V Southern-Summer School on Mathematical Biology

Roberto André Kraenkel, *IFT*

http://www.ift.unesp.br/users/kraenkel

Lecture I

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This school is about understanding the dynamical behavior of populations (how the change in size, how they use space) by means of mathematical formulations.

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Simple Models I: Malthus

Figura : Thomas Malthus, *circa* 1830

Simple Models I: Malthus

The simplest law

- The simplest law governing the time variation of the size of a population
- $$\frac{dN(t)}{dt} = rN(t)$$
- where $N(t)$ is the number os individuals in the population and r is the intrincsic growth rate of the population, sometimes called the *Malthusian parameter*.

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Back-of-the-Envelope calculation

How long would take to cover the whole earth with a thin film of *E. coli*?

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Examples

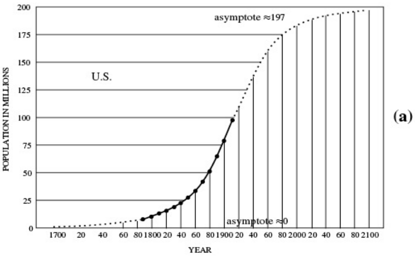

Figura : The population of USA . Until 1920, the growth is well approximated by an exponential.

Examples

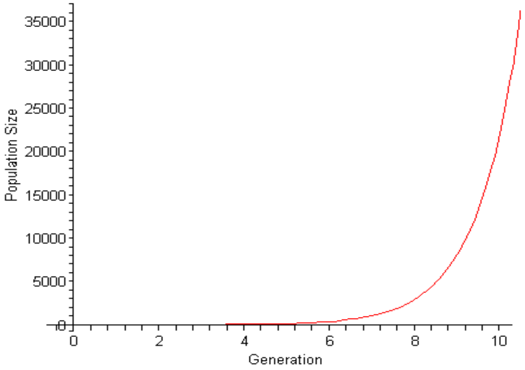

Figura : (*Escherichia coli*) on a Petri dish

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- $$\frac{dN}{dt} = rN(1 - N/K)$$
- The term $-N^2/K$ is always negative (we assume $K > 0$), $\Rightarrow$ it contributes negatively to $\frac{dN}{dt}$ $\Rightarrow$ it tends to slow down growth.
- For $N/K \ll 1$, we may take $1 - N/K \sim 1$ and we recover the Malthusian equation.

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- For $N/K \ll 1$, we may take $1 - N/K \sim 1$ and we recover the Malthusian equation.
- This equation is called the **logistic equation,** or **Verhulst's.**

Logistic equation

Figura : Pierre-François Verhulst, first introduced the logistic em 1838: "'Notice sur la loi que la population pursuit dans son accroissement". On the right side, , Raymond Pearl, who "rediscovered"Verhust's work.

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- $$N(t) = \frac{N_0 K e^{rt}}{[K + N_0(e^{rt} - 1)]}$$
- Here is a plot of the solution, for different values of N_0:

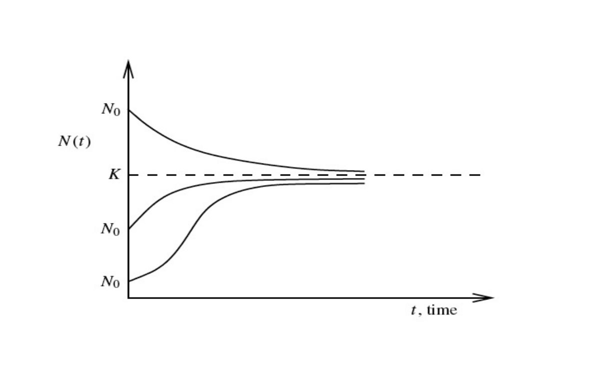

Figura : Temporal evolution of a population described by solution of the logistic equation. Each curve corresponds to a different initial condition. For all initial conditions , $t \to \infty$, we have $N \to K$

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- the first being unstable and the second stable
- Or still: K is an attractor.

More on the logistic equation

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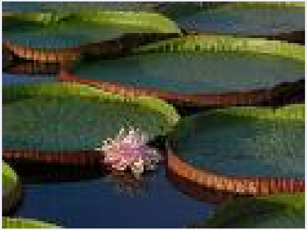
- This is called *intra-specific competition*

Logistic equation

Water lilies on a pond, compete for space:



Logistic equation

Trees in the Amazonian forest compete for light:

Logistic equation

But in semi-arid regions, competition is for water

Logistic equation

Here is a plot of the Tasmanian sheep population

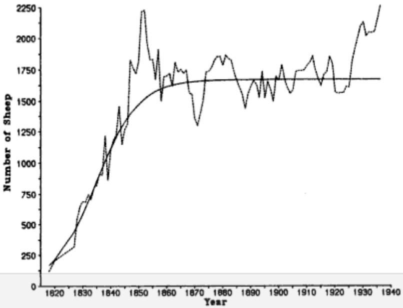


Figure 3.2. Growth of the Tasmanian sheep population (- - -) (thousands) from 1818 to 1936 and the superimposed logistic curve $N(t) = 1670/[1+\exp\{240.81 - 0.131\,25t\}]$ (———) (redrawn from Davidson, 1938b).

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- As we already saw, the population takes the value K for large times.

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- Gompertz growth in tumors (see Kot)

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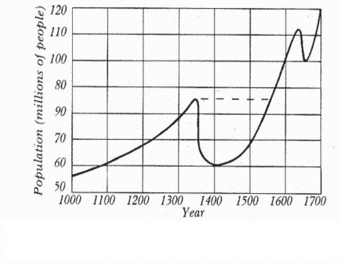

Figura : Europe's population between 1000 e 1700

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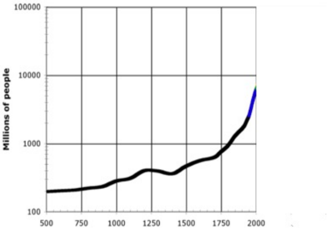

Figura : Earth population between 500 and 2000

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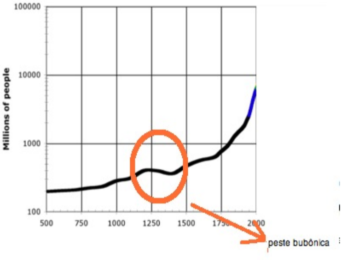

Figura : Earth population between 500 and 2000 , highlighting the effects of bubonic plague .

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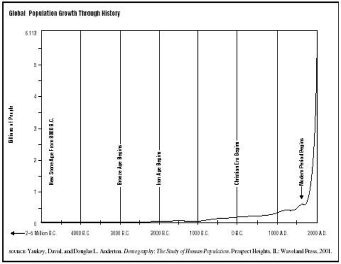

Figura : Estimated Earth's population between -4000 e 2000

Comments: Human population

- As we look at the Human population at different space and time scales, we see different traits...
- Every mathematical model has limited validity.

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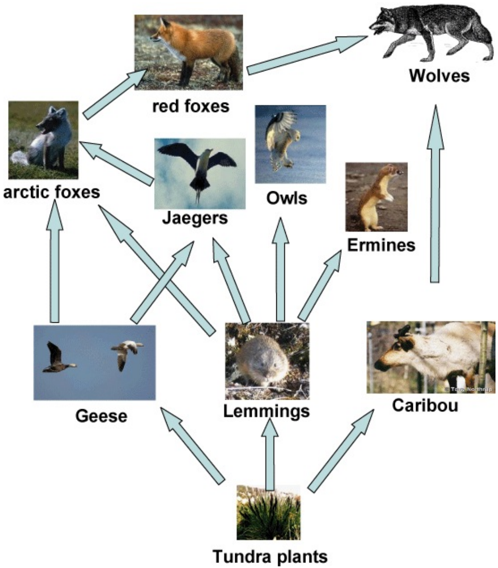
- Thus:"*populations are in fact inter-dependent..*".
- The networks involved can be quite complex.

Trophic network, Arctic region



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What are the single species good for?

- Certain species have their dynamics effectively uncoupled from the others.

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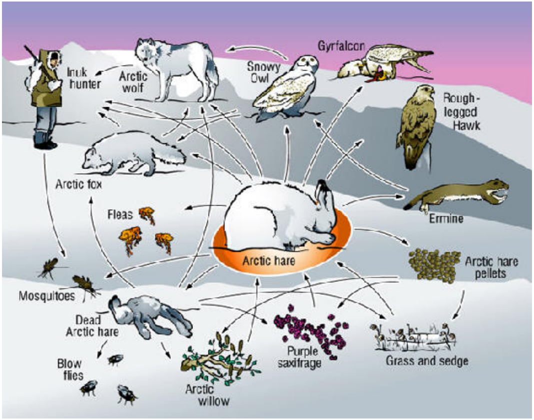

Figura : Simplified trophic network in the Arctic

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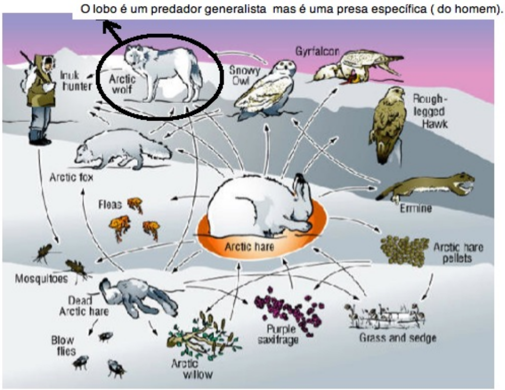

Figura : The wolf preys on many species, but its is itself a prey of a specialist predator. The coupling with human population can be strong.

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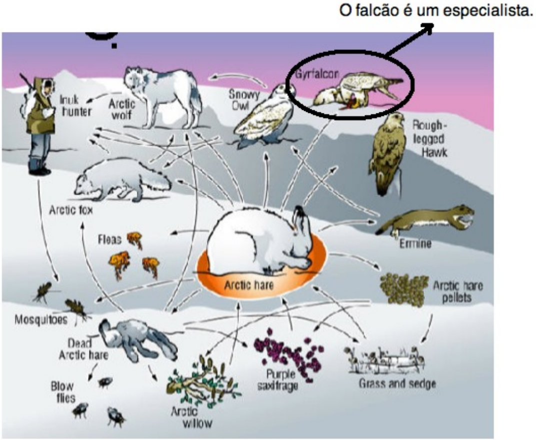

Figura : The gyrfalcon depends essentially on the the artic hare.

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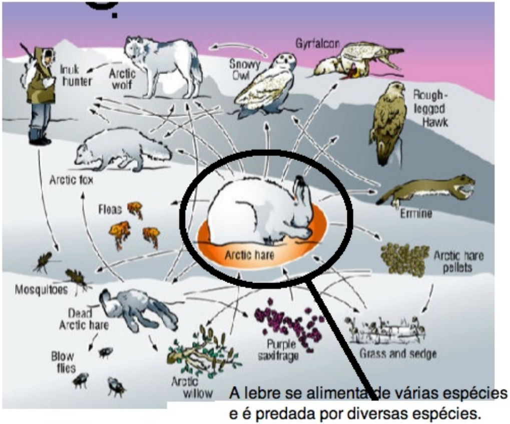

Figura : The Arctic hare is a generalist that is prey to other generalists. Single species models may apply.

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Bibliography

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Online Resources

- http://www.ictp-saifr.org/mathbio5
- http://ecologia.ib.usp.br/ssmb/

Thank you for your attention