, P < 0.0001$) All mortality: Significant Environment effect ($z = 6.66, P < 0.0001$)		
C: Asian juveniles		Natural mortality: not possible due to removal of capture effects All mortality: Significant Environment by Birth Origin interaction ($z = 2.54, P < 0.01$)		
		Zoo CB	Zoo WB	Ref. CB
Zoo Ref. Ref.	WB CB WB, all	NS NS $P < 0.05$	-- $P < 0.001$ $P < 0.0001$	-- -- $P < 0.001$
D: Asian adults		Natural mortality: Significant Environment by Birth Origin interaction ($z = 3.37, P < 0.001$) All mortality: Significant Environment by Birth Origin interaction ($z = 3.37, P < 0.001$)		
		Zoo CB	Zoo WB	Ref. CB
Zoo Ref. Ref. Ref.	WB CB WB, natural WB, all	$P < 0.05$ $P < 0.0001$ $P < 0.0001$ $P < 0.05$	-- $P < 0.0001$ $P < 0.0001$ NS	-- -- NS $P < 0.0001$

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68 **References**

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70 <http://www.zoo.cam.ac.uk/ioz/theses.htm>

71 S2. C. J. Moss, P. C. Lee in *The Amboseli Elephant: A long term perspective on a long lived*
 72 *species* C. J. Moss, H. Croze, Eds. (Univ. Chicago Press, in press, publication date 2009).