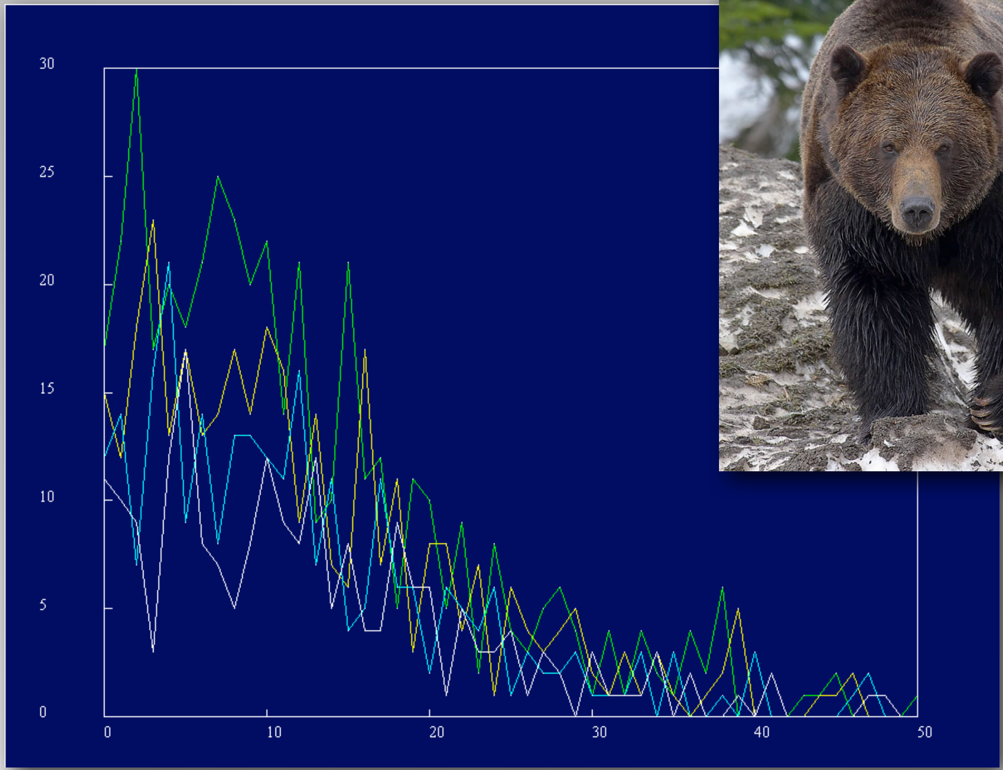
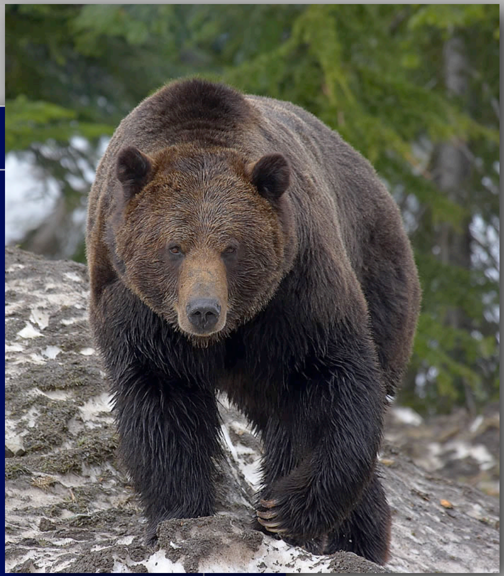
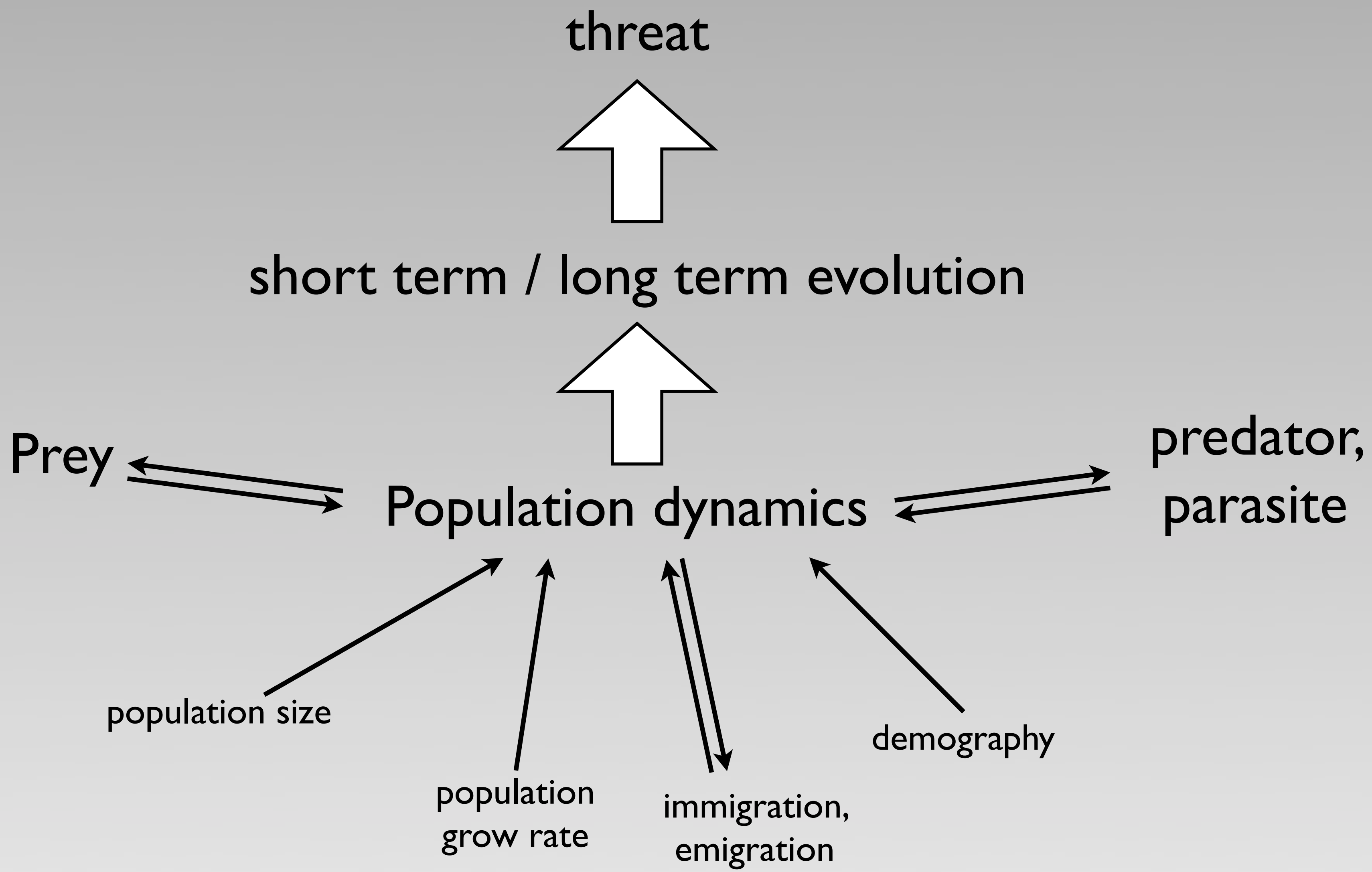
Population dynamics, viability analysis





Sylvain Ursenbacher
NLU, room 36

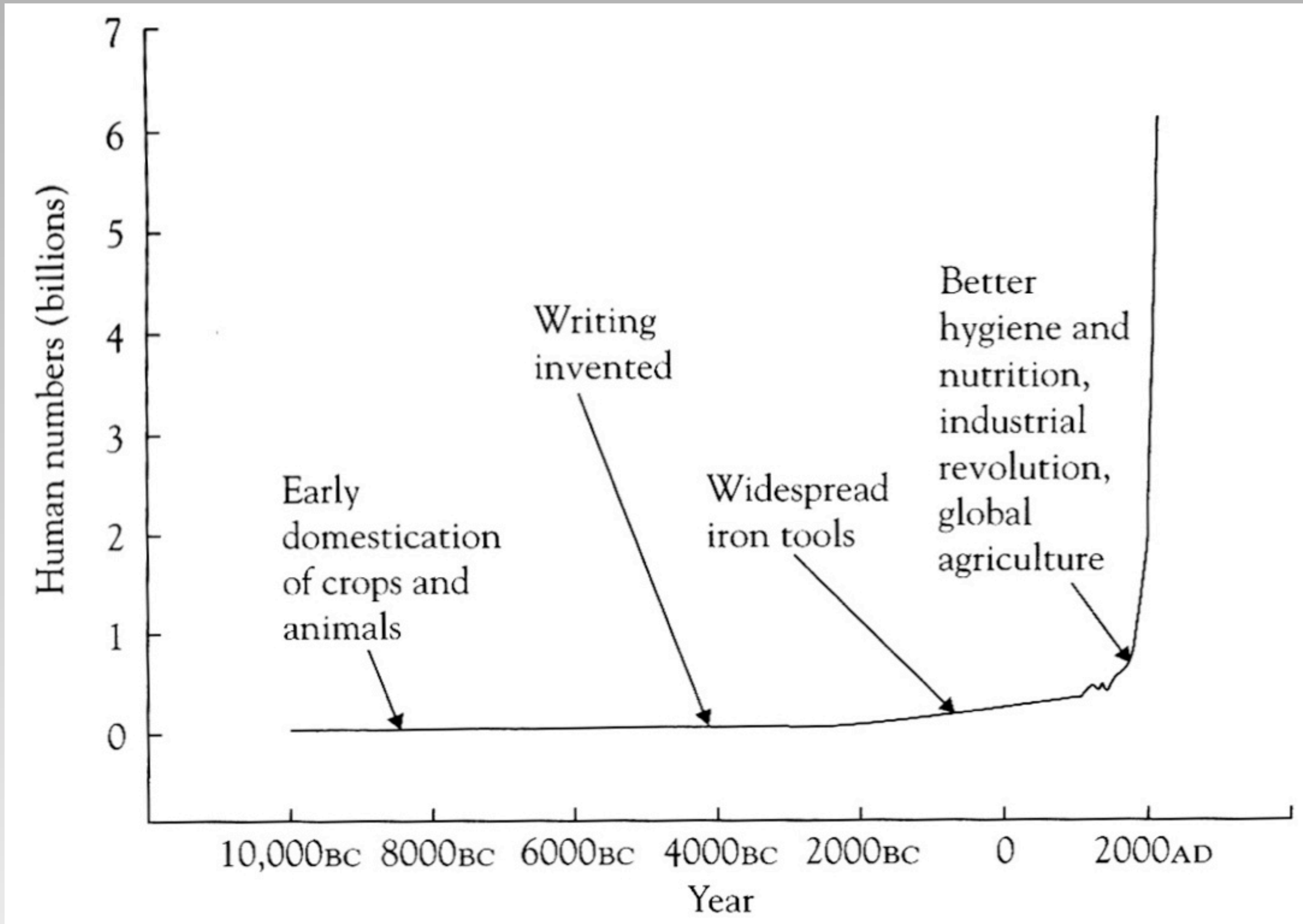
Introduction



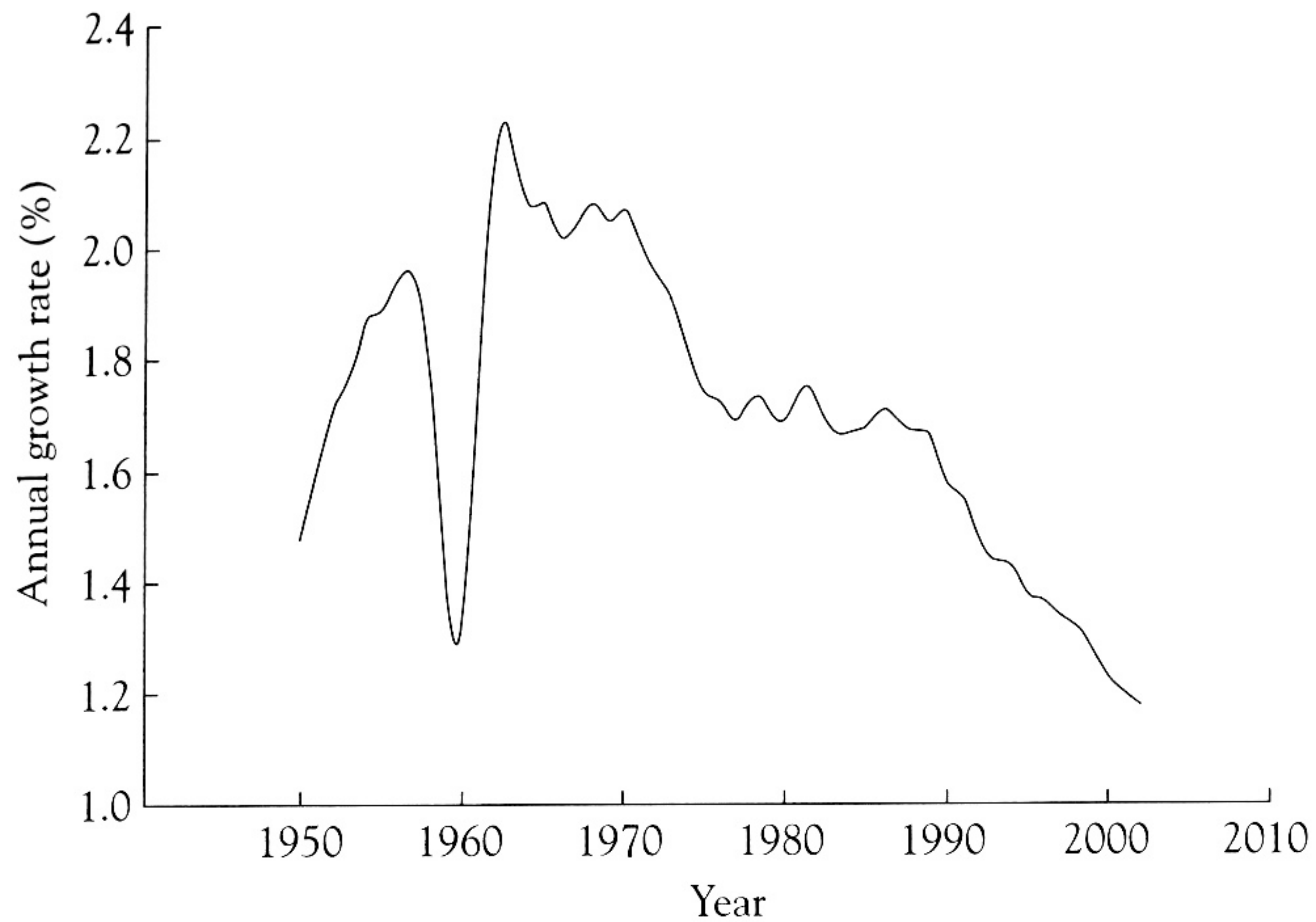
Introduction: *Population dynamics*

- growth rate monitoring
- estimation of demographic parameters
- impact of environment on growth rate
  - predators / prey / parasites
  - carrying capacity

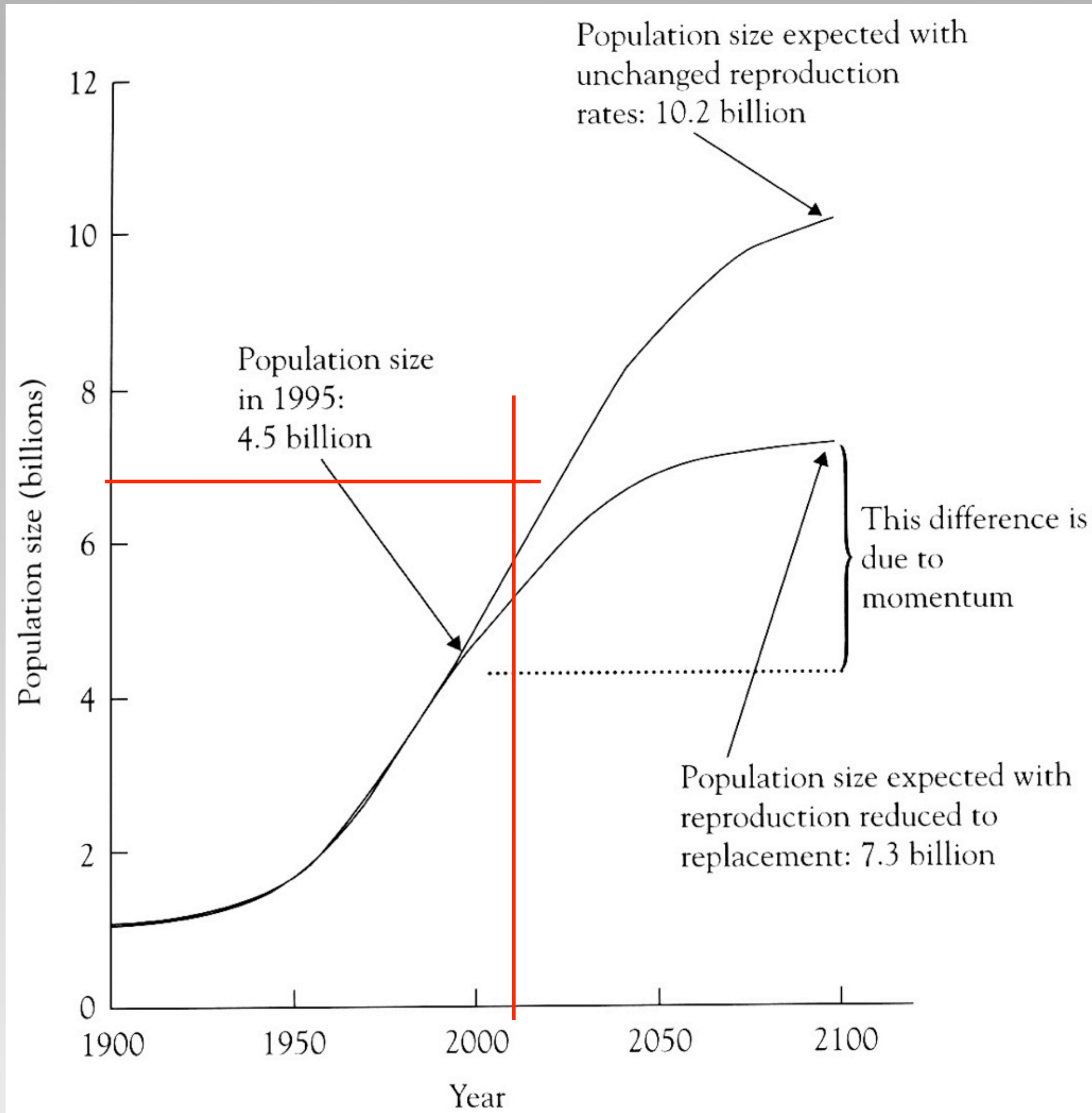
Introduction: *human population*



Introduction: *human population*



Introduction: *human population (conducted in 1995)*



Plan

- Basis information
- requested parameters for the development of simple models
  - Leslie matrix
- more complex models
  - geometric or exponential growth
  - prey-predators (Lotka-Volterra)
  - density-dependence models
  - multiple populations
- Population Viability Analyses (PVA)
  - sensitivity analysis
  - implications for conservation

Introduction

- Population evolution

intrapopulation variation

interpopulation movements

$$N_{t+1} = N_t + \underbrace{B + I}_{\text{new individuals}} - \underbrace{D - E}_{\text{individuals that disappeared}}$$

Population size before

N = abundance at time *t*

B = birth

I = immigration

D = death

E = emigration

Introduction

- Population evolution

N = abundance at time *t*

B = birth

I = immigration

D = death

E = emigration

$$N_{t+1} = N_t + B + I - D - E$$

↓

estimation of abundance and density:

e. g. CMR: Capture-Mark-Recapture methods (B. Baur, Monday & Friday)

Introduction

- Population evolution

N = abundance at time *t*

B = birth

I = immigration

D = death

E = emigration

$$N_{t+1} = N_t + B + I - D - E$$

reproduction:

function of fecundity, sex ratio, ...

Introduction

- Population evolution

N = abundance at time t
B = birth
I = immigration
D = death
E = emigration

$$N_{t+1} = N_t + B + I - D - E$$

estimation of survival (ϕ):
$D = (1-\phi) * N_t$

(e.g. extended CMR method: Cormack-Jolly-Seber methods)

Introduction

- Population evolution

N = abundance at time t
B = birth
I = immigration
D = death
E = emigration

$$N_{t+1} = N_t + B + I - D - E$$

connection(s) with other population(s)

difficult to estimate
(e.g. CMR method: Cormack-Jolly-Seber methods)

requested parameters: survival rate (ϕ)

- 3 groups of survival estimators:
  - if all animals can be relocated
    - captive populations
    - telemetry
    - ⚠ lost of marks, moving out the study area, etc...
  - if only survivors are recorded
    - ?? all individuals recaptured at $t+1$?
    - CMR methods, using Cormack-Jolly-Seber methods add probability of detection
  - if only deaths are recorded
    - band-return approaches (e.g. with hunter / fisherman)

requested parameters: birth rate

- can be related to female only or both sex (depending of the model)
  - ➡ knowledge of sex-ratio important (adults, newborn, etc..)
- field evaluation of embryos / eggs / newborns per female
- mortality rate at the birth/hatching
- mortality rate of newborns (up to sexual maturity)
  - per time unit
  - per year
  - global from birth to sexual maturity

requested parameters: immigration / emigration

- difficult to estimate in wild populations
  - direct methods
    - CMR, evaluation with open population models (e.g. Cormack-Jolly-Seber)
  - indirect estimation
    - genetic evaluation

- see dynamics of multiple populations

Population evolution

$$N_{t+1} = N_t + \underbrace{B}_{(f*N_t)} + I - \underbrace{D}_{([1-\phi]*N_t)} - E$$

$$N_{t+1} = (f + \phi)N_t + \text{dispersal}$$

N = abundance at time t

B = birth

I = immigration

D = death

E = emigration

ϕ = survival at time t

f = fecundity

Closed populations

$$N_{t+1} = (f + \phi)N_t + \text{dispersal}$$

- if the population is close: no recruitment

$$N_{t+1} = (f + \phi)N_t$$

⚠ closed population for CMR could also signify no recruitment, including fecundity and survival

Leslie model

- matrix regrouping survival and fecundity for all age classes
- can be very simple (2 x 2) to very complex (y x y)

from this stage

to this stage...		newborn	adults	
	newborn	0	15.4	← fecundity
	adults	0.43	0.65	← survival (move to an other group)

Leslie model

- matrix regrouping survival and fecundity for all age classes
- can be very simple (2 x 2) to very complex (y x y)

from this stage

to this stage...

	newborn	juveniles	adults class age 1	adults class age 2
newborn	0	0	4.5	6.5
juveniles	0.67	0.10	0	0
adults class age 1		0.61	0.25	0
adults class age 2			0.64	0.89

fecundity variable between diff. class ages

juveniles did not stay at this stage at t+1

similar survival rate between class ages

Populus

Simulations of Population Biology

More complex methods...

- geometric or exponential growth
- density-dependence models
- stochasticity
- prey-predators relationship (Lotka-Volterra equations)
- multiple populations

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geometric and exponential growth

- closed populations

$$N_{t+1} = (f + \phi)N_t$$

$$N_{t+1} = \lambda N_t$$

λ = geometric growth rate

if $\lambda < 1$, reduction of the population size
if $\lambda = 1$, population size stable
if $\lambda > 1$, growth of the population size

geometric = discrete growth rate

geometric and exponential growth

$$N_{t+1} = \lambda N_t$$

- for long t time steps

$$N_t = N_o * \lambda_1 * \lambda_2 * \lambda_3 * \ldots \lambda_t$$

- to estimate constant annual growth

$$N_t = N_o * \lambda^t$$

- for annual growth rate over t time steps

$$\lambda = \sqrt[t]{N_t / N_0}$$

geometric and exponential growth

- exponential (continuous) growth rate
  - not focused on one year (or a time unit)
- when Δt tend to 0
  - tiny change in population size (dN) over a tiny interval of time (dt)

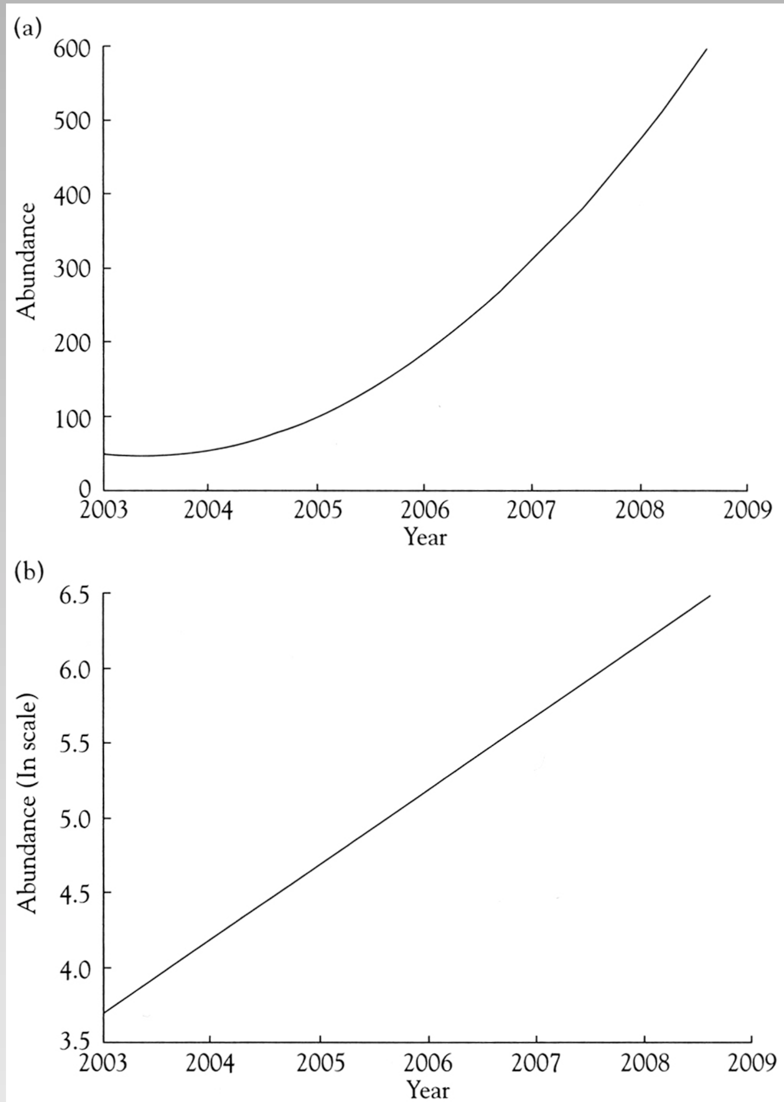
$$dN / dt = rN$$

  - r = instantaneous growth rate per capita (per individual)

- dN / dt = derivative; rN = slope of the tangent of the curve of N plotted against time

geometric and exponential growth

- Example of a exponential growth
  - λ = 1.65



- or plotted against the natural logarithm (ln) of abundance
  - slope in (b): r

More complex methods...

- geometric or exponential growth
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density dependance: *introduction*

- previous models: unaffected by its own density
- but population cannot grow exponentially for long periods...

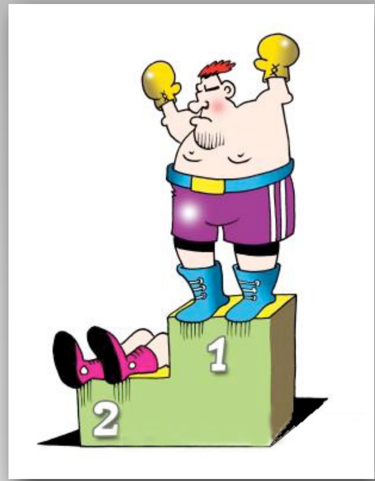
➡ "limitation" of growth due to numerous reasons

  - e.g. food limits, territoriality, ...

- <u>Density dependance</u>: refer to the profound influence that a population's density has on the vital rates of individuals in the population
  changes in vital rates lead to changes in population growth rate

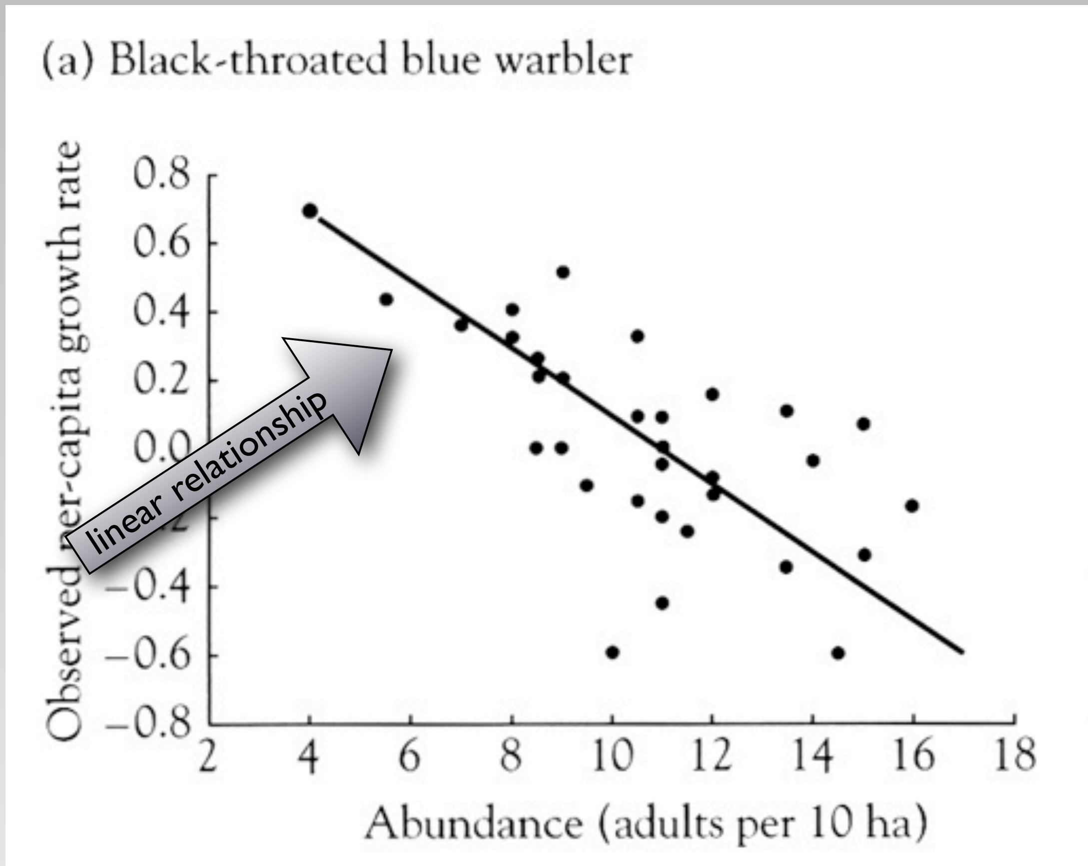
density dependance

- high density → negative impact: competition between individuals
  - direct competition: interference or contests (fights)
    - for food, mates, territories
  - ★ winners can reproduce, losers not
  - predators, parasites or contagious diseases
  - ★ regulates populations
  - others....



- high density → positive impact: avoiding Allee effect
  - difficulties to find a mate in very small populations
  - confusion to avoid predation (e.g. mormont crickets)
  - co-operation for founding food, to defend food
  - ...

density dependance: *some examples of negative density dependance*



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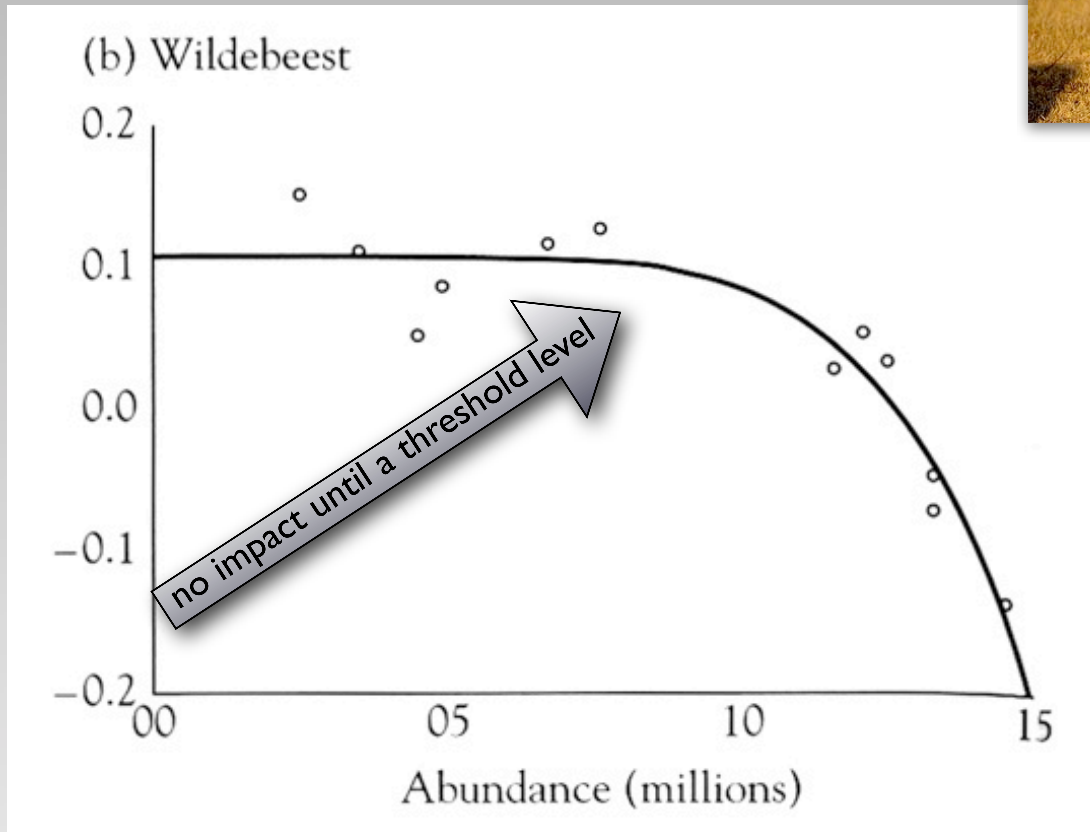

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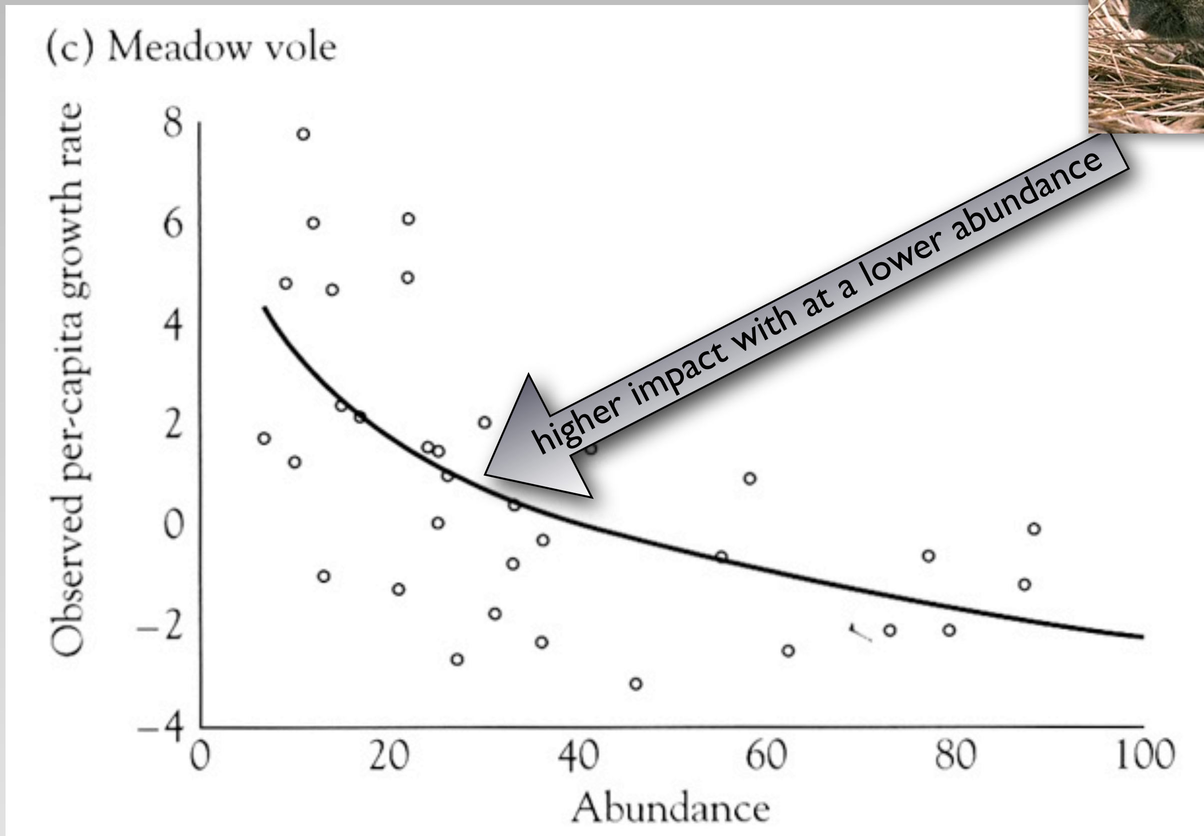

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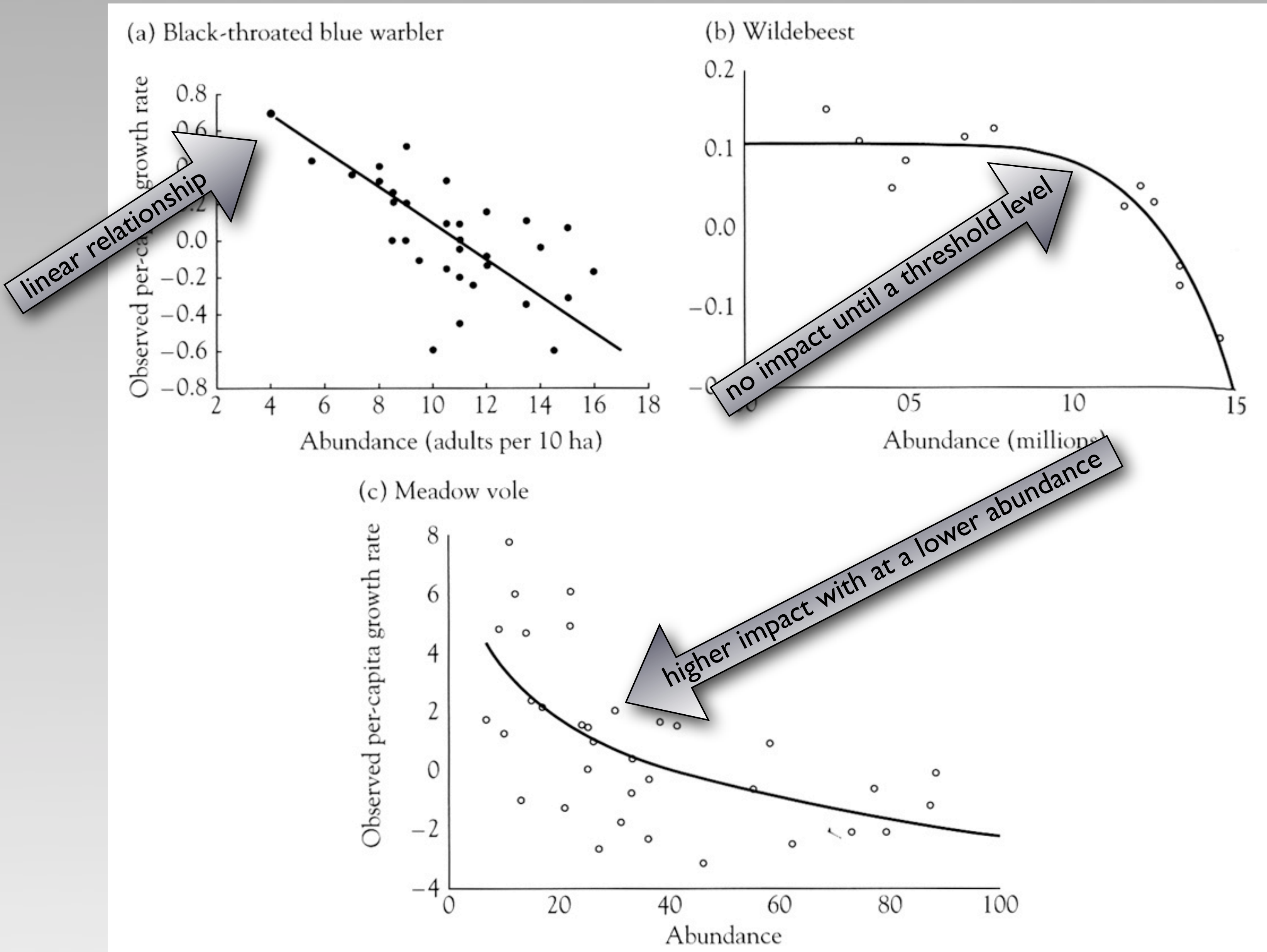
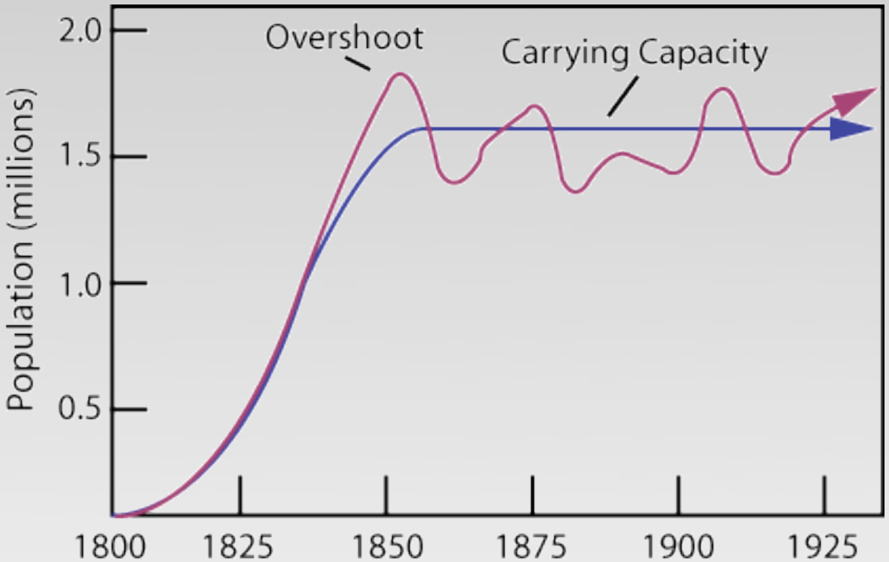


density dependance: *carrying capacity*

<u>Carrying capacity:</u> *K*

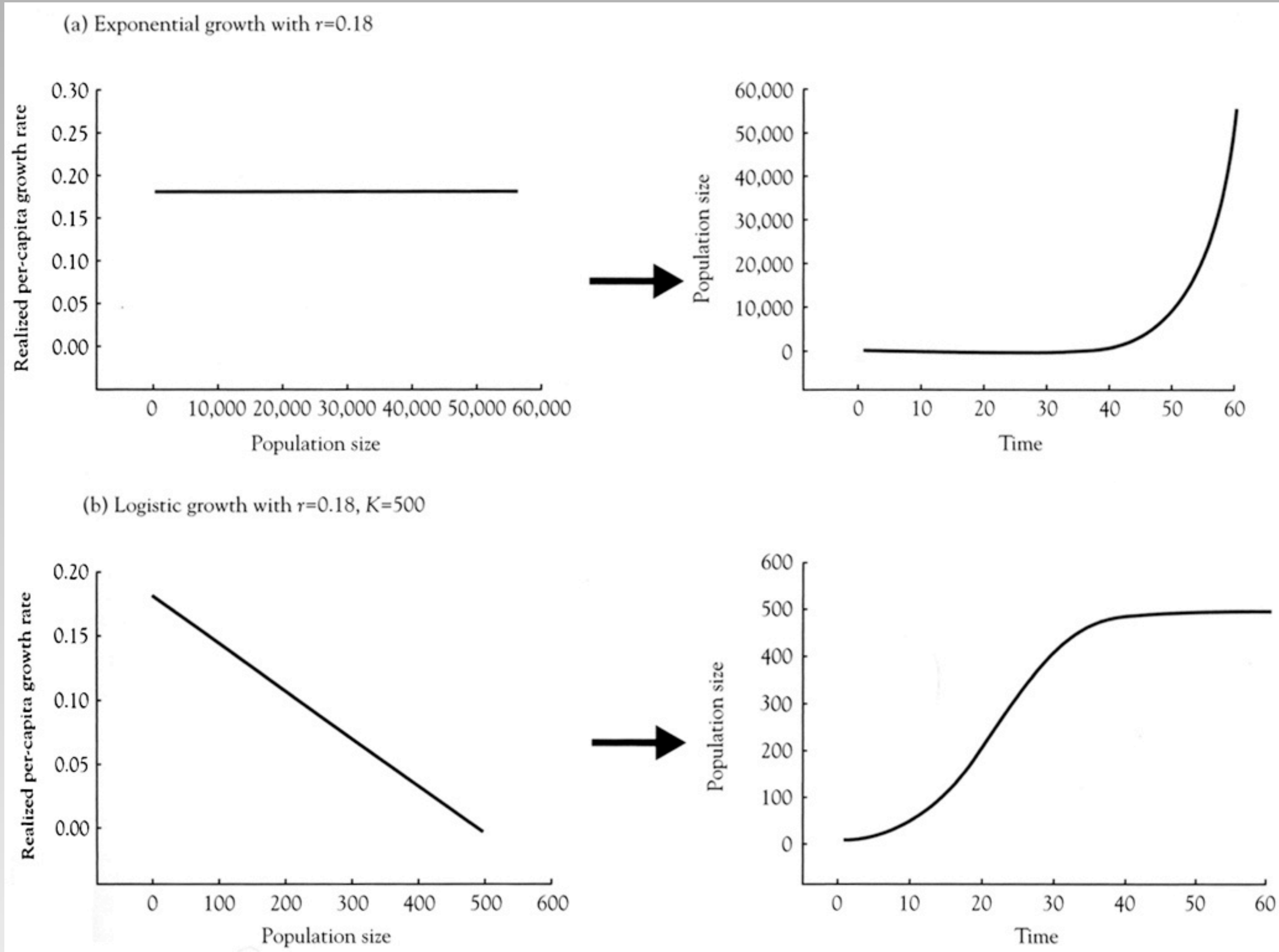
- the point at which per-capita mortality (1-survival) and reproduction are equal, so that the population just replaces itself $\lambda = 1$ ($r = 0$)
- carrying capacity = equilibrium
  if density is greater than *K*: mortality > reproduction
  if density is lower than *K*: reproduction > mortality



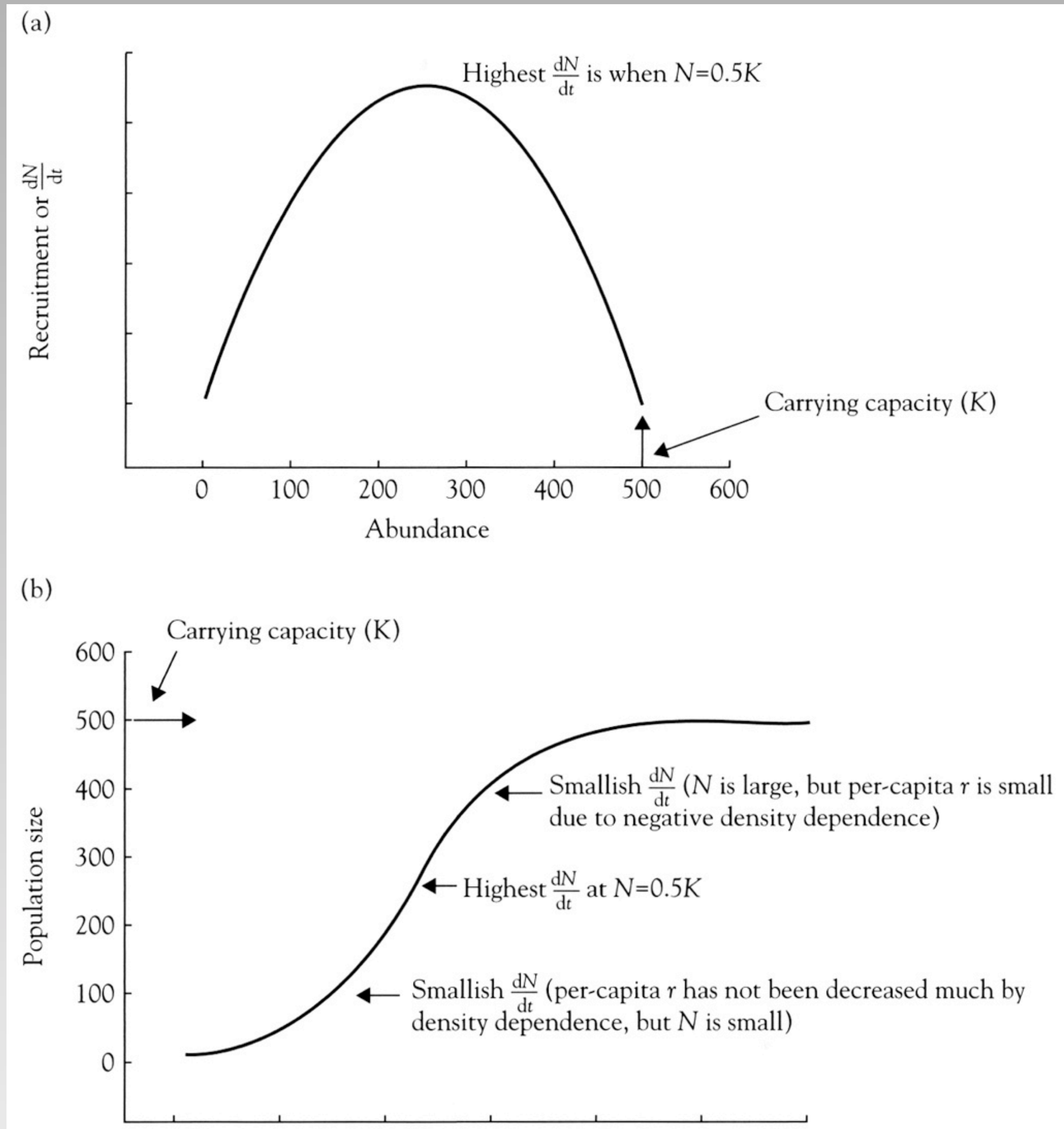
density dependance: *logistic growth model*

- exponential growth:
  - r = constant
- logistic growth:
  - r change f(population size)
  - $r \propto [\ln(N_{t+1}/N_t)]$ = intrinsic growth rate

density dependance: *logistic growth model*



density dependance: *ratio of recruitment and abundance*



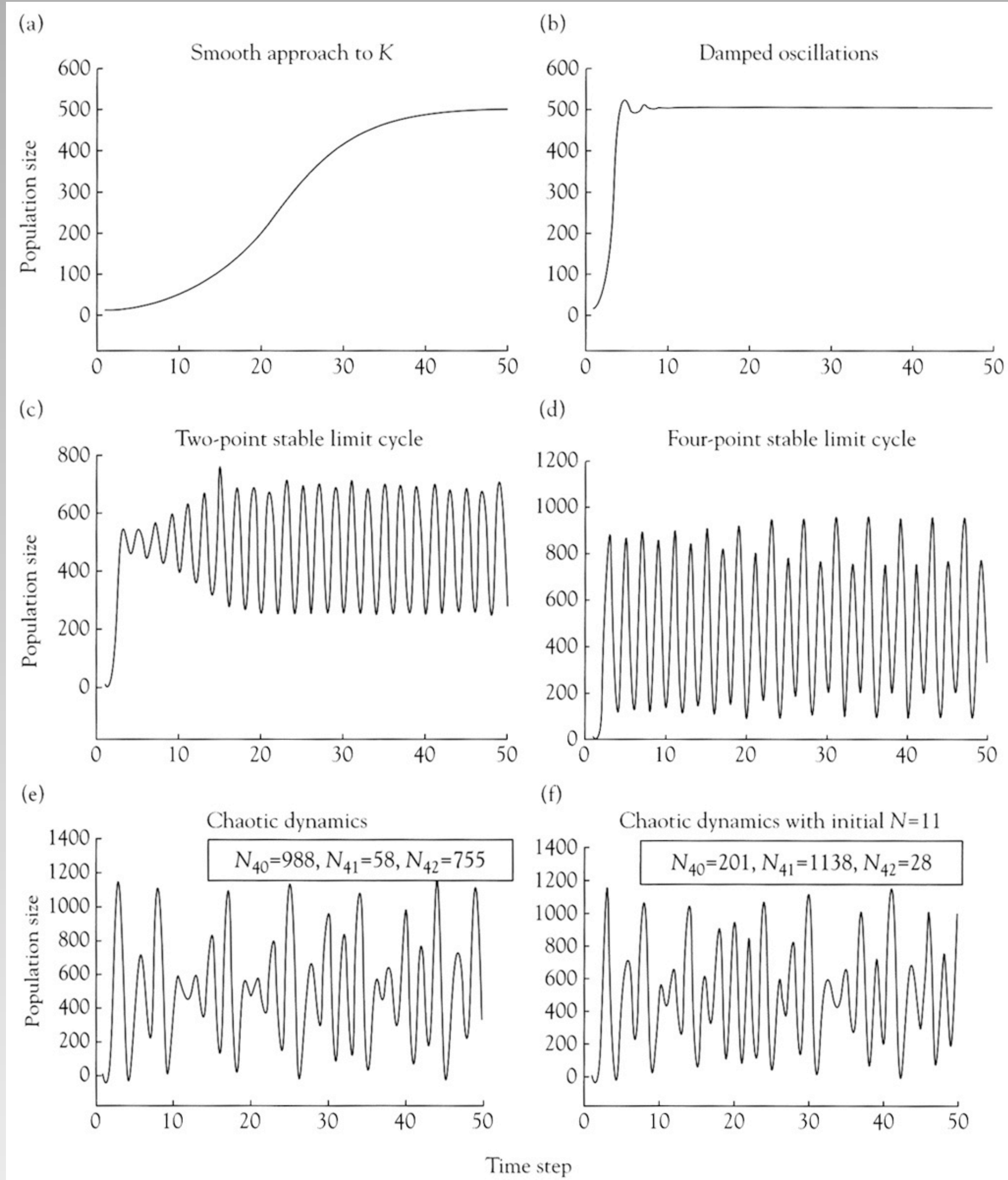
density dependance: *some conterintuitive dynamics*

- with the discrete logistic growth equation:

$$N_{t+1} = N_t e^{\left(r\left[1-\left(\frac{Nt}{K}\right)\right]\right)}$$

<u>without stochasticity</u>

- can become:
    - cycles
    - unpredictable
- for r<1.0: s-shape curve
- for 2.0<r<2.69: predictable cycles
- for r>2.69: chaos



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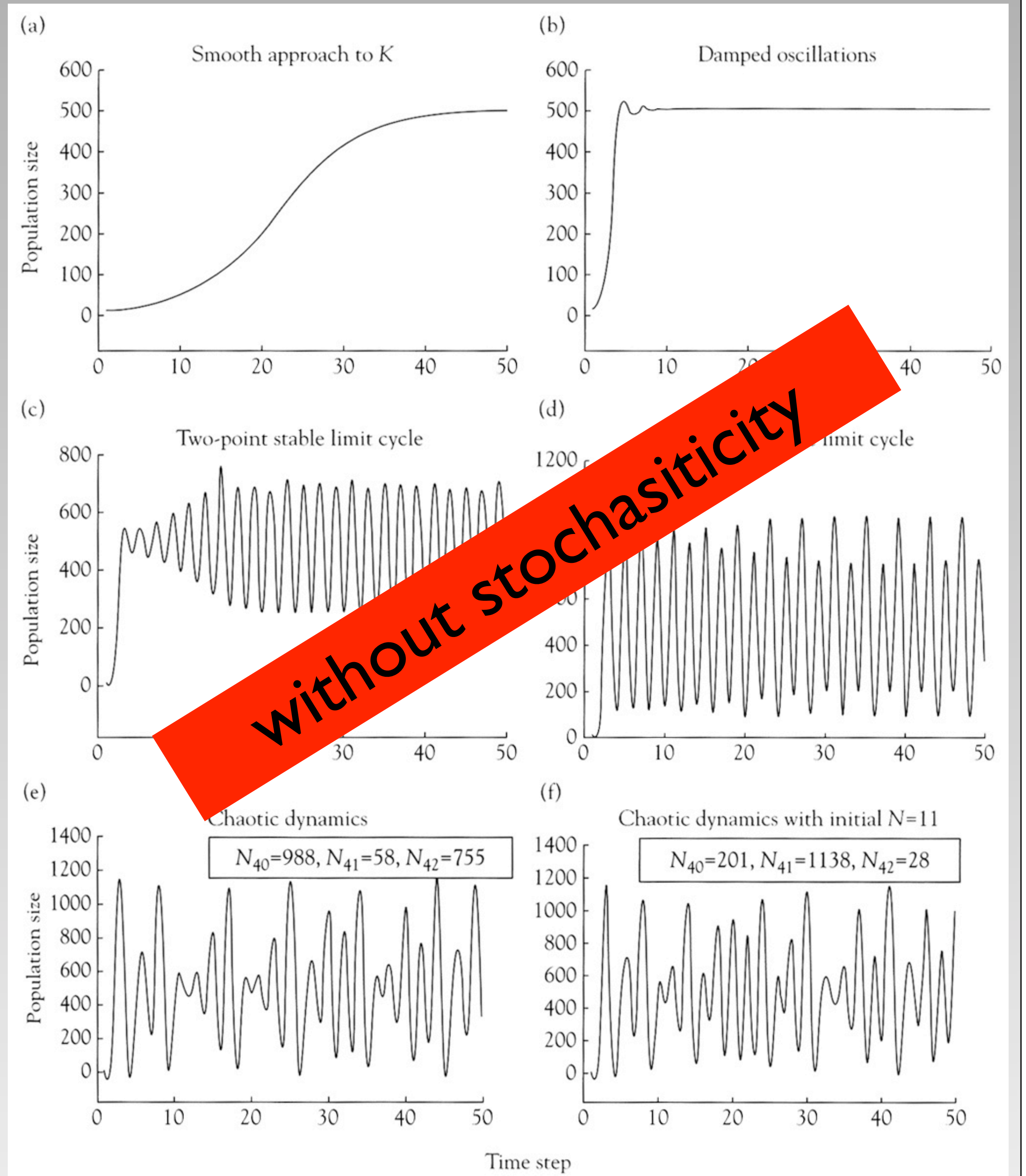
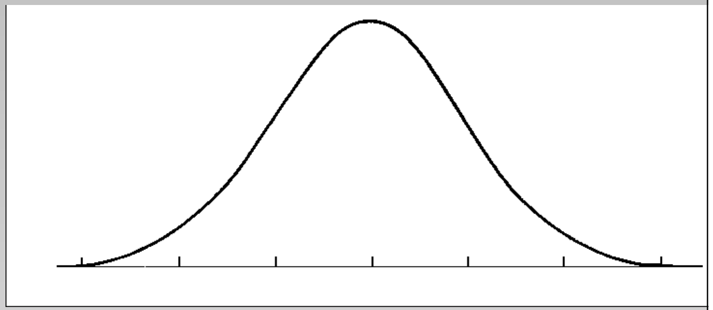


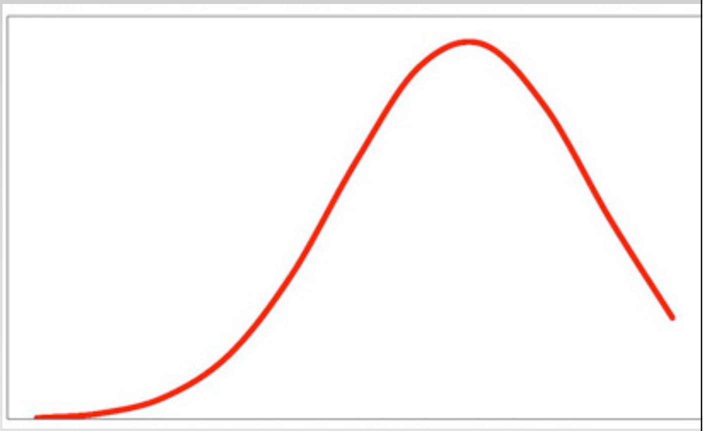
More complex methods...

- geometric or exponential growth
- density-dependence models
- stochasticity
- prey-predators relationship (Lotka-Volterra equations)
- multiple populations

Stochasticity in models

- all presented model: no variation in the different parameters
- add some "variability" in different parameters
- distribution of 1 parameter:
  - uniform distribution between min and max
  - central tendency (e.g. lognormal, normal, ...)
  - pick up several values measured in the field





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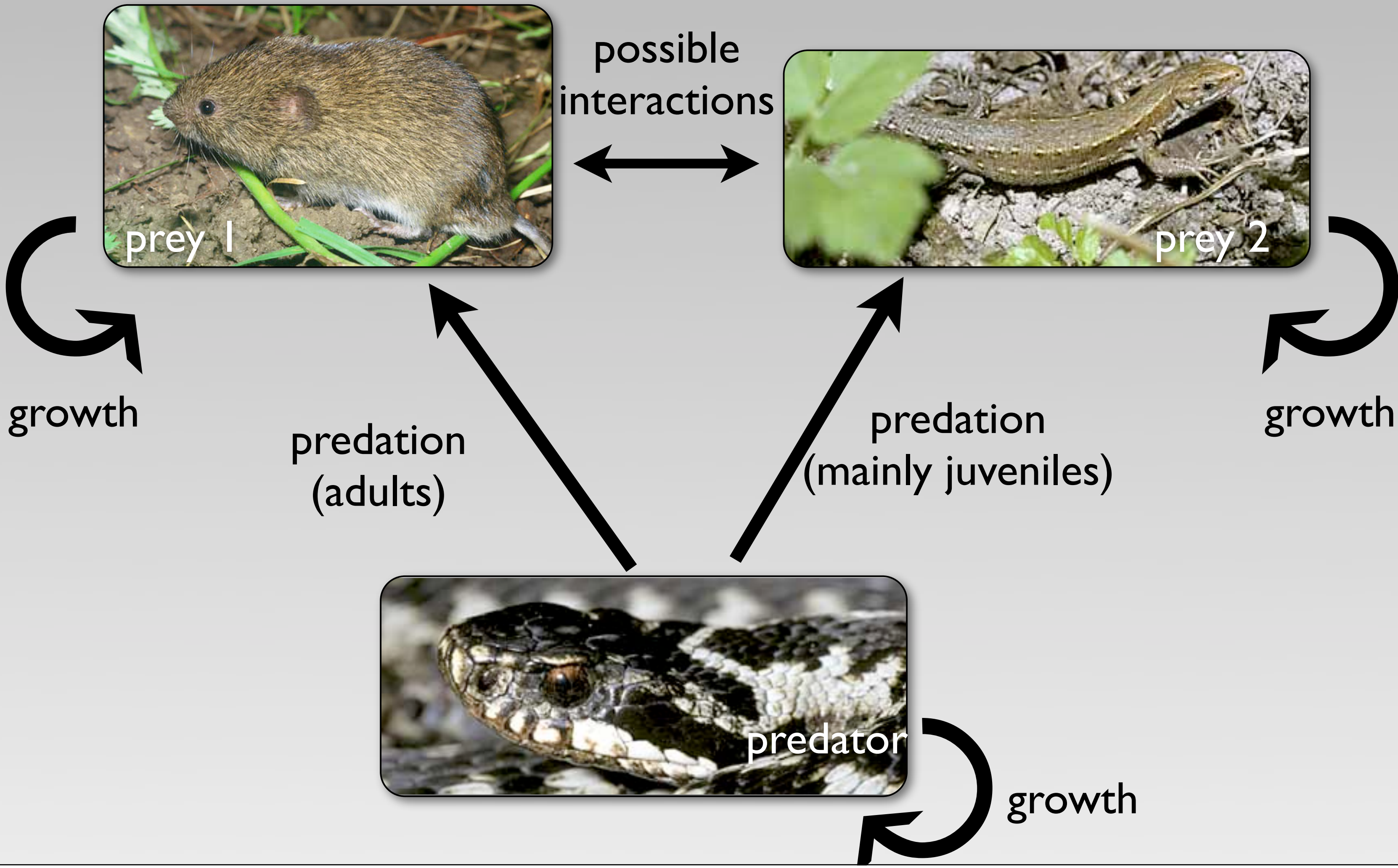
Prey-predation relationships

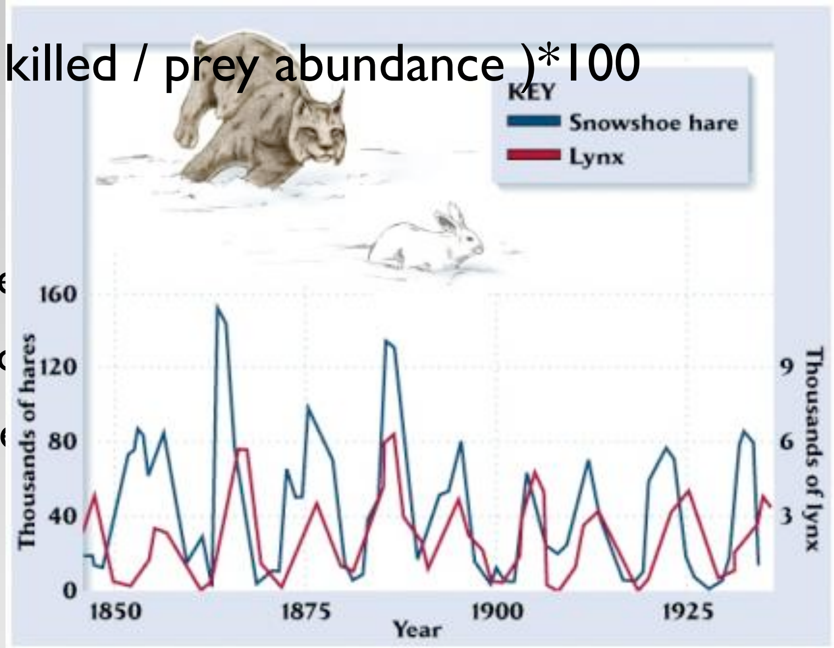


Prey-predation relationships: *introduction*

- predators (or parasites) can have an impact on population abundance
- close relationship between prey and predator densities
- predation rate:

  Predation rate = (number of prey killed / prey abundance)*100

- numerous possible responses:
  - high level of prey → higher survival rate
  - high level of prey → increase of predato
  - generally not only one prey and one pre



from Purves et al., 1992

Prey-predation relationships: *Lotka-Volterra equations*

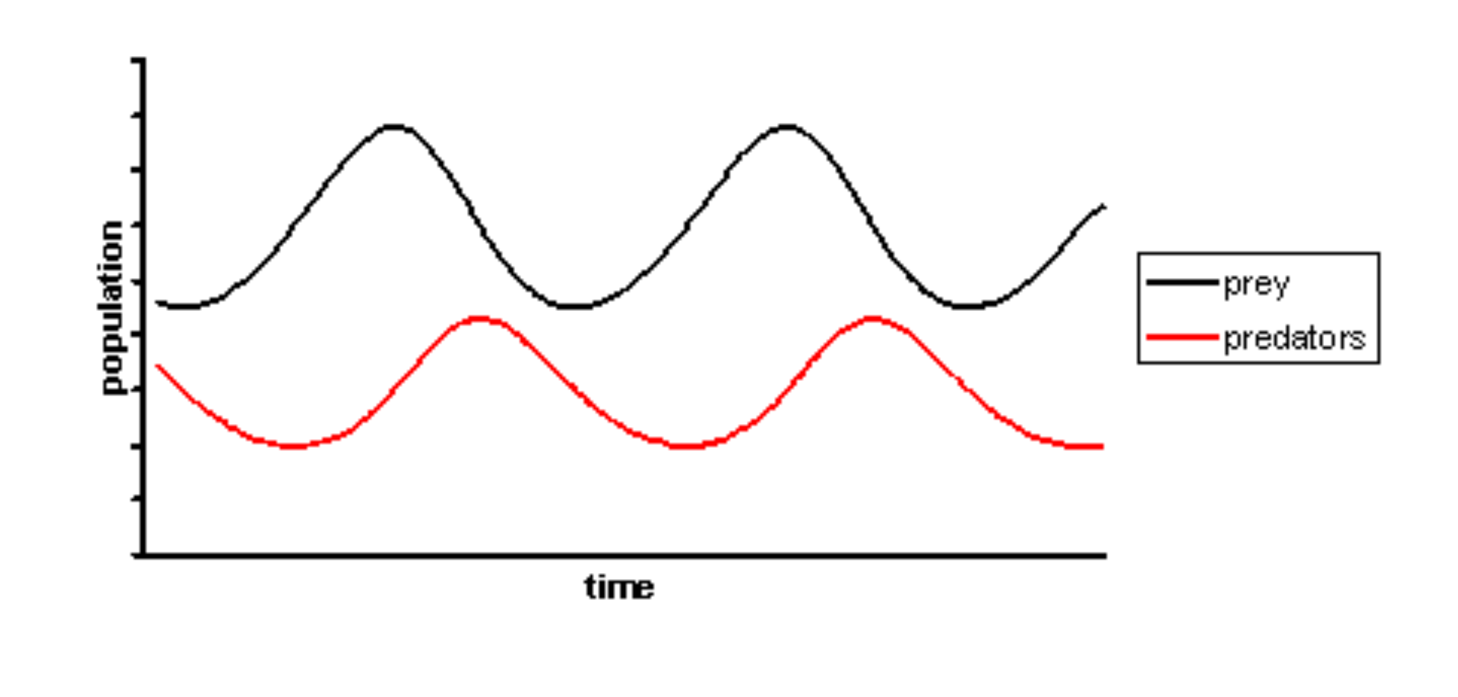
$$\frac{dx}{dt} = x(\alpha - \beta y)$$

$$\frac{dy}{dt} = -y(\gamma - \delta x)$$

- y = predator abundance
- x = prey abundance
- dy/dt and dx/dt = growth of the two populations against time
- α, β, γ and δ = parameters representing the interaction between the two species

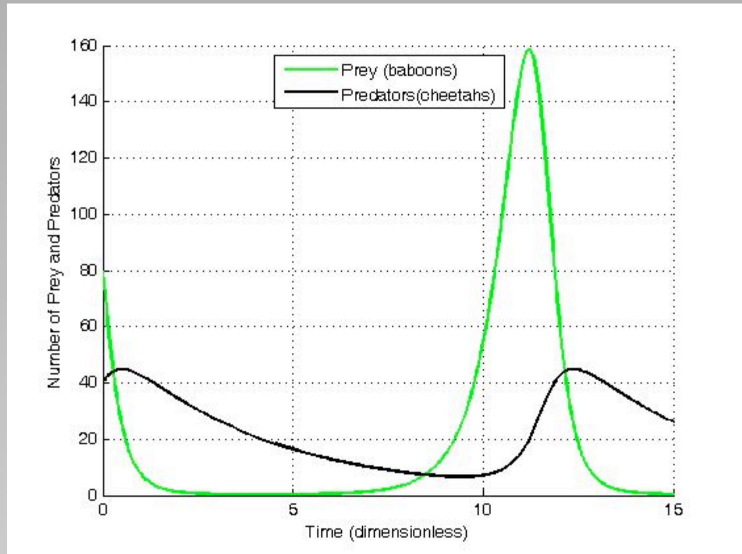
- prey: unlimited food supply; exponential reproduction (αx); rate of predation (βxy), function of meeting frequency between predator and prey
- predator: growth rate of the predator (δxy); γ natural death of the predator

Prey-predation relationships: *Lotka-Volterra solutions*



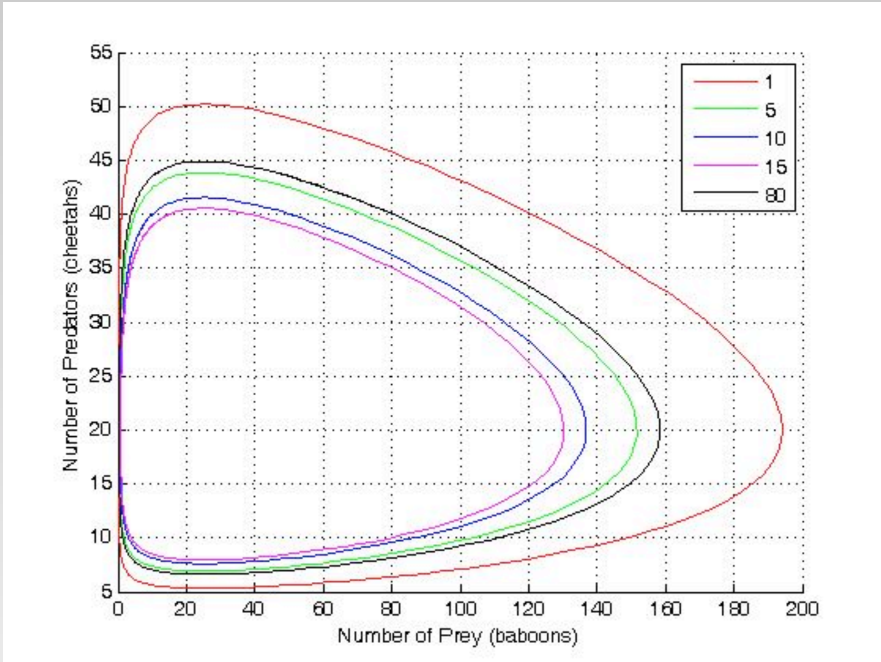
Prey-predation relationships: *Lotka-Volterra solutions*

- Example: baboons and cheetahs



- oscillations

- relationship between prey and predator abundance



Populus

Simulations of Population Biology

More complex methods...

- geometric or exponential growth
- density-dependence models
- stochasticity
- prey-predators relationship (Lotka-Volterra equations)
- multiple populations

Multiple populations

- Until now: no emigration / immigration
- "closed population"

N = abundance at time *t*
B = birth
I = immigration
D = death
E = emigration

$$N_{t+1} = N_t + B + I - D - E$$

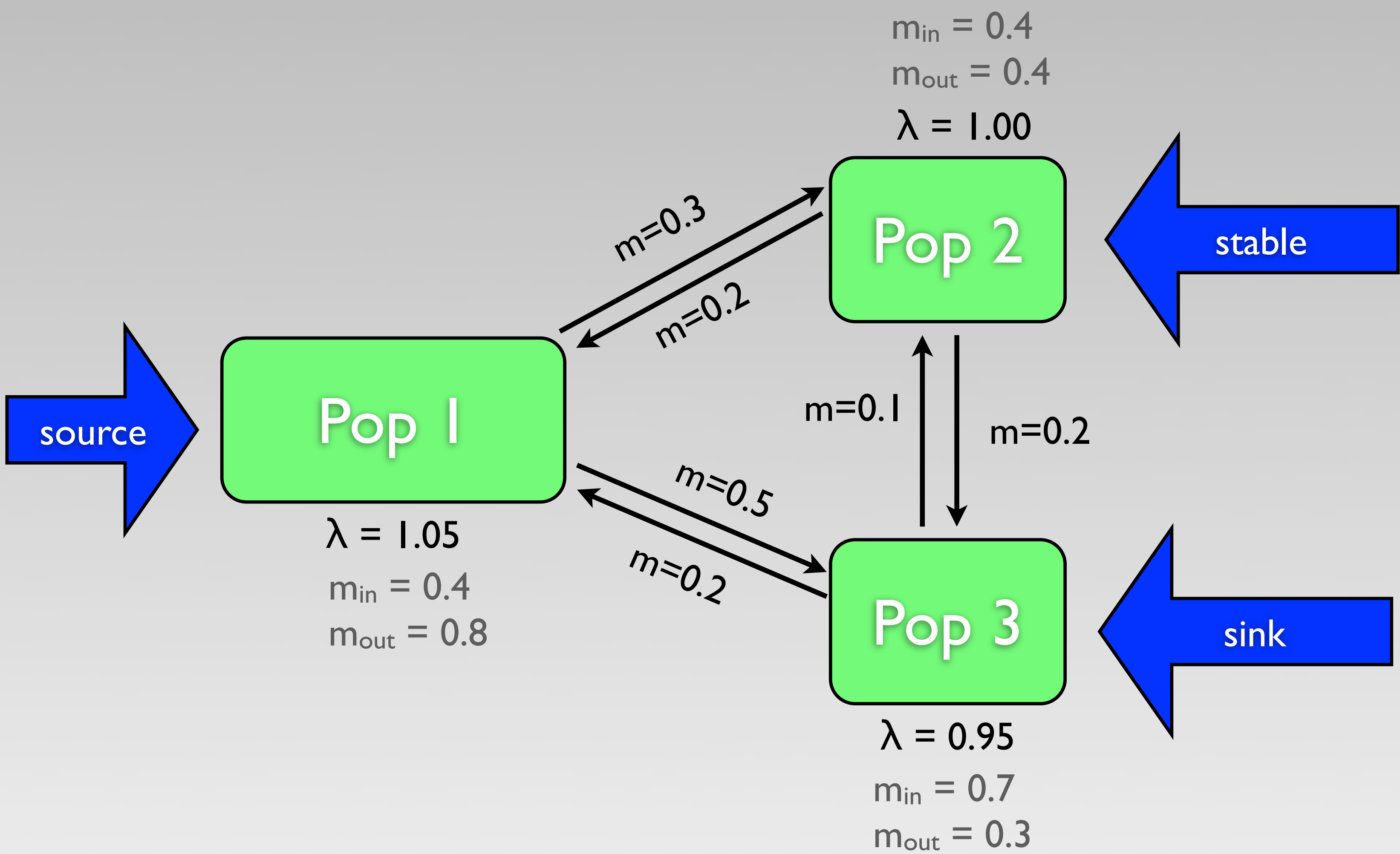
$$N_{t+1} = (f + \phi)N_t + \boxed{\text{migration}}$$

ϕ = survival at time *t*
f = fecundity

Multiple populations

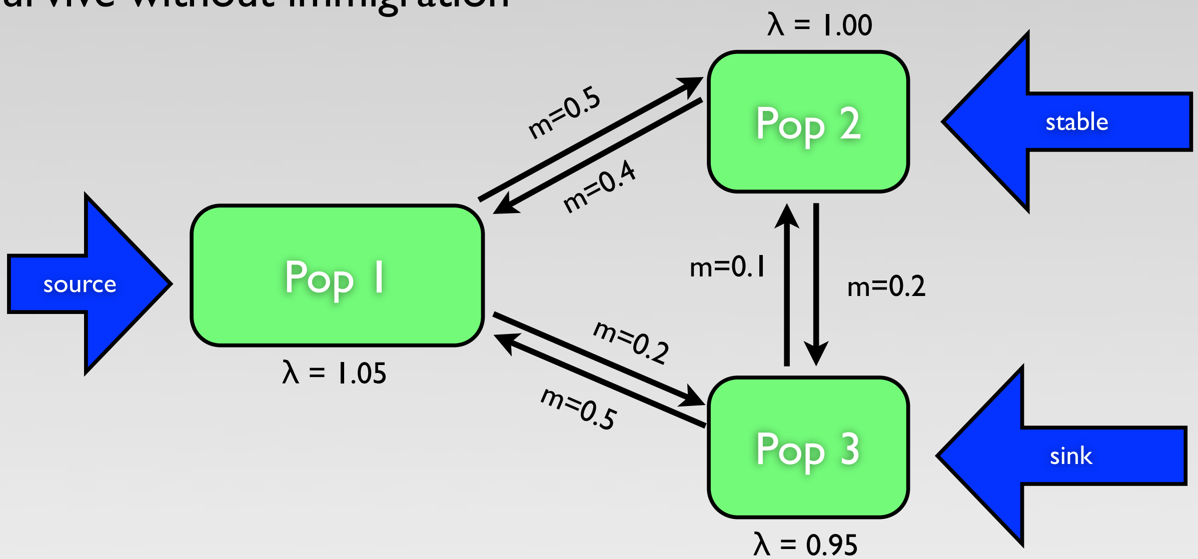
- immigration /emigration: difficult to estimate
    - radio-tracking / Capture-Mark-Recapture
    - ...
- Complex model, implying population dynamic for each deme

Multiple populations: *source/sink populations*



Multiple populations: *source/sink populations*

- source population: population that is strong contributor
  - more emigration than immigration
  - often: $\lambda > 1.0$
- sink population: population that drains on the system (metapopulation)
  - more immigration than emigration
  - population cannot survive without immigration

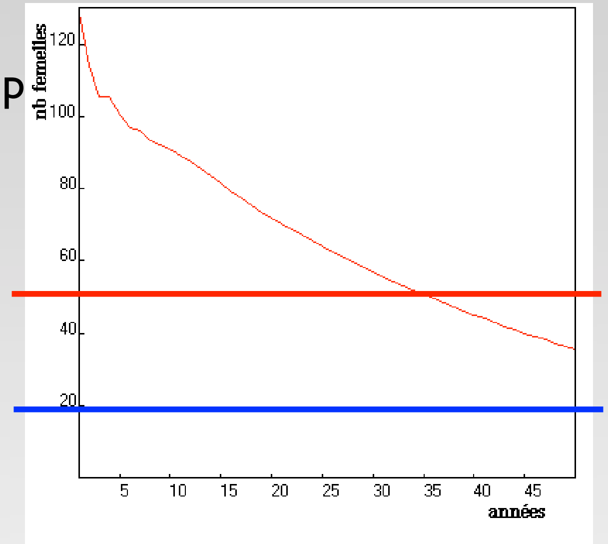


Population dynamic: summary

- important tools to estimate if population has a positive or negative growth rate.
- can be used for testing impact of treatments on experimental populations (e.g. test of parameters on the fitness, using the complete life cycle)
- can be use with natural populations
- ⚠ difficulties to evaluate all parameters (survival, fecundity), with the complete variance
- ⚠ complexity of some models...
- allow to evaluate the future of populations:
  PVA (Population Viability Analysis)

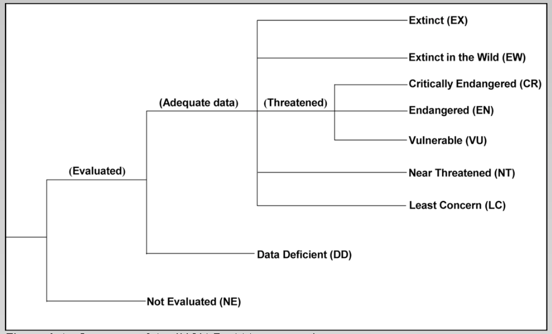
Population Viability Analysis: *estimate the future evolution...*

- PVA: application of data and models to estimate probabilities that a population will persist for a specific time into the future (and to give insights into factors that constitute the biggest threats)
- include:
    - survival rate, fecundity of different class ages
    - stochasticity
      (on different variables, following specific models)
      try to ground it on the field observation
    - density dependence models
      (not necessary for small, low density - threaten - p
    - (predator / parasites interaction)
- Minimum Viable Population (MVP)
    - difficulty do define



Population Viability Analysis: *estimate the future evolution...*

- implication for conservation aspect
  - prediction of risks in small populations
    (risk of extinction, quasi-extinction, ...)
- IUCN Red List: Categories and Criteria (Version 3.1)
  - some criteria related to the probability of extinction:
    E. Quantitative analysis of extinction risk

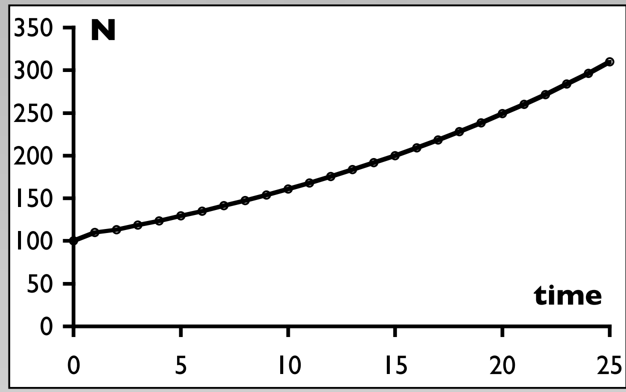


Use any of the criteria A-E	**Critically Endangered**	**Endangered**	**Vulnerable**
E. Indicating the probability of extinction	50% in 10 years or 3 generations (100 year max)	20% in 20 years or 5 generations (100 years max)	10% in 100 years

Population Viability Analysis: *simple model*

- based on a 2x2 Leslie Matrix

N=100	class age 0	class age 1
class age 0	0	1.2
class age 1	0.3	0.7



N=100	class age 0	class age 1
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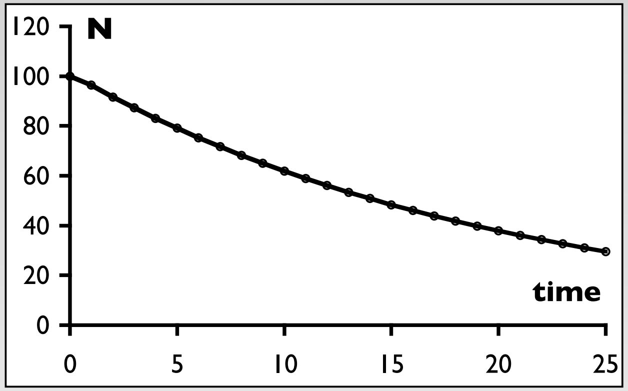
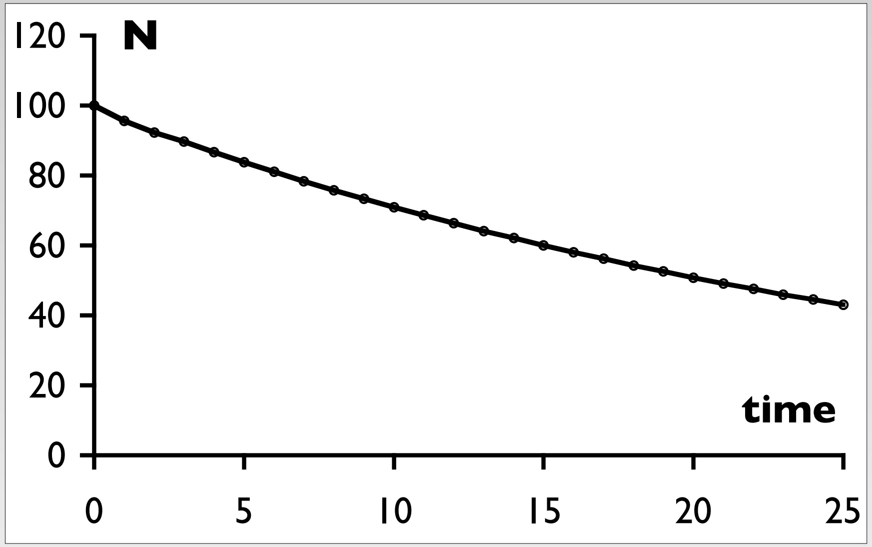


Population Viability Analysis: *simple model*

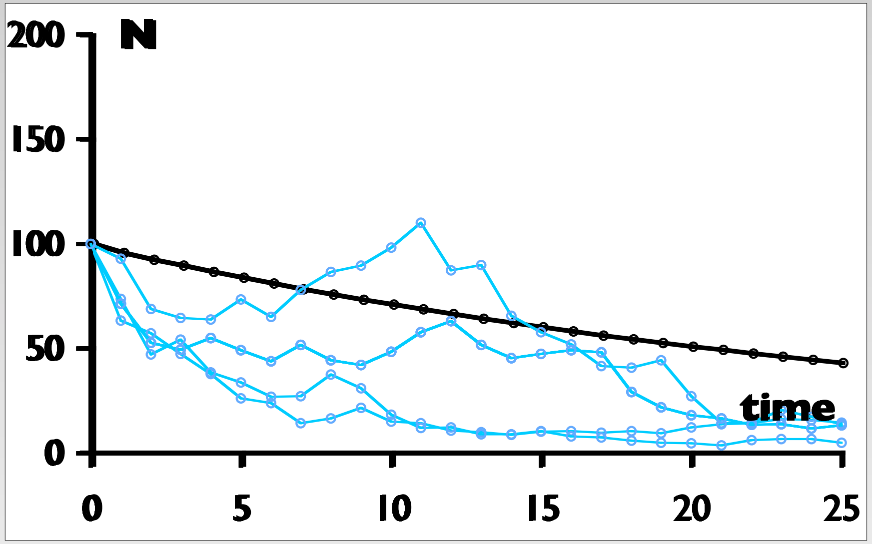
- based on a 5x5 Leslie Matrix

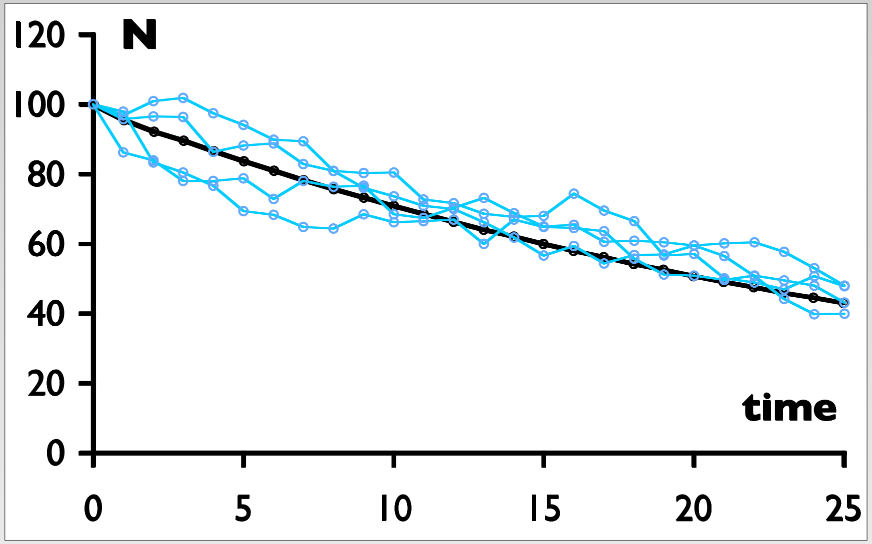
N=100	class age 0	class age 1	class age 2	class age 3	class age 4
class age 0	0	0	1	1	1
class age 1	0.5	0	0	0	0
class age 2	0	0.5	0	0	0
class age 3	0	0	0.7	0	0
class age 4	0	0	0	0.7	0.7



Population Viability Analysis: *add complexity in the model*

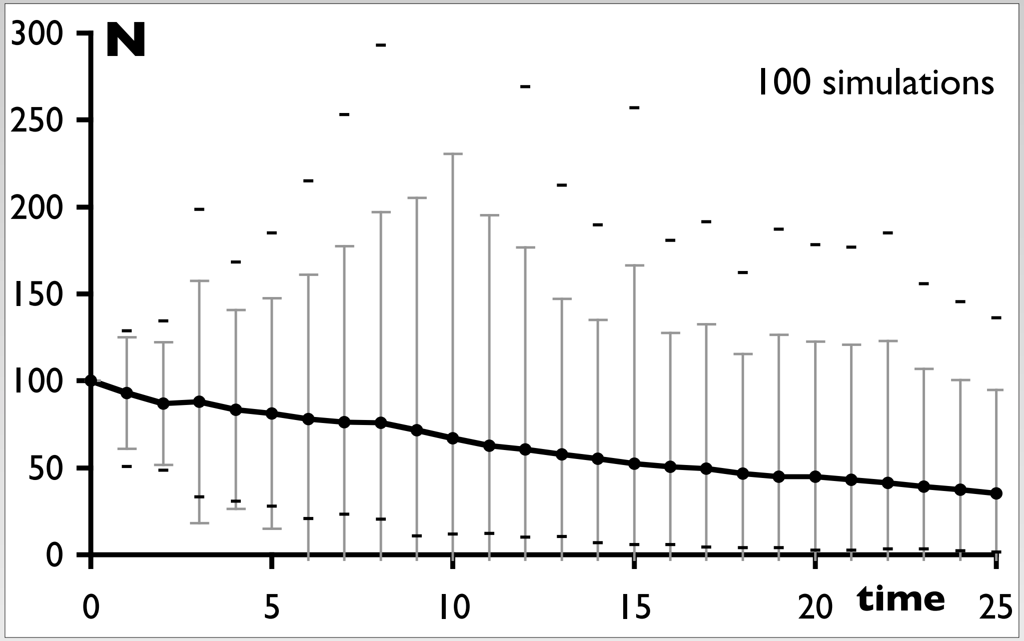
- stochasticity

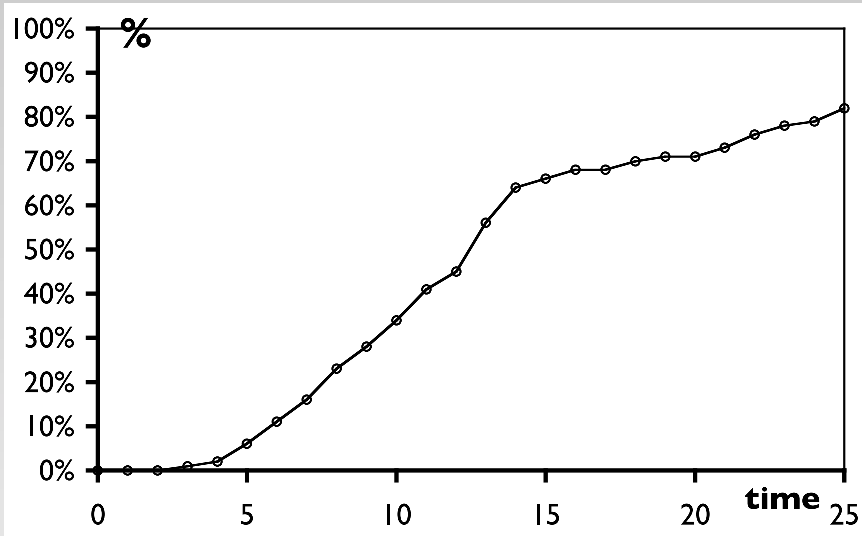




Population Viability Analysis: *add complexity in the model*

- stochasticity

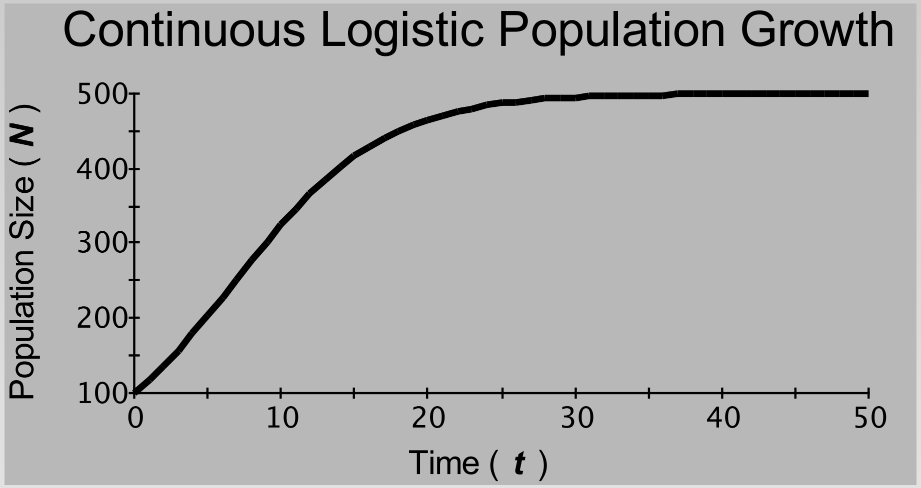




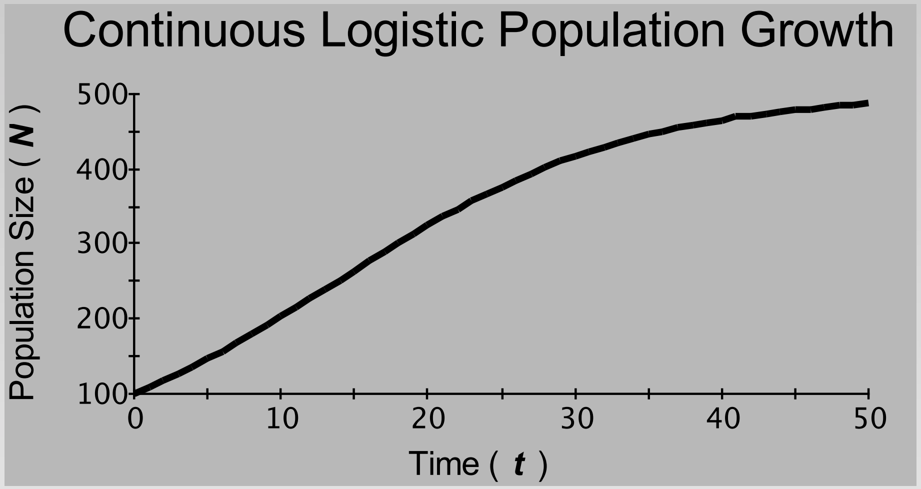
risk that the population go under a fixed threshold (N = 40)

Population Viability Analysis: *add complexity in the model*

- stochasticity
- density dependance



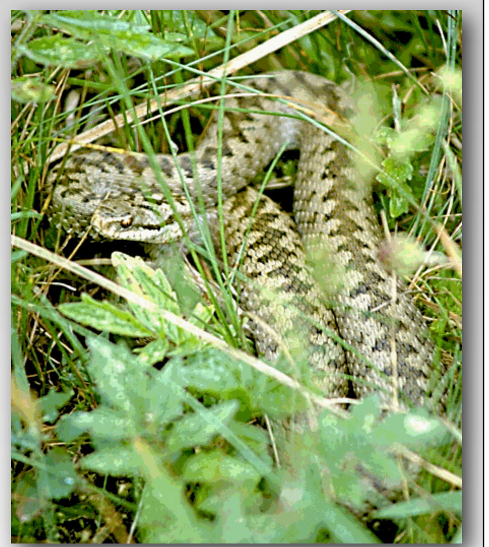
N_0=100; K=500; r=0.2



N_0=100; K=500; r=0.1

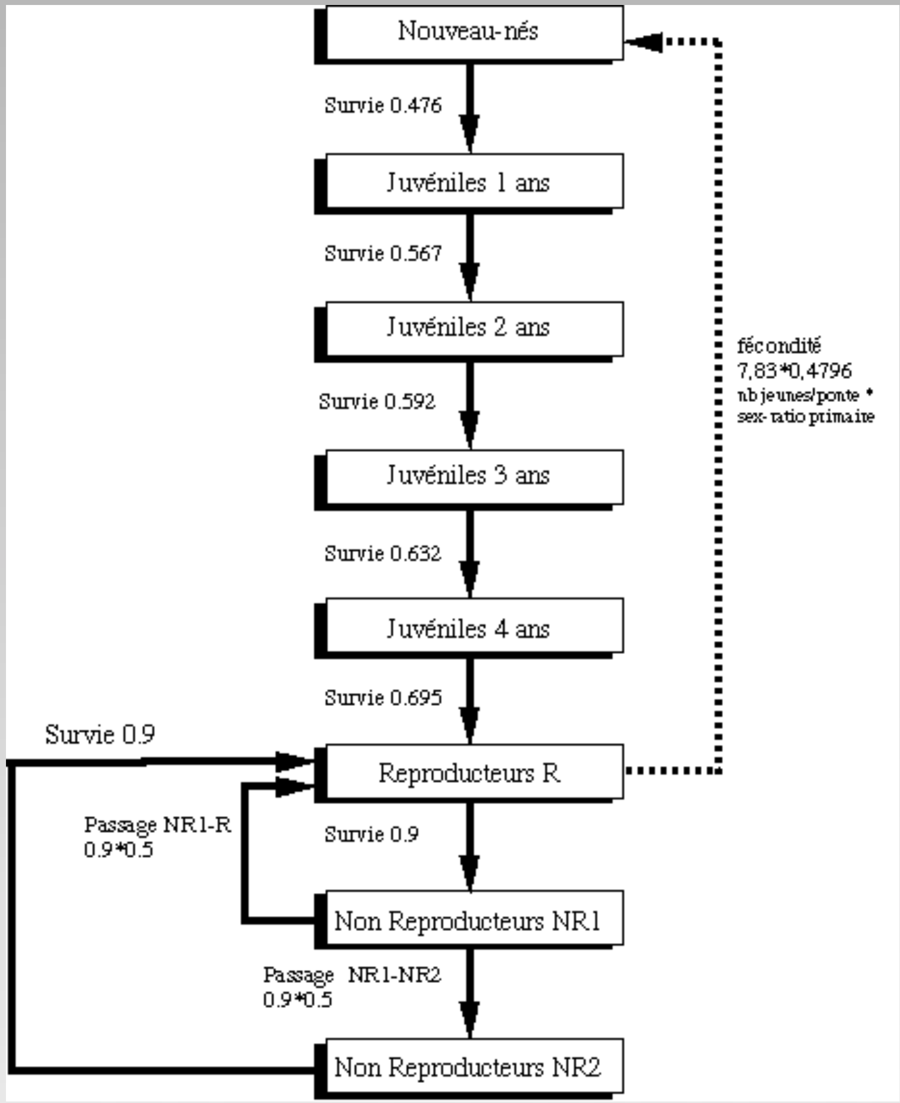
Population Viability Analysis: *sensitivity analysis*

- try to define the impact on the population size of changes in a single parameter
  - example:
    - with an increase of 10% of the survival rate of the adults, the population will increase by 5% every year
    - with an increase of 10% of the survival rate of the juveniles, the population will increase by 1% every year
    - with an increase of 90% of the fecundity, the population will increase by 5% every year
- important for conservation aspect
  - determine on which parameter the impact of improvement will be the highest
- example: *Vipera berus*



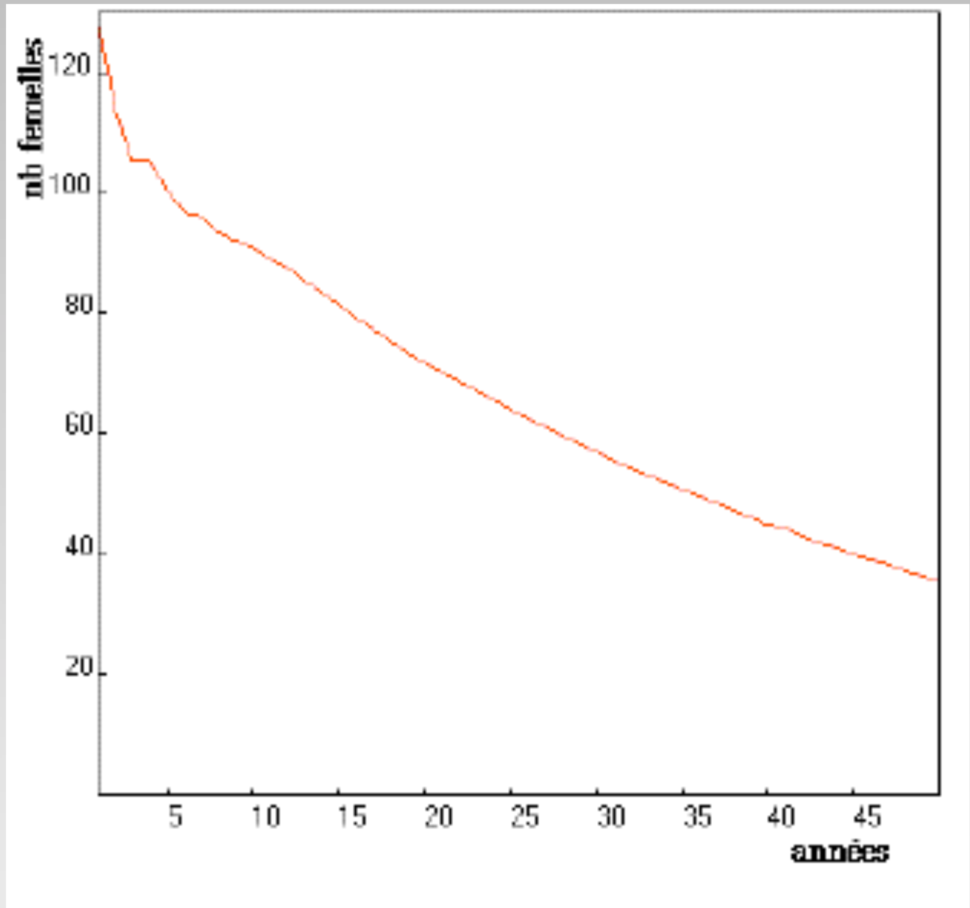
Population Viability Analysis: *Vipera berus*

Model 1



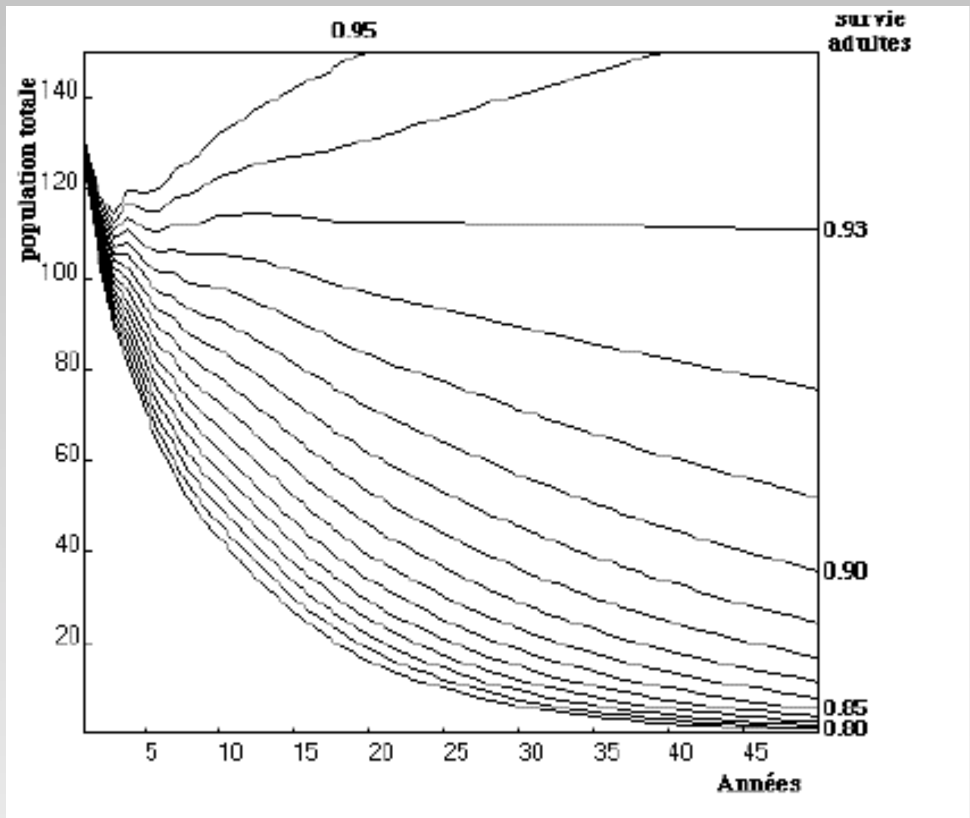
Population Viability Analysis: *Vipera berus*

PVA: mean female adult population size



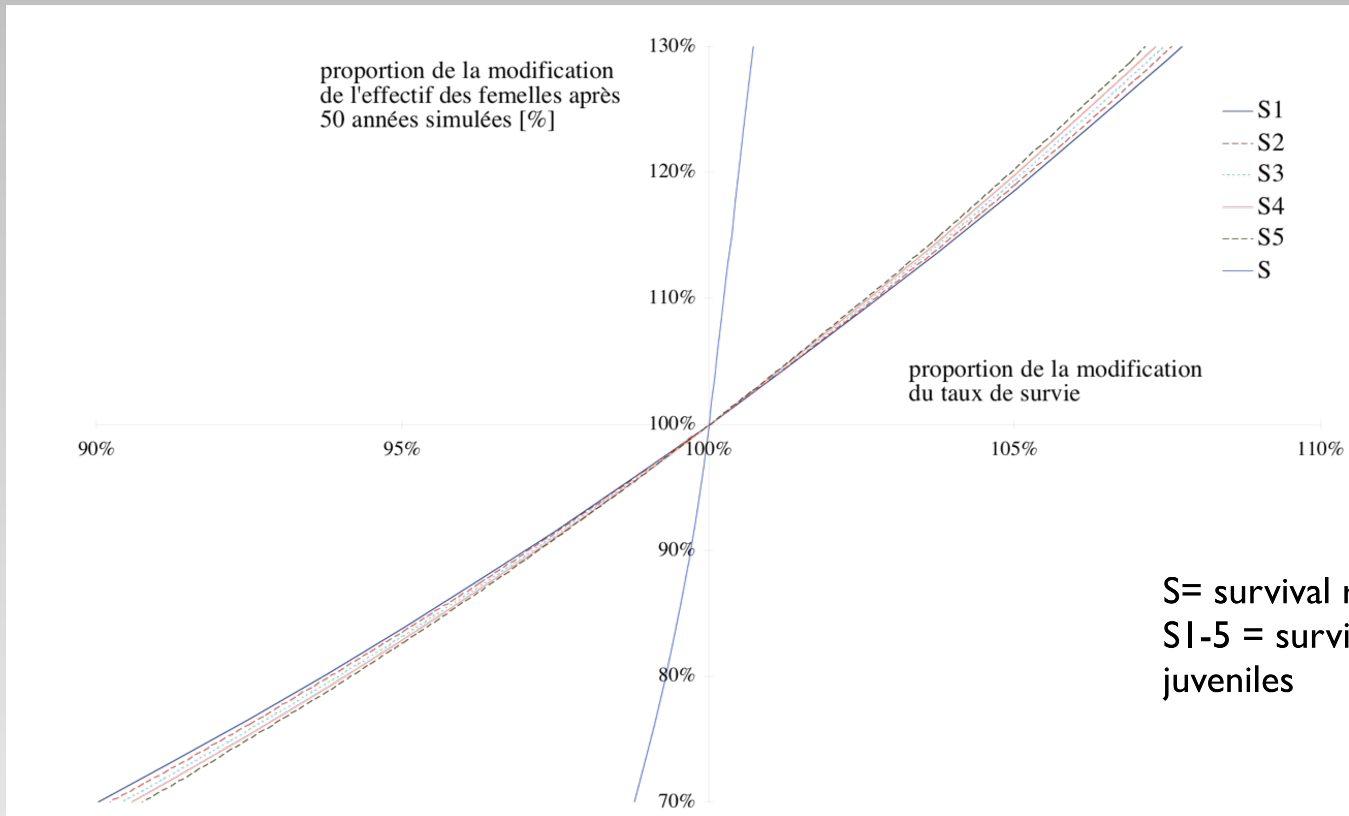
Population Viability Analysis: *Vipera berus*

PVA: mean female adult population size: impact of female survival rate



Population Viability Analysis: *Vipera berus*

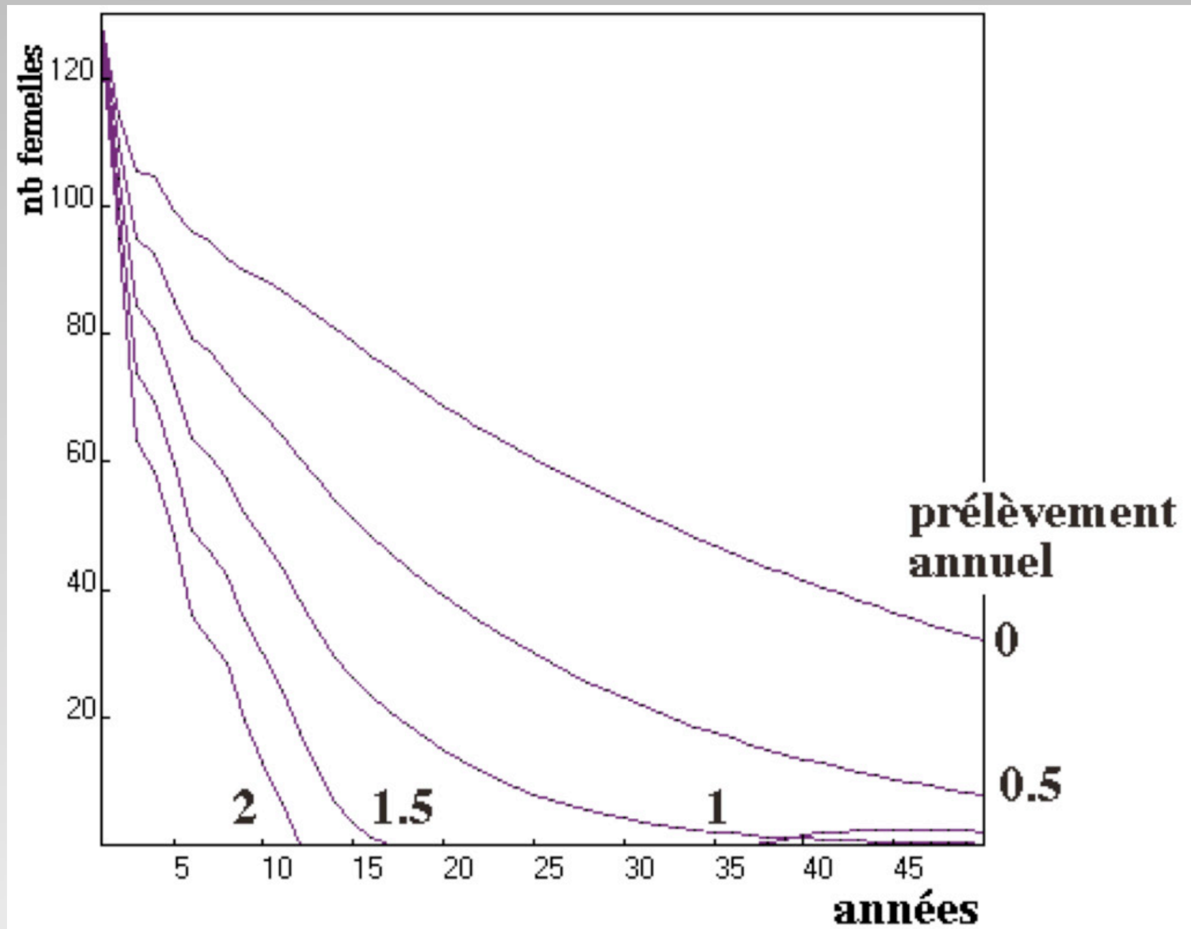
PVA: sensitivity analysis: variation of survival rate and it impact on the population size after 50 years



S= survival rate of the adults
S1-5 = survival rate of the juveniles

Population Viability Analysis: *Vipera berus*

PVA: mean female adult population size: with additional culling



Conclusions

- simple models can already explain observed/expected increase/decrease/fluctuation of populations
- complexity for complex life cycles
- test the complete life cycle
- important impact on conservation aspects

some softwares and links

- RAMAS: www.ramas.com
  - most commonly used software
  - not free!
- ULM: http://www.biologie.ens.fr/~legendre/ulm/ulm.html
  - free
  - numerous models, high level of complexity
- POPULUS: http://www.cbs.umn.edu/populus/
  - very simple, numerous models
  - more for demo than for analyses