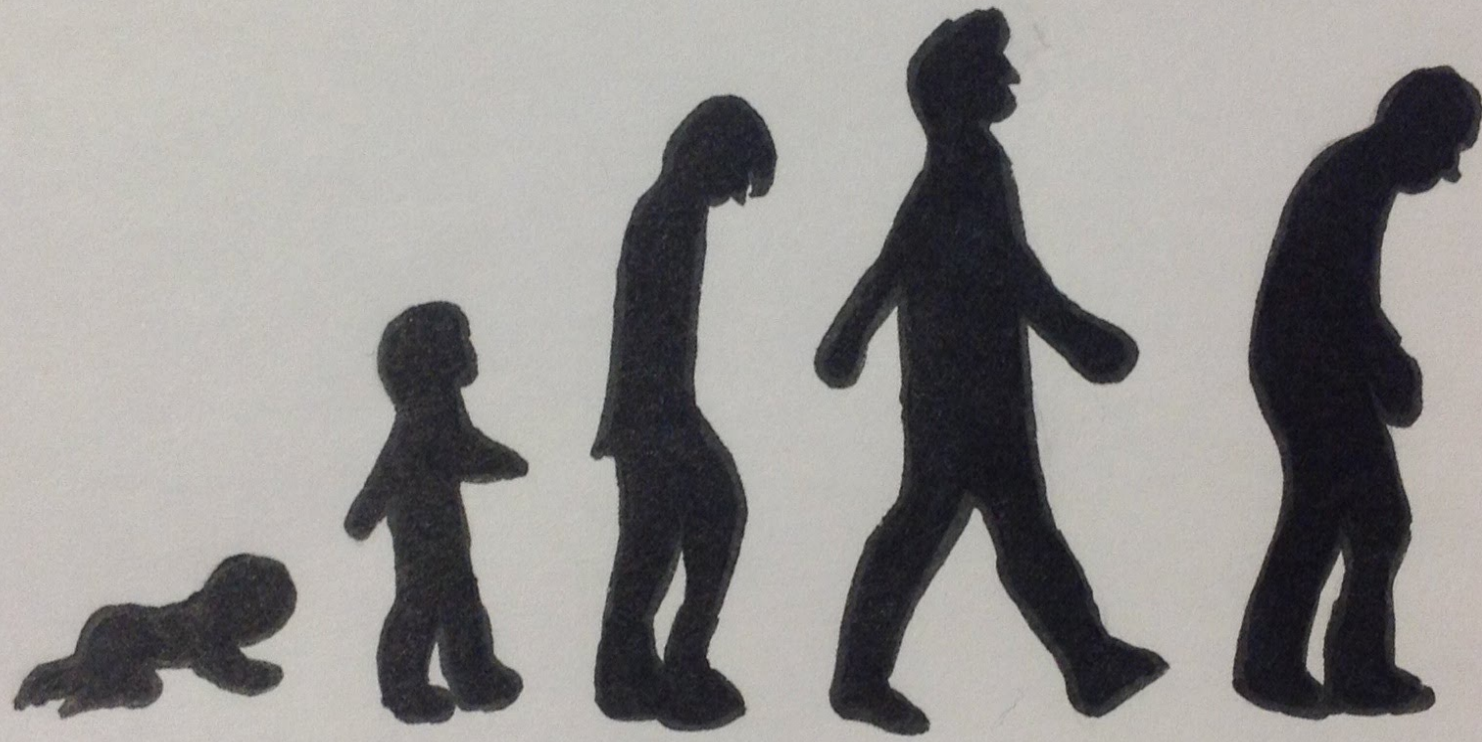
# *Towards a transdisciplinary framework to analyze birth and death patterns*

Annette Baudisch

Padova 21.-23.09.2022

Conference on Statistics for Complex Data

*With Gratitude to the late James W. Vaupel*



# Why do we AGE?

# Definition

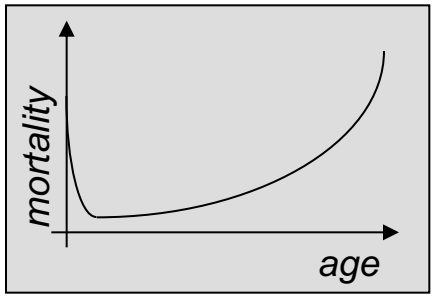
**Aging ("Senescence"):** increase in mortality with adult age

Demographic

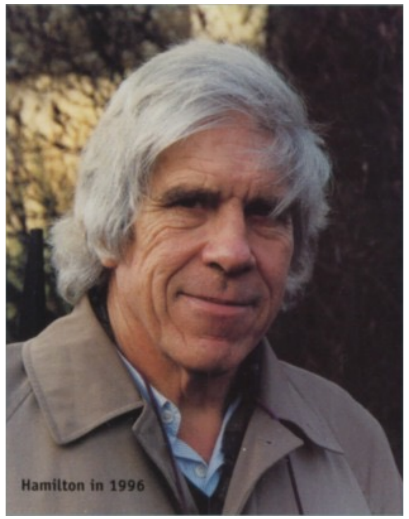
Physiological

Genetic

Environment




# Classic Answer




**William D. Hamilton**
*1936 - 2000*

**Hamilton 1966:**

*We grow old because later ages*

*matter less and less*

*to evolutionary success:*

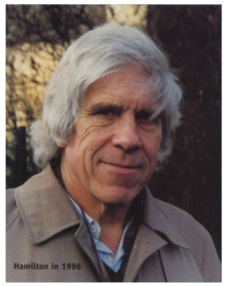
***Senescence is inevitable.***

# Demography ↔Evolution

Fitness

$$\int_{\alpha}^{\omega} e^{-ra}\, l(a)\, m(a)\, da \;=\; 1$$

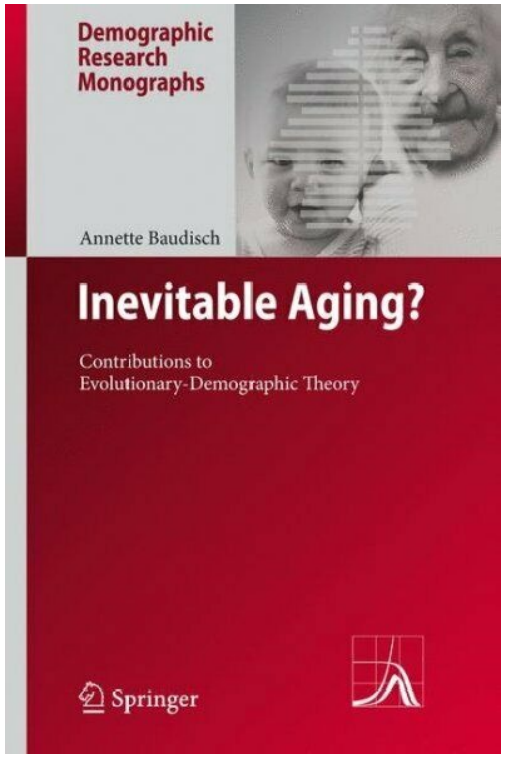
**Change in fitness** with respect to **change in age-specific mortality**




→Declines with age

→Later ages matter less less for evolutionary success

# Challenging these results




Open Access Online Available
Baudisch 2008 Springer

Evolutionary demographic models

Vaupel et al. 2004
Baudisch 2008
Baudisch & Vaupel 2010

Theoretically, a diversity of patterns can be evolutionary optimal

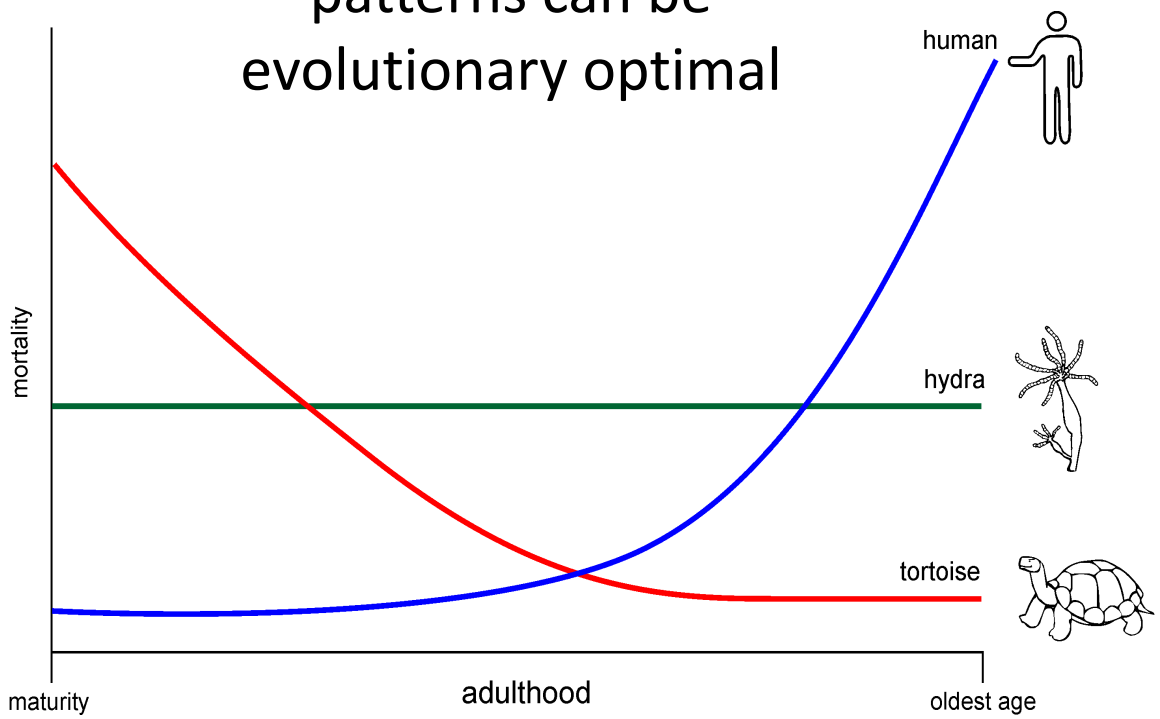
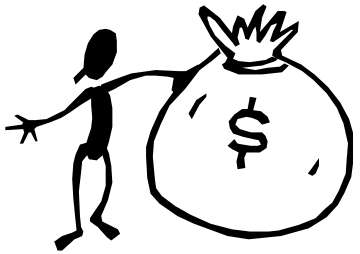



Fig. adapted from Baudisch & Vaupel 2012 Science

# *TRADEOFFS CAN EXPLAIN "NON"-AGING*

Resource allocation

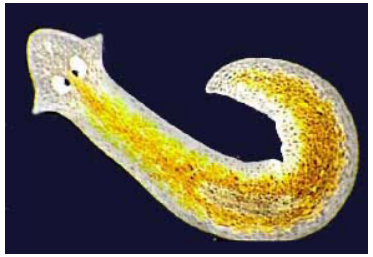


**Survival** **Reproduction**

How much survival must be sacrificed to gain how much reproduction, and vice versa?

→

**Species' life history tradeoffs**



# *TRADEOFFS CAN EXPLAIN "NON"-AGING*

## Optimal Allocation Framework

Optimal energy allocation

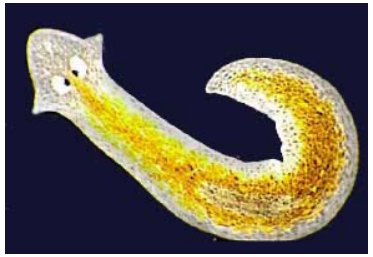
Damage

State

Repair & Regeneration

Type of Ageing

| Aging | Negligible Aging | "negative" Aging |
|---|---|---|
| > | = | < |



Baudisch 2008

# *TRADEOFFS CAN EXPLAIN "NON"-AGING*

## Optimal Allocation Framework

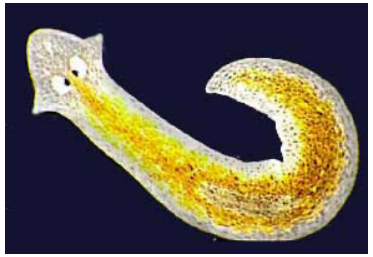
*Maximize Lifetime Reproductive Success*

$$R = \sum_{x=0}^{\infty} l_x \, m_x$$

All resources to growth

How much to growth
How much to reproduction ?

0 *maturity?* *age*

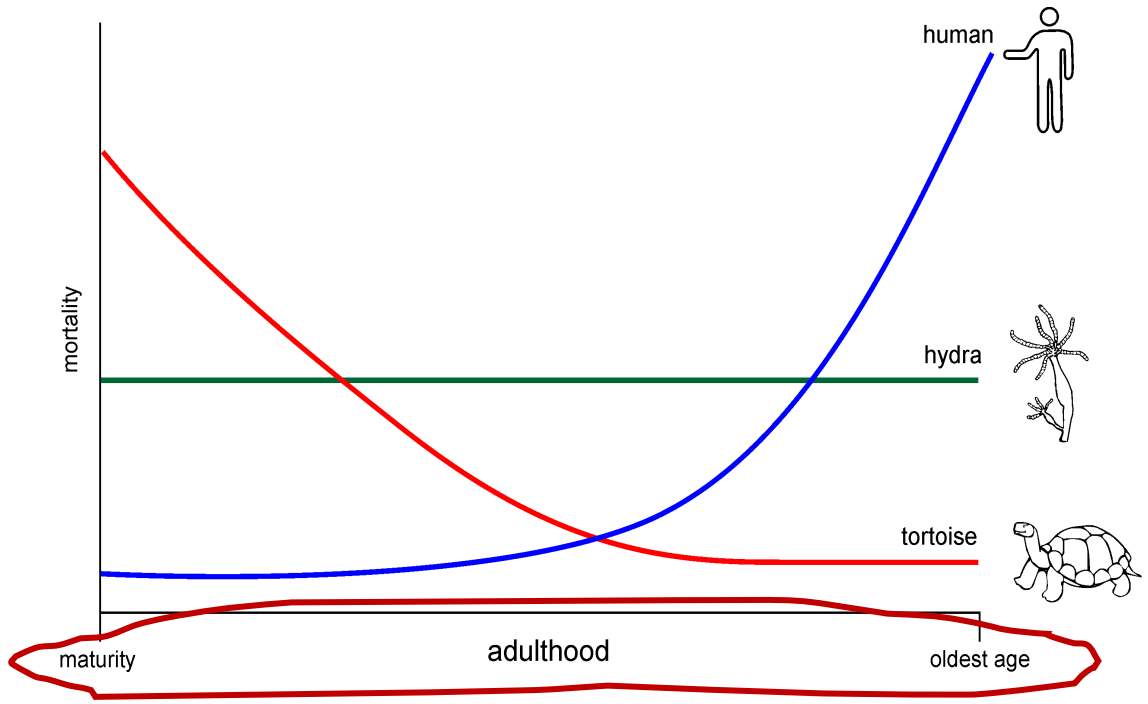


# FORWARD

Evolutionary demographic models

Vaupel et al 2004
Baudisch 2008
Baudisch, Vaupel 2010
Wensink, Wrycza, Baudisch 2014

1) **Shifted question**: from ”why we age” to ”why we age, but some species may not




no matter what time units!

# FORWARD

Evolutionary demographic models

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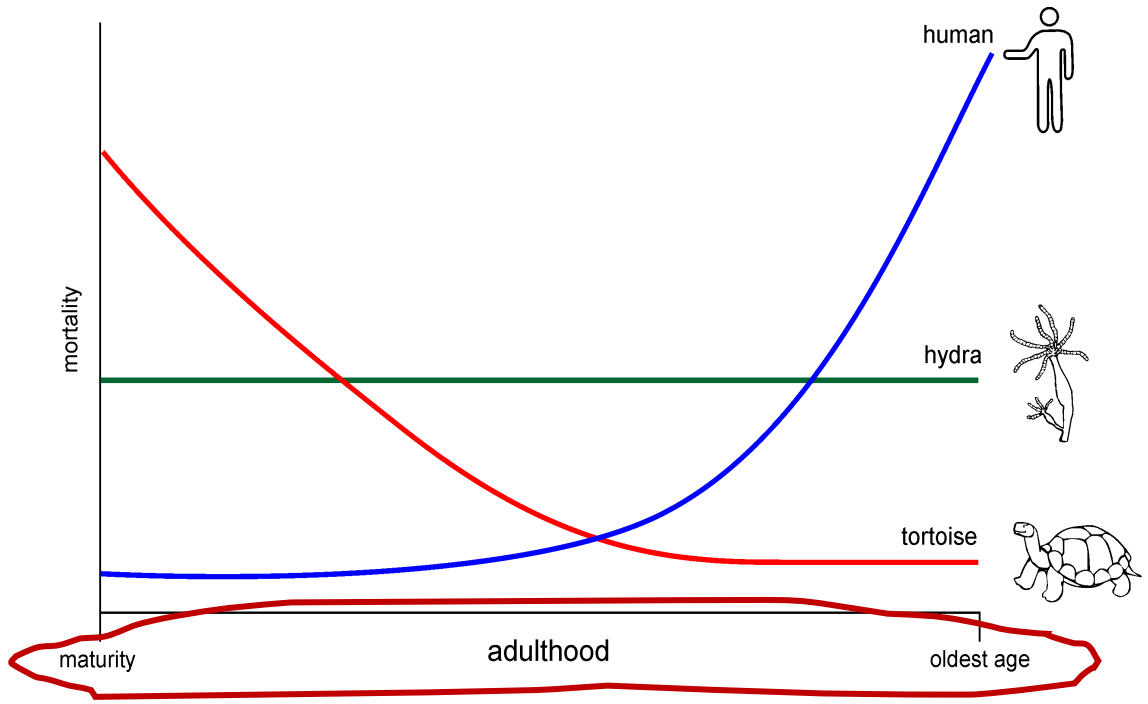
Wensink, Wrycza, Baudisch 2014

2) <u>Theoretically motivate</u> to measure and study **lifespan & aging as two dimensions**

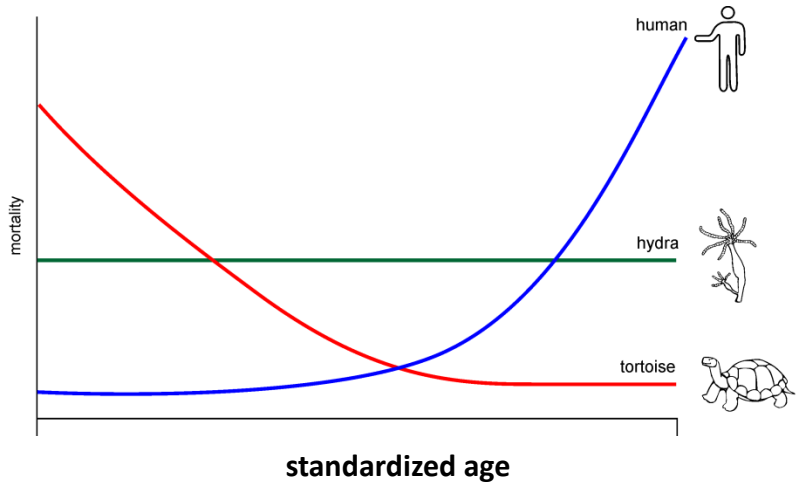



no matter what time units!

# Pace Shape Framework

**Pace standardized trajectories!**

**SHAPE**




**PACE**

days

years

centuries

**Classify patterns assigning summary measures**

Shape value:

- Dimensionless
- Measures of **relative** spread ↔ equality

Pace value:

- In units of time
- Measures of lifespan

Baudisch (2007) In: *Die Zukunft des Alterns.* Gruss, P., *Beck Verlag*. Baudisch (2008) *Springer Verlag*. Baudisch (2011) *Methods in Ecology and Evolution*, Wrycza, Baudisch (2012,2014) *Demographic Research*, Baudisch et al. (2013) *Journal of Ecology*, Wrycza, Missov, Baudisch (2015) *Plos ONE*.

# A theoretically motivated framework

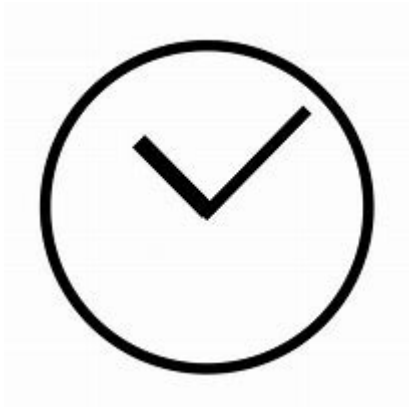
Baudisch (2011) The Pace and Shape of Aging. *Methods in Ecology & Evolution*

**Pace of mortality**

Time scale of life

-Lifespan

-Death rate



## Preferable Measure

*Life-expectancy, e0, at initial age 0*

*Fraction dying at age x*

$$e_0 = \int_0^{\omega} x\, f(x)\, dx$$

Wrycza & Baudisch (2014)The Pace of Aging. *Demographic Research*

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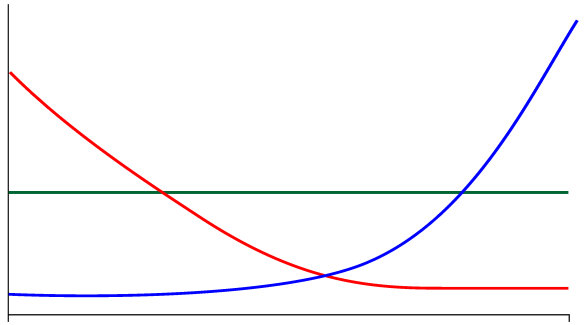
The Pace and Shape of Aging.
*Methods in Ecology & Evolution*

## Shape of mortality

Time-standardized pattern over the life course



**Preferable Measures**

Measures of relative inequality in ages at death

- Gini coefficient
- Life table entropy
- Coeff. of Variation

Wrycza, Missov & Baudisch (2016)
Quantifying the shape of aging.
*Demographic Research*

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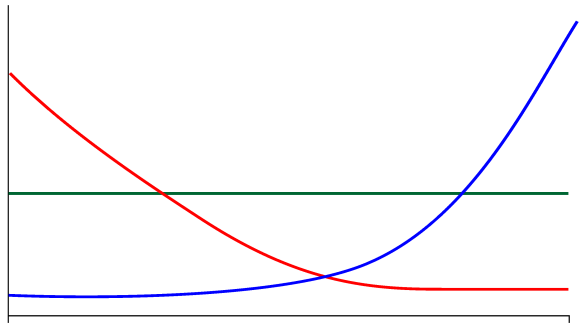

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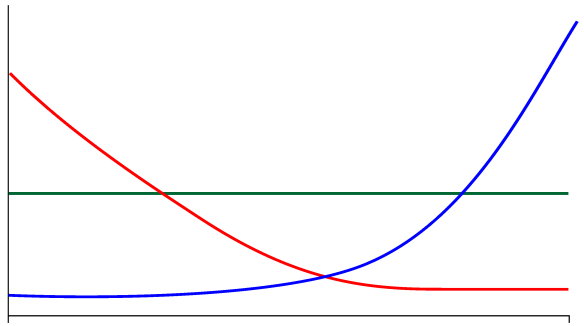

Helpful concept

Life-years lost due to death $e^{\dagger}$

$$e^{\dagger} = \int_0^{\omega} e(x)\, f(x)\, dx$$

*Life-years left at age x*

*Fraction dying at age x*

Vaupel and Canudas-Romo, 2003
Goldman and Lord 1986, Hakkert 1987, Vaupel 1986

# A theoretically motivated framework

Baudisch (2011) The Pace and Shape of Aging. *Methods in Ecology & Evolution*

## Shape of mortality

*Life-years lost* / *Life-expectancy*

$$\frac{e^{\dagger}}{e_0}$$

| | 1950 | 2010 |
|---|---|---|
| $\frac{e^{\dagger}}{e_0}$ | $\frac{15.2}{66.1} = 0.23$ | $\frac{10.4}{78.9} = 0.13$ |

Average values across countries in the HMD

### Helpful concept

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# A theoretically motivated framework

Baudisch (2011) The Pace and Shape of Aging. *Methods in Ecology & Evolution*

## Shape of mortality

A measure of
relative lifespan inequality

$$\frac{e^{\dagger}}{e_0}$$

Lifetable Entropy

Leser 1955, Demetrius 1974, Keyfitz 1977

## Helpful concept

Life-years lost due to death $e^{\dagger}$

$$e^{\dagger} = \int_0^{\omega} e(x)\, f(x)\, dx$$

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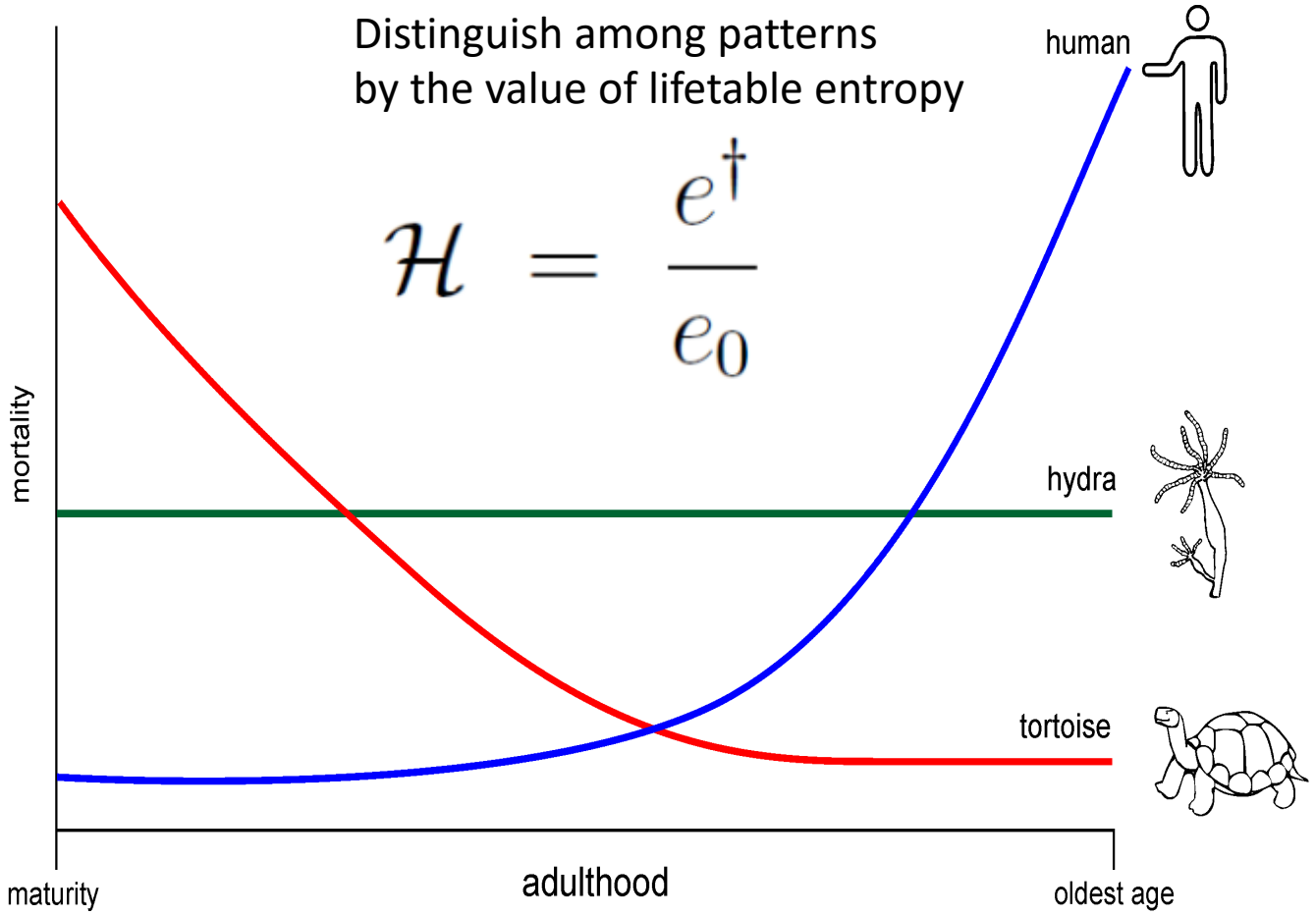
# Lifespan disparity measures capture <u>shape of aging</u>

Distinguish among patterns
by the value of lifetable entropy

$$\mathcal{H} = \frac{e^{\dagger}}{e_0}$$




$$\mathcal{H} < 1 \quad if \quad e^{\dagger} < e_0$$

$$\mathcal{H} = 1 \quad if \quad e^{\dagger} = e_0$$

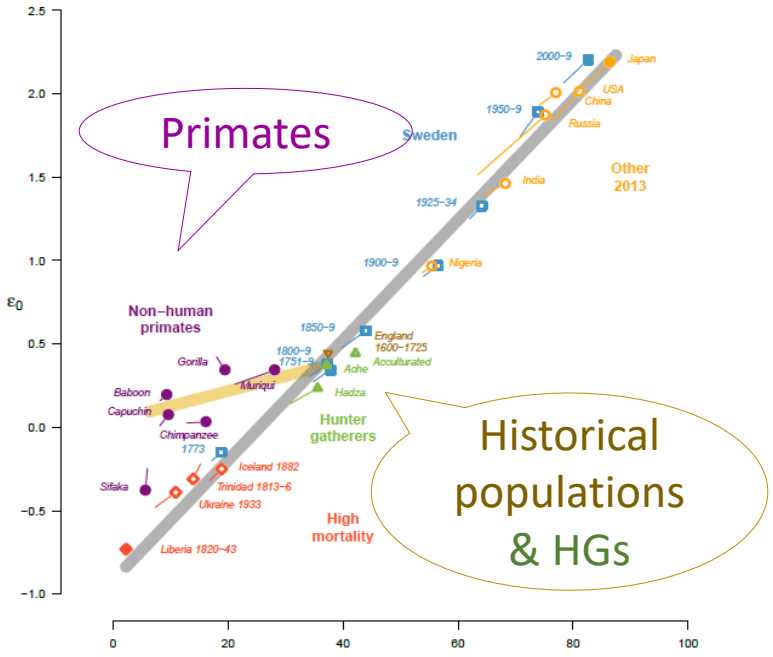
$$\mathcal{H} > 1 \quad if \quad e^{\dagger} > e_0$$

Fig. adapted from Baudisch & Vaupel 2012 Science

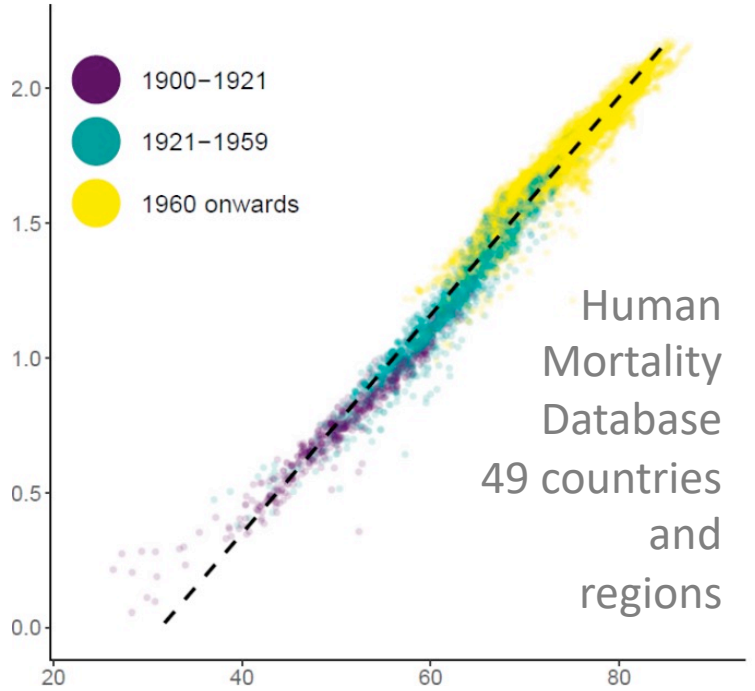
# Rigid Linear Constraint

*"Shape"*

$$\log \frac{e_0}{e^\dagger}$$




$$\log \frac{e_0}{e^\dagger}$$

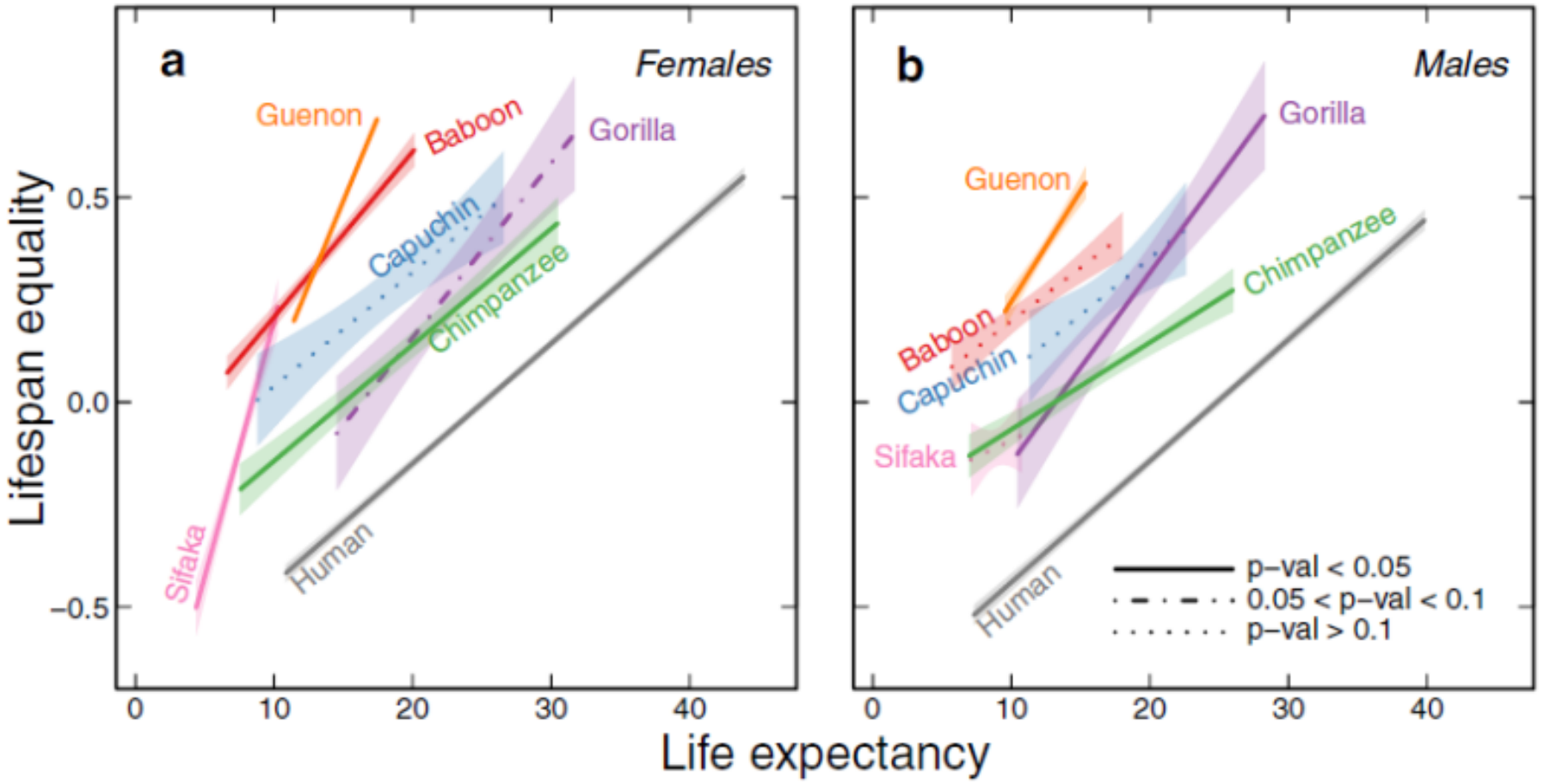



*"Pace"*

Colchero et al 2016, PNAS

Aburto et al. 2020 ,PNAS

# Fixed rate of aging in humans and primates?




Colchero et al 2021 Nature Communications

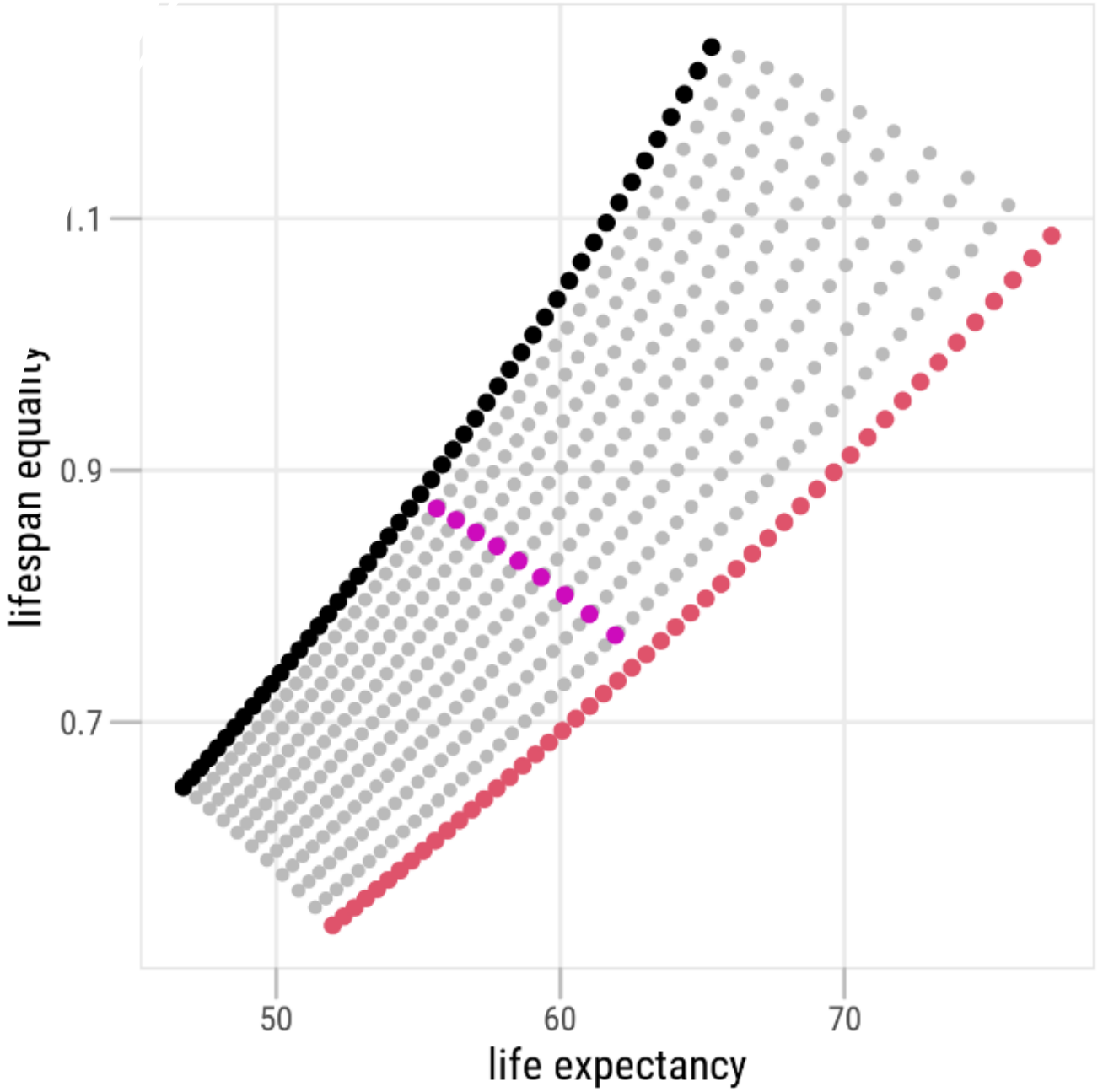
# Simulated populations

**Black dots:** high, fixed rate of aging; changing mortality level*

**Red dots:** low, fixed rate of aging; changing mortality level*

**Pink Dots:** intermediate, fixed level*, changing rate of aging

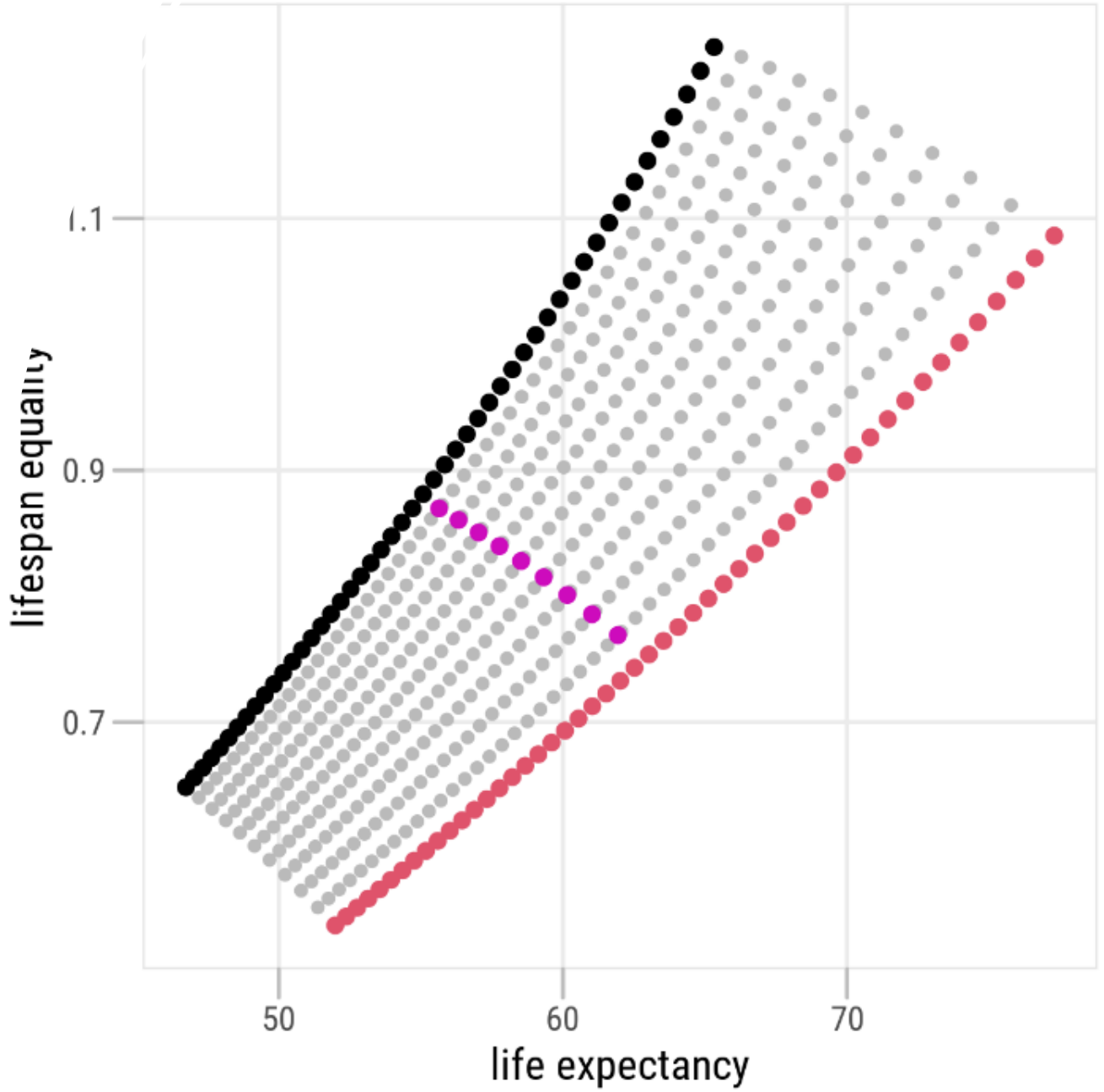
***level – additive constant of Siler mortality model**



# Simulated populations

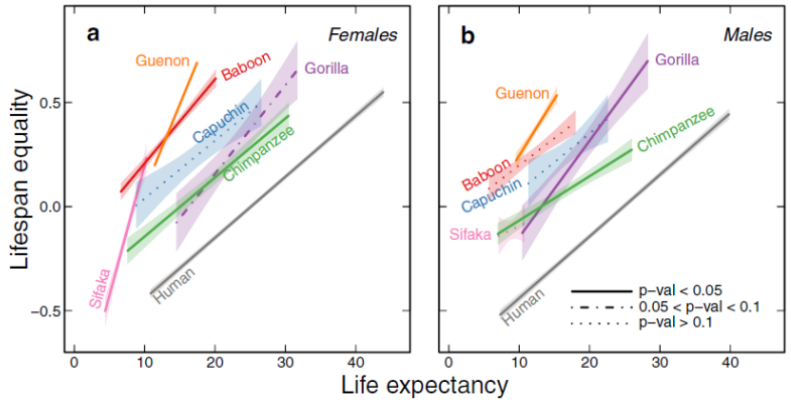
Changing mortality level moves species **along** the species line

Changing rate of aging pushes species **off** the species line



# Fixed rate of aging in humans and primates?

**High societal relevance:** Will future generations have to cope with lifespan extensions of **a few more decades – or a few centuries?**




**Key research questions:** Is the rate of aging truely fixed? What is its evolutionary ballpark? Under what conditions could it change?

# Extended the framework to fertility

**Born once.** **Die once.**

(2019) A pace and shape perspective on fertility
Baudisch & Stott. *Methods in Ecology and Evolution*

(2021) Born once, die once: Life table relationships for fertility
Baudisch & Alvarez. *Demographic Research*

# Mirrored methods for birth and death analysis

1  :  1

**Born once.** **Die once.**

(2019) A pace and shape perspective on fertility
Baudisch & Stott. *Methods in Ecology and Evolution*

(2021) Born once, die once: Life table relationships for fertility
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# ERC Consolidator grant 2022.

## Towards a Transdisciplinary Demographic Theory of Birth and Death Trajectories

**Ambition 1:**

Systematic search for and modeling of macro level regularies in human fertility patterns, applying mathematical tools from mortality analysis

**Ambition 2:**

COMPLEX DATA!

Study **the birth and death of <u>collectives</u>** and work towards a shared, transdisciplinary framework of birth and death analysis.

Comments  Questions

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CPop

SDU