Aging and Evolution

Thadeu Penna

Instituto de Física
UFF
tjpp@if.uff.br

1 de agosto de 2007

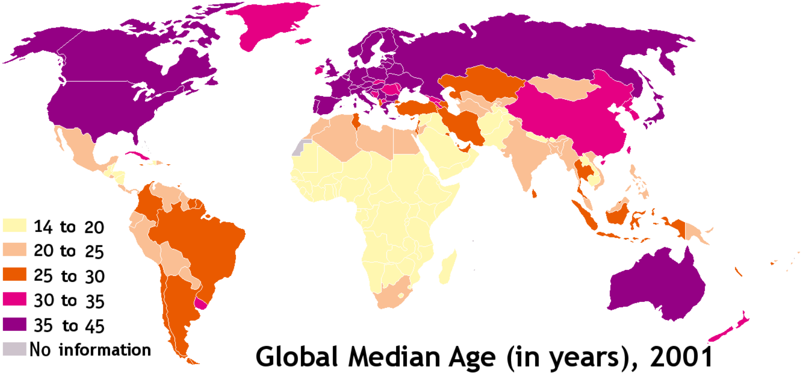
1. Aging and Mortality
    - Definitions
    - Facts
    - Gompertz Law

1. Aging and Mortality
   - Definitions
   - Facts
   - Gompertz Law
2. Evolutionary Theory of Aging
   - Theories
   - Special Cases of Aging

Aging

- **Ageing** or **aging** is the process of systems' deterioration with time.
- **Senescence** is the combination of processes of deterioration which follow the period of development of an organism. It is a biological concept.
- **Organismal senescence** is the **aging** of whole organisms. We will use both.
- **Cellular senescence**, or Hayflick limit, is when normal cells lose the ability to divide.
- **Why do we age?** Is aging the result of fundamental limitations that apply to all living things, or because a limited life span conveys some advantage?

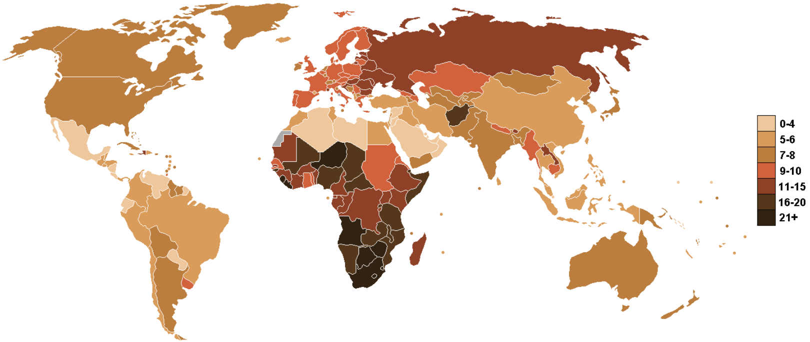
Median Age


14 to 20
20 to 25
25 to 30
30 to 35
35 to 45
No information
Global Median Age (in years), 2001

How to Measure Aging

Mortality rate, or **death rate**, is a measure of the number of deaths (in general, or due to a specific cause) in some population, scaled to the size of that population, per unit time.

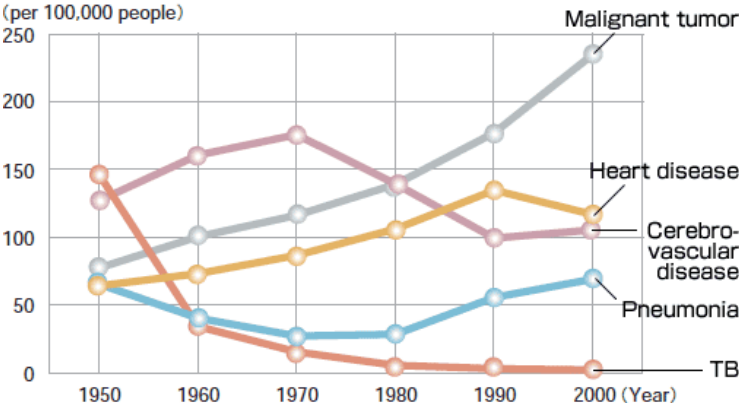
Death Rate (deaths for 1,000)



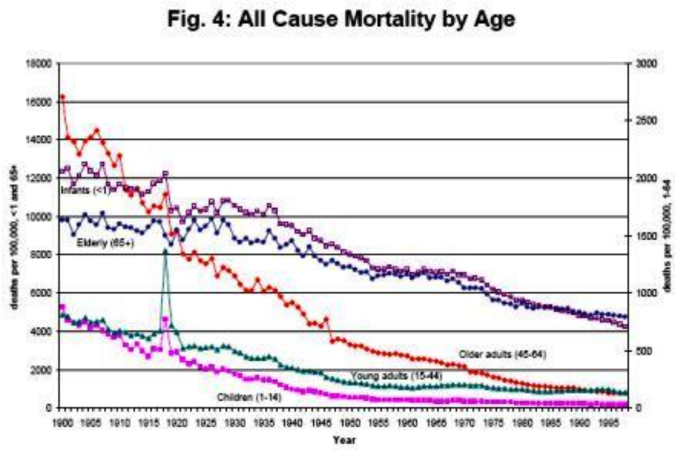
Many Causes

Rank	Cause	Total deaths	%
1.	Ischaemic heart	7,208	12.6
2.	Cerebrovascular	5,509	9.7
3.	Lower respiratory infections	3,884	6.8
4.	HIV/AIDS	2,777	4.9
5.	Chronic obstructive pulmonary	2,748	4.8
6.	Diarrheal diseases	1,798	3.2
7.	Tuberculosis	1,566	2.7
8.	Malaria	1,272	2.2
9.	Cancer of trachea/bronchus/lung	1,243	2.2
10.	Road traffic accidents	1,192	2.1

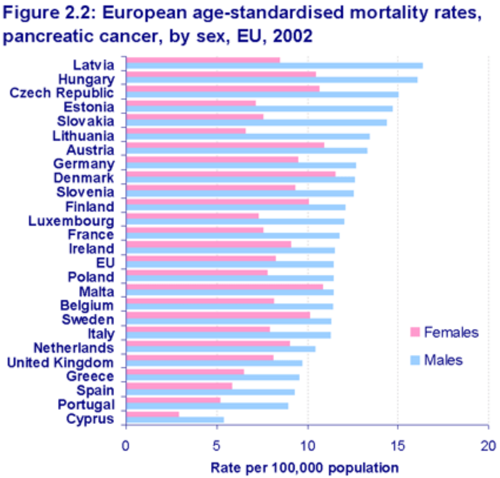
Transition of Mortality Rates by main causes in Japan



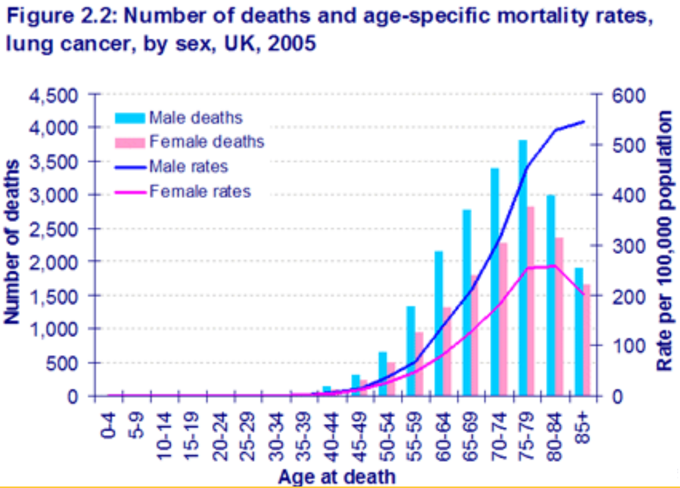
Time Evolution of Mortality Rates by Age



Pancreatic Cancer in EU by Country and Sex



Lung Cancer by Age and Sex



Aging and Physics

- Physicists do not die. We reach a maximum entropy state.
- Aging of Materials (glasses, mostly).
- We refer to biological aging.
- Aging depends on so many factors and causes.
- More a complicated system rather than a Complex system.
- So, what is the link ?

Gompertz law

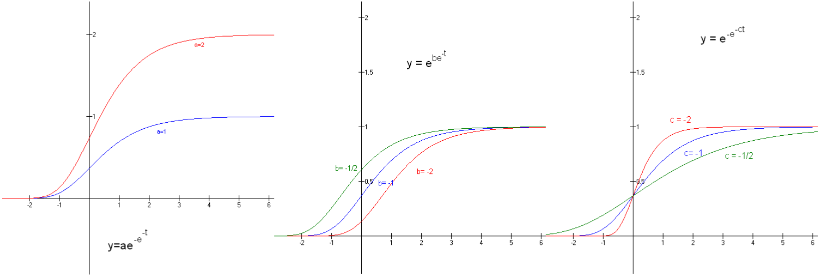

BENJAMIN GOMPERTZ

Gompertz - 1779, 1865

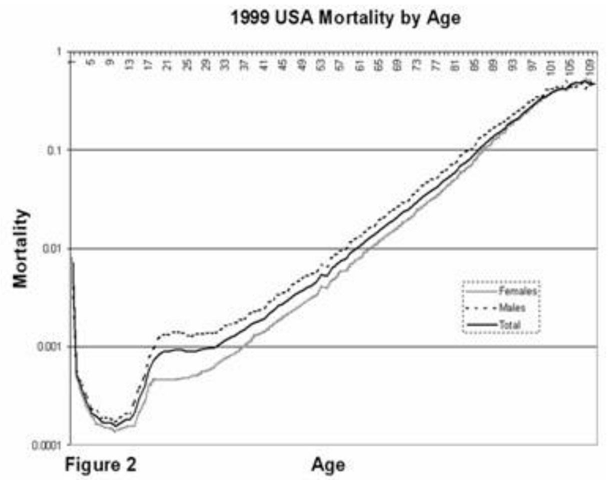
$$N(t+dt) = rN(t)\log\left(\frac{K}{N(t)}\right)$$

- r, growth rate
- K, equilibrium size
- tested on populations since 1825.

Gompertz Curves



USA mortality by age 1999



USA survival rates by age 1999

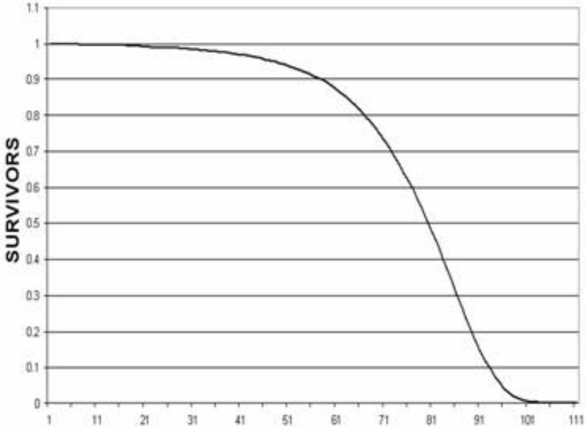
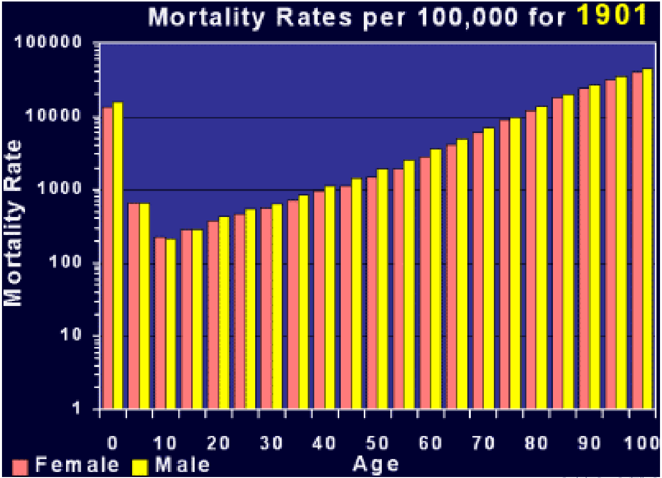
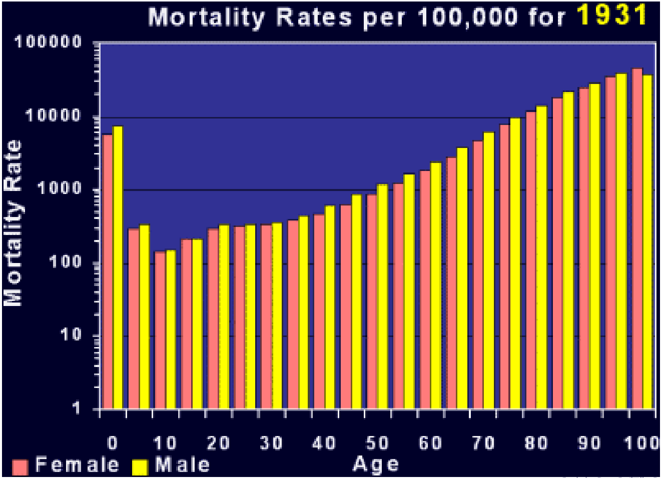


Figure 3

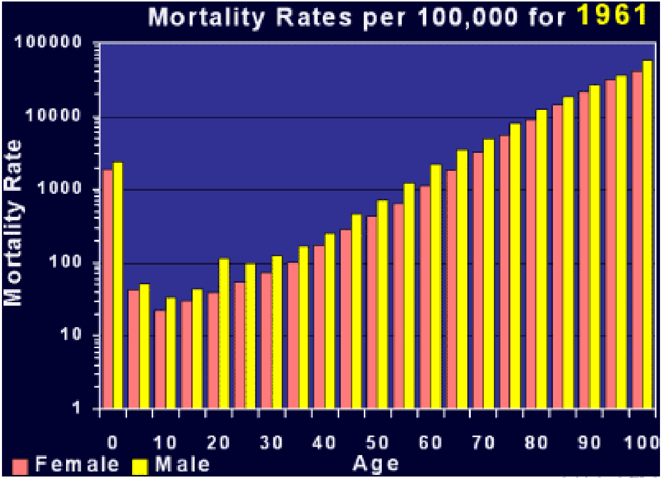
USA mortality by age from 1901 to 1991



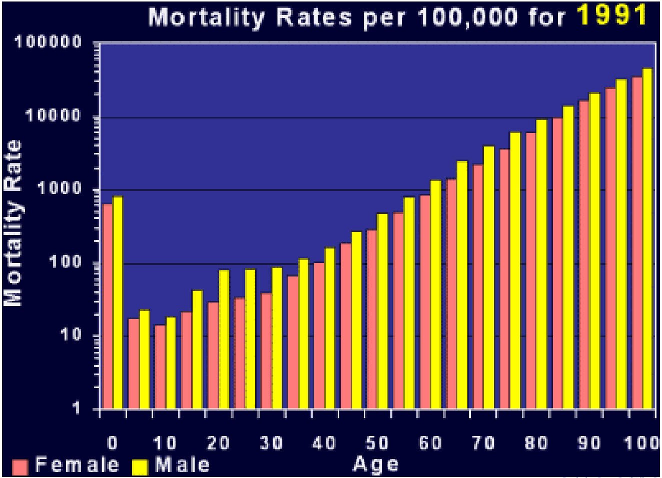
USA mortality by age from 1901 to 1991



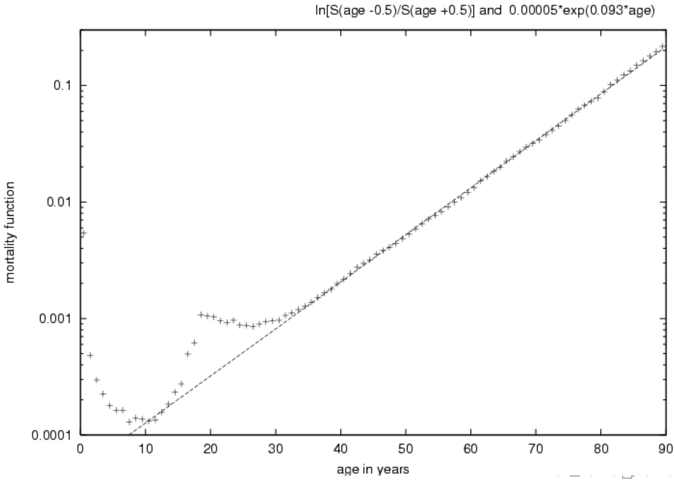
USA mortality by age from 1901 to 1991



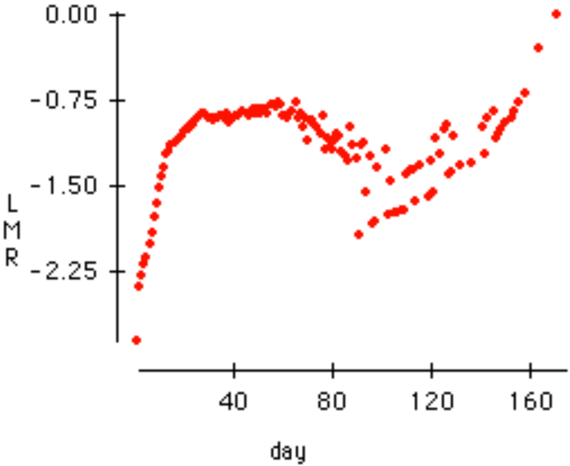
USA mortality by age from 1901 to 1991



German Mortality

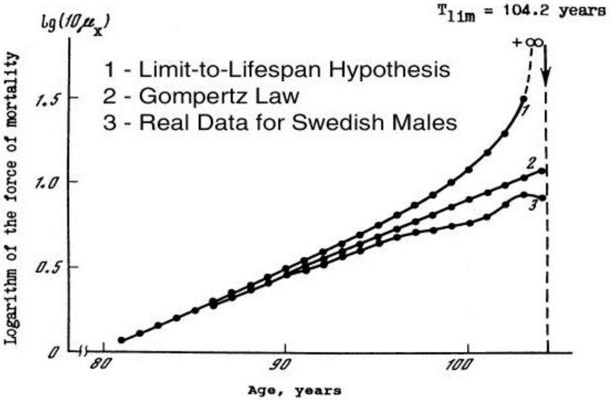


Medflies Mortality (10^6, 80000, 70000), days (1,35,36).

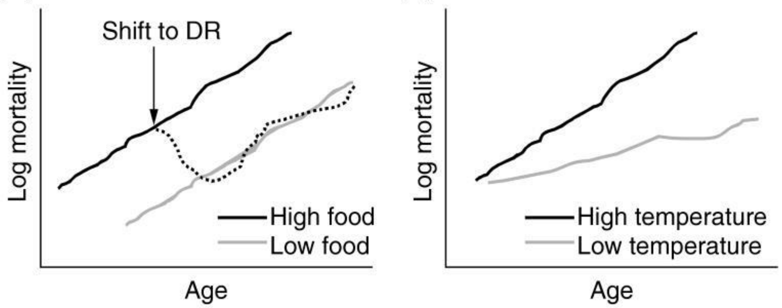


The Oldest Old

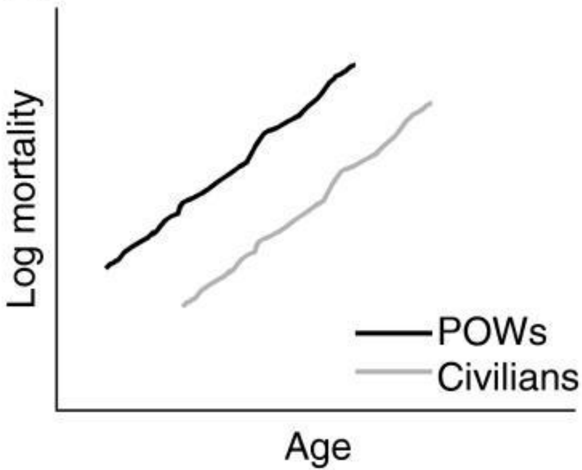
Mortality at Advanced Ages



Dietary restrictions and Temperature variations



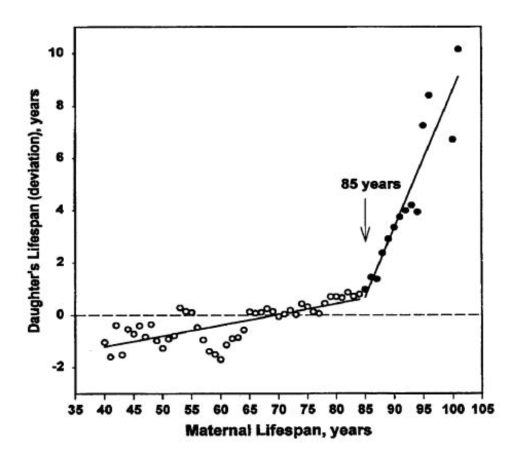
Australian on the 2nd War



Universality ?

- Lifespan is dependent on the species but is roughly the same on similar species.
- More important, the exponential behavior of the mortalities is quite robust. Although mortalities rates depend on the time, cultural aspects (including nutrition), sex, races, etc.; under very different circumstances, the mortality grows exponentially with age
- Notable exceptions are the "oldest old" survivors (humans and flies). There is no reliable statistics of other species.
- Evolution is a clue. Physicists know how to do it.

Correlation between Mothers and Daughters



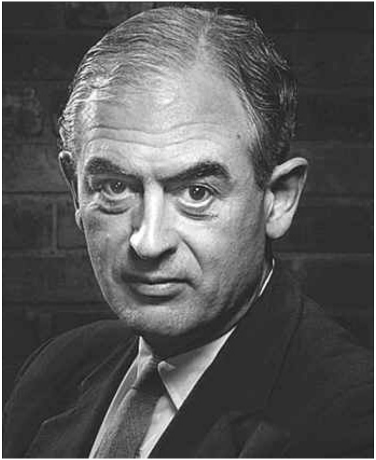
Programmed Death

- **Programmed Death**, *Weismann* (1834 – 1914) : removing older members by programmed death provided more resources for the youngers (assumedly more evolved).
- Pro: it explained the inter-species differences in life span.
- Con: a trait has to be expressed in such a way that it affects survival or reproduction.
- if an individual die before the programmed death, it will not affect natural selection.

Damage Accumulation

- damage to DNA
- poisonous byproduct of life processes
- limit on the number of divisions
- Aging is a defect

An Unsolved Problem on Biology



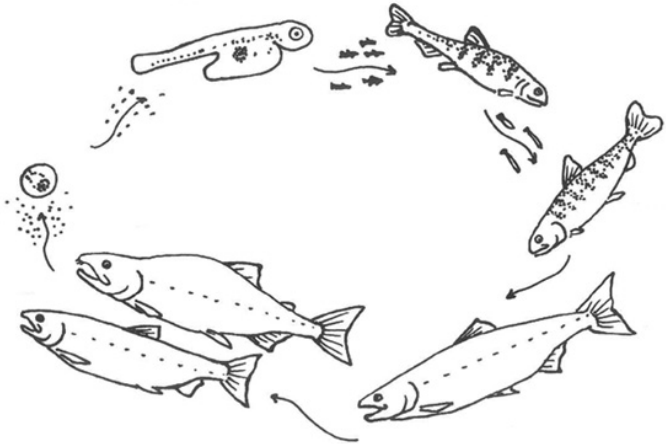
Mutation Accumulation Theory

- the force of natural selection decreases once an organism reaches an age where it has had some opportunity to reproduce.
- random mutations causing adverse aging characteristics.
- ties aging to sexual maturity and reproduction

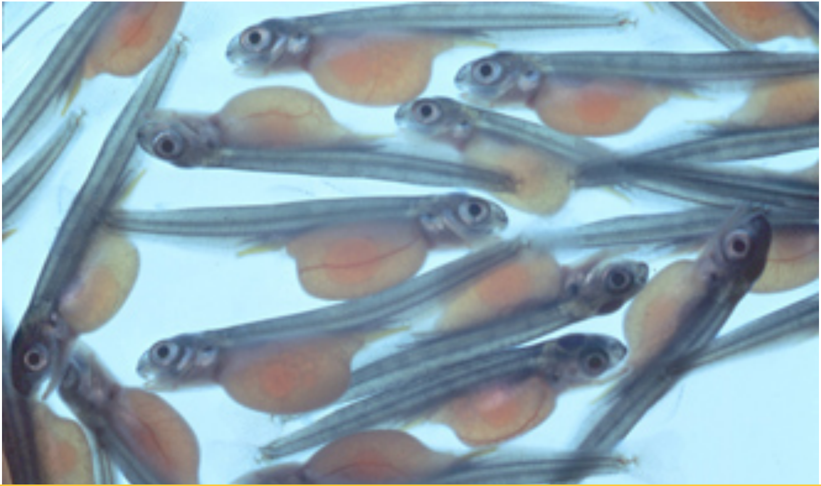
Antagonistic Pleiotropy Theory

- Pleiotropy, Natural Selection, and the Evolution of Senescence
- Pleiotropy: a single allele or form of a gene (see Genetics) may affect more than one trait.
- combined effect of many pleiotropic genes that each had a beneficial effect in an animal's youth but had an adverse side effect in older age.

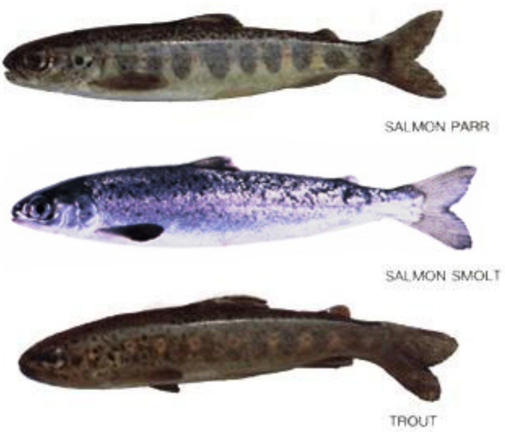
Salmon Catastrophic Senescence



Babys



Young



Old

Final Stage

Other questions

- Humans have 2 sets of teeths. Elephants have six. What no more? Programmed death?
- Benefitial mutations are difficult.
- Canine longevity: wild animals tend to have both longer times to develop to sexual maturity and longer life spans. Larger dogs have shorter lifespan than the smaller breeds.
- Progeria: individuals usually die by age 14.
- Im summary, is aging a bug or a feature ?

Journal of Statistical Physics, Vol. 78, Nos. 5/6, 1995

A Bit-String Model for Biological Aging

T. J. P. Penna[1]

Received September 14, 1994

We present a simple model for biological aging. We study it through computer simulations and fint it to reflect some features of real populations.

KEY WORDS: Aging, Monte Carlo simulations.

Dynamics

- Time is discrete.
- Each individual will be represented by a string of bits
- The string is not the genotype but a temporal reading of it.
- It matters **when** a mutation become active and not if it is present on the genotype.
- There is a limit on the number of active mutations (individuals will die)
- Individuals will reproduce at age R, newborns will have the same temporal genotype and additional mutations.

An example

An example

An example

An example

An example

An example

An example


Loving Memory of
WILLIAM TAYLOR,
WHO DIED DEC. 14TH 1925,
IN HIS 37TH YEAR.
ALSO THE ABOVE NAMED
JOE BRIGGS,
WHO DIED MARCH 21ST 1931,
AGED 66 YEARS.
ALSO LILY BRIGGS,
BELOVED WIFE OF ABOVE
DIED JULY 7TH 1932,
HER 70TH YEAR.

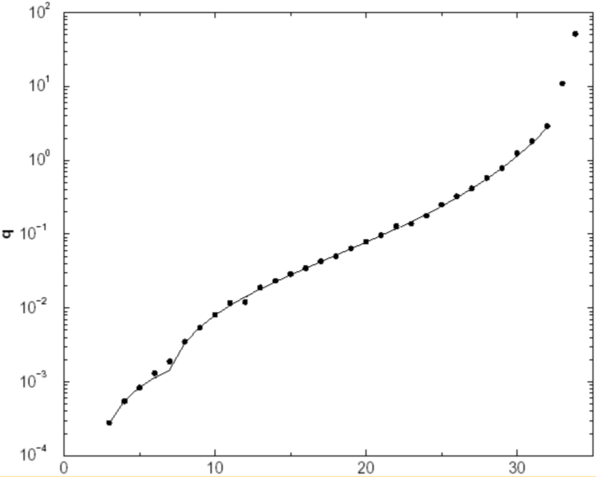
An example

An example

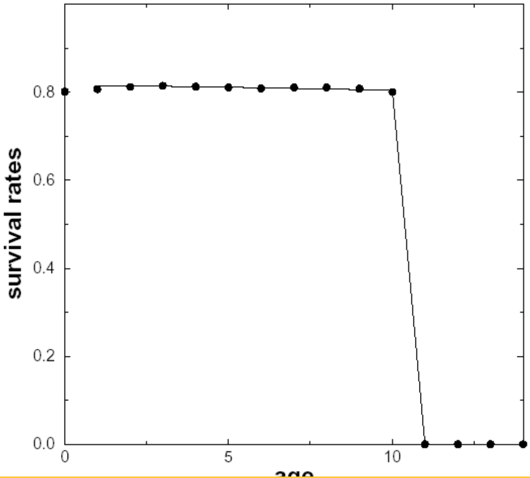
Algorithm

- We start with a population with random genotypes.
- We test if the individual survives with a few active mutations
- We test if survives to a food and space limitation
- Can it reproduce ?
- Its age is then increased
- Repeat for many steps

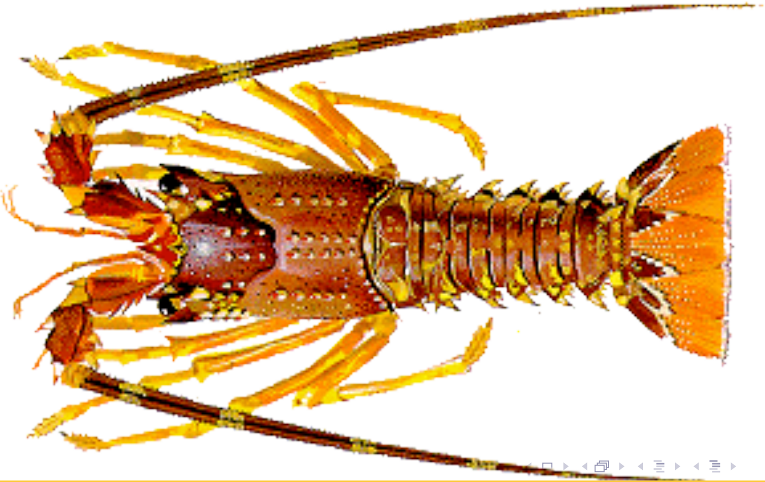
Mortality



Salmon



Lobsters



Lobsters

- Fertility (cabo-verde *"Panulirus laevicaudas"*):

$$b(i) \sim 1 - \exp(-0.171\, i)^{2.86}$$

- Fertility is proportional to its weight
- Only 3 eggs reach maturity age
- Fishing is $\approxeq 65\%$ of the stock.
- We proposed a new rule for lobster catching: save the older ones

Simulation

34 T.J.P. Penna et al. / Physica A 295 (2001) 31–37

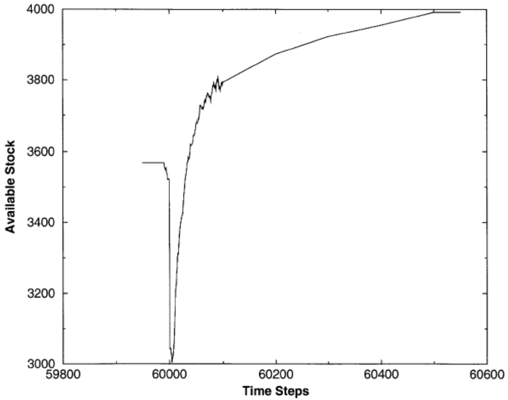


Fig. 1. Stock of lobsters at function of the time ("years"). After 60000 time steps, a maximum age for catching equal to 12 is imposed. The stock decreases at the very first years of regulation but it fastly

Results

- Optimal limit: 12 years old (to save 5%)
- The lifespan of the lobsters is increased (22 yrs)
- They are genetically fitter.
- It is hard to convince the fishmen
- Huge lobsters are not the tastier ones.

What next ?

- The model is extremely simple and easily extensible
- Should be use for any problem where age plays a role.
- 200 papers using it, but
- ... a few analytical ones (Coe and Mao, PRL)
- ... a few papers on predictions and ecological situation
- speciation ?
- why sex ?
- AIDS and therapy
- space reserved for your contribution