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Supplementary Information for

Periodic catastrophes over human evolutionary history are necessary to explain the forager population paradox

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SI Section 1. Variable definitions, population statistics and extended information

Table S1. Population metadata and source citations. Human populations are arranged by subsistence type (H: hunter-gatherers, A: acculturated hunter-gatherers, F: forager-horticulturalists, P: pastoralists) and chimpanzees are identified as wild (W). Columns contain information on location, region or continent, habitat type, population size, sample information, study period and data sources for fertility and mortality rates. Sample information includes total individual risk-years and # cases (births, deaths). Sample information here reflects pre-contact or foraging periods, to extent possible. Post-contact, settled, peasant, acculturated or reservation periods for some populations (E.g. Ache, Tsimane, Gainj, Agta) are not included here (see SI Section 4).

	Population		Location	Region	Habitat	Population Size	m_x # risk yrs (# births)	q_x risk yrs (# deaths)	Risk Period	Data Source(s) (fertility, mortality)
Small-scale societies	Ache	H	Paraguay	South America	Tropical Rainforest	537	3309 (587)	16099 (351)	1890-1970	Hill & Hurtado 2017 (Tables 8.1, 6.1)
	Agta	H	Phillipines	Oceania	Tropical Dry Forest	9,000	2569 (149)	2566 (117)	1950-1964	Early & Headland 1998 (Tables 7.3, 8.1)
	Hadza	H	Tanzania	East Africa	Savannah Woodland	750	3009 (551)	6100 (227)	1985-2000	Blurton Jones 2007 (Tables 7.1, 8.2)
	Hiwi	H	Venezuela, Columbia	South America	Neotropical Savannah	779	1664 (220)	4108 (126)	1985-1992	Hill & Hurtado, unpublished, Hill et al. 2007 (Table 2)
	Ju/'huansi	H	Botswana, Namibia	East Africa	Desert	454	1434 (179)	4512 (75)	1963-1973	Howell 1979 (Table 7.1, 4.5; Table 4.4)
	Aborigine	A	Northern Territory	Australia	Desert	17,469	8261 (1953)	69876 (1115)	1958-1960	Jones 1965 (Table 5)
	Gainj	F	Papua New Guinea	Oceania	Tropical Dry Forest	1,318	1751 (169)	9102 (287)	1970-1978	Wood 1987 (Table 6); Wood & Smouse 1982 (Table 1)
	Tsimane	F	Bolivia	South America	Tropical Rainforest	16,000	9110 (1989)	47854 (648)	1950-2000	Kaplan et al. 2015 (Figure 12.1), Gurven et al. 2007 (Table 6)
	Yanomamo	F	Venezuela, Brazil	South America	Tropical Rainforest	96-120	319 (79)	2843 (64)	1930-1956	Early & Peters 2000 (Tables 19.3, 19.5)
	Herero	P	Namibia	East Africa	Desert	10-15,000	3892 (438)	26564 (405)	1909-1966	Pennington & Harpending 1993
Chimpanzees	Gombe	W	Tanzania	East Africa	Tropical Rainforest	288	923 (138)	1826 (80)	1963-2013	Emery Thompson et al. 2007 (Table S1), Bronikowski et al. 2016
	Kanyawara	W	Uganda	East Africa	Tropical Rainforest	46-56	317 (38)	1129 (56)	1989-2013	Emery Thompson et al. 2007 (Table S1), Muller & Wrangham 2014 (Table 1)
	Mahale	W	Tanzania	East Africa	Tropical Rainforest	47-101	1148 (165)	163 (23)	1966-1999	Emery Thompson et al. 2007 (Table S1), Nishida et al. 2003 (Table III)
	Ngogo	W†	Uganda	East Africa	Tropical Rainforest	114-144	n/a	1396 (31)	1995-2016	Emery Thompson et al. 2007 (Table S1)†; Wood et al. 2017 (Table 2)
	Taï	W	Ivory Coast	West Africa	Tropical Rainforest	54-82	388 (75)	577 (58)	1982-1994	Boesch & Boesch-Acherman 2000 (Figure 3.6, Table 2.4)

† Note: Ngogo analyses use fertility data from nearby Kanyawara.

SI Table S2. Variable Definitions. Columns contain variable symbols, variable name, and mathematical definition or equation.

Symbol	Variable	Definition/Equation
$\mathbf{A}$	population projection matrix	$N_{t+1} = \mathbf{A}\, N_t$
a_{ij}	matrix element	$\mathbf{A} = \{a_{ij}\} = \{m_x, p_x\}$
$\mathrm{COV}_{ij,kl}$	covariance	$\mathrm{COV}_{ij} = \mathrm{COV}(a_{ij}, a_{kl})$
CV_{ij}	coefficient of variation	$\mathrm{CV}_{ij} = \mathrm{std}(a_{ij}) / \mathrm{mean}(a_{ij})$
e_0	life expectancy	$e_0 = \sum_x l_x$
e_{ij}	elasticity	—
f	shock frequency	$f = \Pr(\mathrm{shock})$
l_x	survivorship	$l_x = \prod_{a=0}^{x-1} p_a$
m_x	fertility rate (female offspring)	$m_x = a_{1x}$
N_t	population size (at time t)	$N_{t+1} = \mathbf{A}\, N_t$
p_x	annual survival probability	$p_x = a_{x+1,x}$
q_x	annual mortality probability	$1 - p_x$
R_0	net reproductive rate	$R_0 = \sum_x l_x m_x$
r	intrinsic growth rate	$r = \ln(\lambda)$
s_{ij}	sensitivity	$\partial\lambda / \partial a_{ij}$
N_t	population size (at time t)	$N_{t+1} = \mathbf{A}\, N_t$
T_g	generation time	$T_g = \log(R_0) / \lambda$
T_s	shock period	$T_s = 1 / f$
TFR	total fertility rate	$TFR = \sum_x m_x / SRB$
Z^m	fertility scaling factor	$Z^m = m_x^* : m_x$
Z^q	mortality scaling factor	$Z^q = q_x^* : q_x$
Z^Σ	covariance scaling factor	$Z_{ij,kl}{}^\Sigma = \mathrm{COV}_{ij,kl}^* : \mathrm{COV}_{ij,kl}$
Z^σ	variability scaling factor	$Z^\sigma = \mathrm{CV}_{ij}^* : \mathrm{CV}_{ij}$
λ	asymptotic growth rate	$N_{t+1} = \lambda\, N_t$
$\log \lambda_S$	stochastic growth rate	$\log \lambda_S = \lim_{t\to\infty} \frac{1}{t} \log \frac{N_t}{N_0}.$
$\rho_{ij,kl}$	matrix element correlation	$\rho_{ij,kl} = \mathrm{corr}(a_{ij}, a_{kl})$
τ	force of stochasticity	$\tau = \frac{1}{2} \quad {}_{i,} \; e_{ij} e_{kl} CV_{ij} CV_{kl} \rho_{ij,kl}$

Table S3. Life history traits, stationarity and ZPG conditions. (Extension of Table 1 from the main text)**.** For ten small-scale societies and five wild chimpanzee populations, columns contain: (1) Baseline rates for net reproductive rate (R_0), mean generation time (T_g, years). (2) Stationarity conditions (scaling factor Z^a for all adult mortality with associated life expectancy e_0^a. (3) Variance scalars (Z^σ) that would produce a force of stochasticity sufficient to drive ZPG via stochastic (uncorrelated) noise, as a multiple of cross-population variability estimated through the coefficient of variation, applied only to survival (Z_p^σ) or only to fertility (Z_m^σ). Negative variance multipliers indicate the amount of variance that would have to be present and eliminated completely to attain ZPG in declining populations. (4) Critical covariance driving ZPG as a multiple of cross-population coefficients of variation (CV) in vital rates underling scaled covariance, applied only to survival (Z_p^Σ), to fertility (Z_m^Σ), or only to fertility-survival correlations at each age (Z_x^Σ). Separate rows show results for the mean human life history and for the mean life histories of declining ($r < 0$) and increasing ($r > 0$) chimpanzee populations. Negative covariance scalars ($Z^\Sigma < 0$) indicate cases where correlations must be reversed to drive ZPG.

			Baseline					Stationarity						Variance		Covariance		
	Population		R_0	T_g	CDR	ADR	IBI	Z^a	e_0^a	CDR^a	Z^c	e_0^c	CDR^c	Z_p^σ	Z_m^σ	Z_X^Σ	Z_p^Σ	Z_m^Σ
Small-Scale Societies	**Ache**	**H**	2.17	29.4	0.66	0.05	3.3	4.00	21.3	0.85	2.88	18.6	0.67	60	82	708	29	18
	Agta	**H**	1.16	29.1	0.72	0.05	3.3	1.57	18.2	0.84	1.15	18.5	0.79	27	40	237	13	8.6
	Hadza	**H**	1.49	28.7	0.62	0.13	3.7	3.59	21.8	0.83	1.64	24.1	0.99	43	62	431	21	14
	Hiwi	**H**	1.11	27.5	0.51	0.08	4.0	1.36	24.1	0.57	1.17	24.6	0.53	22	31	275	11	7.2
	Ju/'hoansi	**H**	1.05	28.4	0.60	0.22	4.1	1.31	30.8	0.66	1.08	32.5	0.63	15	23	135	7.4	5.1
	HG Mean LH	**H***	1.38	28.8	0.54	0.08	3.7	2.35	21.4	0.67	1.52	22.2	0.58	39	57	394	19	12
	Aborigine	**A**	1.54	26.0	0.37	0.11	5.1	4.00	34.2	0.35	2.50	32.7	0.33	43	44	357	22	13
	Gainj	**F**	1.08	31.0	1.01	0.05	3.9	1.44	28.3	1.09	1.16	29.0	0.99	20	31	136	9.4	6.6
	Tsimane	**F**	2.91	28.0	0.73	0.03	3.0	4.00	26.5	0.63	4.00	16.2	0.50	68	83	1267	34	21
	Yanomamo	**F**	2.33	25.5	0.90	0.05	3.1	4.00	24.3	0.97	2.82	18.9	0.84	58	52	2650	31	16
	Herero	**P**	1.13	26.3	0.47	0.28	5.2	3.14	35.2	0.59	1.41	44.7	0.52	23	27	374	12	7.2
	***H.s.* Mean LH**	*****	1.59	28.1	0.45	0.06	3.9	3.34	21.6	0.58	1.99	22.6	0.49	46	63	611	23	15
Chimpanzees	**Gombe**	**E**	0.72	23.7	0.61	<0.01	4.8	0.46	19.4	0.62	0.58	20.1	0.76	-14	-94	-100	-3.5	-13
	Kanyawara	**E**	1.27	25.0	0.61	0.01	3.9	1.53	17.2	0.81	1.38	16.8	0.73	12	75	78	2.9	11
	Mahale	**E**	0.91	24.4	0.46	<0.01	3.9	0.38	16.6	0.41	0.93	15.1	0.42	-7.6	-52	-59	-1.8	-7.1
	Ngogo	**E**	2.32	25.4	0.59	0.01	3.9	4.00	20.9	0.68	3.17	15.3	0.51	22	138	150	5.4	20
	Taï	**W**	0.17	18.3	0.70	0.02	4.6	0.02	26.9	0.49	0.00	16.6	1.68	-35	-170	-246	-10	-32
	Mean LH ($r < 0$)	*****	0.45	22.0	0.58	<0.01	4.5	0.15	20.2	0.47	0.21	19.7	0.88	-23	-147	-270	-5.8	-21
	Mean LH ($r > 0$)	*****	1.72	25.2	0.60	0.01	3.9	2.80	17.4	0.87	2.15	16.2	0.67	17.8	112	119	4.3	17
	Mean LH (all)	*	0.74	23.3	0.59	<0.01	4.2	0.57	17.5	0.64	0.62	18.1	0.78	-14	-88	-117	-3.4	-13

Table S4. Age effects for Scenarios 2 and 3. Scaling factors Z^{σ} that would drive long-term zero population growth (ZPG) through uncorrelated stochastic variation (noise) applied to the coefficient of variation (CV) estimated across all ten small-scale societies or all five chimpanzee populations. Scaling factors are applied either to all vital rates (Z^{σ}), only mortality rates ($Z_q{}^{\sigma}$), only juvenile mortality ($Z_{juv}{}^{\sigma}$), only adult mortality ($Z_{ad}{}^{\sigma}$), only infant mortality ($Z_{inf}{}^{\sigma}$), only child mortality ($Z_{child}{}^{\sigma}$), only prime-age adult mortality ($Z_{prime}{}^{\sigma}$), all fertility rates ($Z_m{}^{\sigma}$), only fertility between ages 5 and 15 ($Z_{m5}{}^{\sigma}$), ages 15 and 25 ($Z_{m15}{}^{\sigma}$), ages 25 and 35 ($Z_{25}{}^{\sigma}$) or ages 35 45 ($Z_{35}{}^{\sigma}$). The second set of columns contain scaling factors Z^{Σ} that would drive ZPG through covariation between: all rates (Z^{Σ}), on all mortality rates ($Z_q{}^{\Sigma}$), only juvenile mortality ($Z_{juv}{}^{\Sigma}$), only adult mortality ($Z_{ad}{}^{\Sigma}$), only infant mortality ($Z_{inf}{}^{\Sigma}$), only child mortality ($Z_{child}{}^{\Sigma}$), only prime-age adult mortality ($Z_{prime}{}^{\Sigma}$), all fertility rates ($Z_m{}^{\Sigma}$), or fertility between ages 5 and 15 ($Z_{m5}{}^{\Sigma}$), ages 15 and 25 ($Z_{m15}{}^{\Sigma}$), ages 25 and 35 ($Z_{25}{}^{\Sigma}$) or ages 35 45 ($Z_{35}{}^{\Sigma}$). $Z_x{}^{\Sigma}$ reflects fertility and mortality at the same age, *x*. In each case, units for the scaling factors are in multiples of the cross-population variability estimated through the coefficient of variation (CV), assuming no correlation (in the case of stochastic noise), or correlations equal to those estimated across populations (critical covariance). Negative covariance scalars ($Z^{\Sigma} < 0$) indicate cases where correlations must be reversed to drive ZPG.

			Stochastic Noise													Critical Covariance											
			All	Mortality						Fertility						All		Mortality						Fertility				
	Population		Z^{σ}	$Z_p{}^{\sigma}$	$Z_{juv}{}^{\sigma}$	$Z_{ad}{}^{\sigma}$	$Z_{inf}{}^{\sigma}$	$Z_{child}{}^{\sigma}$	$Z_{prime}{}^{\sigma}$	$Z_m{}^{\sigma}$	$Z_{m5}{}^{\sigma}$	$Z_{m15}{}^{\sigma}$	$Z_{m25}{}^{\sigma}$	$Z_{m35}{}^{\sigma}$	Z^{Σ}	$Z_x{}^{\Sigma}$	$Z_p{}^{\Sigma}$	$Z_{juv}{}^{\Sigma}$	$Z_{ad}{}^{\Sigma}$	$Z_{inf}{}^{\Sigma}$	$Z_{child}{}^{\Sigma}$	$Z_{prime}{}^{\Sigma}$	$Z_m{}^{\Sigma}$	$Z_{m5}{}^{\Sigma}$	$Z_{m15}{}^{\Sigma}$	$Z_{m25}{}^{\Sigma}$	$Z_{m35}{}^{\Sigma}$
Small-Scale Human Societies	**Ache**	**H**	48	60	61	350	62	332	350	82	244	115	191	191	16	708	29	33	18	35	43	38	18	44	26	35	31
	Agta	**H**	22	27	27	150	27	148	150	40	NA	61	70	83	8.3	237	13	16	8.9	17	20	18	8.6	26	13	15	14
	Hadza	**H**	35	43	44	250	44	239	250	62	427	84	120	160	13	431	21	25	14	26	31	29	14	39	19	25	24
	Hiwi	**H**	18	22	23	135	23	124	135	31	90	41	63	97	6.5	275	11	12	7.1	13	16	15	7.2	17	10	13	13
	Ju/'hoansi	**H**	12	15	15	85	15	83	85	23	NA	32	37	66	4.9	135	7.4	9.0	5.3	9.8	11	10	5.1	15	7.3	8.5	9.0
	HG Mean LH	*	32	39	39	225	40	216	225	57	340	80	109	138	12	394	19	22	12	24	29	26	12	34	18	23	21
	Aborigine	**A**	30	43	43	286	44	236	286	44	68	63	150	249	11	357	22	20	12	22	27	24	13	22	16	26	25
	Gainj	**F**	17	20	21	104	21	113	104	31	NA	84	39	65	6.7	136	9.4	12	7.2	14	15	15	6.6	20	14	10	11
	Tsimane	**F**	52	68	68	426	70	375	426	83	196	106	233	292	18	1267	34	35	20	38	46	42	21	45	26	41	38
	Yanomamo	**F**	39	58	59	398	60	322	398	52	NA	54	257	369	14	2650	31	28	15	30	34	34	16	53	17	34	33
	Herero	**P**	18	23	24	148	24	129	148	27	NA	30	80	127	6.5	374	12	12	7.0	13	15	15	7.2	22	8.2	14	14
	***H.s.* Mean LH**	*	37	46	46	276	47	254	276	63	317	79	138	184	13	611	23	26	14	27	33	29	15	38	19	27	26
Wild Chimpanzees	**Gombe**	**E**	-14	-14	-19	-21	-25	-29	-21	-94	-247	-127	-180	-614	-3.3	100	-3.5	-5.8	-3.9	-24	-5.5	-4.0	-13	-17	-10	-11	-15
	Kanyawara	**E**	12	12	16	17	22	24	17	75	214	101	141	501	2.7	78	2.9	5.2	3.1	19	4.9	3.2	11	14	8.5	9.3	13
	Mahale	**E**	-7.5	-7.6	-10	-11	-14	-16	-11	-52	-115	-77	-96	-240	-1.8	59	-1.8	-3.4	-2.0	-14	-3.1	-2.1	-7.1	-9.5	-5.8	-6.1	-8.4
	Ngogo	**E**	22	22	30	33	40	45	33	138	370	184	267	1007	5.1	150	5.4	9.6	5.8	36	9.1	6.1	20	27	16	17	23
	Taï	**W**	-35	-35	-43	-63	-57	-64	-63	-170	-208	-327	-779	-2467	-10	246	-10	-16	-12	-60	-15	-12	-32	-67	-28	-31	-36
	Mean LH ($r < 0$)	*	23	23	30	36	40	45	36	147	259	217	337	998	5.6	270	5.8	10.2	6.5	40	10	6.6	21	31	17	19	24
	Mean LH ($r > 0$)	*	18	17.8	24	26	32	37	26	112	309	150	214	784	4.1	119	4.3	7.8	4.7	29	7.3	4.9	17	22	13	14	19
	Mean LH (all)	*	14	14	18	21	24	27	21	88	182	123	183	601	3.3	117	3.4	6.0	3.8	23	5.7	3.9	13	18	10	11	15

SI Section 2. Ethnographic details on human study populations, and supplementary information on chimpanzee populations

Contemporary hunter-gatherers have been affected by global socioeconomic forces and are not living replicas of our Stone Age ancestors. Each group has been exposed to a particular set of historical, ecological, and political conditions, and extant groups occupy only a small subset of the environments that foragers occupied in the past. Thus, even without the variable impact of infectious diseases and modernization, no single group can accurately represent all modern foragers or pristine foragers typical of our ancestral past (see (1)). Isolation from outsiders, small-scale social structure, and absence of amenities also characterize many incipient horticulturalist populations, many of whom also engage in foraging. Remote populations of forager-horticulturalists or pastoralists therefore merit attention, especially when considering analogues for Holocene domestication during the Neolithic demographic transition.

The ethnographic record of hunter-gatherers includes hundreds of cultures, but only fifty or so groups have ever been studied. Our sample of foraging societies does not adequately cover all geographical areas. Only five foraging societies have been explicitly studied using demographic techniques—Hadza of Tanzania (2-4), Ju/'hoansi !Kung (5, 6), Ache of Paraguay (7), Agta of Philipines (8), and the Hiwi of Venezuela (9). We limit ourselves to samples where: (a) estimates of both fertility and mortality exist, (b) age estimation is reliable, (c) age coverage is relatively complete (e.g. from infancy to at least age 60), (d) careful cross-checking, validation and other methods to insure data quality. As mentioned in the main text (Discussion), restricted information on only fertility or only (say) child mortality exists for a broader range of populations – lending support to the estimates in our more limited sample. Sources of fertility and mortality information from these other populations come largely from (10-12).

Hunter-gatherers

Nancy Howell's **Ju/'hoansi !Kung** study in the Kahalari desert of Botswana and Namibia is one of the first and most impressive demographic accounts of a foraging society. The majority of !Kung have been settled during the last sixty years, and have been rapidly acculturating in close association with nearby Herero and Tswana herders. At the time of study, many of the adults had spent most of their lives foraging, despite ethnohistorical evidence showing interactions with mercantile interests in the 19th century and archaeological evidence suggesting trade with pastoral and agricultural populations. An early !Kung sample refers to the time period before the 1950's when the Bantu influence in the Dobe area was minimal. Later !Kung samples refer to the prospective time of study when the lifeways of the Kung were rapidly changing. At the time of study, there were about 454 people living in the study site. Note, in the text we conservatively report a total fertility rate (TFR) of 4.3, consistent with Howell's Table 7.1, based on 1,434 risk-years among 179 women during the period 1963-1973. Howell reports a slightly higher TFR=4.7 based on reproductive histories of 62 living women age 45+ (310 risk-years). Similarly, Tanaka (13) reports that among a related San group of the Central Kalahari in the ≠Kade area (includes the G/wi and G//ana), the population growth rate over the period between 1967 and 1972 was estimated to be between 1-2%, higher than what Howell reports for the Dobe Ju/'hoansi (0.5%). He also estimates life expectancy at birth e_0 as 39.8 (~6 years

higher than among Ju/'hoansi). Tanaka's sample included 128 births to 52 women and comparison of censuses between 1967 and 1972 (213 to 232 people). Given the smaller sample and less rigorous methodology, we report in the main text the more conservative Ju/'hoansi estimates based on Howell.

The **Ache** were full-time, mobile tropical forest hunter-gatherers until the 1970's. Hill and Hurtado (7) separate Ache history into three time periods—a precontact "forest" period of pure foraging with no permanent peaceful interactions with neighboring groups (before 1970), a "contact" period (1971-77) where epidemics had a profound influence on the population, and a recent "reservation" period where they live as forager-horticulturalists in relatively permanent settlements (1978-1993). During this latter period, the Ache have had some exposure to health care. The pre-contact Ache period shows marked population increase, due in part to the open niche that was a direct result of high adult mortality among Paraguayan nationals during the Chaco War with Bolivia in the 1930's. No life table is published for the high mortality contact period which killed many older and young individuals. Hill and Hurtado improve on Howell's methods of age estimation by using averaged informant ranking of age, informant estimates of absolute age differences between people, and polynomial regression of estimated year of birth on age rank. Apart from living individuals, reproductive histories of a large sample of adults built the samples used for mortality analysis. At the time of study, there were roughly 570 Northern Ache.

The **Hadza** in the eastern rift valley of Tanzania were studied in the mid-1980's by Nicholas Blurton Jones and colleagues. Trading with herders and horticulturalists has been sporadic among Hadza over the past century, and the overall quantity of food coming from horticulturalists varies from 5-10% (2). The Hadza have been exposed to a series of settlement schemes over the past fifty years, but none of these has proven very successful. The 1990's saw a novel form of outsider intervention in the form of further habitat degradation and "ethno-tourism" (ibid). Although some Hadza have spent considerable time living in a settlement with access to maize and other agricultural foods, most have not and continue to forage and rely on wild foods. The population was aged using relative age lists, a group of individuals of known ages, and polynomial regression. Two censuses done about fifteen years apart, with an accounting of all deaths during the interim, allowed Blurton Jones to construct a life table, and to further show that sporadic access to horticultural foods and other amenities cannot account for the mortality profile. There were roughly 750 Hadza in the study population.

The **Hiwi** are neotropical savanna foragers of Venezuela studied by Kim Hill and Magdalena Hurtado in the late 1980's (14, 15). They were contacted in 1959 when cattle ranchers began encroaching into their territory. Although living in semi-permanent settlements, Hiwi continue to engage in violent conflict with other Hiwi groups. At the time of study, almost the entire diet was wild foods, with 68% of calories coming from meat, and 27% from roots, fruits, and an arboreal legume. The study population contains a total of 781 individuals. Nearby Guahibo-speaking peoples practice agriculture, while the Hiwi inhabited an area poorly suited for agriculture. As among the Hadza, repeated attempts at agriculture by missionaries or government schemes had failed among this group. Mortality information comes from (9).

The Casiguran **Agta** of the Philippines are Negrito foragers studied by Tom Headland from 1962-1986. They live on a peninsula close to mountainous river areas and the ocean. There are 9,000 Agta in eastern Luzon territory, and demographic study was focused on the San Ildefonso group of about 200 people (8). Although the Luzon area is itself very isolated, Agta have maintained trading relationships with lowlander horticulturalists for at least several centuries (16). The twentieth century introduced schooling, and brief skirmishes during American and Japanese occupation. Age estimation was achieved through reference to known ages of living people and calendars of dated events. As in the Ache study, the Agta demography is divided into a "forager" period (1950-1965), a transitional period of population decline (1966-1980), and a "peasant" phase (1981-1993). These latter phases are marked by guerilla warfare, and subjugation by loggers, miners and colonists.

Forager-horticulturalists

The above five populations comprise the foraging sample because the typology "hunter-gatherer" defines their mode of subsistence, and therefore a lack of reliance on domesticated foods. To the forager sample described above, we add the Yanomamo of Venezuela and Brazil, Tsimane of Bolivia and Gainj of Papua New Guinea.

Yanomamo, Tsimane and Machiguenga are forager-horticulturalist populations in Amazonian South America. Several different Yanomamo studies have been carried out over the past thirty years. Although often construed as hunter-gatherers, **Yanomamo** have practiced slash and burn horticulture of plantains for many generations (17). They mostly live in small villages of less than fifty people. The effects of the rubber boom and slave trade before the 18th century on Yanomamo were minimal. The Yanomamo remained mostly isolated until missionary contact in the late 1950's. The most complete demography comes from Early and Peters(18) based on prospective studies of eight villages in the Parima Highlands of Brazil. Births and deaths were recorded by missionaries and FUNAI personnel since 1959. The precontact period (1930-56) predates missionary and other outside influence. The contact period (1957-60), "linkage" period (1961-81) and Brazilian period (1982-96) saw increased interaction with miners, Brazilian nationals and infectious disease. Ages for Xilixana (Mucajai) during this period were estimated using a chain of average interbirth intervals for people with at least one sibling of known age, and relative age lists in combination with estimated interbirth intervals. Due to historical precedent, we include the Neel and Weiss (1975) life table for Yanomamo based on 29 villages in Venezuela even though it does not meet our inclusion criteria. It applies a best fit model life table using census data, a growth rate based on repeated censuses, and age-specific fertility. These censuses were taken during the 1960's, and ages were obtained by averaging different researchers' independent guesses.

The **Tsimane** inhabit tropical forest areas of the Bolivian lowlands, congregating in small villages near large rivers and small tributaries. There are roughly 16,000 Tsimane living in dispersed settlements in the Beni region. The Tsimane have had sporadic contact with Jesuit missionaries since before the 18th century, although were never successfully converted or settled. Evangelical and Catholic missionaries set up missions in the early 1950's, and later trained some

Tsimane to become teachers in the more accessible villages. However, the daily influence of missionaries is minimal. Market integration is increasing, as are interactions with loggers, merchants and colonists. Most Tsimane continue to fish, practice horticulture, hunt and gather for the majority of their subsistence. The demographic sample used here is based on reproductive histories collected by Gurven of 348 adults in 12 remote communities during 2002-2003. Changes in mortality are evident over the past ten years, and so mortality data used here are restricted to the years 1950-1989. Age estimation of older individuals was done by a combination of written records of missionaries, relative age rankings, and by photo and verbal comparison with individuals of known ages.

The **Gainj** are swidden horticulturalists of sweet potato, yams and taro in the central highland forests of northern Papua New Guinea. Meat is fairly rare (19). At the time of study by Patricia Johnson and James Wood in 1978-79 and 1982-83, there were roughly 1,318 Gainj living in twenty communities. Contact was fairly recent, in 1953 with formal pacification in 1963, and there is genetic and linguistic evidence of their relative isolation (20). Prior to contact, population growth had been zero for at least four generations (21). An A2 Hong Kong influenza epidemic reduced the population by 6.5% in 1969-70, and probably accounts for the dearth of older people in this population. Data were obtained from government censuses from 1970-77, include non-Gainj Kalam speakers, and it is likely that ages are fraught with error for older adults ((see 21)). Additionally, published mortality estimates were already fitted with a Brass two-parameter logit model.

Other populations

We also add the Northern Territory Aborigines of Australia, an acculturated group of hunter-gatherers, and the pastoralist Herero of Botswana and Namibia.

The **Northern Territory Australian Aborigine** mortality data come from analysis of vital registration from 1958-1960 by Lancaster Jones (22, 23). At this time, few Aborigines in the region were still full time foragers. There was a significant amount of age-clumping at five year intervals, and so a smoothing procedure was done on the age distribution of the population. It is likely that infant deaths and more remote-living individuals are under-renumerated, and Lancaster Jones made adjustments to impute missing deaths. We view these data with caution but include them because no other reliable data exist for Australia, apart from a Tiwi sample, culled from the same author.

The **Herero** are Bantu-speaking pastoralists studied by Renee Pennington and Henry Harpending from 1987-1989 (24). They are traditionally cattle and goat herders in the Kalahari Desert of the Ngamiland District of northwestern Botswana, numbering 10-15,000 during time of study. They had migrated to this area in the early 20th century, due to displacements from the Herero-German War. They live in extended family homesteads without running water or electricity, remain endogamous, and are now very successful cattle herders. They also raise more drought-resistant goats and other livestock. Total fertility rates increased from 2.7 in the first half of the 20th century to 7 in the 1980s; the lower earlier fertility was likely due to pelvic inflammatory disease stemming from sexually transmitted infections (25).

For more details on these study populations, including methodological information on demographic samples, age estimates and mortality, see (26).

Chimpanzees

Demographic data are available for five wild populations of the common chimpanzee (*Pan Troglodytes*). We complement the chimpanzee mortality data compiled by Hill and colleagues (27) using recent estimates, and with additional wild populations included in our updated composite chimpanzee reference life history. More recent mortality rates based on larger risk sets have been estimated at **Gombe** (28), **Kanyawara** (29) and **Mahale** (30). We also include recent low-mortality data from **Ngogo** (31) and extremely high-mortality data on one West African population at **Taï** suffering from poaching and Ebola outbreaks (32). Emery Thompson and colleagues (33) compiled fertility rates for three wild populations in East Africa – two in Tanzania (**Gombe** and **Mahale**) and one in Uganda (**Kanyawara**) (their Table S1). These authors include other populations for which we do not have comparable mortality data, and so those data are not included here (but are roughly similar). We combine the Emery Thompson et al. data with fertility rates published for the West African **Taï** (Figure 3.6 in Boesch & Boesch-Acherman 2000). Lacking fertility data on **Ngogo** we use *ASFR* from nearby Kanyawara published in (33).

High TFRs but high IBIs?

The relatively high TFRs we estimate for chimpanzees stands in stark contrast to actual fertility, as TFR represents a synthetic cohort of females reproducing through all of their reproductive years (i.e. complete survival from ages at first to last reproduction). Many chimpanzees will not live throughout adulthood and so realized fertility will be lower than the TFR. Given relatively lower adult mortality, human TFR is closer to actual cumulative fertility. Combined with somewhat lower infant and child mortality rates, and extended juvenility, human mothers are more likely than chimpanzees to simultaneously have multiple dependents (34). To illustrate this, we compute the Net Reproductive Rate (NRR) for wild chimpanzees and hunter-gatherers. NRR refers to the average number of daughters a female produces over her lifespan, and is equal to $\sum l_x m_x$, where here m_x = ASFR/2 (assuming equal sex ratio at birth). Despite similar TFRs, the NRR for human hunter-gatherers is 2.2 times greater than that for chimpanzees (1.67 vs. 0.76).

The high TFR and low average IBI we report may also seem at odds with common reports that chimpanzee IBIs are relatively long, e.g. 5-6 years (35). Indeed, average IBIs vary from 61 to 86 months in the wild, and about 50 months in captivity (32). Upon the death of an infant, however, chimpanzees tend to resume oestrous cycle within a month of the infant death (ibid), and become pregnant roughly two months later. In a sample of 13 mother-infant dyads, mean±SD months until the next birth after an infant death was 12.9 ± 2.9 months. After considering the ages that these infants died, the IBI for Tai chimpanzee females after offspring death is 21.9 ± 9.2 months (33: Table 3.3). Similarly, Emery Thompson et al. (33) report an IBI of 2.2 years in the case where the infant dies before age 4 yrs. Our average IBI based on the ASFRs of 3.8 yrs is thus a weighted average of IBIs under conditions of infant survival and death. Given

that on average, 59% of chimpanzees survive to age 4, we can roughly approximate the duration of the average IBI experienced by a female: 0.59*(5.7 years) + 0.41*(2.2 years) = 4.3 years, a number much closer to the average IBI we report. Thus, perhaps counterintuitively, when environmental conditions favor greater infant survival in both chimpanzees and humans, the species gap in IBIs is greatest.

Supplemental Section 3. Derivation of zero population growth (ZPG) conditions

Here we include the derivations of the variance scaling factor Z^{σ} producing stochastic noise with a force of stochasticity (τ^*) yielding long-term zero population growth (ZPG) without significant covariance or changes in mean vital rates (Scenario 2 in main text), and (2) the covariance scaling factor Z^{Σ} that would provide a force of stochasticity (τ^*) driving long-term ZPG without changing mean vital rates (Scenario 3 in main text).

We begin with the small noise approximation(36) (SNA) of the stochastic growth rate ($\log \lambda_S$) incorporating vital rate elasticities (e_{ij}) and scaled covariance (covariance calculated using coefficients of variation CV_{ij} instead of standard deviations σ_{ij}),

$$\log \lambda_S \approx r - \frac{1}{2}\sum_{ij,kl} e_{ij} e_{kl} \mathrm{CV}_{ij} \mathrm{CV}_{kl} \rho_{ij,kl} = r - \tau \,, \qquad \text{(B1)}$$

in which the force of stochasticity $\tau\left(\tau = \frac{1}{2}\sum_{ij,kl} e_{ij} e_{kl} \mathrm{CV}_{ij} \mathrm{CV}_{kl} \rho_{ij,kl} \right)$ is a scaled covariance-weighted sum ($\mathrm{COV}_{sc}(a_{ij}, a_{kl}) = \mathrm{CV}_{ij}\,\mathrm{CV}_{kl}\,\rho_{ij,kl}$) of vital rate elasticities e_{ij} and e_{kl} $\left(e_{ij} = \frac{a_{ij}}{\lambda} s_{ij} = \frac{a_{ij}}{\lambda}\frac{\partial \lambda}{\partial a_{ij}}, e_{ij} = \frac{a_{ij}}{\lambda} s_{kl} = \frac{a_{ij}}{\lambda}\frac{\partial \lambda}{\partial a_{kl}} \right)$, each scaled relative to the population growth rate (λ) and mean vital rates (a_{ij}, a_{kl}). Whether mean vital rates yield population growth or decline, we can calculate the force of stochasticity (τ^*) that would yield long-term ZPG ($\log \lambda_S = 0$; $\tau^* = r$) without changing mean vital rates (a_{ij}, a_{kl}).

SI Section 3.1. ZPG due to stochastic noise (Scenario 2)

If we assume only stochastic noise with no significant covariance ($\rho_{ij=kl} = 1$, $\rho_{ij\neq kl} = 0$) and equal scaling of variability (CV_{ij}) across all vital rates ($Z_{ij}^{\sigma} = Z^{\sigma}$ for $\forall$ *ij*), long-term ZPG is described by a stochastic population growth rate (λ_S) near zero:

$$\log \lambda_S = 0 \approx r - \frac{1}{2}\sum_{i=j} e_{ij}^2 \mathrm{CV}_{ij}^2 . \qquad \text{(B2)}$$

If we insert the variance scalar Z^{σ} applied evenly to the coefficients of variability (CV_{ij}) of all matrix elements (a_{ij}) and solve for Z^{σ}:

$$\log \lambda_S = 0 \approx r - \frac{1}{2}\sum_{ij=kl} e_{ij}^2 \left(Z^{\sigma} \mathrm{CV}_{ij} \right)^2 \text{ and} \qquad \text{(B3)}$$

$$r = \frac{1}{2}\left(Z^{\sigma}\right)^2 \sum_{ij} e_{ij}^2 \mathrm{CV}_{ij}^2 \text{, so} \tag{B4}$$

$$Z^{\sigma} = \sqrt{\frac{2r}{\sum_{i=j} e_{ij}^2 \mathrm{CV}_{ij}^2}}\,. \tag{B5}$$

We also calculate the scaling factor Z_m^{σ} that would provide stochastic noise driving ZPG when applied evenly to fertility rates m_x without changing mortality or introducing covariance:

$$Z_m^{\sigma} = \sqrt{\frac{2r}{\sum_x m_x^2 \mathrm{CV}_{m_x}^2}}, \tag{B6}$$

and the proportion Z_p^{σ} of the variance observed in survival (p_x) that would drive ZPG without changing fertility:

$$Z_p^{\sigma} = \sqrt{\frac{2r}{\sum_x p_x^2 \mathrm{CV}_{p_x}^2}}. \tag{B7}$$

SI Section 3.2. ZPG due to vital rate covariance (Scenario 3)

As with uncorrelated stochastic noise, we compute the scaling factor Z^{Σ} that would magnify coefficients of variation (CV_{ij}, CV_{kl}) sufficiently to provide covariance with a force of stochasticity (τ^*) driving long-term ZPG in the absence of changes in mean vital rates but with correlations equal to those estimated across populations in our sample. We insert the scalar Z^{Σ} into the small noise approximation expression (equation B1):

$$\log \lambda_S = 0 \approx r - \frac{1}{2}\sum_{ij,kl} e_{ij} e_{kl} \left(Z^{\Sigma}\mathrm{CV}_{ij}\right)\left(Z^{\Sigma}\mathrm{CV}_{kl}\right)\rho_{ij,kl};, \tag{B8}$$

which can be written $r = \frac{1}{2}\left(Z^{\Sigma}\right)^2 \sum_{ij,kl} e_{ij} e_{kl} \mathrm{CV}_{ij} \mathrm{CV}_{kl} \rho_{ij,kl}$; (B9)

We solve for Z^{Σ}:

$$Z^{\Sigma} = \sqrt{\frac{2r}{\sum_{ij,kl} e_{ij} e_{kl} \mathrm{CV}_{ij} \mathrm{CV}_{kl} \rho_{ij,kl}}}, \tag{B10}$$

where elasticities (e_{ij}, e_{kl}) are calculated from the population vital rates (a_{ij}) and scaled covariances ($\mathrm{CV}_{ij}\mathrm{CV}_{kl}\rho_{ij,kl}$) are calculated between vital rates across populations in our sample (either the ten small-scale societies or five wild chimpanzee populations).

This equation identifies the critical covariance threshold and scaling factors Z^{Σ} that would drive long-term ZPG when applied to the CVs of temporal within-population covariance, scaled relative to the covariance we calculate across populations. We also calculate scaling factors for covariance when only survival probabilities (p_x) covary with one another

$$Z_p^{\Sigma} = \sqrt{\frac{2r}{\sum_{x,a} e_{x+1,x} e_{a+1,a} \mathrm{CV}_{x+1,x} \mathrm{CV}_{a+1,a} \rho(p_x, p_a)}}, \tag{B11}$$

when only fertility rates (m_x) covary

$$Z_m^{\Sigma} = \sqrt{\frac{2r}{\sum_{x,a} e_{1x} e_{1a} \mathrm{CV}_{1x} \mathrm{CV}_{1a} \rho(m_x, m_a)}}, \quad \text{(B12)}$$

or when only considering fertility-survival covariance at each age

$$Z_x^{\Sigma} = \sqrt{\frac{2r}{\sum_{x} e_{1x} e_{x+1,x} \mathrm{CV}_{1x} \mathrm{CV}_{x+1,x} \rho(m_x, p_x)}}, \quad \text{(B13)}$$

where correlations $\rho(m_x, p_x)$ are between survival probabilities p_x and fertility m_x at each age x..

SI Section 3.3. Combined changing of vital rates, variance and covariance (Scenarios 1-3)

To estimate the simultaneous combinations of mean vital rate changes and variance or covariance that would drive long-term ZPG, we first apply scalars Z^m, Z^c and Z^a yielding single-rate changes or vital rate combinations shifting the population growth rate toward ZPG (just as in Scenario 1). Then, we compute new elasticities from these altered vital rates and the resulting population growth rate is taken as the new baseline from which to assess stochastic effects. Finally, using the same methods applied in Scenarios 2 or 3 we solve for the co/variance scalars Z^{σ} or Z^{Σ} that would drive ZPG beginning with these altered vital rates. We predict ZPG conditions when only fertility changes (Z^m), or when only mortality changes at all ages (Z^q), when mortality changes only across childhood (Z^c), or only across adulthood (Z^a). We also predict ZPG conditions (Z^{all}) when both fertility and mortality change by equal proportions (e.g. 10% change in both fertility and mortality, $Z^m = 0.9$, $Z^q = 1.1$).

SI Section 4. Comparing vital rate variability within vs. between human populations

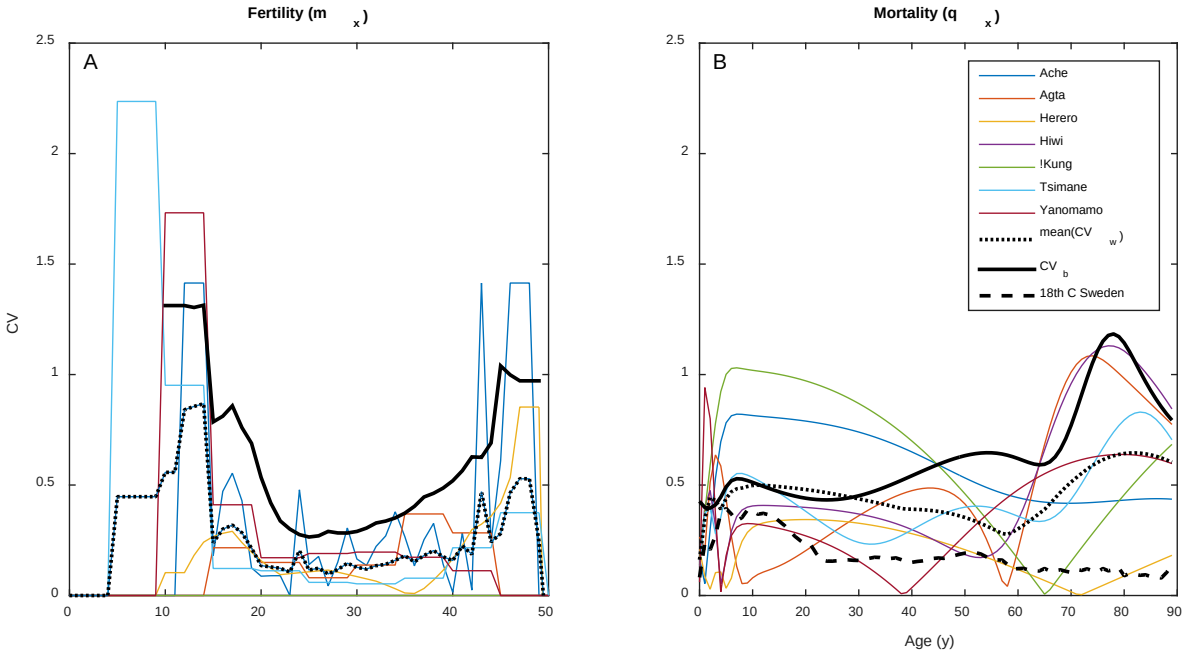
Variability in fertility is greater near the beginning and end of the reproductive lifespan, both within populations over time and across populations. Fertility also varies more across populations (CV_b) than across the short time frames (mean CV_w) we have for individual populations (Supplemental Figure 1A; Supplemental Table 4). Mortality varies the most across populations at old ages, due to genuine population-level differences, but perhaps also from noise in small sample sizes at advanced ages (Supplemental Figure 1B; Supplemental Table 4). Compared to younger ages, mortality at old ages also varies more within populations over time, but to a lesser degree than cross-population variation. Mean temporal variability in mortality (CV_w) is comparable to between-population variability (CV_b) up to age 30 or so but at older ages mortality varies more between populations than over the short time-frames we have for within-population fluctuations (Supplemental Table S5).

As an additional comparison of within vs. between-population differences in vital rates, we employ time series of 18th century Swedish mortality data from the Human Mortality Database to assess preindustrial agrarian population dynamics (Supplemental Table S5; Supplemental Fig. S1). Mortality (μ_x) is higher on average among small-scale societies, especially hunter-gatherers, compared to pre-industrial Sweden (1751-1800), though there is considerable overlap in mortality rates(26). Temporal variation in 18th Century Swedish mortality is lower than among small-scale societies, but is comparable to the mean of CV_w across small-scale populations up to age 15 and between ages 50 and 60. In contrast to the small-scale society variability (across or within populations), old age mortality in Sweden varies less than child mortality across the mid- to late-18th Century.

Table S5. Vital rate coefficients of variation (CV) within populations. Number of observations refers to the number of separate time periods of observation. Yrs refers to the total time period of coverage. "Within Human" reflects the average CVs, # observation periods and years for the eight human populations with time series data.

Ages	Sweden	Ache	Agta	Herero	Hiwi	Kung	Tsimane	Yano	Within Human	Btw Human
q_x										
0-4	0.23	0.35	0.44	0.11	0.28	0.57	0.31	0.44	0.36	0.42
5-19	0.34	0.81	0.15	0.28	0.38	1.01	0.49	0.30	0.49	0.49
20-39	0.17	0.74	0.35	0.32	0.36	0.86	0.28	0.15	0.44	0.46
40-59	0.17	0.54	0.35	0.21	0.23	0.46	0.37	0.26	0.35	0.61
60+	0.11	0.43	0.85	0.08	0.90	0.32	0.58	0.60	0.54	0.87
m_x										
15-29	n/a	0.24	0.15	0.16	n/a	n/a	0.10	0.26	0.18	0.48
30-44	n/a	0.28	0.26	0.13	n/a	n/a	0.12	0.16	0.19	0.45
# obs	5	2	3	2	2	2	5	3	3	
Yrs	49	59	44	40	55	54	49	66	52	

Figure S1. Coefficients of variation for human societies with time series data. For seven small-scale societies with time series data that enables estimation of temporal variability, coefficients of variation (CV) are shown for **(A)** fertility (m_x) and **(B)** mortality (q_x). Colored lines refer to Ache, Agta, Herero, Hiwi, Ju/'hoansi (!Kung), Tsimane and Yanomamo populations; the dotted black lines show the mean CV across the 7 populations with variability estimates within populations over time, the solid black lines show the variability between (across) all ten small-scale societies, and the dashed black line in (b) shows the CV(q_x) across time in pre-industrial Sweden (1751-1800).



SI Section 5. Descriptive information on human and chimpanzee vital rates, variability and population growth

Mean mortality is lower among humans than among wild chimpanzees at all ages except during infancy (<1y), but variation among the two species overlaps at early ages (Figure 1a). Mean human fertility is higher than among wild chimpanzees between ages 25 and 35, similar between ages 35 to 40, and lower outside this age range (Figure 1b). However, given species-specific variability, fertility rates among humans and chimpanzees overlap at all ages except where chimpanzees exceed humans during early (ages 10 to 16) and late reproduction (ages 47 to 50). Although R_0 of chimpanzees spans most of the human R_0 range, chimpanzee generation times are shorter, resulting in lower annual population growth rates among declining populations and relatively high growth rates in increasing populations (Supplemental Fig. S3a). Chimpanzee total fertility rate *TFR* is clustered near the top of the human range, with all populations above the human mean. Only Ngogo e_0 (based on a recent study(31); see main text) surpasses that of any human population (Supplemental Fig. S3b, Table 1).

All human populations in our sample are growing, some very rapidly (e.g. forager-horticulturalists: Tsimane r = 3.8%, Yanomamo r = 3.2%), others fairly rapidly (e.g. hunter-gatherers: Ache r = 2.6%, Hadza r = 1.4%). Two hunter-gatherers hover near stationarity (Hiwi r = 0.05%, Ju/'hoansi r = 0.02%) (Supplemental Fig. S3a; Table 1). On average, human population growth rate is moderate (r = 1.6 ± 1.4%). Contrary to prior comparisons (37), we find that *TFR* is notably higher among chimpanzees than humans (*TFR* 7.3 vs. 5.9; Supplemental Fig. S3b; Table 1), yet only two of the five chimpanzee populations are growing (Kanyawara r = 0.95%, Ngogo r = 3.3%). Chimpanzees at Gombe and Mahale are declining slowly (r = -0.6%, r = -0.3%, respectively), whereas the Taï group is crashing (r = -9.1%). Generation times are longer among humans than among declining chimpanzees (T_g = 28.4 y ± 2.0 y; T_g = 15.8 ± 3.6, respectively) but comparable with growing chimpanzee populations (T_g = 25.6 ± 0.5). Across species, populations with higher e_0 have longer generation time T_g, but this relationship is marginally reversed among humans (Supplemental Fig. S3c).

Figure S3. Population growth and life history. (a) For ten small-scale societies and five wild chimpanzee populations, population growth rates ($r = \log \lambda$, z-contour lines) are decomposed into contributions from the generation time (T_g, x-axis) and the net reproductive rate describing population growth per generation (R_0, y-axis). Green circles indicate hunter-gatherer societies (Ac: Ache, Ag: Agta, Ha: Hadza, Hi: Hiwi, J: Ju/Huansi), blue circles indicate non-foragers (Ab: Northern Territory Aborigines, G: Gainj, He: Herero, Ts: Tsimane, Y: Yanomamo) and red squares indicate chimpanzee. Black outlines indicate composite life histories with vital rates averaged across hunter-gatherers (HG, green), non-foragers (NF, blue), declining chimpanzees (WC-, red) or increasing chimpanzee populations (WC-, red). **(b)** Populations are arranged by total fertility rate (*TFR, y*-axis) and life expectancy (e_0, x-axis). **(c)** Populations are arranged by generation time (T_g, y-axis) and life expectancy (e_0, x-axis). Solid line shows significant regression for all populations pooled ($r = 0.23$, $p = 0.04$) and dashed line shows marginally significant decline for humans alone ($r = -0.26$, $p = 0.07$).

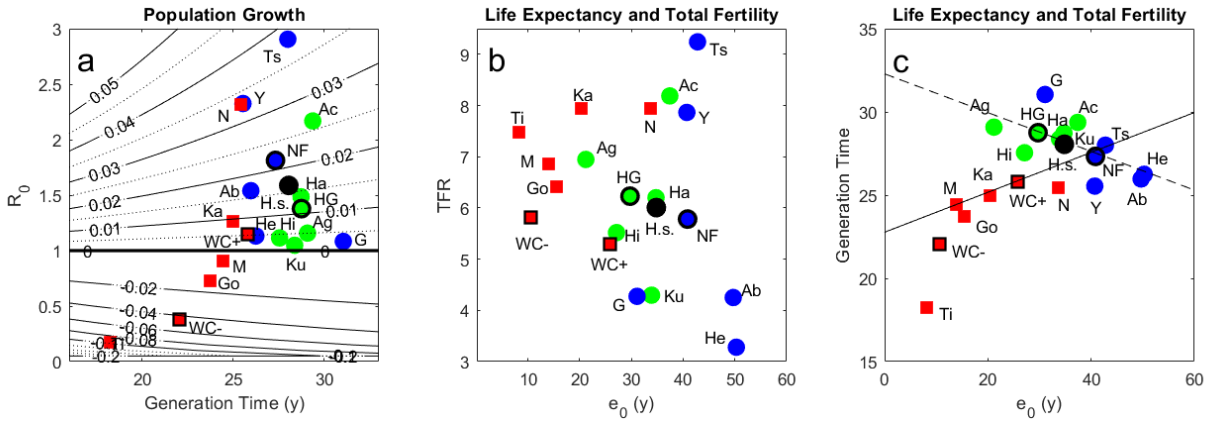
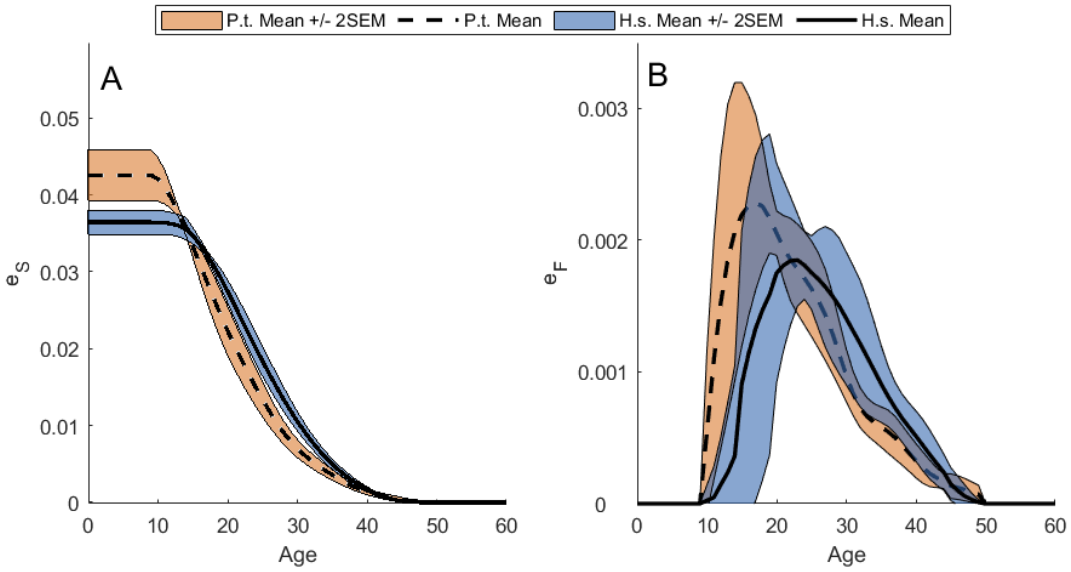


Figure S4. Vital rate sensitivities for humans and chimpanzees. 95% Confidence Intervals (Mean ± 2 SEM) are calculated across ten small-scale human societies (blue fill, solid lines) or across five wild chimpanzee populations (red fill, dotted lines). (a) Elasticity to survival (E_s), and (b) Elasticity to fertility (E_f). In general, humans and chimpanzees show similar age profiles of vital rate elasticities. However, chimpanzees show higher E_s than humans early in life, though E_s declines earlier in chimpanzees. Chimpanzee E_f also is higher at earlier ages.



Supplemental Section 6. Vital rate covariance among humans and chimpanzees

Summary of covariance patterns

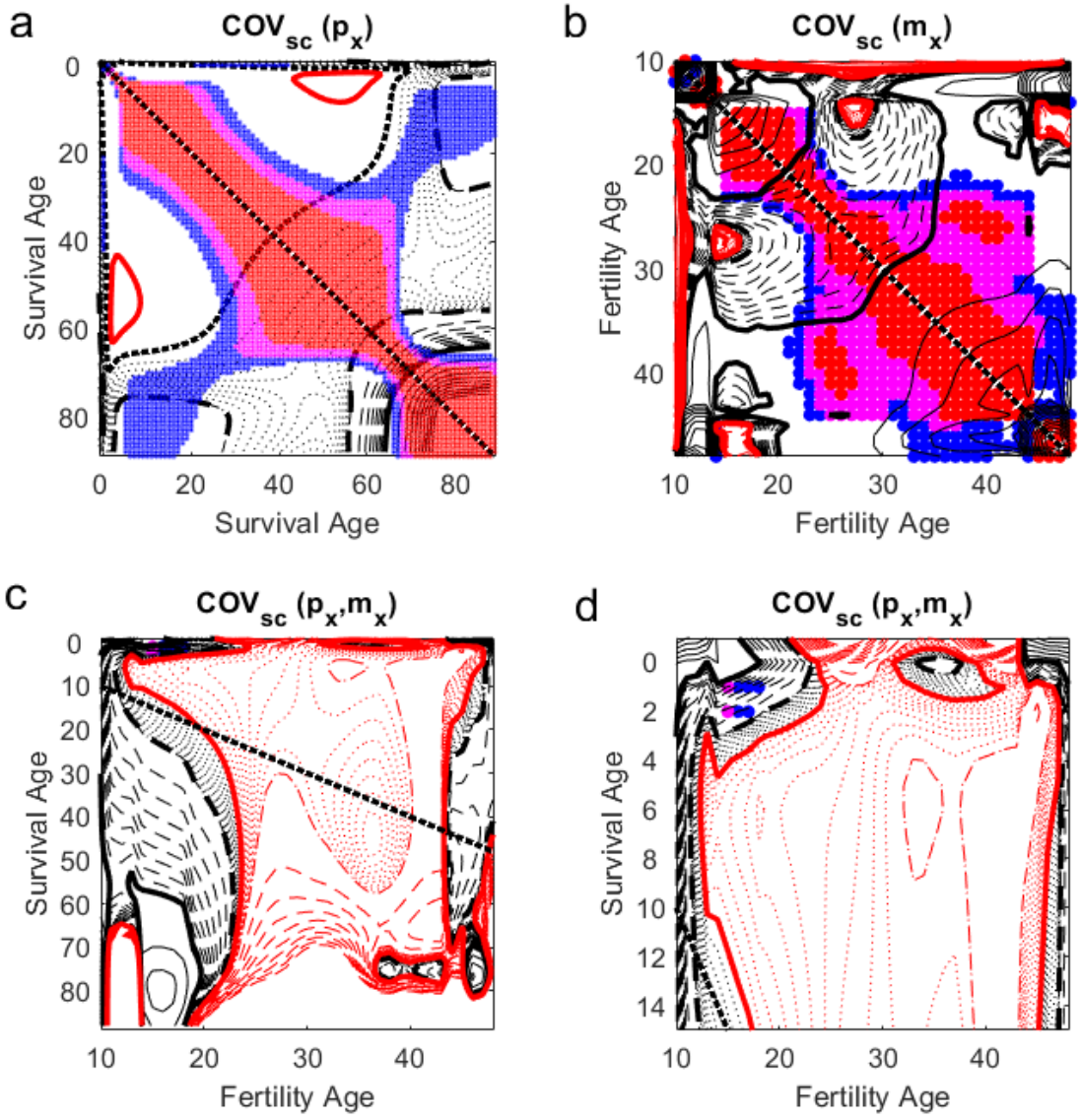
Here we describe the patterns of between-population covariance in age-rates of survival, fertility and survival/fertility for humans, and chimpanzees in further detail. It is these patterns of observed covariance that are used as a baseline for stochastic effects in Scenarios 2 and 3 in the paper. The scalar multipliers of this baseline scaled covariance (standardized by means like coefficients of variation) are calculated to scale the level of covariance necessary to achieve ZPG.

Human Mortality. Across small-scale societies, covariance between survival probabilities is positive at all ages and increases exponentially with age (note contour scaling in Supplemental Fig. S5a). Correlations are most significant across survival at similar ages and are more significant among the old (over age 70) and among middle-aged (ages 30-60). There are peaks in covariance among old-age survival (over age 60) and to a lesser degree between the old and young (over age 70 and under age 40).

Human Fertility. Human fertility rates co-vary positively across most childbearing ages, especially in early adulthood (ages 15-20)(Supplemental Fig. S5b). Although not significant ($p > 0.05$), fertility at the earliest ages (10-13) is negatively correlated with fertility at other ages, suggesting that populations where mothers give birth before the age of 15 have lower overall fertility, and fertility of prime-age mothers (ages 27-30) is negatively correlated with early fertility (ages 15-18). Fertility at similar ages covary positively, with the strength increasing with age and significance increasing with closer ages.

Human survival and fertility. Across human small-scale societies, fertility and survival are negatively covary across a wide range of ages, but correlations are not significant ($p > 0.05$)(Supplemental Fig. S5c). Early fertility (before age 25) is positively associated with survival, especially after age 60, suggesting that similar conditions favor early fertility and old age survival. The only significant correlations between survival and fertility are between early fertility (ages 16-19) and young child survival (ages 2 and 3), suggesting that populations with high early fertility also have low child mortality.

Figure S5. Human vital rate covariance. Covariance estimated across ten small-scale societies is plotted as contours of age-specific survival and fertility. Colors in each panel indicate significant correlations (blue for $p < 0.05$, magenta for $p < 0.01$ and red for $p < 0.001$) among age-specific vital rate pairs. **(a)** Covariance between mortality rates at ages x and y (COV(p_x, p_y)), **(b)** covariance between fertility rates at different ages (COV(m_x, m_y)), **(c)** covariance between fertility and survival across the life cycle (COV(p_x, m_y)), **(d)** covariance between child mortality and fertility across the life cycle (COV($p_{x<15}$, m_y); detail of panel c). In each panel, bold red contours denote the zero covariance threshold, separating positive and negative covariances (negative contours in red); diagonal dotted lines in panels indicate variance (a, b) or covariance between fertility and survival at the same age (c,d). To increase legibility and avoid crowding in (a,c,d), contours in dotted lines indicate steps of 10^{-4} up to bold thresholds $\pm10^{-3}$, followed by dashed lines in steps of 10^{-3} up to bold thresholds at $\pm10^{-2}$, then by solid lines in steps of 10^{-2}. In (b) contours are scaled up by 10x (dotted steps of 10^{-3}, dashed steps of 10^{-2}, solid steps of 10^{-1}).



Chimpanzee mortality. Survival probabilities covary more strongly among wild chimpanzee populations than among humans (note scaling in Fig. S6 vs. Fig. S5). In contrast to humans, where survival correlations were the most significant among adults (ages 20-70), chimpanzee survival rates are significant across larger age differences among younger (ages 5 to 40) and older adults (above age 50) but not between individuals at different ages in midlife (ages 30 to 50) (Supplemental Fig. S6a). As in humans, however, survival covariance is the strongest at older ages (especially above age 50, beyond which few chimpanzees live in the wild). In contrast to the positive survival covariance prevailing among humans, chimpanzee survival of those under 40 and older adults over 50 is negatively correlated.

Chimpanzee fertility. Fertility covariance is strongest and positive among the oldest mothers (above age 40) but very few survive to those late ages at which fertility declines in all populations (Fig. S6b). Fertility covaries positively (and significantly) within distinct age blocks (ages 10-17, ages 17-30, ages 30-40 and, most strongly, above age 40 (but very few survive to those late ages, at which fertility declines in all populations). Early fertility (below age 15) also covaries positively with fertility ages 30-40. In contrast, fertility covaries negatively across these age block: fertility ages 10-17 with ages 17-30 and over age 40; fertility ages 17-30 with fertility before age 17 or after age 30; fertility ages 30-40 with ages 17-30 and ages 40-45; fertility ages 40-45 with fertility before age 40; fertility ages 45 and older with fertility before age 30.

Chimpanzee fertility/mortality. Whereas humans exhibit negative covariance between fertility and survival at most ages but positive covariance of survival with early fertility, chimpanzee survival is correlated negatively with early fertility and positively with fertility ages 15-30 (Fig. S6c). Fertility after age 30 is negatively correlated with survival up to age 40 and fertility between ages 40 and 45 is negatively correlated with survival at all ages. Positive association between fertility over age 45 and survival over age 50 suggests that similar conditions favor fertility and survival at old ages.

Figure S6. Chimpanzee vital rate covariance. Covariance is estimated across five wild chimpanzee populations, plotted as contours along age for one vital rate (*x*-axis) and another (*y*-axis). Colors in each panel indicate significant correlations (blue for $p < 0.05$, magenta for $p < 0.01$ and red for $p < 0.001$) among age-specific vital rate pairs. **(a)** Covariance between mortality rates at ages *x* and *y* (COV(p_x, p_y)), **(b)** covariance between fertility rates at different ages (COV(m_x, m_y)), **(c)** covariance between fertility and survival across the life cycle (COV(p_x, m_y)). In each panel, bold red contours denote the zero covariance threshold, separating positive and negative covariances (negative contours in red); diagonal dotted lines in panels indicate variance (a, b) or covariance between fertility and survival at the same age (c,d). To increase legibility and avoid crowding in (a,c,d), contours in dotted lines indicate steps of 10^{-4} up to bold thresholds $\pm10^{-3}$, followed by dashed lines in steps of 10^{-3} up to bold thresholds at $\pm10^{-2}$, then by solid lines in steps of 10^{-2}. In (b) contours are scaled up by 10x (dotted steps of 10^{-3}, dashed steps of 10^{-2}, solid steps of 10^{-1}).

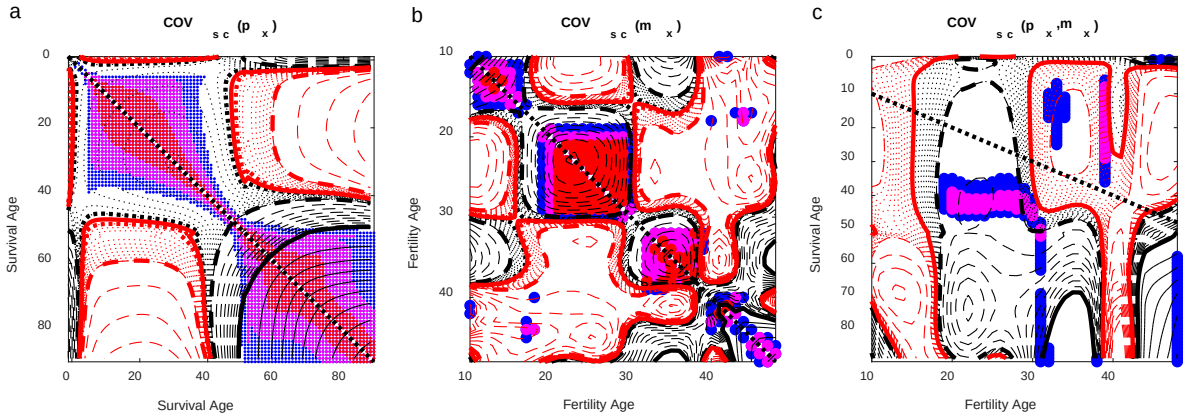


Figure S7. Population growth rates and ZPG conditions under different combinations of altering mean vital rates (Scenario 1) and their (a) variance (Scenario 2) or (b) covariance (Scenario 3). Both the level of stochastic noise and covariance required to drive ZPG increases with lower fertility ($Z^m < 1$), higher child mortality ($Z^c > 1$) and higher mortality at all ages ($Z^q > 1$), but decreases with higher adult mortality ($Z^a > 1$).

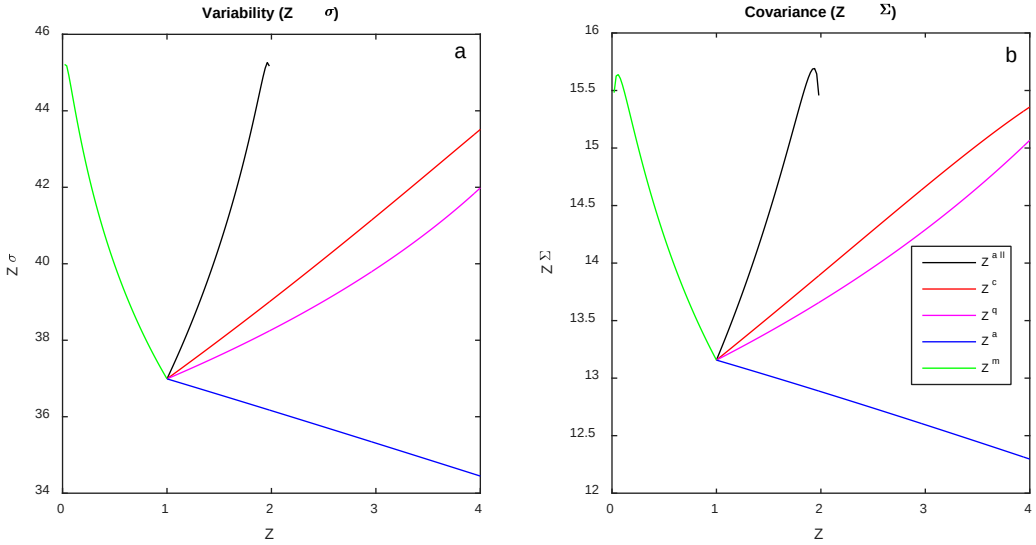


Table S6. Percentage of population dying in a catastrophe year. Cell values correspond to the ZPG conditions of Table 2 combining different intensities of shocks on child mortality (Z_q^c, top row header) and on adult mortality (Z_q^a, second row header).

		Mortality Scalar																			
Child ($Z^q{}_c$):		1				2				3				4				5			
Adult ($Z^q{}_a$):		1	5	10	20	1	5	10	20	1	5	10	20	1	5	10	20	1	5	10	20
Population		**Percent of Population Dying in a Catastrophe Year**																			
Ache	**H**	3	7	12	23	4	8	13	24	5	10	15	25	7	11	16	27	8	13	18	28
Agta	**H**	5	13	22	42	8	15	25	44	11	18	28	47	13	21	31	50	16	24	34	53
Hadza	**H**	3	8	13	25	5	9	15	27	6	11	17	29	8	13	19	30	10	15	20	32
Hiwi	**H**	4	11	21	40	5	13	23	42	7	15	25	44	9	17	26	46	11	18	28	47
Ju/'hoansi	**H**	3	10	18	34	4	11	19	36	6	12	20	37	7	13	22	38	8	15	23	40
HG Mean LH	*	3	10	17	33	5	11	19	35	7	13	21	37	9	15	23	39	11	17	25	40
Aborigine	**A**	2	6	10	20	2	6	11	21	3	7	12	21	4	8	12	22	5	8	13	23
Gainj	**F**	3	11	20	40	4	12	22	41	6	13	23	42	7	15	24	43	8	16	25	45
Tsimane	**F**	2	5	8	15	3	6	10	17	5	8	11	18	6	9	12	19	7	10	14	21
Yanomamo	**F**	2	5	9	17	4	7	11	19	6	9	12	20	7	10	14	22	9	12	16	23
Herero	**P**	2	7	14	27	2	8	14	27	3	8	15	28	4	9	15	28	4	9	16	29
***H.s.* Mean LH**	*	2	7	12	23	3	8	13	24	4	9	14	25	5	9.7	15	26	6	11	16	27

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