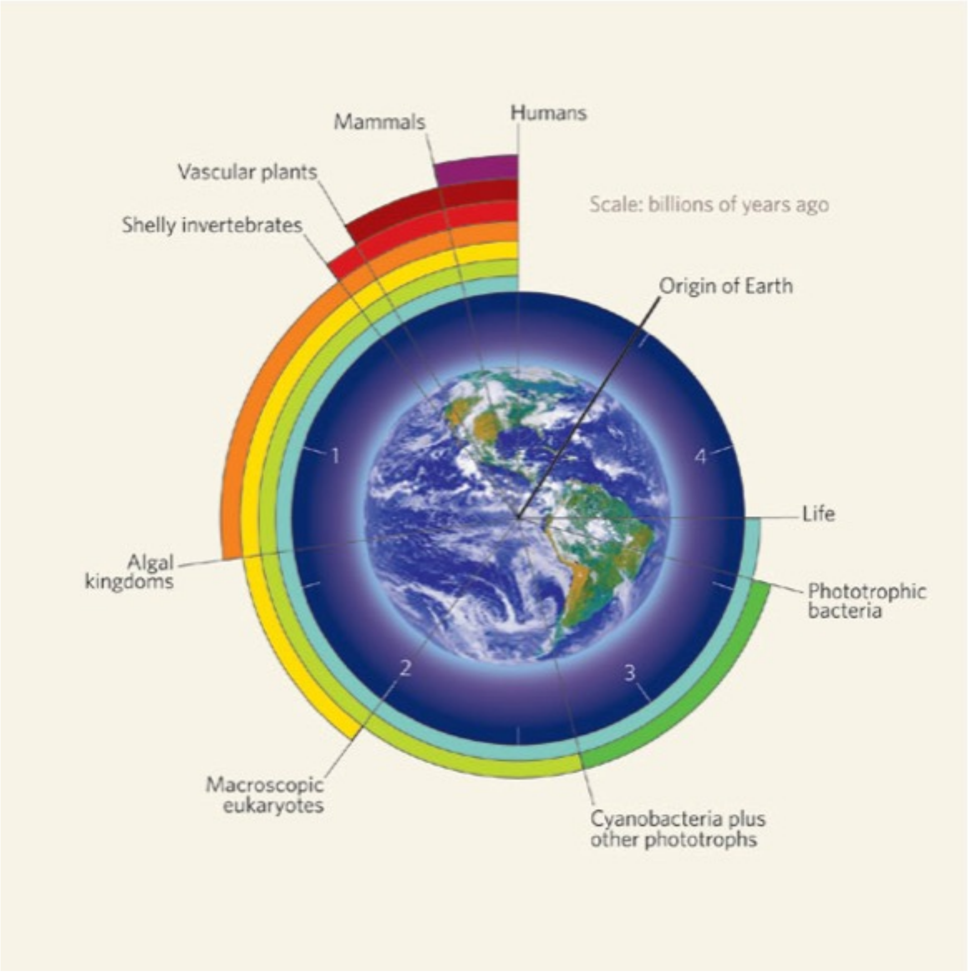
Populations and species threatened by extinction risk

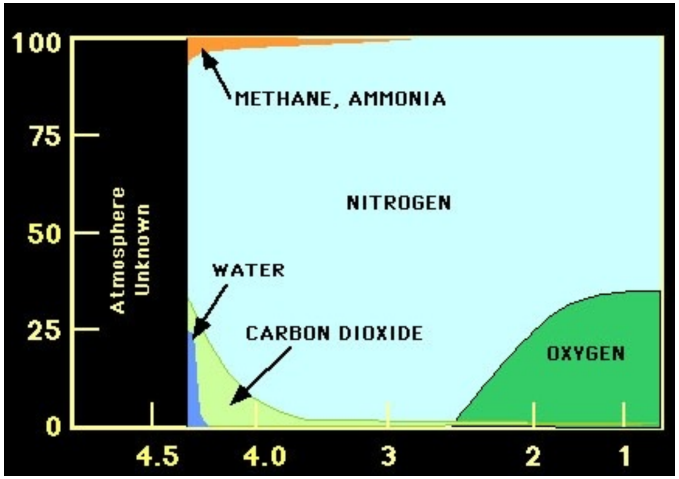
- Loss of biodiversity
- Extinction risk analysis
  - Allee effect
  - Genetic deterioration
  - Demographic and environmental stochasticity
  - Population viability analysis (PVA).

The living Earth clock

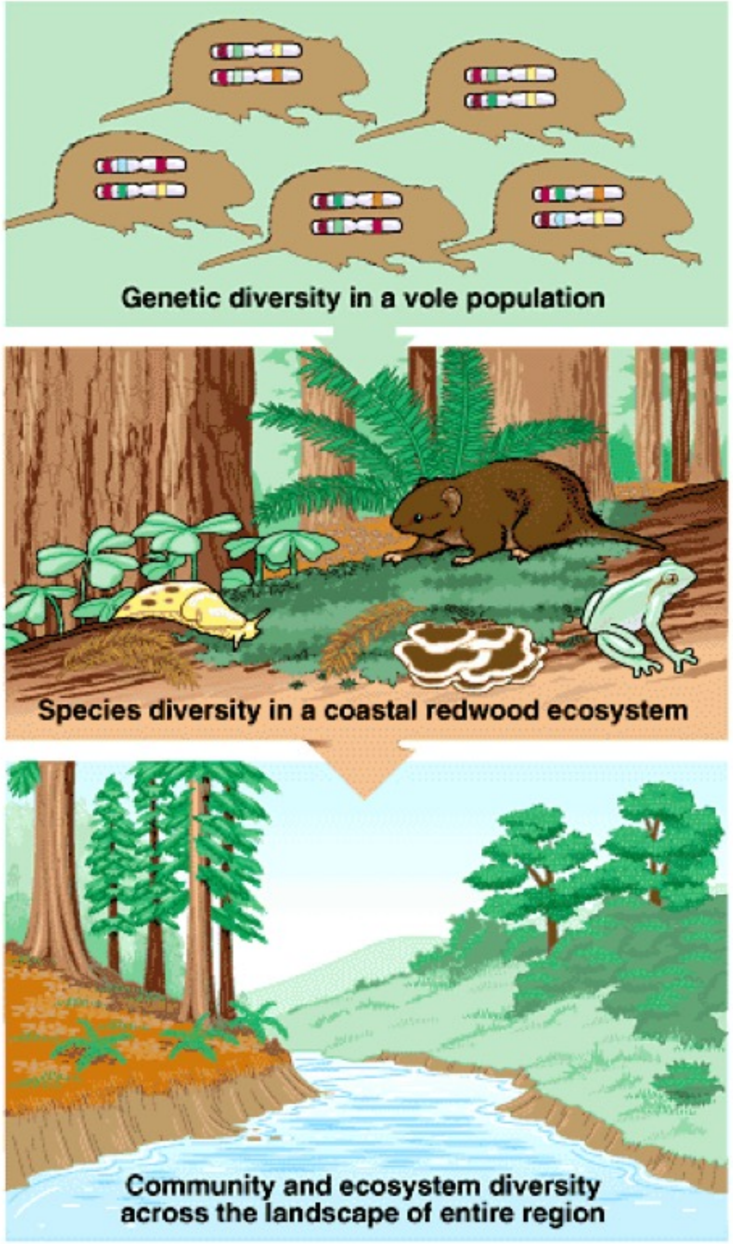


Evolution of life = diversification

BIODIVERSITY



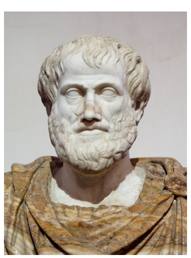
Hierarchies of biodiversity

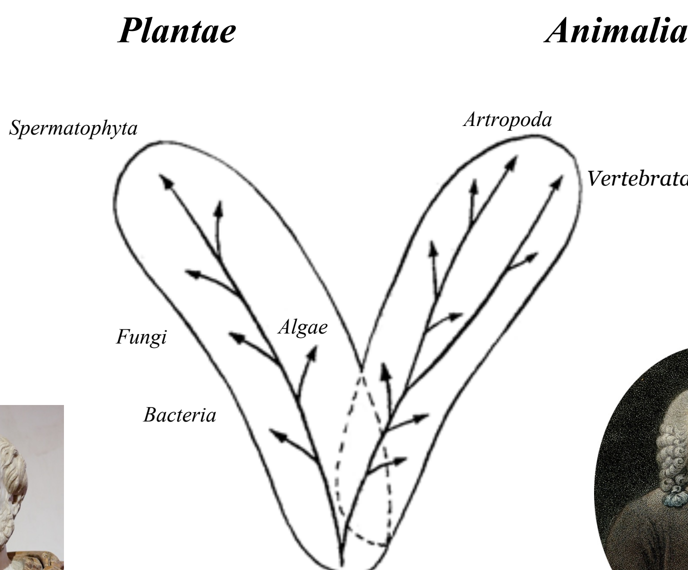


Classifying organisms

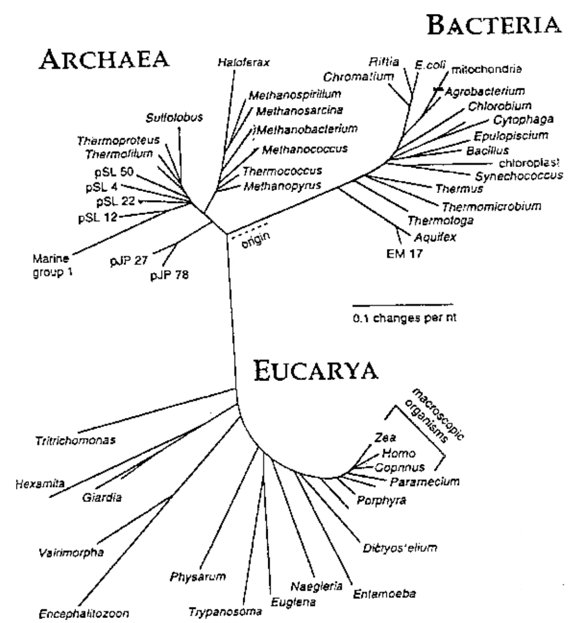
Do they move?	**Do they eat?**	**How do they grow?**	
No	No	Indefinitely	***PLANTS***
Yes	Yes	In a finite way	***ANIMALS***

Two-kingdom system (Aristoteles to Linnaeus)...

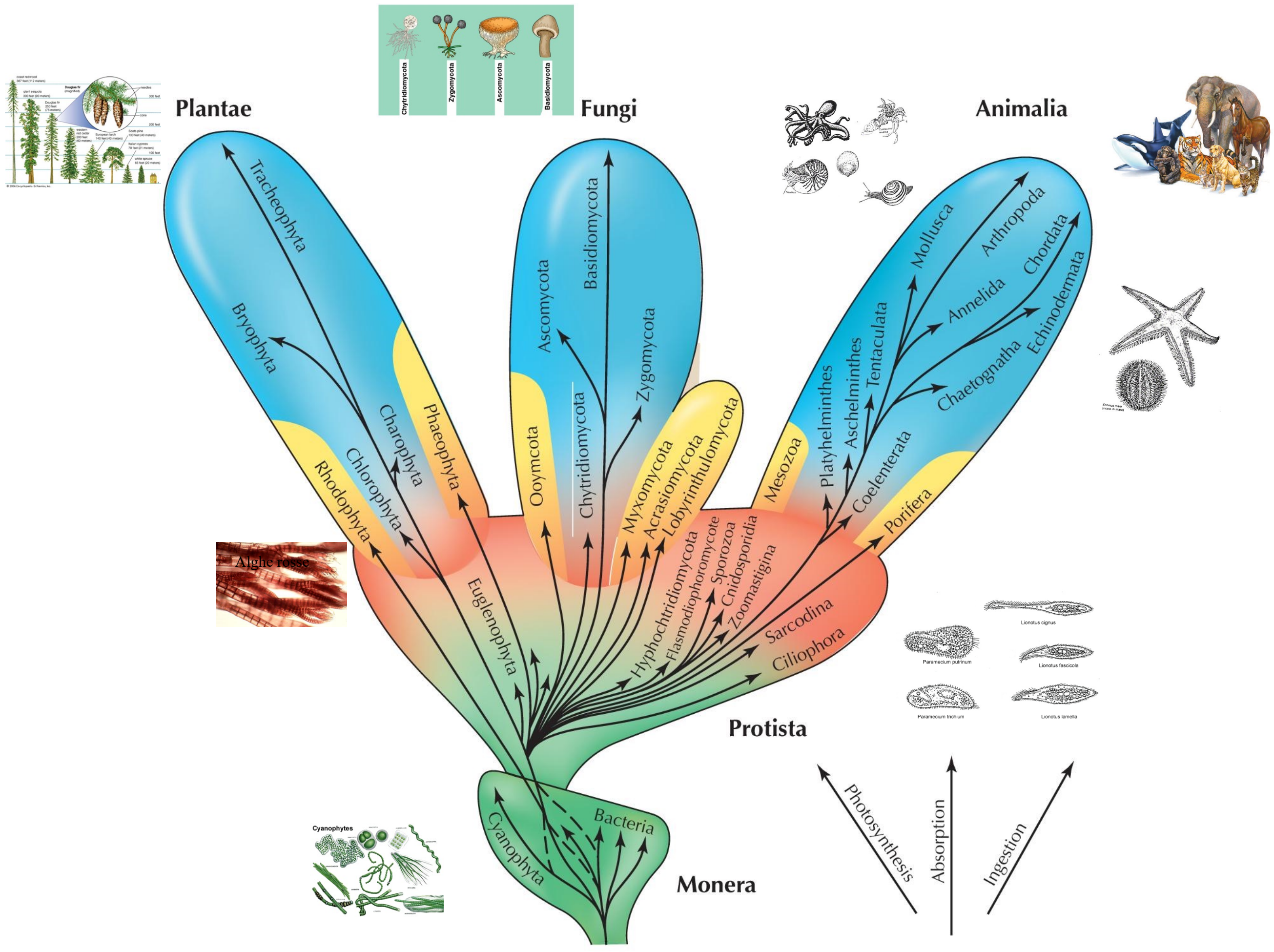




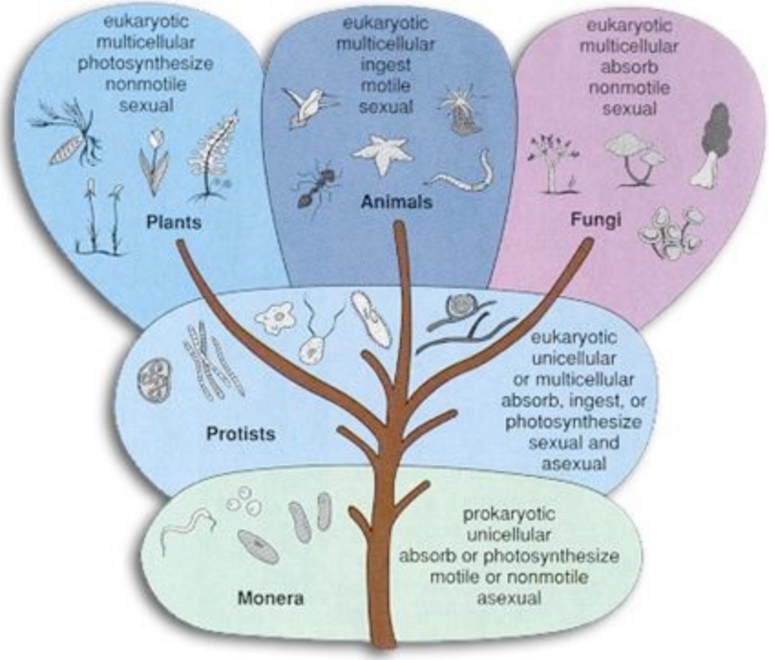
… and the very recent 3 domains



The 5-kingdom system (Whittaker, 1969)



The characteristics of the 5 kingdoms

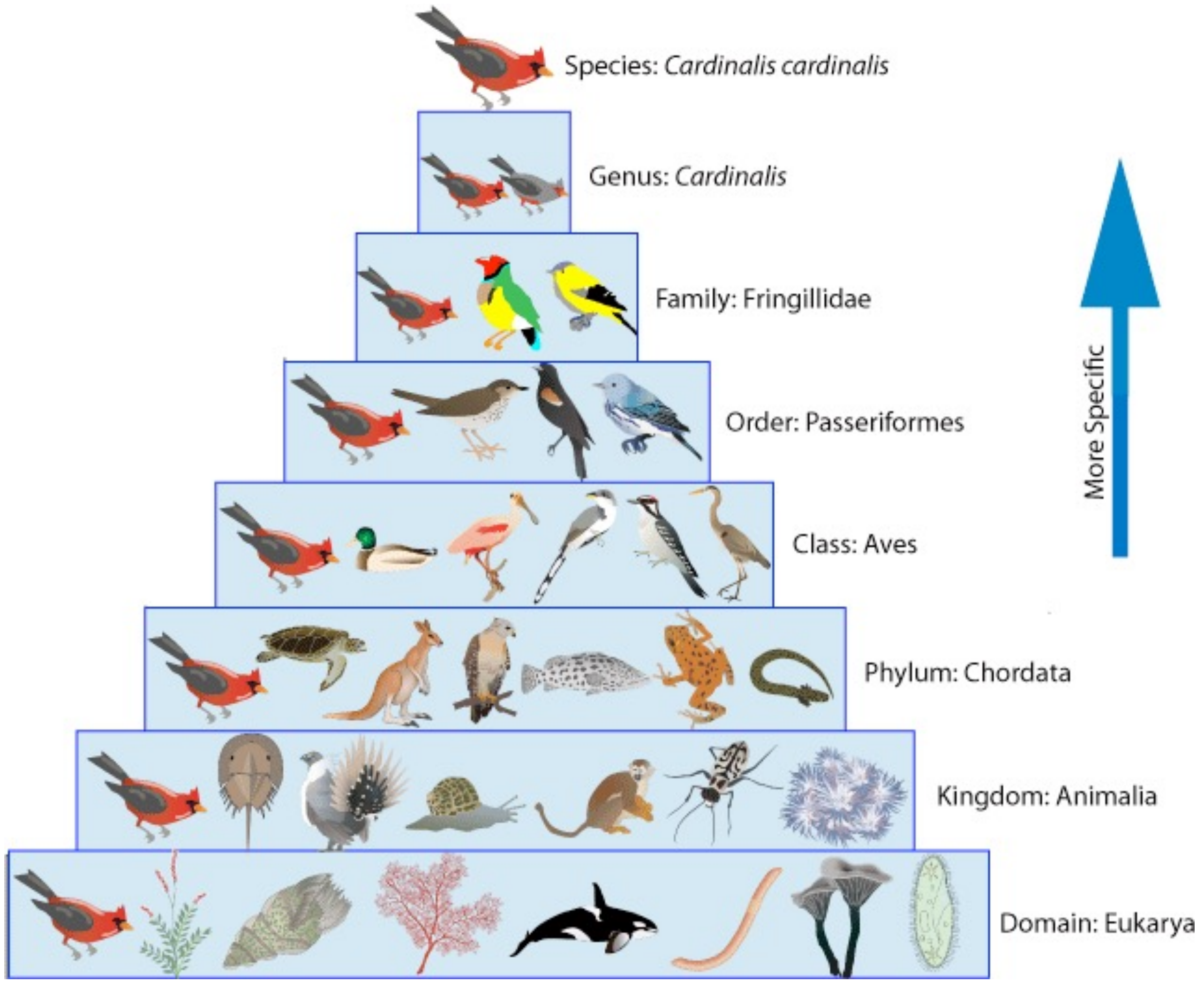


A COMPARISON OF THE FIVE KINGDOMS

Characteristic	Monera	Protista	Plantae	Fungi	Animalia
Internal cell membranes	Absent Present (Prokaryotes)	Present (Eukaryotes)	Present (Eukaryotes)	Present (Eukaryotes)	Present (Eukaryotes)
Cell wall	Present	Present or Absent	Present	Present	Absent
Organization	Unicellular	Unicellular or Multicellular	Multicellular	Mainly Multicellular	multicellular
Mode of nutrition	Autotrophs or Heterotrophs	Autotrophs or Heterotrophs	Autotrophs	Heterotrophs	Heterotrophs
Representative groups	Archaea, eubacteria	Protozoa, algae, slime molds	Mosses, ferns, seed plants	Molds, yeasts, mushrooms	Animals with and without backbones

Note: An autotroph is an organism that uses solar energy or energy from inorganic chemicals to make organic molecules. A heterotroph obtains organic molecules by consuming other organisms or their products.

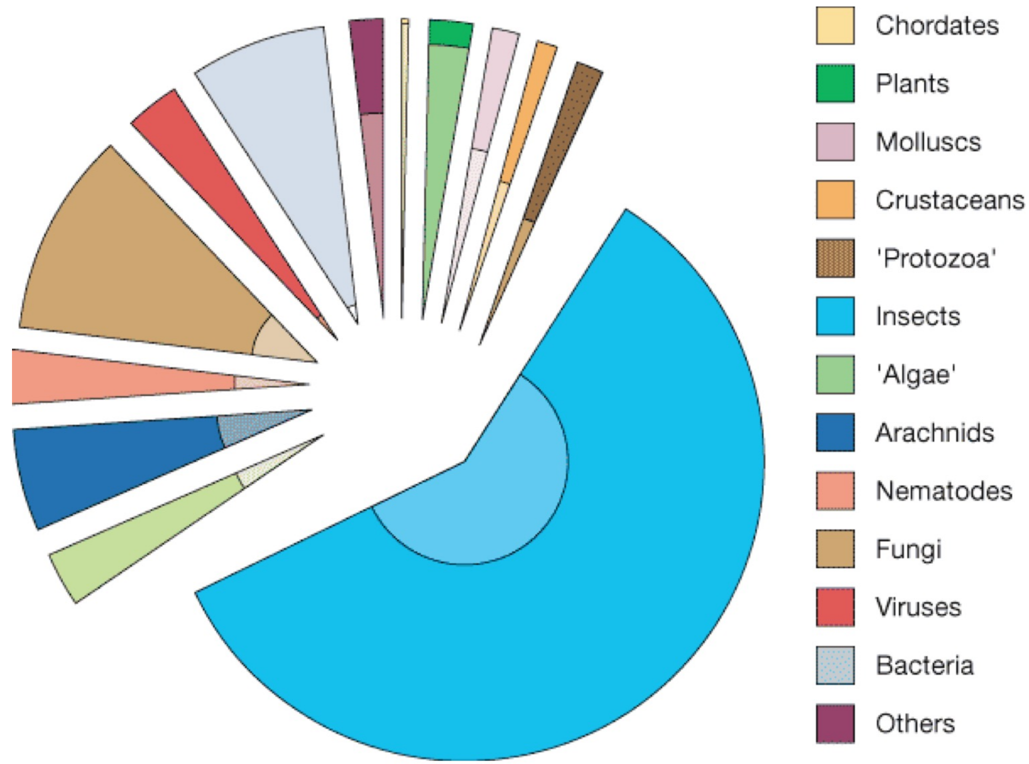
Taxonomic classes (Linnaeus)



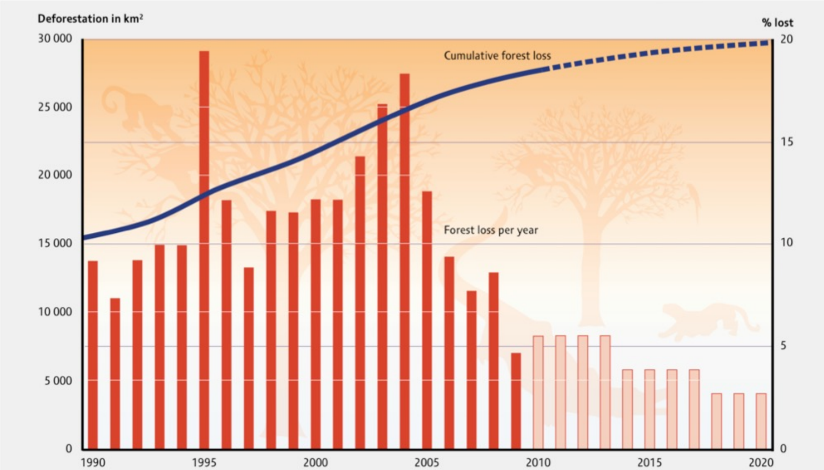
Biodiversity: *How many species?*

classified species:
1.8 million

Estimated # species:
3-30 million



The scale of the human impact

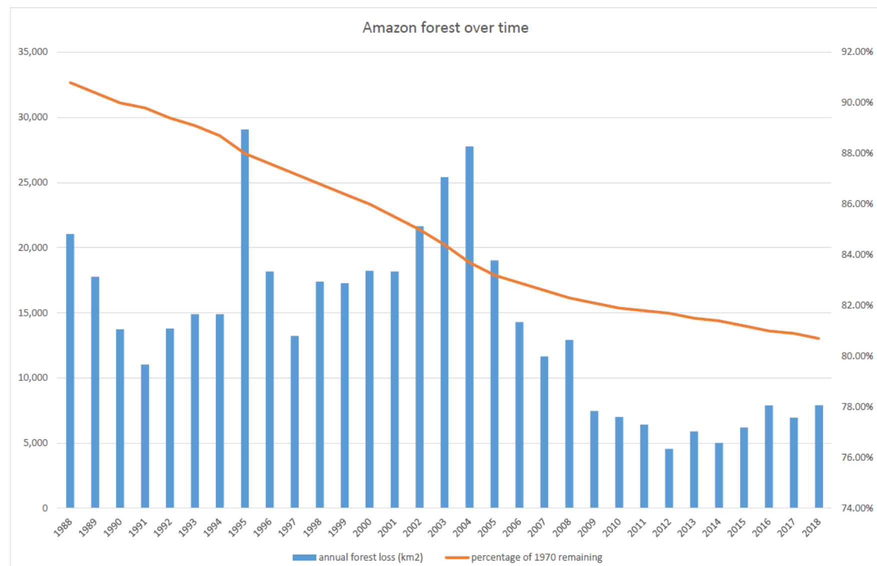


The darker bars represent the actual area of the Brazilian portion of the Amazon deforested each year between 1990 and 2009 (figures on left vertical axis), as observed from satellite images analysed by the National Space Research Agency (INPE). The lighter bars represent the projected average annual rate required to fulfill the Brazilian government target to reduce deforestation by 80% by 2020 (from the average between 1996 and 2005). The solid line shows cumulative total deforestation (figures on right vertical axis) as a percentage of the estimated original extent of the Brazilian Amazon (4.1 million km²).

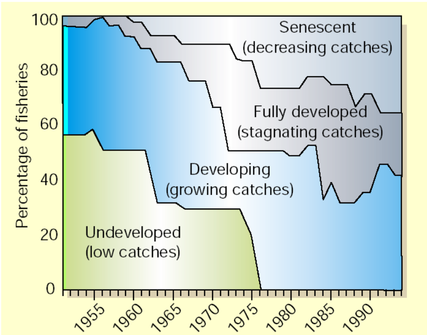
Source: Brazilian National Space Research Agency (INPE)

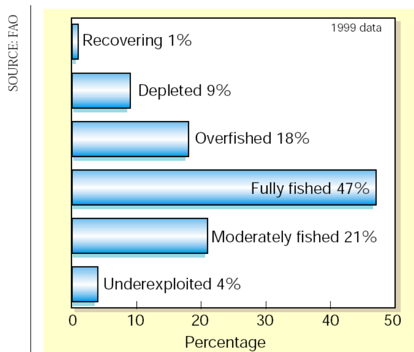
Projection in 2009

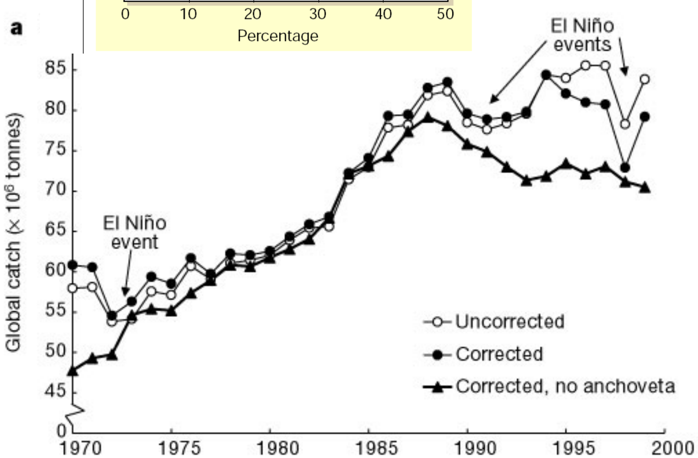
Actual data

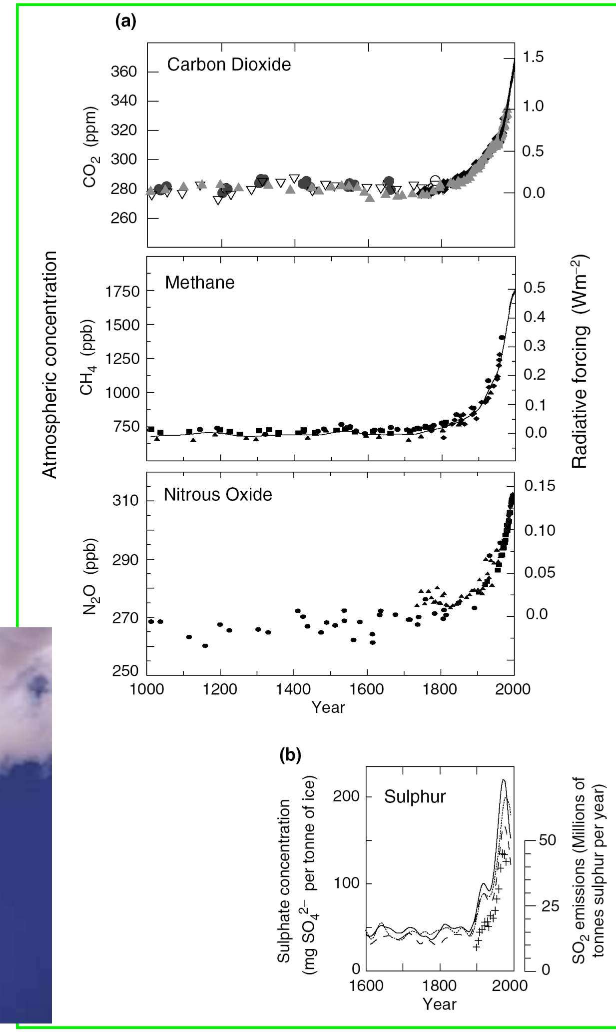


The scale of the human impact





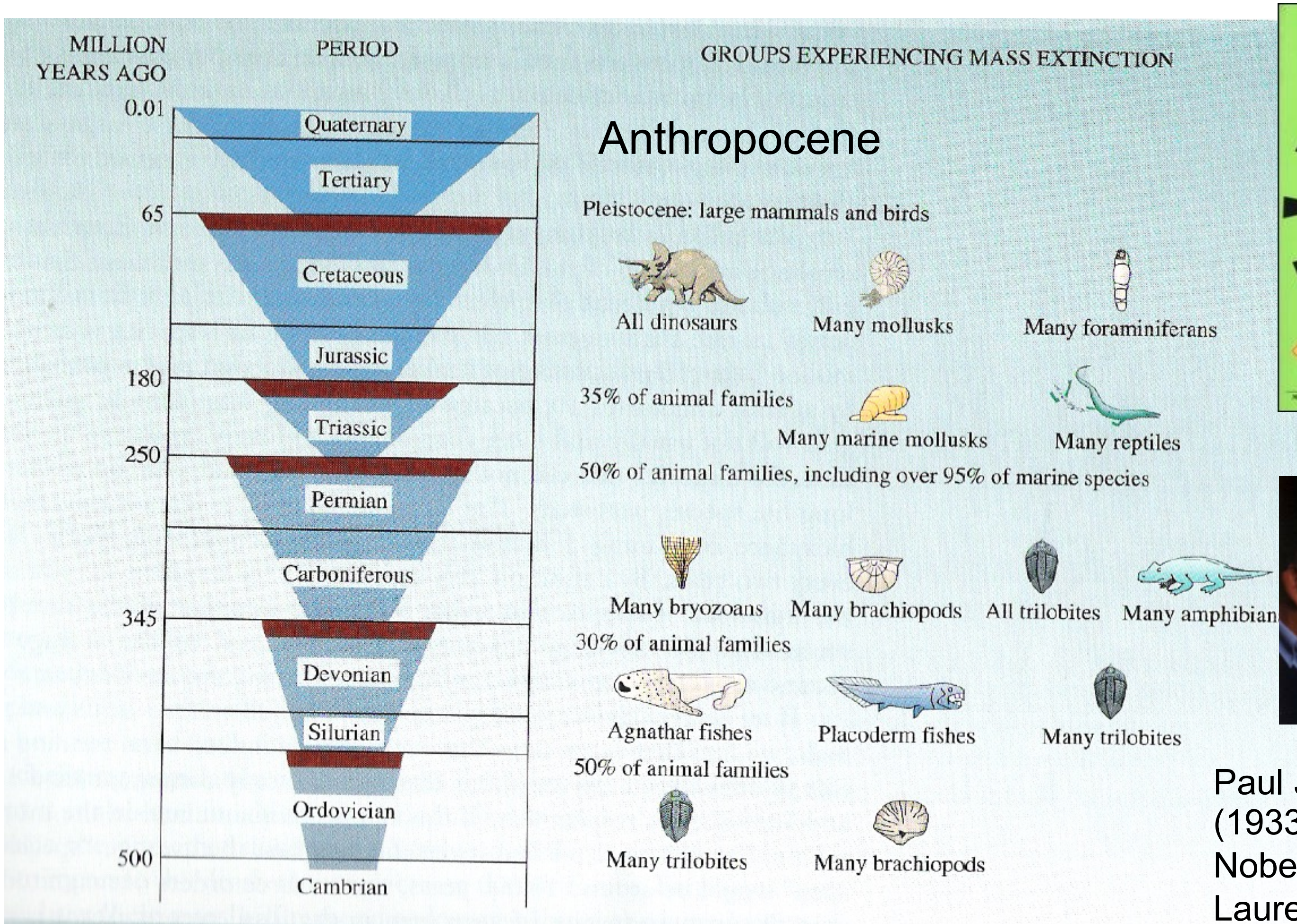


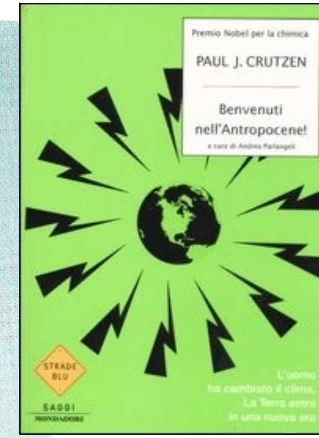


A few numbers

- In the past century
  - Human population has increased 4fold
  - Cattle population 4fold (1 cow/family)
  - Urbanisation 10fold (half population in cities or megacities)
  - Industrial output 40 times
  - Energy use 16 times
  - Water use 9fold (to 800 cubic meters per capita per year)
  - Fish catch 40 times
- Almost 50% of land surface now transformed by human action

Historical extinctions and the 6th extinction





Paul J. Crutzen
(1933-2021)
Nobel Prize Chemistry 1995
Laurea ad honorem
Environmental Engineering
Politecnico Milano 2007

The economist's perspective

11

Sustainability: An Economist's Perspective

ROBERT M. SOLOW

This paper was presented as the Eighteenth J. Seward Johns… Lecture to the Marine Policy Center, Woods Hole Oceanogr… Institution, at Woods Hole, Massachusetts, on June 14, 1991

It makes perfectly good sense to insist that certain unique and irreplaceable assets should be preserved for their own sake; nearly everyone would feel that way about Yosemite or, for that matter, about the Lincoln Memorial, I imagine. But that sort of situation cannot be universalized: it would be neither possible nor desirable to 'leave the world as we found it' in every particular.

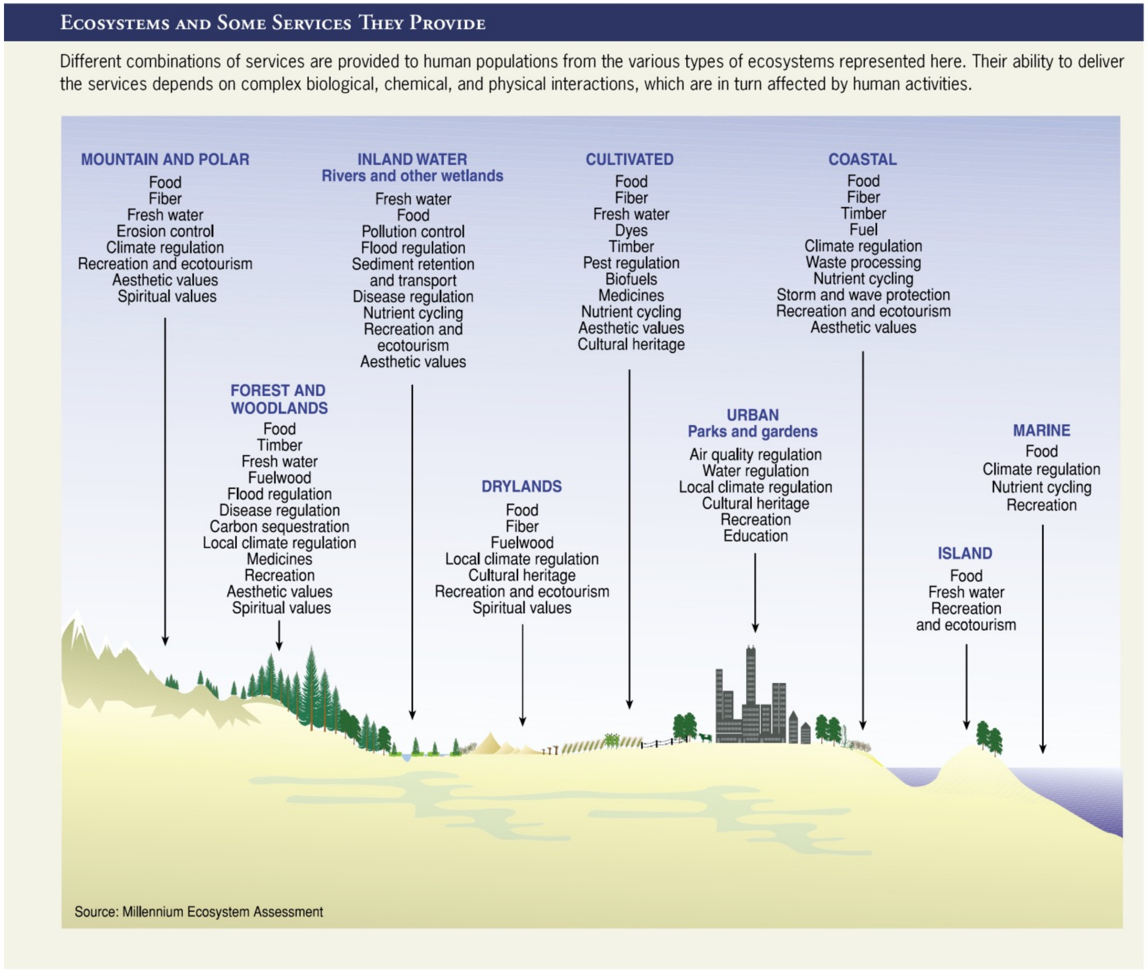
Most routine natural resources are desirable for what they do, not for what they are. It is their capacity to provide usable goods and services that we value. Once that principle is accepted, we are in the everyday world of substitutions and trade-offs.

because you know, as well as I do, that I can't do it.

If you define sustainability as an obligation to leave the world as we found it in detail, I think that's glib but essentially unfeasible. It is, when you think about it, not even desirable. To carry out literally the injunction of UNESCO would mean to make no use of mineral resources; it would mean to do no permanent construction or semi-permanent construction; build no roads; build no dams; build no piers. A mooring would be all right but not a pier. Apart from being essentially an injunction to do something that is not feasible, it asks us to do something that is not, on reflection, desirable. I doubt that I would feel myself better off if I had found the world exactly as the Iroquois left it. It is not clear that one would really want to do that.

Robert M. Solow
1987 Nobel Prize
for Economics

Ecosystem services (they do because they are)



http://www.millenniumassessment.org/en/index.aspx

Ecosystem services in the EU

Ecosystems / Services	Agro ecosystems	Forests	Grasslands	Heath and scrubs	Wetlands	Lakes and rivers
Provisioning						
Crops/timber	Mixed ↓	Enhanced ↑			Degraded ↓	
Livestock	Mixed ↓	Degraded =	Degraded =	Degraded =	Degraded ↓	
Wild Foods	Degraded =	Degraded ↓	Degraded ↓	Unknown	Mixed =	Unknown
Wood fuel		Mixed =		Degraded =		
Capture fisheries					Degraded =	Degraded =
Aquaculture					Degraded ↓	Degraded ↓
Genetic	Degraded =	Mixed ↓	Degraded ↓	Degraded =	Mixed =	Unknown
Fresh water		Degraded ↓	Unknown	Unknown	Mixed ↑	Mixed ↑
Regulating						
Pollination	Mixed ↑	Degraded ↓	Degraded =	Unknown		
Climate regulation		Enhanced ↑	Unknown	Mixed =	Degraded =	Degraded =
Pest regulation	Mixed ↑	Unknown	Degraded =		Unknown	
Erosion regulation		Mixed =	Degraded =	Degraded =	Unknown	Unknown
Water regulation	Unknown	Mixed =	Unknown	Mixed ↑	Enhanced ↑	Degraded =
Water purification		Unknown	Unknown	Unknown	Mixed =	Degraded =
Hazard regulation		Unknown	Unknown	Unknown	Mixed =	Degraded =
Cultural						
Recreation	Mixed ↑	Mixed =	Degraded ↓	Mixed ↑	Mixed ↑	Mixed =
Aesthetic	Mixed ↑	Mixed =	Degraded =	Degraded =	Mixed ↑	Degraded =

Status for period 1990–present ■ Degraded ■ Mixed ■ Enhanced ■ Unknown □ Not applicable

Trend between periods

↑ Positive change between the periods 1950–1990 and 1990 to present

↓ Negative change between the periods 1950–1990 and 1990 to present

= No change between the two periods

Biodiversity and ecosystem functioning

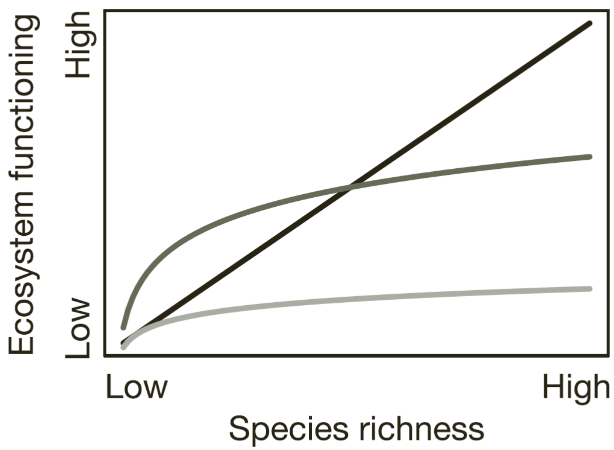
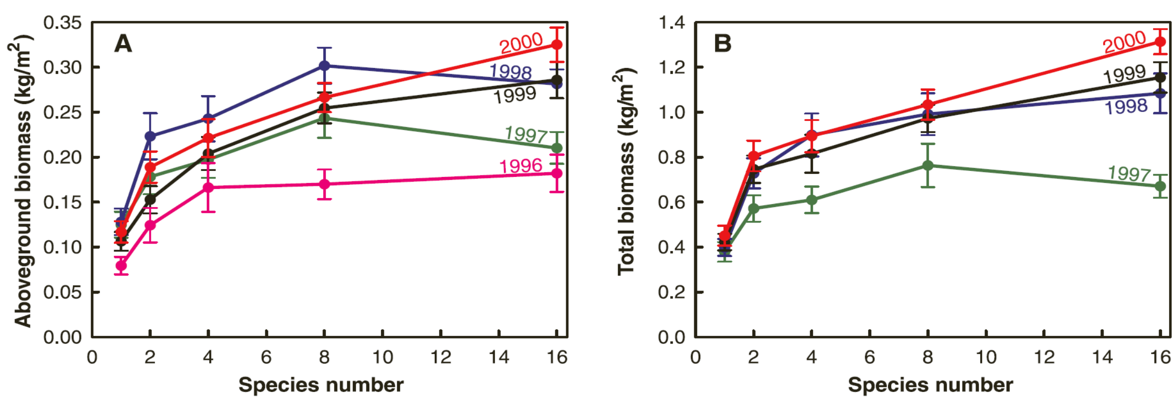


Figure 1 | The relationship between species richness and ecosystem functioning. Illustration of how the complementarity mechanism and the selection mechanism alter the shape of the relationship between species richness and some measure of ecosystem functioning. If all species contribute approximately equally to ecosystem functioning, species effects are (1) additive if the species are completely complementary (black line) or (2) decelerating if the species are to some extent functionally redundant (light grey line). If the same pool of species now contains a few species that, when present in a given mixture, are able to attain maximum ecosystem functioning, the shape of the curve will also be decelerating (dark grey line).

- Productivity



Tilman et al. (2001) *Science* **294**:843-845

Biodiversity geographical distribution

Myers *et al.* ***Nature*** (2000)

Biodiversity hotspots for conservation priorities

44% of all vascular plants and
35% of all species in four vertebrate groups are hosted in
25 hotspots that include
1.4% of the Earth land area.

Extinction statistics

Table 1.1 Recorded extinctions, 1600 to present

Taxa	Number of extinctions on: Island	Mainland	Ocean	Total	Percentage of extinctions on islands	Percentage of taxon extinct
Mammals[a]	51	30	4	85	60	2.1
Birds[a]	92	21	0	113	81	1.3
Reptiles[a]	20	1	0	21	95	0.3
Amphibians[a]	0	2	0	2	0	0.05
Fish[a]	1	22	0	23	4	0.1
Molluscs[b]	151	40	0	191	79	
Invertebrates[a]	48	49	1	98	49	0.01
Flowering plants[a]	139	245	0	384	36	0.2

Notes:
[a] From Primack (1998).
[b] From WCMC (1992).

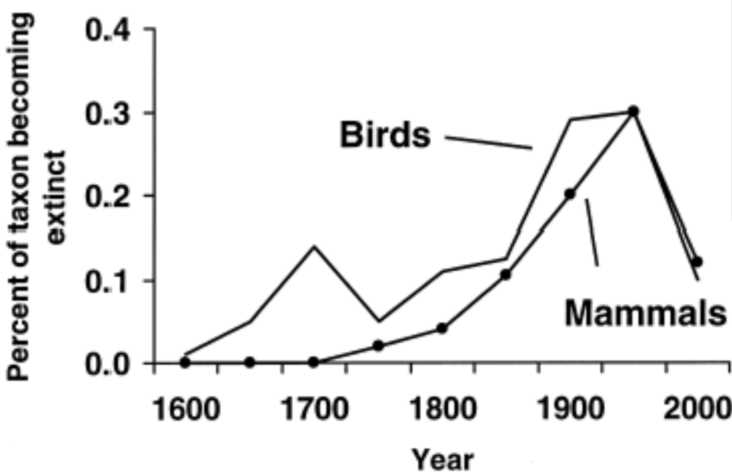
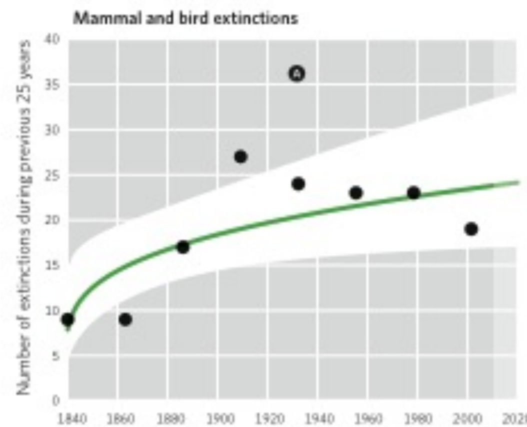
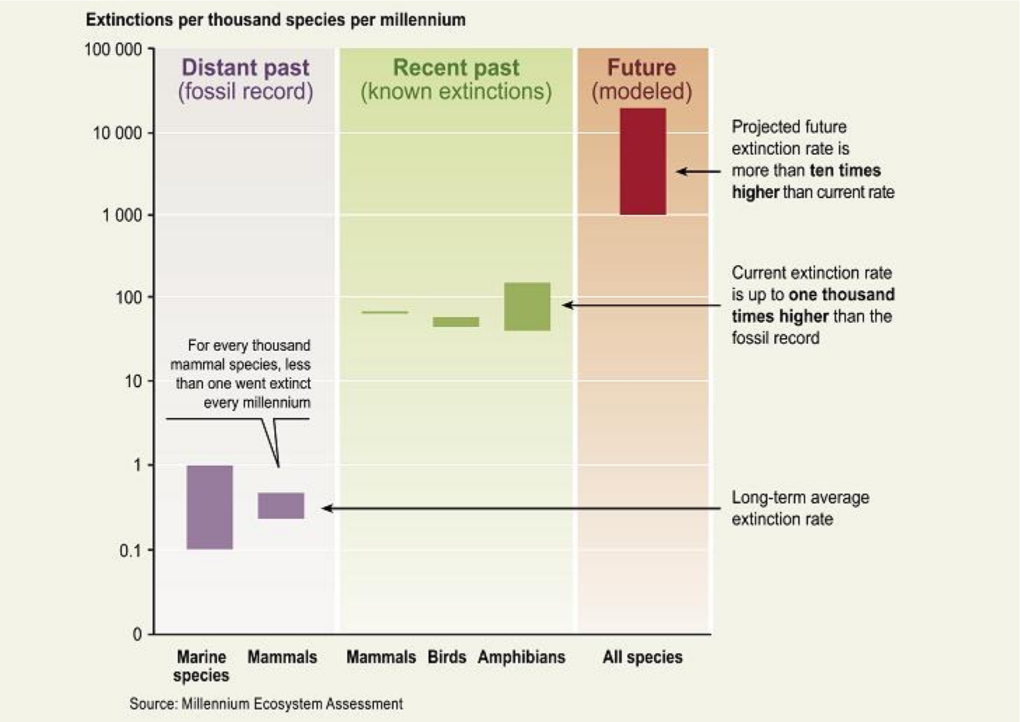


Fig. 1.2 Changes in extinction rates over time in mammals and birds (after Primack 1998, based on Smith *et al.* 1995). *Extinction rates have generally increased for successive 50-year periods.*



Global Biodiversity Outlook 2014

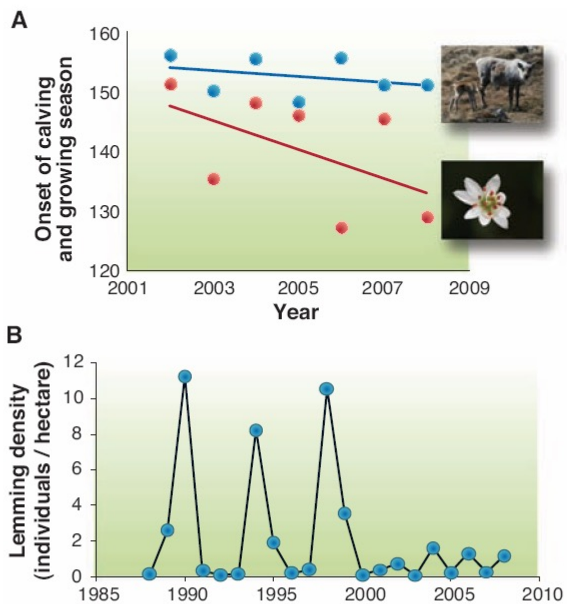
Extinction rates



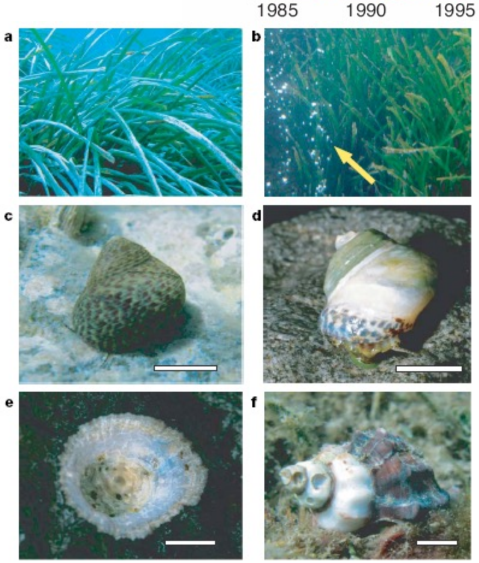
Average lifetime of an animal species from fossil records: 1-10 million years

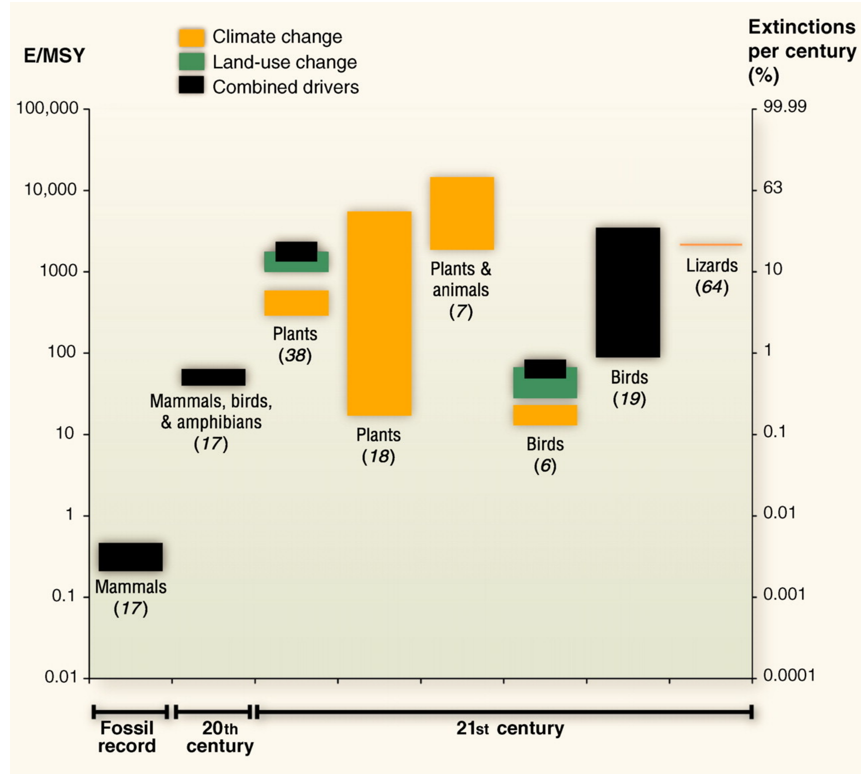
From extinction rates documented in the past 2 centuries one obtains a reduction to 10,000 years

From current extinction rates residual lifetime for birds and mammals: 200-400 years

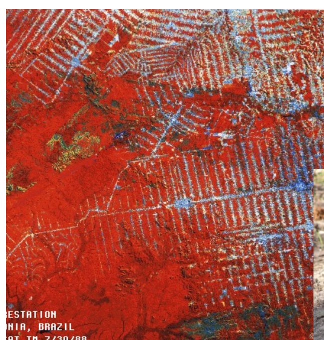


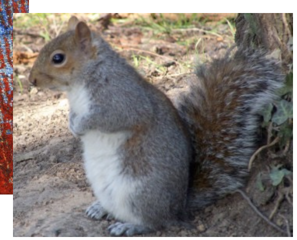
r





H M Pereira et al. Science 2010;330:1496-1501





Threatened species

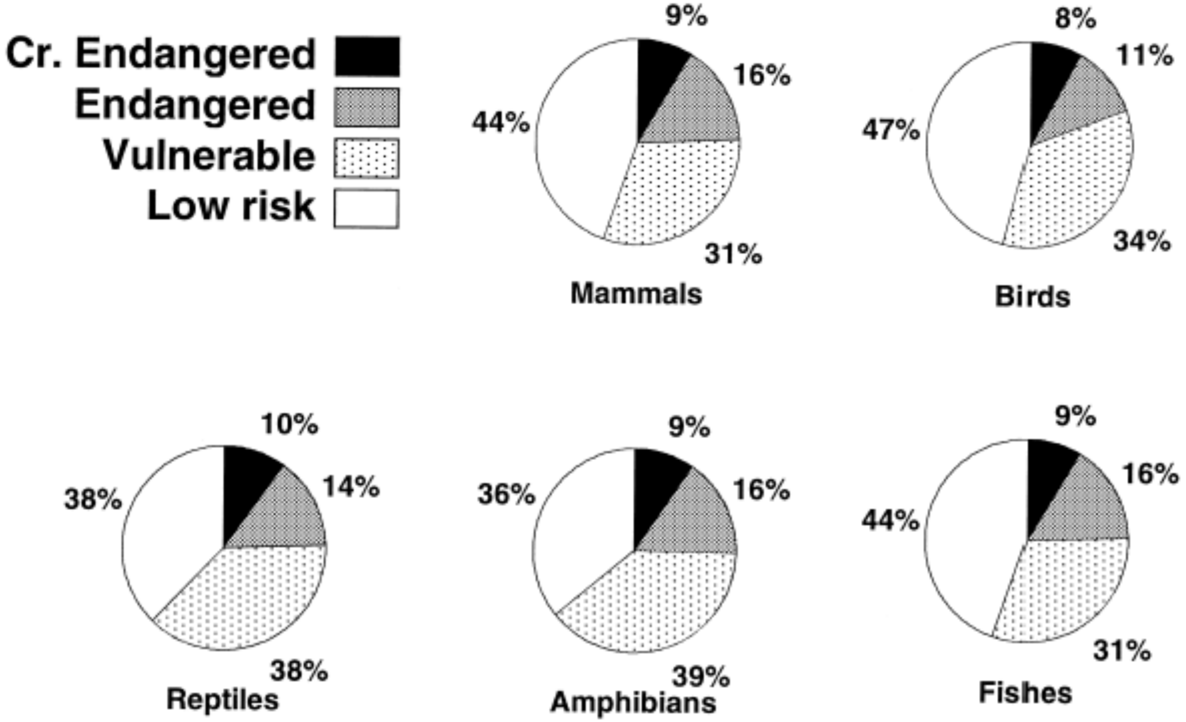
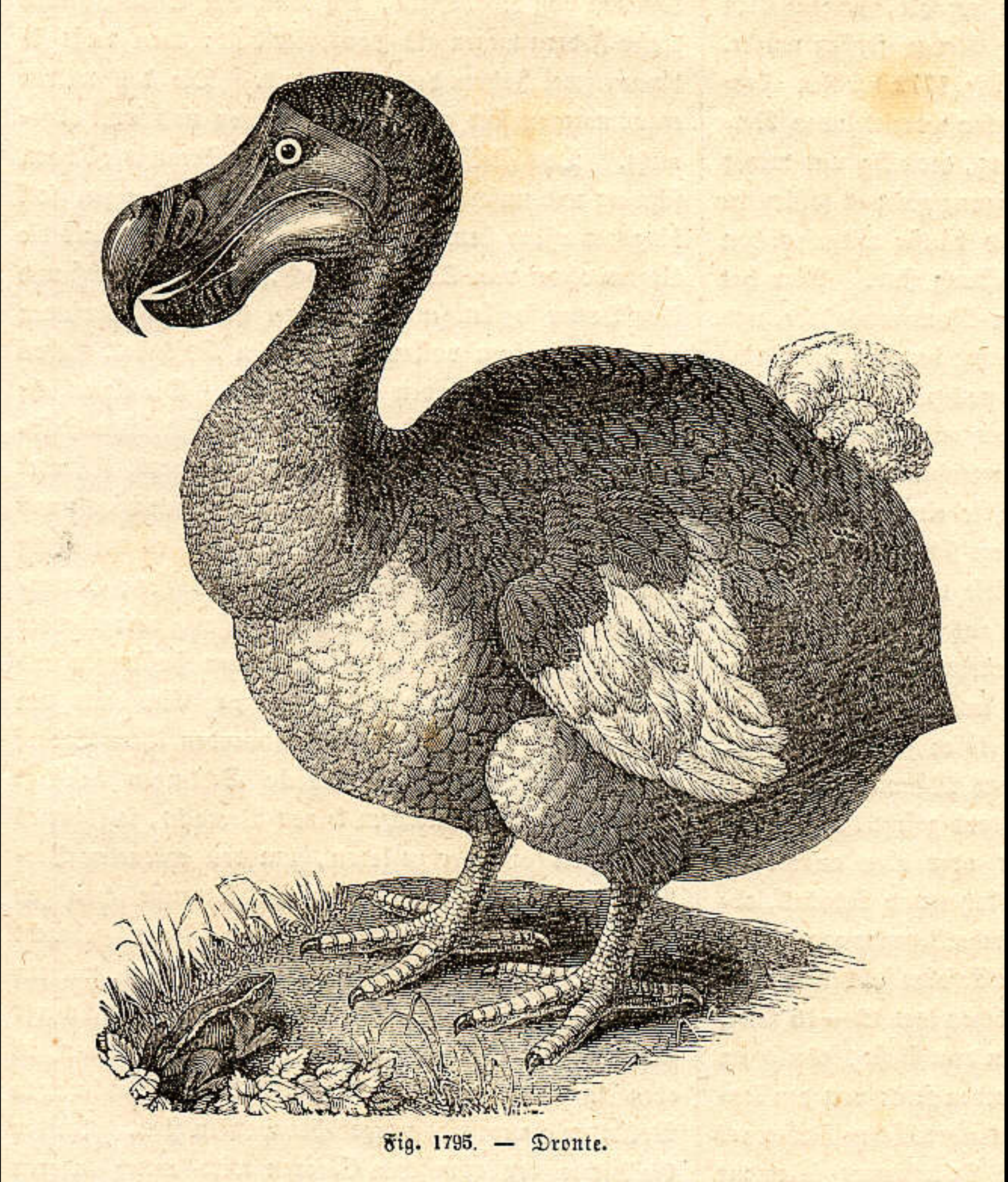


Fig. 1.1 Which vertebrates are the most threatened? Percentages of mammals, birds, reptiles, amphibians and fishes categorized as critically endangered, endangered, vulnerable and at lower risk (after IUCN 1996).

Mauritius Dodo (extinct in 1660)

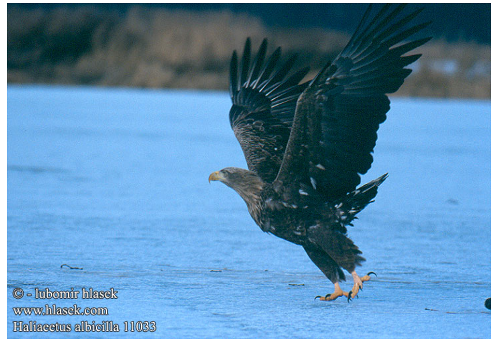


The passenger pigeon

(extinct in 1914)

Extinct species in Italy

Gobbo rugginoso



Aquila di mare

Anchusa littorea

266 threatened species in 2006 red list of the IUCN (International Union for Conservation of Nature)

Najas marina

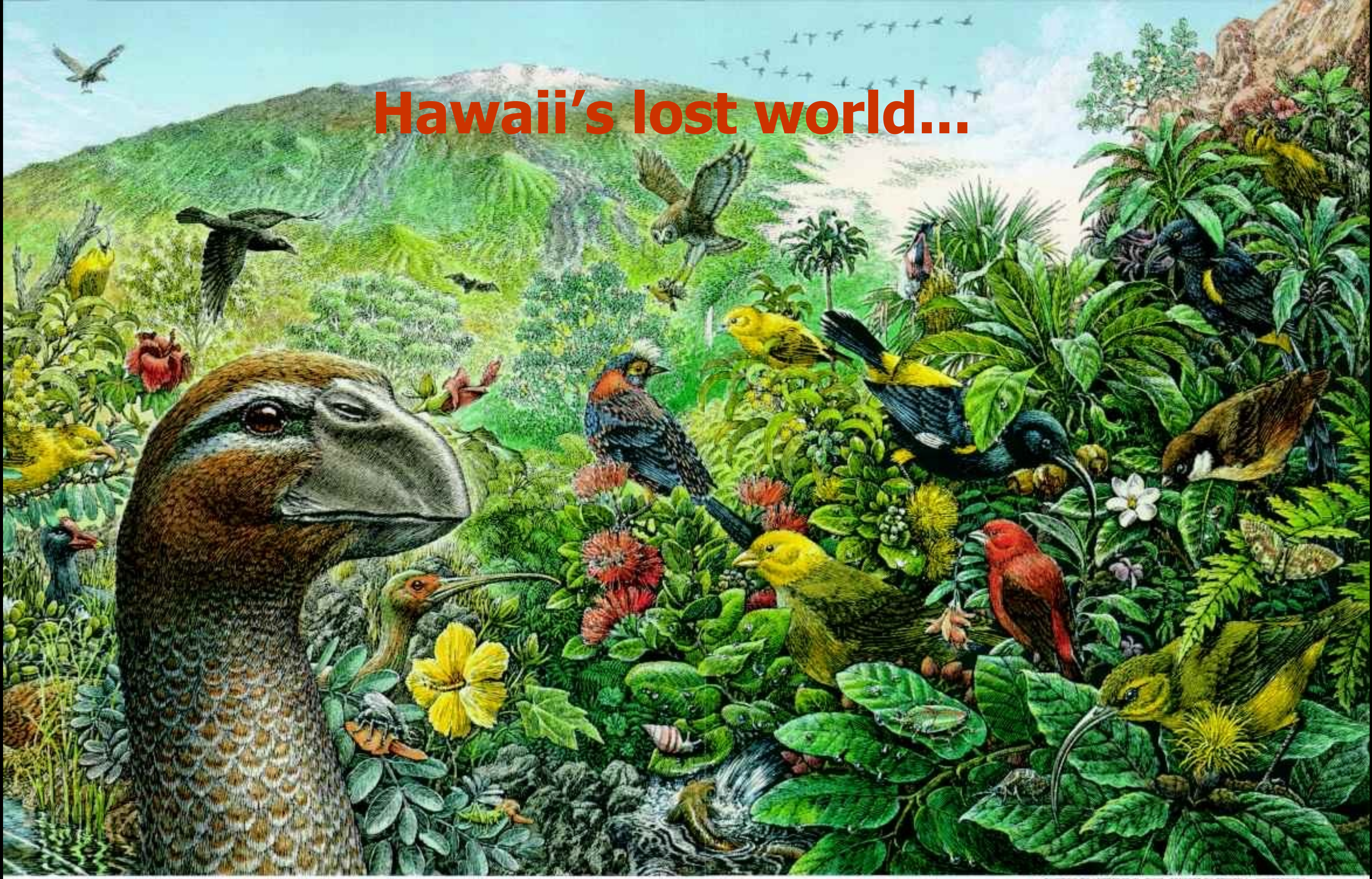
Tabella 1 Numero di specie della lista rossa delle piante d'Italia distinte secondo le categorie IUCN (1994) in base all'aggiornamento del 1997.

Estinte	7
Estinte in natura	22
Gravemente minacciate	128
Minacciate	149
Vulnerabili	275
A minor rischio *	406
Dati insufficienti	24
Non valutate	0
Totale	1011

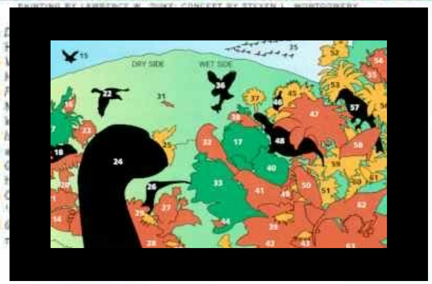
Fonte: Conti et al., 1997.

* Rispetto all'aggiornamento del 2000 [cfr. IUCN (2001), bibliografia generale], la categoria «a minor rischio» corrisponde alle nuove categorie «quasi a rischio» e «a rischio minimo».

Hawaii's lost world…



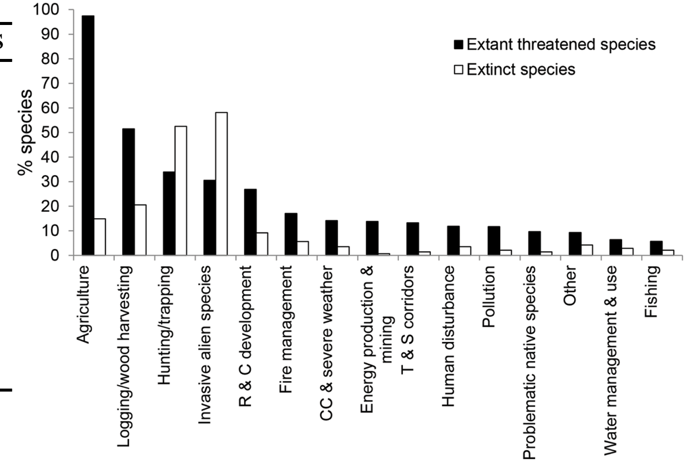
7 *Megalagrion xanthomelas*, orangeblack damselfly, pinao
8 *Pterodroma phaeopygia sandwichensis*, Hawaiian petrel, 'ua'u
9 *Sophora chrysophylla*, māmane
10 *Loxioides bailleui*, palila
11 *Rhodacanthis palmeri*, greater koa finch, hōpue
12 *Kokia drynarioides*, tree cotton, koki'o
13 *Achyranthes splendens* var. *rotundata*, round-leaved chaff-flower
14 *Anas laysanensis*, Laysan duck
15 *Haliaeetus* sp., Hawaiian sea eagle
16 *Hemignathus munroi*, 'akiapōlā'au
17 *Acacia koa*, koa
18 *Dysmorodrepanis munroi*, Lanai hookbill
19 *Chamaesyce celastroides* var. *kaenana*, spurge, 'akoko
20 *Gallinula chloropus sandvicensis*, Hawaiian common moorhen, 'alae'ula
21 *Scaevola coriacea*, dwarf naupaka
22 *Corvus impluviatus*, deep-billed crow
23 *Kokia cookei*, Cooke's koki'o
24 *Chelychelynechen quassus*, tortoise-jawed moa nalo
25 *Hibiscadelphus giffardianus*, ka'u hau kuahiwi
26 *Apteribis glenos*, flightless ibis
27 *Hibiscus brackenridgei*, ma'o hau hele
28 *Sesbania tomentosa*, 'ōhai
29 *Hylaeus hula*, hula yellow-faced bee
30 *Banza nihoa*, coneheaded katydid
31 *Lasiurus cinereus semotus*, Hawaiian hoary bat, 'ōpe'ape'a
32 *Palmeria dolei*, crested honeycreeper, 'ākohekohe
33 *Metrosideros polymorpha*, 'ōhi'a lehua
34 *Lentipes concolor*, goby, 'o'opu alamo'o
35 *Branta sandvicensis*, Hawaiian goose, nēnē
36 *Grallistrix erdmani*, long-legged Maui owl
37 *Delissea undulata*, 'ōhā
38 *Loxops coccineus ochraceus*, Maui 'ākepa
39 *Coleotichus blackburniae*, koa bug
40 *Metrosideros polymorpha*, 'ohi'a lehua
41 *Psittirostra psittacea*, 'ō'ū
42 *Tetraplasandra gymnocarpa*, 'ohe'ohe
43 *Micromus swezeyi*, Swezey's flightless brown lacewing
44 *Achatinella rosea*, rosy tree snail, pūpū kani oe
45 *Pritchardia schattaueri*, fan palm, loulu
46 *Ciridops anna*, 'ula 'ai hāwane
47 *Clermontia lindseyana*, 'ōhā wai



... and Hawaii's landscape

Percent importance of extinction and threat drivers for birds all over the world.

	Extinct species	Threatened species
Habitat destruction	20%	60%
Alien species	22%	12%
Hunting	18%	11%
Commerce (zoological gardens, pets)	1%	9%
Disease	1%	1%
Pollution	0%	1%
Human disturbance	0%	2%
Accidental killing	1%	1%
Unknown cause	37%	3%
	100%	*100%*

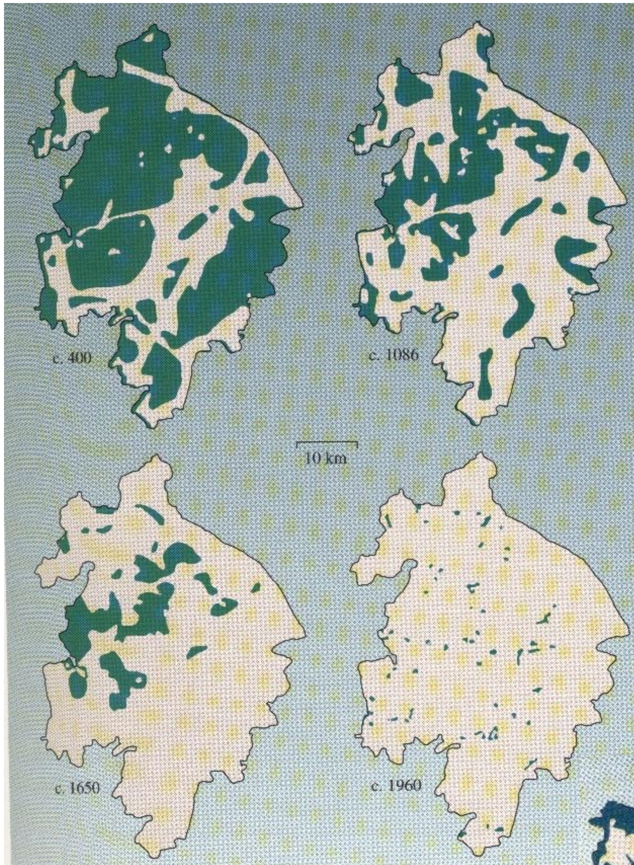


Cause di minaccia delle specie in pericolo negli Stati Uniti. Per ciascuna causa è indicata la percentuale delle specie, sottospecie o popolazioni per cui essa costituisce pericolo di estinzione. Le categorie in cui sono suddivise le cause di minaccia non sono mutuamente esclusive e quindi la somma delle diverse percentuali può essere maggiore di 100. Le specie considerate costituiscono il 75% delle specie minacciate negli Stati Uniti.

	Tutte le specie	Vertebrati	Invertebrati	Piante
Degradazione e distruzione dell'habitat*	85%	92%	87%	81%
Introduzione specie esotiche	49%	47%	27%	57%
Inquinamento	24%	46%	45%	7%
Sovrasfruttamento	17%	27%	23%	10%
Malattie	3%	11%	0%	1%

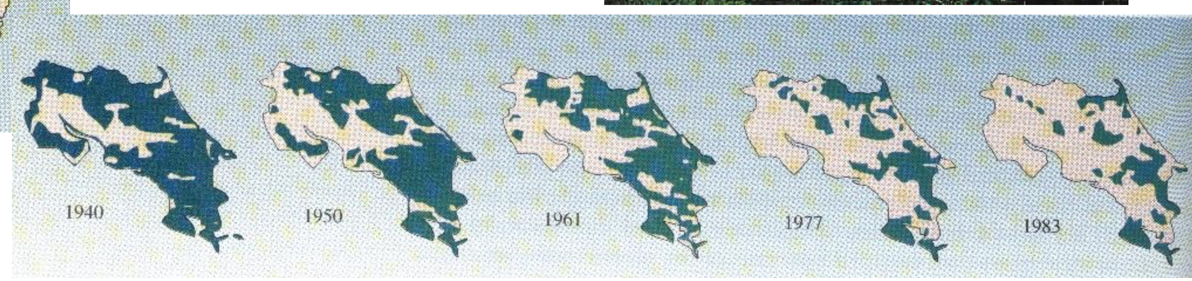
** il disturbo antropico associato alle attività ricreative, sportive e militari è incluso nella degradazione dell'habitat*

Habitat destruction and fragmentation



Forests in England

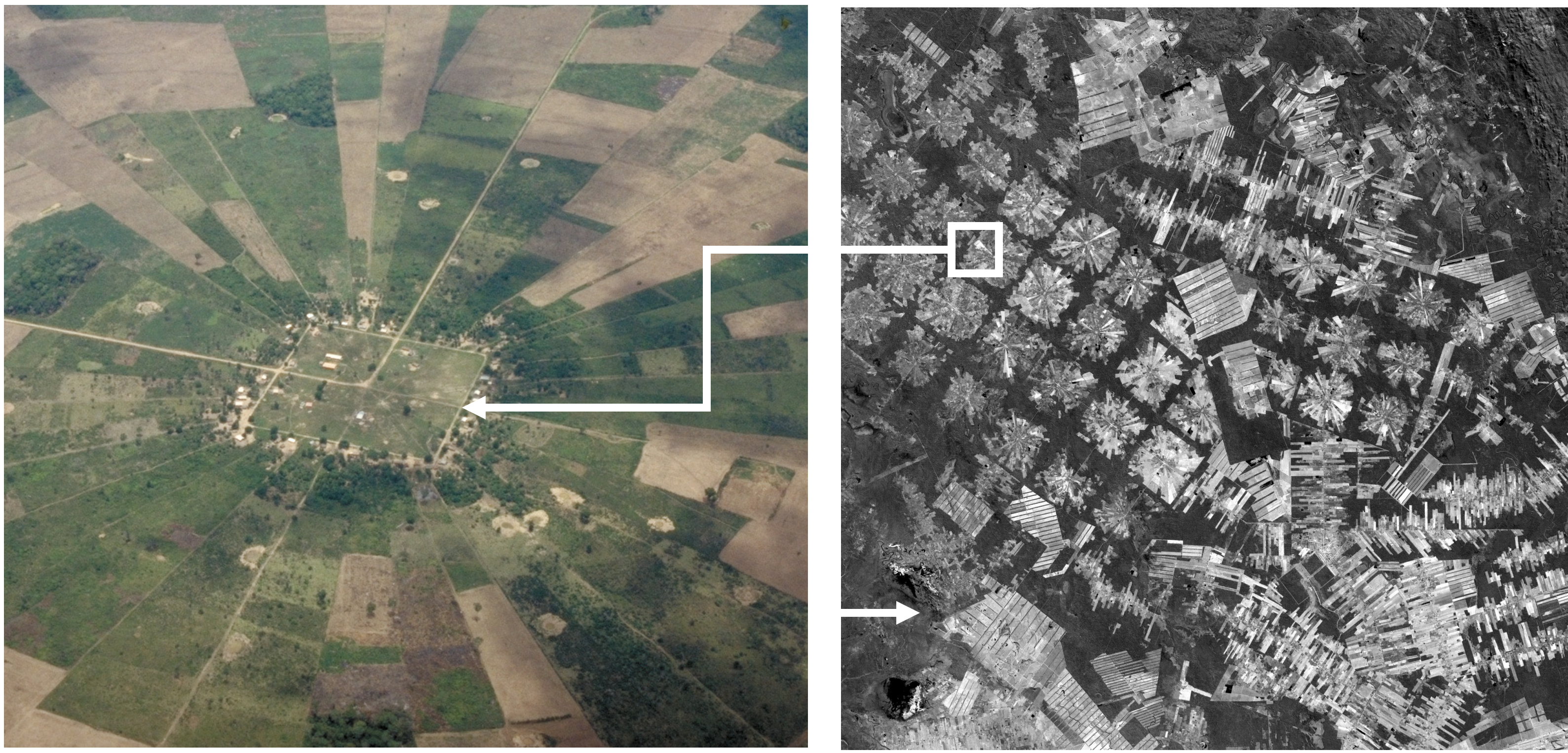
Brazil



Forests in Costarica

Habitat destruction and fragmentation

http://landsat.usgs.gov/gallery/detail/381/



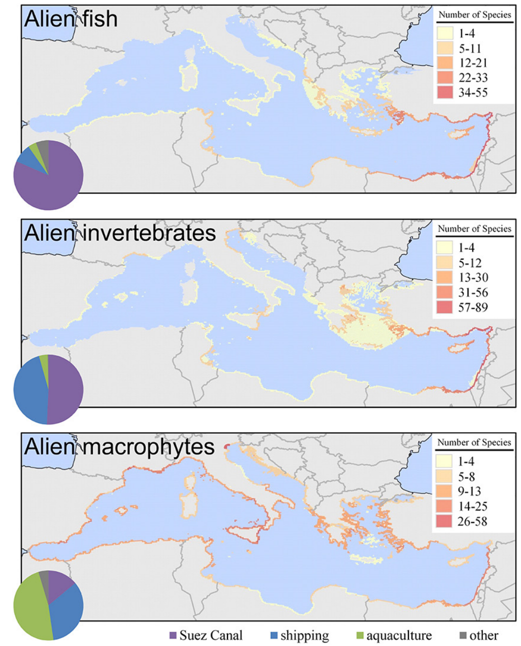
Santa Cruz de la Sierra, Bolivia

Habitat destruction and fragmentation

The alien species impact

Marine ctenophore
Mnemiopsis leidyi
introduced in the
Black Sea

Nile perch
Lates niloticus
introduced to Lake
Victoria



Alien species in
the Mediterranean

The impact of global warming and diseases

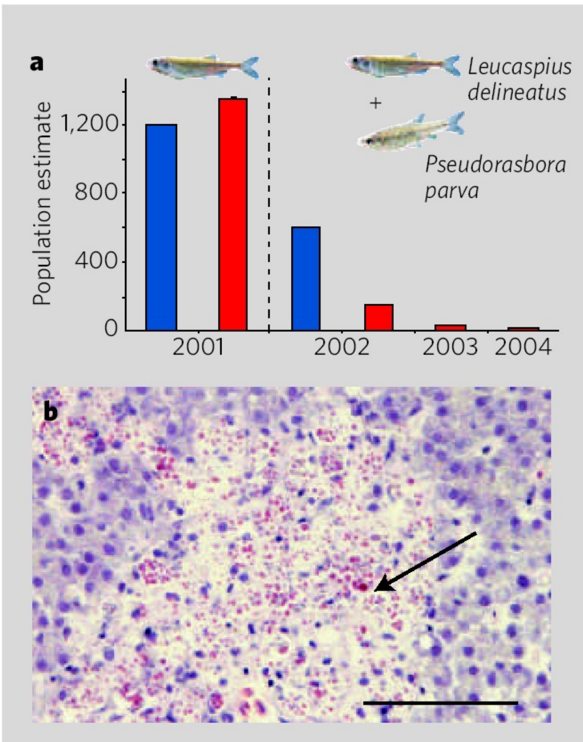


Figure 1 | Decline of *Leucaspius delineatus* population in a large natural pond after the introduction of *Pseudorasbora parva* and its associated pathogen, *Sphaerothecum destruens*.

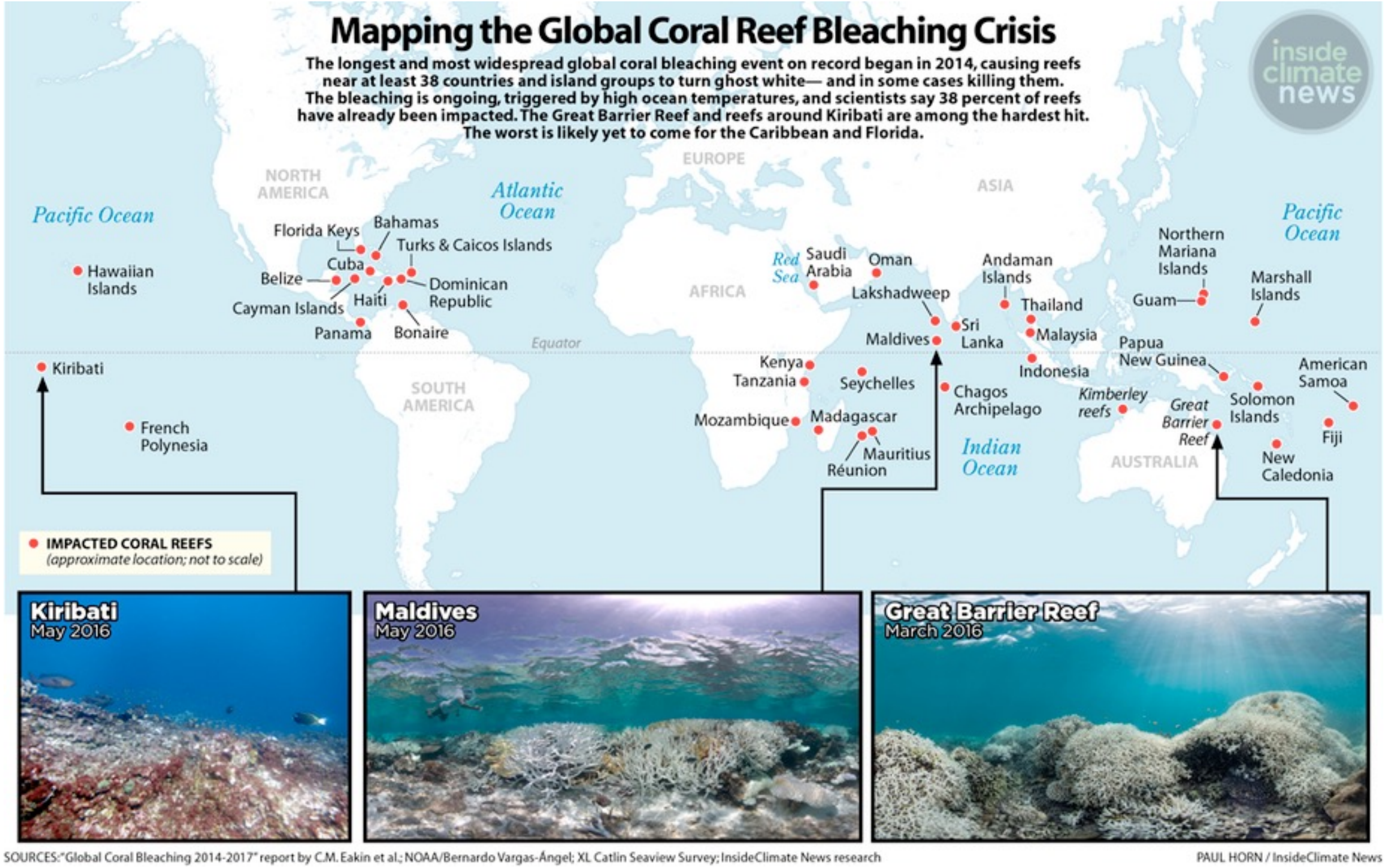
Gozlan R. E., S. St-Hilaire, S.W. Feist, P. Martin, M.L. Kent, 2005, *Nature* 435, 1046-1046

Panama, where a chytrid fungal epidemic caused a >90% decline
% decline in species richness. (*Inset*) One of many dead amphibians
robatidis. The ecosystem consequences of amphibian declines and

Figure 1 | Amphibian alarm call. The Panamanian golden frog is one of roughly 110 species of harlequin frog (*Atelopus*), many of which are dying out. Although this species still survives, its numbers have fallen significantly.

- 67% of the 110 species of harlequin frog (*Atelopus*; Fig. 1) endemic to the region have died out in the past 20 years.
- A pathogenic chytrid fungus, *Batrachochytrium dendrobatidis,* is implicated as the primary cause
- **Pounds *et al.* 2006 *Nature* 439: 161-167** have shown that large-scale warming is a key factor in the disappearances, because temperatures at many highland localities are shifting towards the growth optimum of *Batrachochytrium*, thus encouraging outbreaks.

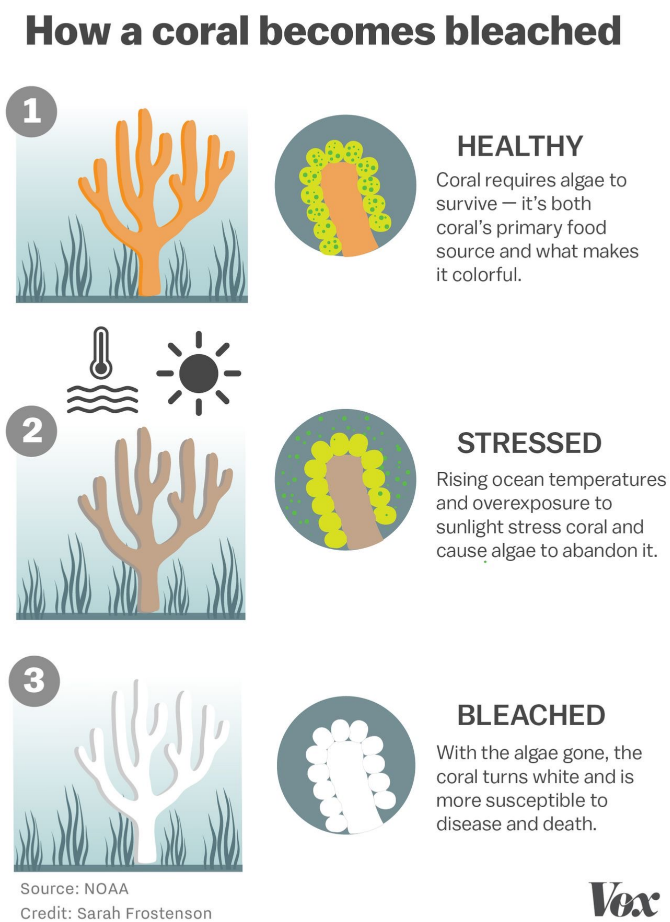
Coral bleaching

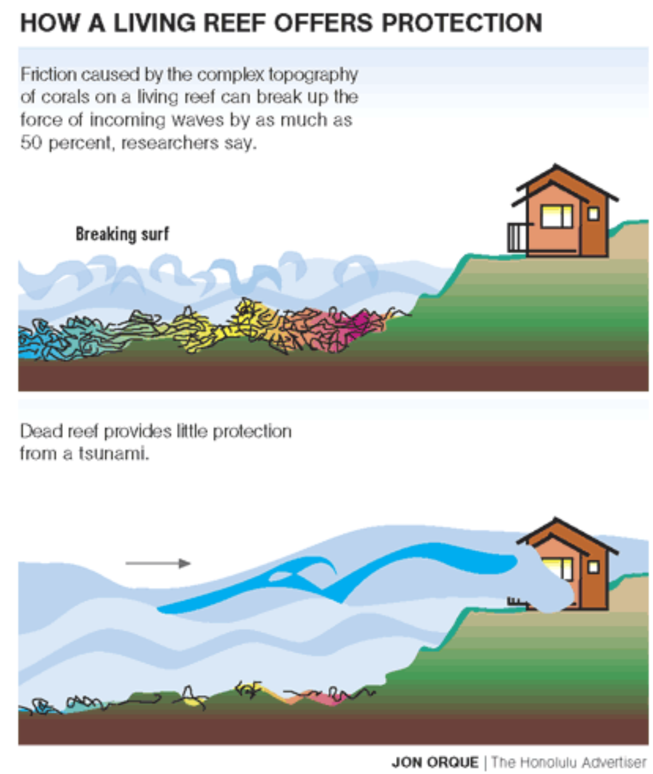


Bramble Cay Melomys (Australia)

Declared extinct because of global warming

Coral bleaching

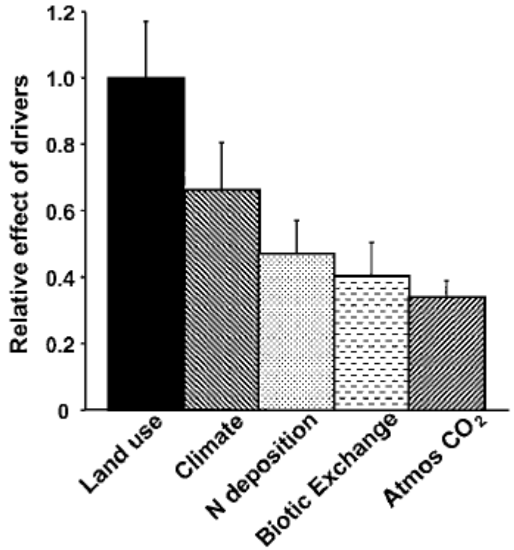




Corals can survive in warm water, though not too warm (typically between 23° and 29° C); in too warm water corals bleach and die.

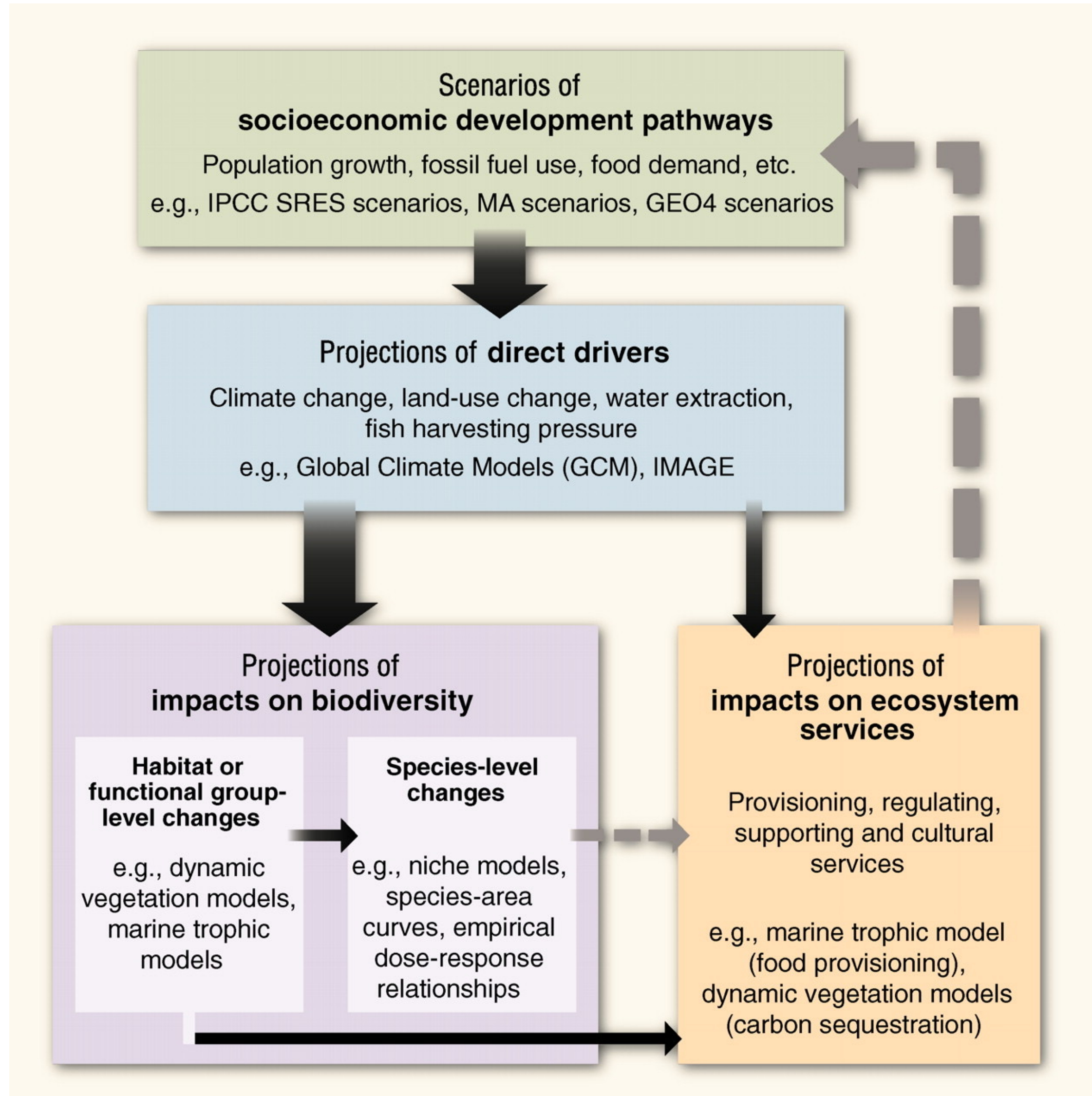
Coral bleaching

Scenarios of future biodiversity



Major drivers of change year 2100

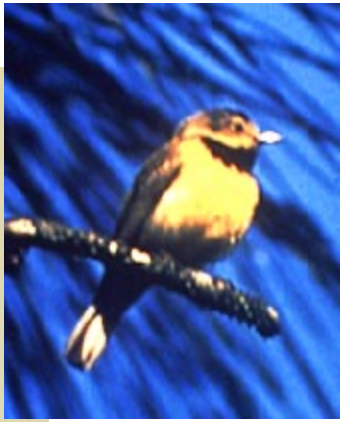
O. Sala et al., Science 2000; 287: 1770-1774.



H M Pereira et al. Science 2010;330:1496-1501

Extinction definitions: global/local/in the wild

Franklinia altamaha
Only in botanical gardens

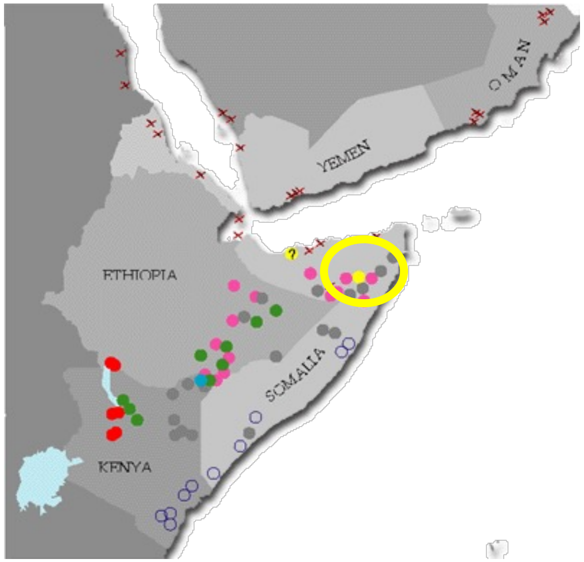


Vermivora bachmanii
Bachman's warbler
Globally extinct because of deforestation

American burying beetle: once present in western and central USA

Nicrophorus americanus

The “living dead”



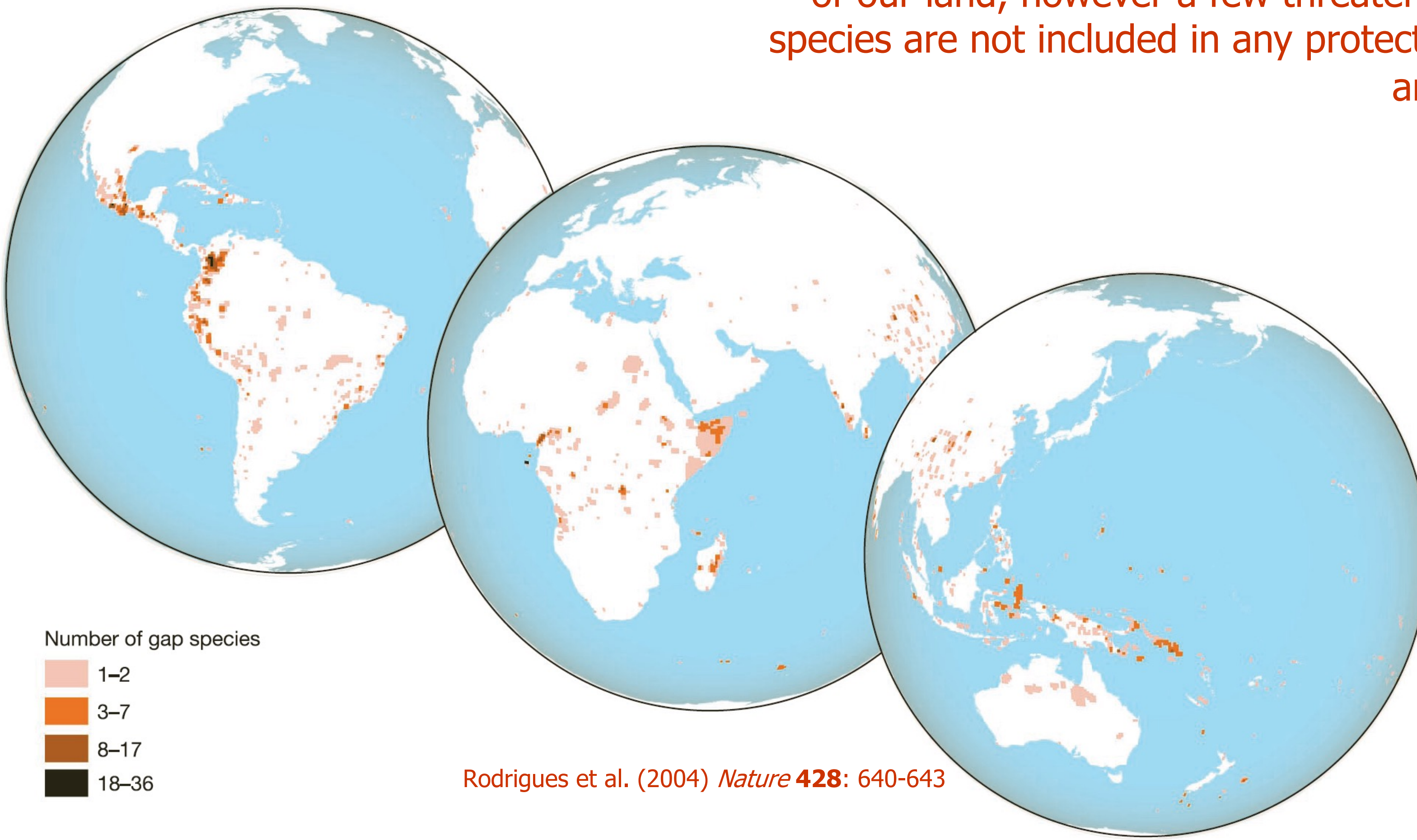
Moringa sp.

One of two specimens spotted in Somaliland during 2001

Moringa pygmaea

The “gap” species

The planet’s protected areas cover 11.5% of our land, however a few threatened species are not included in any protected area



Rodrigues et al. (2004) *Nature* **428**: 640-643

Figure 1 Density map of gap species per half-degree cell, created by overlaying the ranges of all species not covered by any protected area.

What to do?
Preserving habitats and biomes

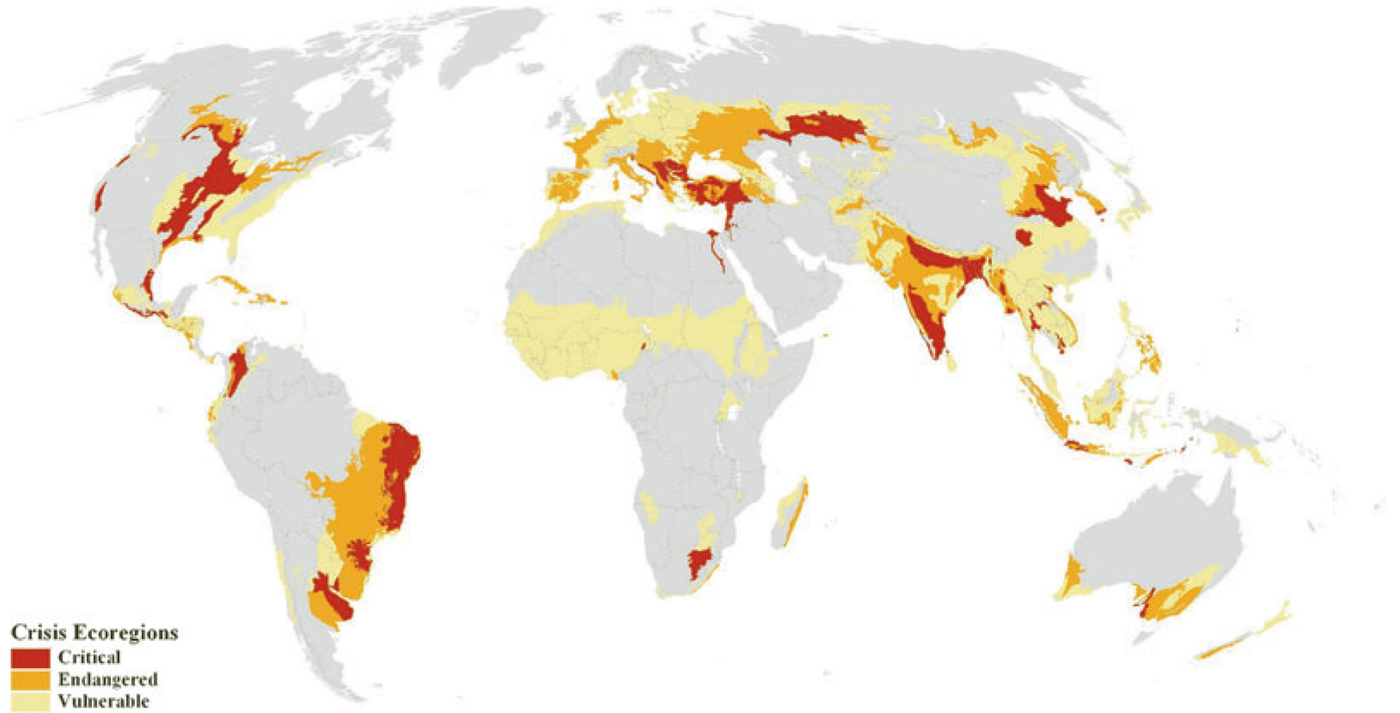
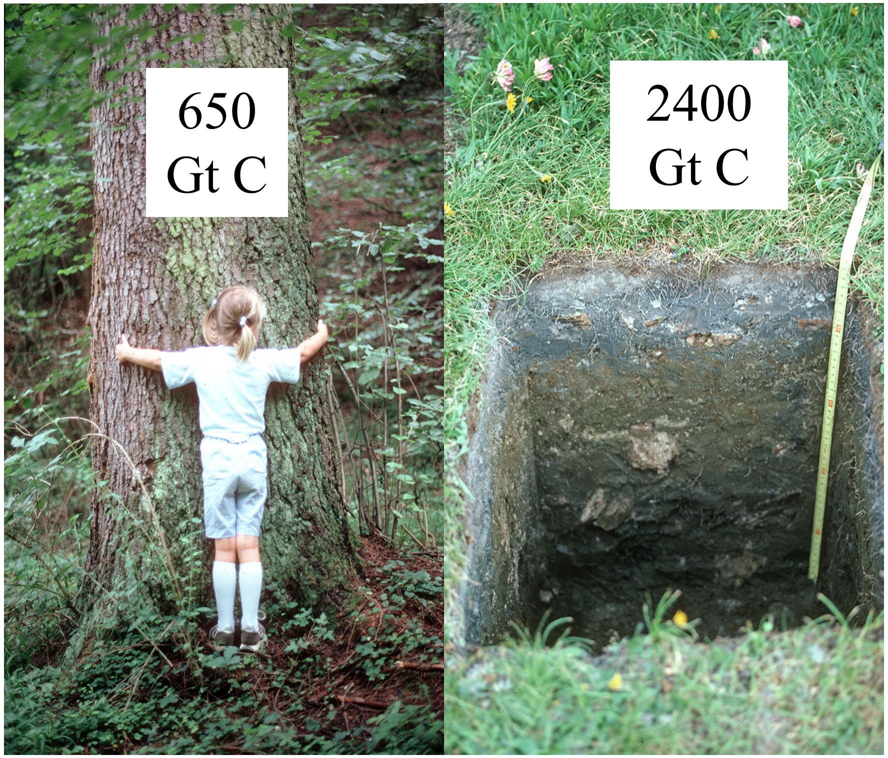


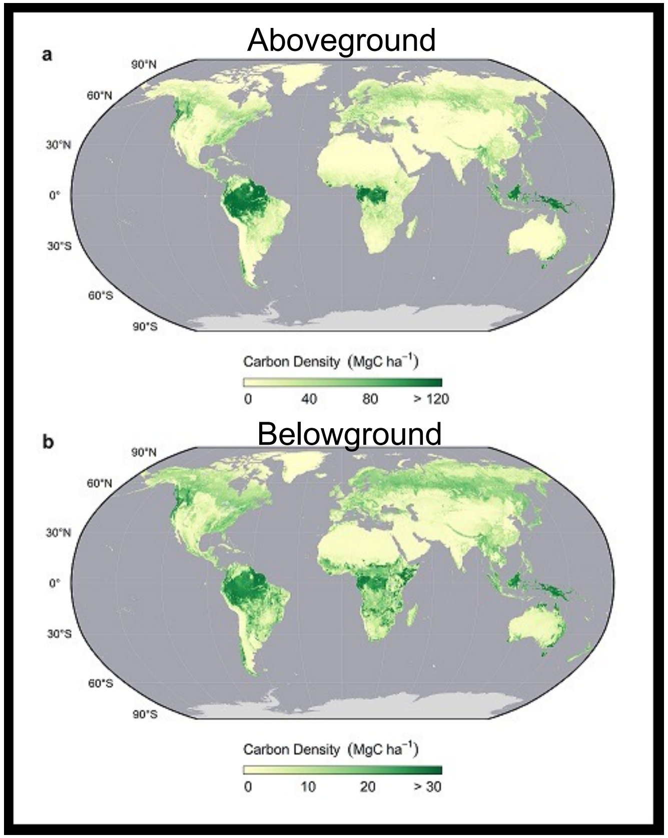
Figure 4 Map of crisis ecoregions. Vulnerable, Endangered, and Critically endangered, ecoregions were classified as described in text and shown in Fig. 3.

Hoekstra, J. M. *et al. Ecol. Lett.* 8, 23–29 (2005)

Global Biodiversity Outlook https://www.cbd.int/gbo5

What to do?
Preserving habitats and biomes



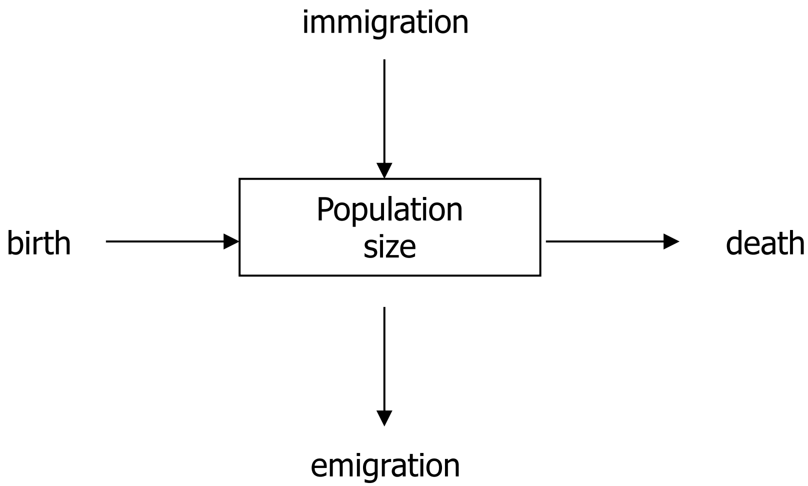


Summary of single-population models

1. Malthusian demography
    1. Discrete reproduction
    2. Continuous reproduction

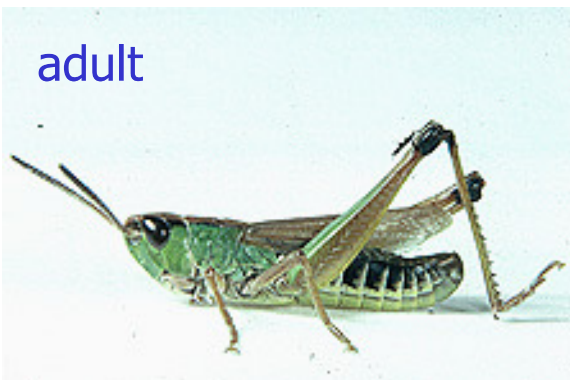
2. Density-dependent demography
    1. Beverton-Holt and Ricker models
    2. Logistic model

The balance equation and the Malthusian model

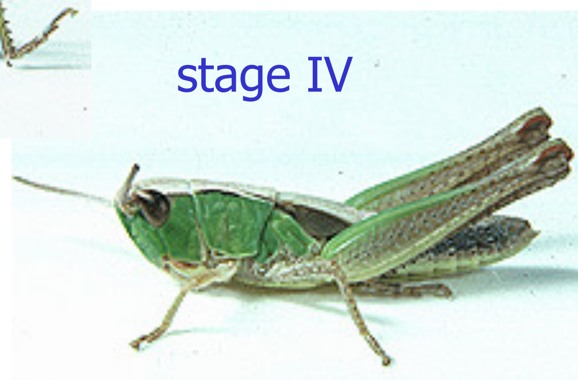


Example: the grasshopper dynamics...

pods and eggs

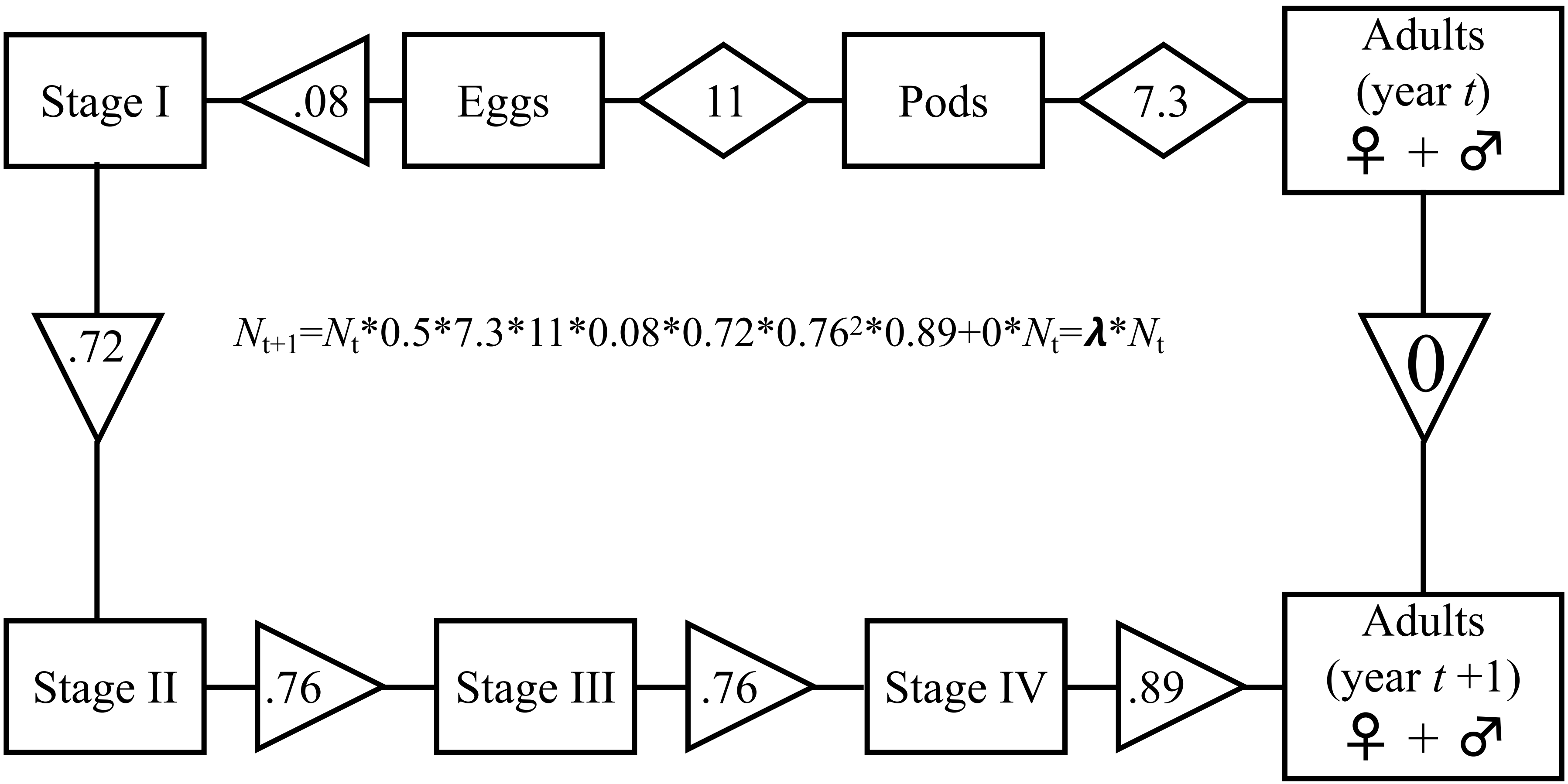


Chorthippus curtipennis



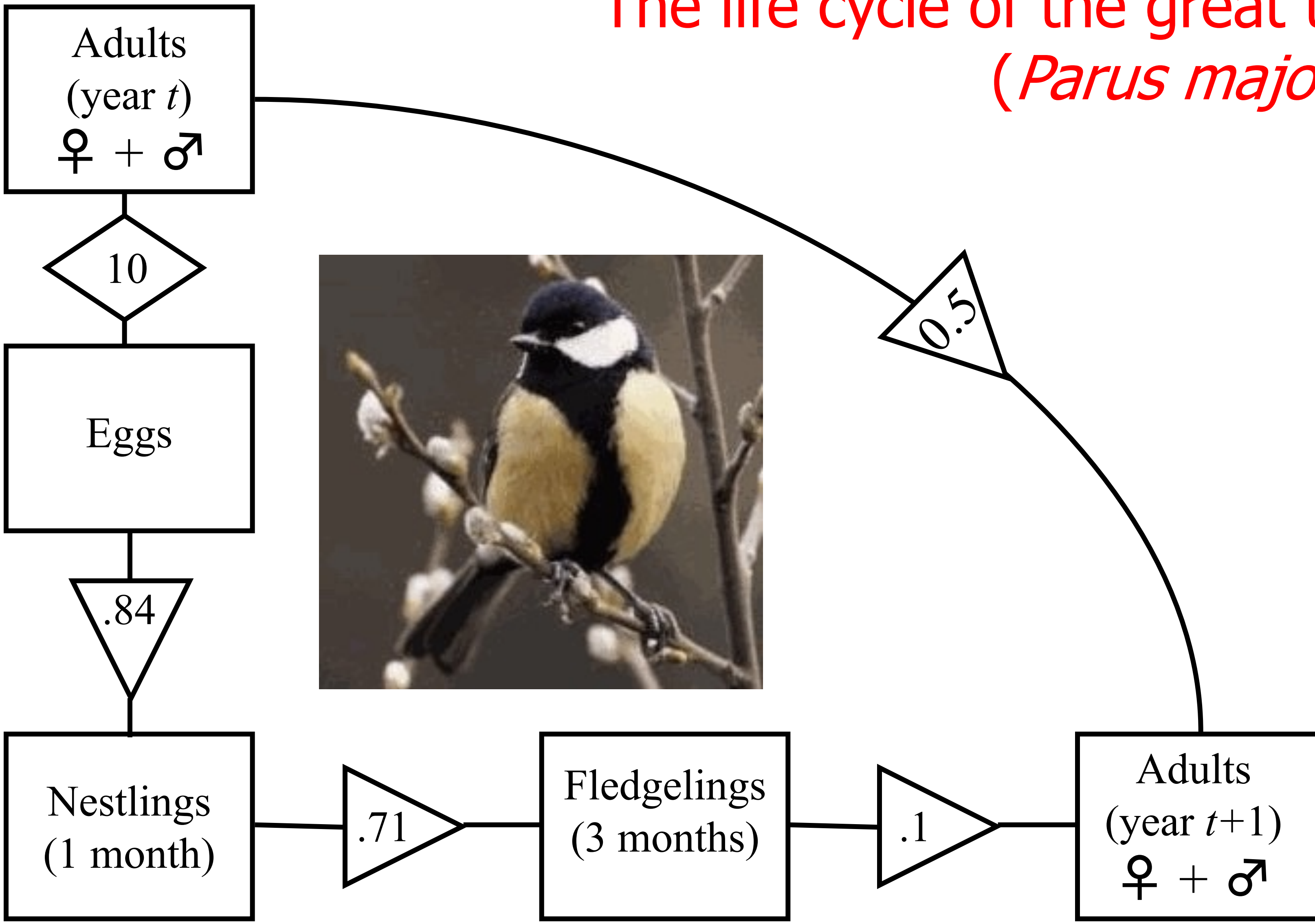
C. brunneus

The life cycle of the grasshopper (*Chorthippus brunneus*)



$$N_{t+1}=N_t*0.5*7.3*11*0.08*0.72*0.76^2*0.89+0*N_t=\boldsymbol{\lambda}*N_t$$

The life cycle of the great tit (*Parus major*)



$$N_{t+1}=N_t*0.5*10*0.84*0.71*0.1+0.5N_t= \boldsymbol{\lambda}*N_t$$

Finite rate of increase

In both cases we obtain

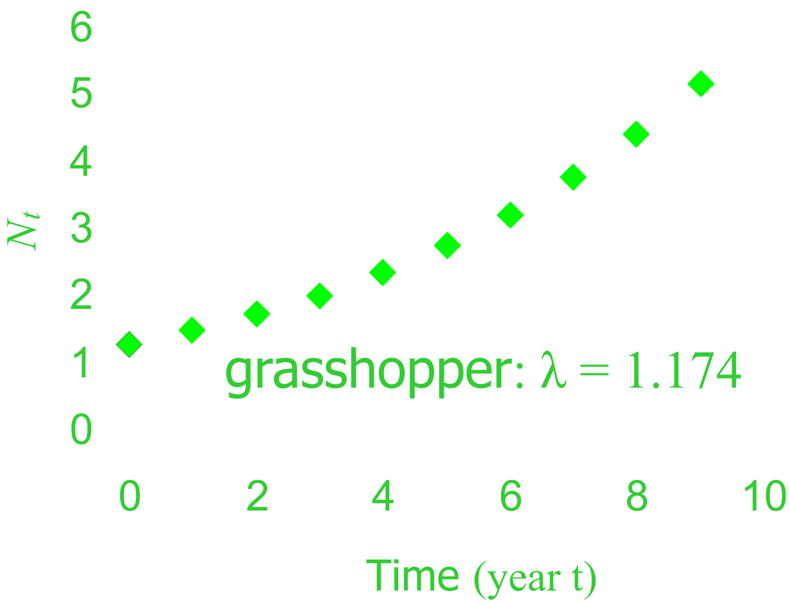
Finite rate of increase

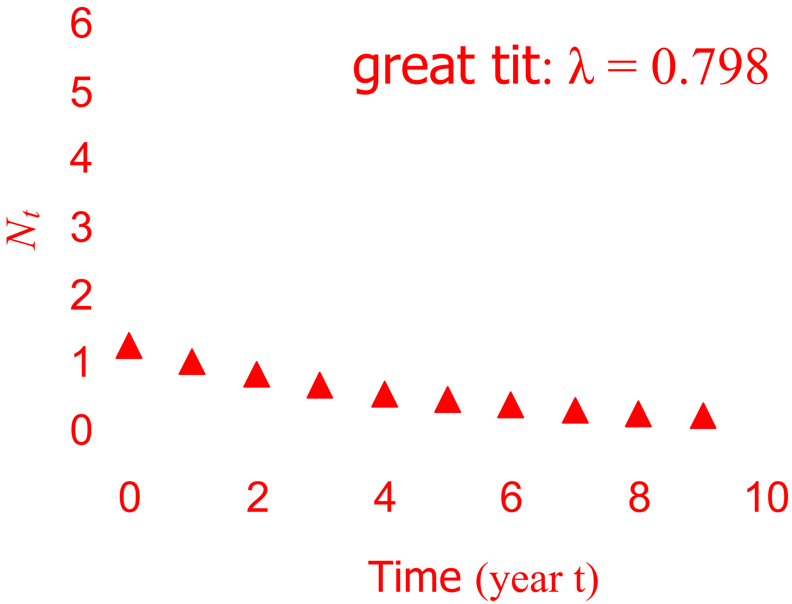
$$N_{t+1} = \lambda N_t$$

$\lambda > 1$ population increases

$\lambda < 1$ population decreases and becomes extinct

$\lambda = 1$ population is stationary





How to estimate λ from subsequent censuses

$$N_1 = \lambda N_0 \qquad N_2 = \lambda N_1 = \lambda (\lambda N_0) = \lambda^2 N_0$$

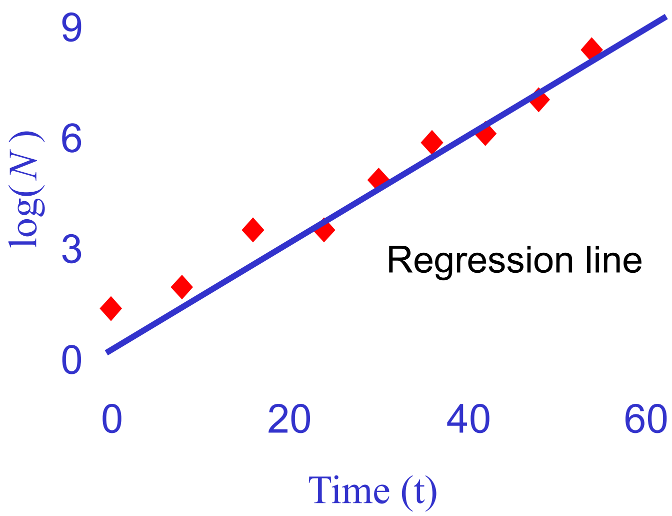
$$N_3 = \lambda N_2 = \lambda (\lambda^2 N_0) = \lambda^3 N_0$$

Taking logarithms

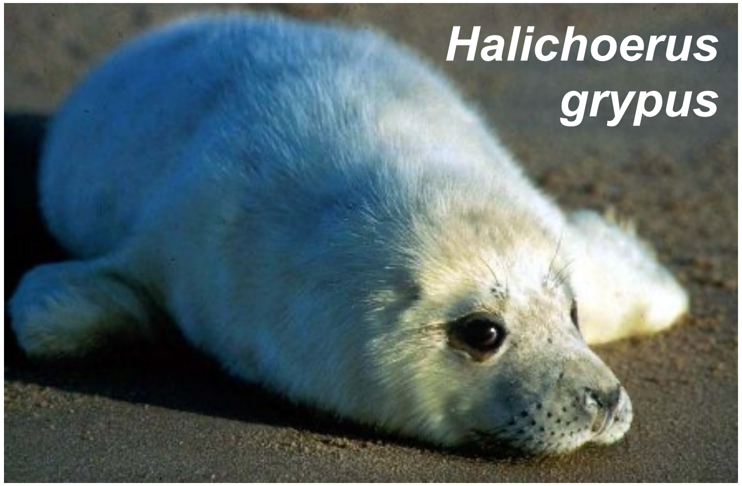
$$\log(N_t) = \log(\lambda^t) + \log(N_0) =$$
$$= t \log(\lambda) + \log(N_0)$$

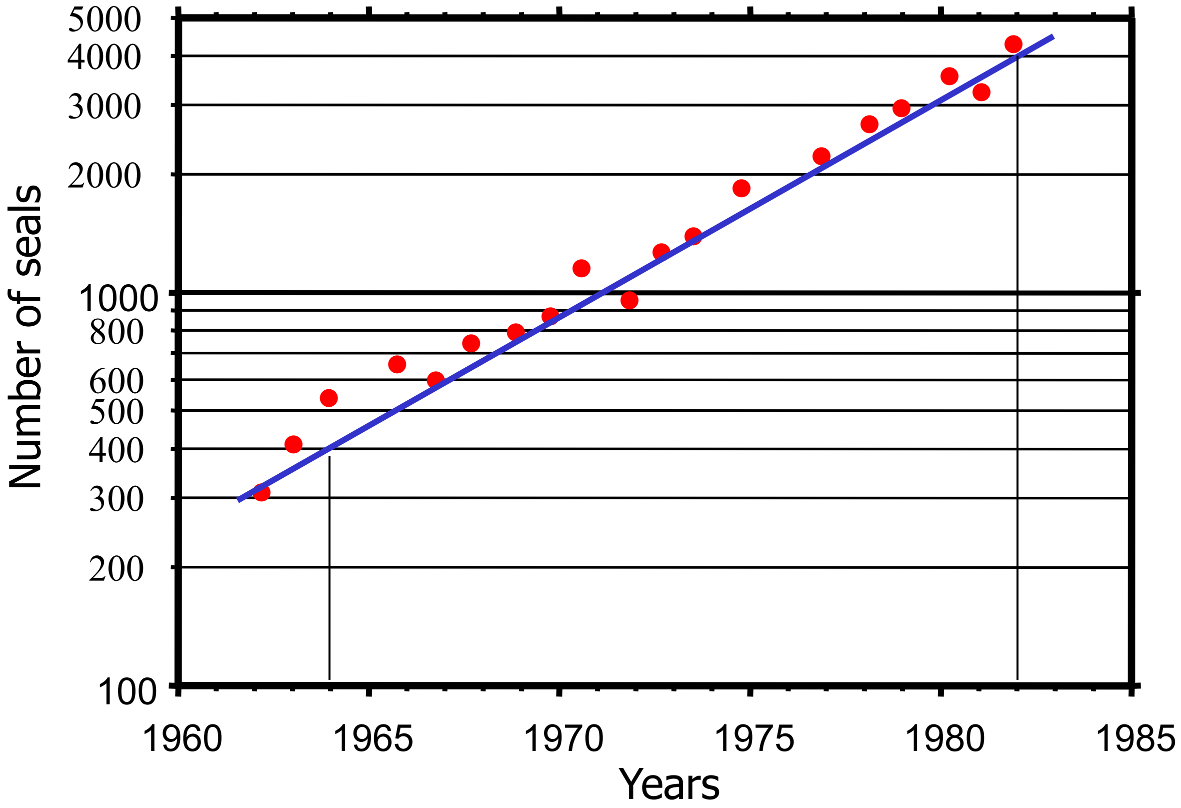
$$N_t = \lambda^t N_0$$

$$y = b\, t + a$$



The grey seal





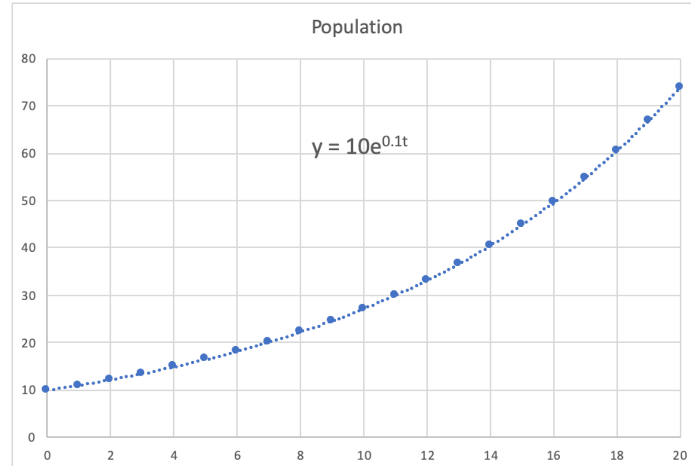
Year	# seals
1962	302
1963	403
1964	549
1966	671
1967	587
1968	741
1969	784
1970	887
1971	1135
1972	978
1973	1228
1974	1269
1976	1935
1977	2106
1978	2609
1979	2892
1980	3666
1981	3083
1982	4367

The Malthusian model with continuous reproduction

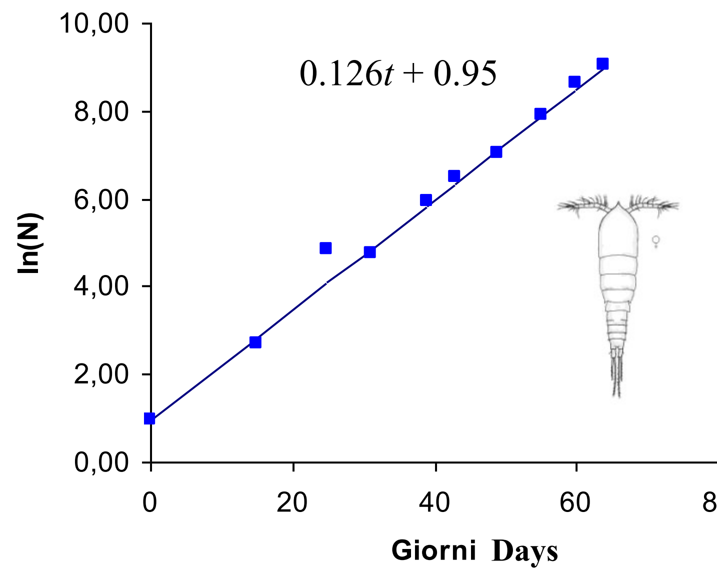
$$\frac{dN}{dt} = (\nu - \mu) N = rN$$

$\boldsymbol{\nu}$ = birth rate (time^{-1})
$\boldsymbol{\mu}$ = death rate (time^{-1})
r = growth rate (time^{-1})

$$N(t) = N(0)\exp(r\,t)$$



Estimating the intrinsic instantaneous growth rate from data



Doubling time?

$N(t_D)=2*N(0)=N(0)*\exp(r*t_D)$ $\quad 2=\exp(r*t_D)$

$\ln(2)=r*t_D$ $\quad t_D=\ln(2)/r$

Are there truly Malthusian populations ?

TABLE 3

FECUNDITY SCHEDULE FOR *Phlox drummondii* AT NIXON, TEXAS, BASED ON SEED PRODUCTION

$x - x'$	B_x^{seed}	N_x	b_x^{seed}	l_x	$l_x b_x$
0–299	.000	996	.0000	1.0000	.0000
299–306	52.954	158	.3394	.1586	.0532
306–313	122.630	154	.7963	.1546	.1231
313–320	362.317	151	2.3995	.1516	.3638
320–327	457.077	147	3.1904	.1476	.4589
327–334	345.594	136	2.5411	.1365	.3470
334–341	331.659	105	3.1589	.1054	.3330
341–348	641.023	74	8.6625	.0743	.6436
348–355	94.760	22	4.3072	.0221	.0951
355–362	.000	0	.0000	.0000	.0000
					$\sum = 2.4177$

Nixon, Texas (Leverich e Levin, 1979)

Phlox drummondii

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

λ=2.4177

Starting with a population of **996** individuals, we would have, in **32** years, ca. 80 million di individuals, i.e. a density of about **80 individuals per square meter** from Southern Mexico to Alaska

Requirements for a population to be Malthusian

Two conditions:

- resources *per capita* are constant (though not necessarily abundant)
- no direct intraspecific interaction

Black grouse (*Tetrao tetrix*)

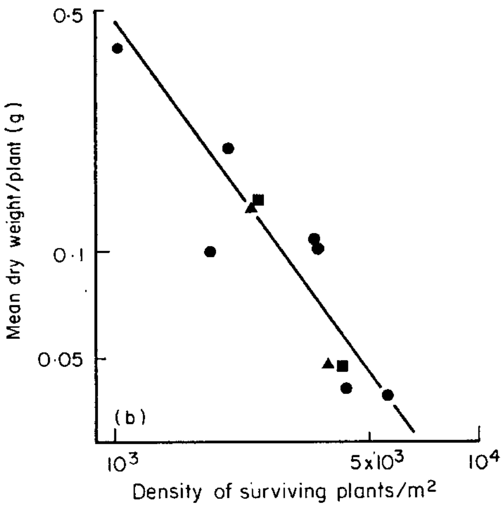
Social mechanisms (attack and defense)

Many demographic parameters depend upon density

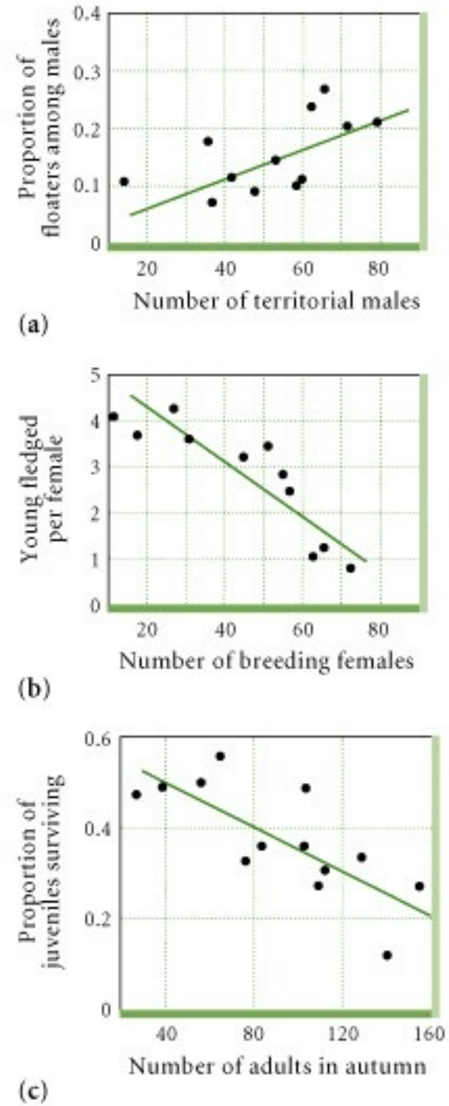
Medicago sativa

$$w \propto N^{-3/2}$$

3/2 self-thinning law



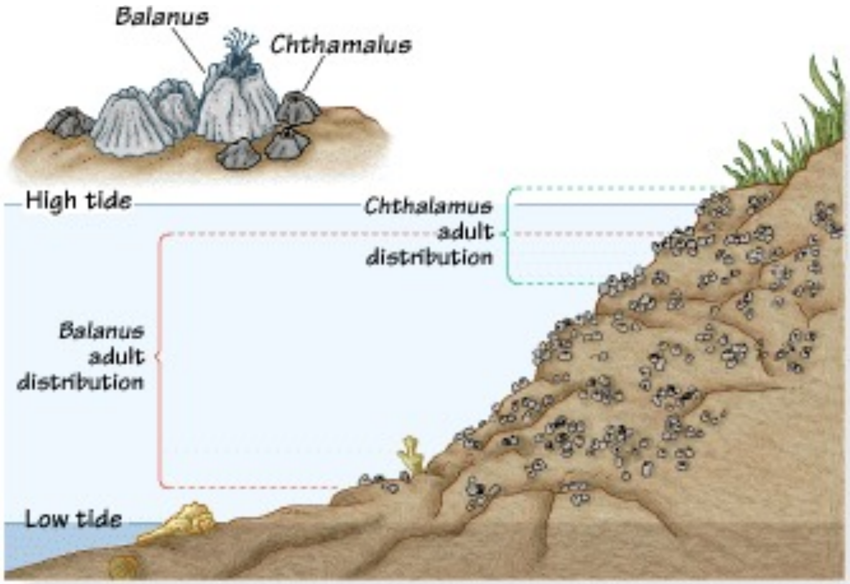
(White and Harper 1970)



Song sparrow

Melospiza melodia

Interference competition

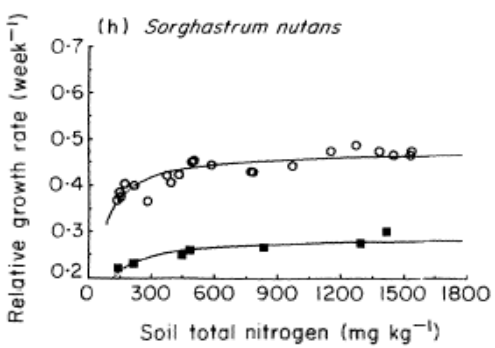


Competition for space

Territory defense

Exploitative competition (common resources)

Sorghastrum nutans



(Tilman and Cowan 1989)

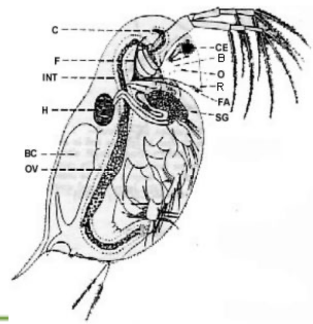


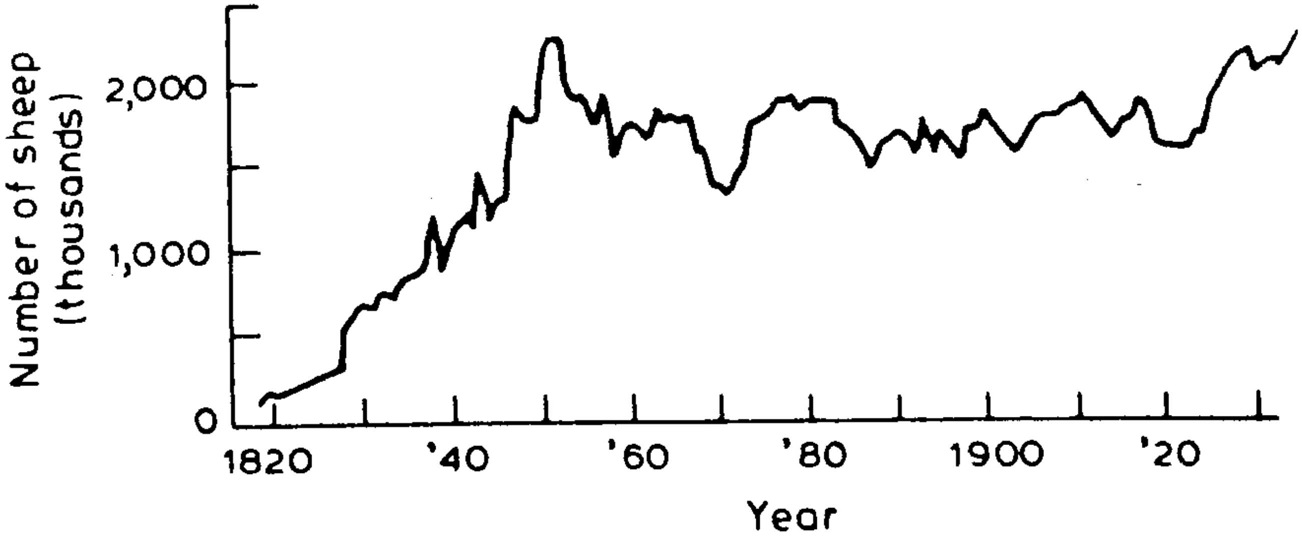
TABLE 20-2 Reproductive parameters for *Daphnia magna* cohorts fed a range of *Chlamydomonas reinhardi* concentrations at 20°C

	Food concentration (cells cm^{-3})			
	10^3	10^4	10^5	10^6
Percentage reproducing	50	87	97	50
Eggs per brood	2.8	2.6	15.5	21.1
Broods per female	1.7	7.5	8.2	3.4
Days between broods	5.4	3.6	3.1	3.3
Age at first brood (days)	23.4	16.9	9.8	9.1
Net reproductive rate (R_0)	2.25	16.23	99.33	34.80
Exponential rate of increase (r)	0.03	0.10	0.28	0.20

(From Porter et al. 1983.)

Continuous reproduction: A very general pattern

Tasmanian sheep (*Ovis aries*)



Interference competition model

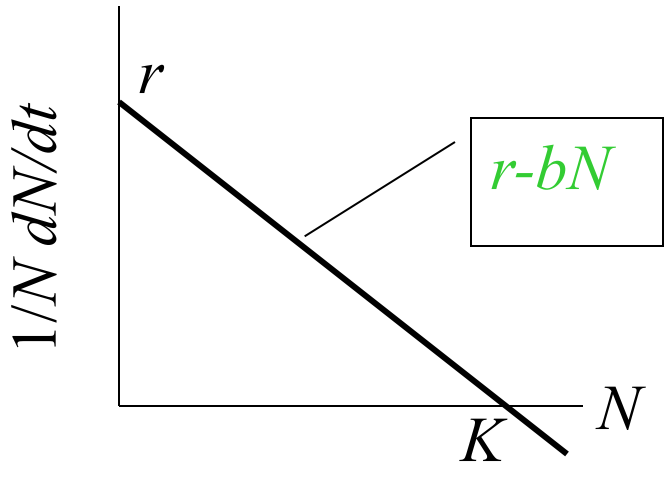
- Assumptions:
  - Without competition (low density) per capita growth rate = r
  - Probability of encounter between two individuals ÷ N^2
  - Mortality rate ÷ prob. encounter
- Model equation?
- How do we derive the growth rate?
- Model solutions

Damselfish

Logistic model (Verhulst 1838)

$$\frac{dN}{dt} = \dot{N} = rN - bN^2 = rN\left(1 - \frac{b}{r}N\right) = rN\left(1 - \frac{N}{K}\right)$$

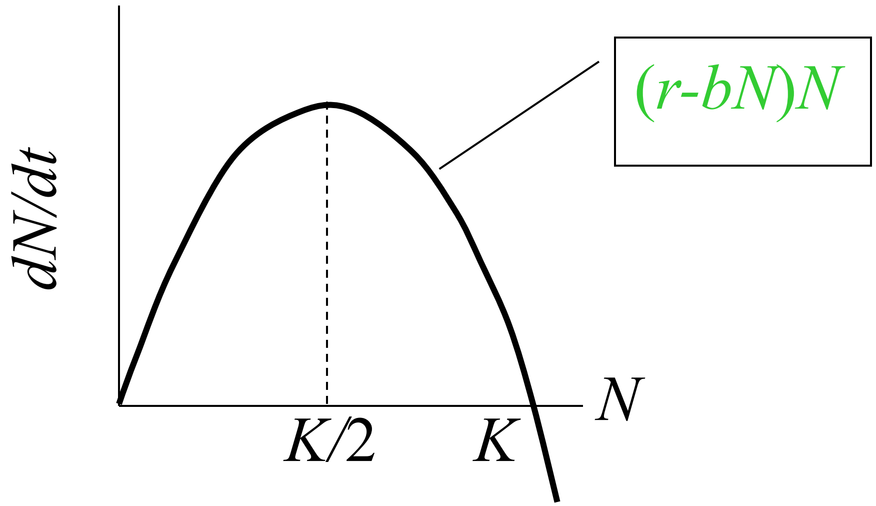
$$\frac{1}{N}\frac{dN}{dt} = \textit{Per capita} \text{ growth rate}$$



$K = r/b =$ ***Carrying capacity* (of the environment)**

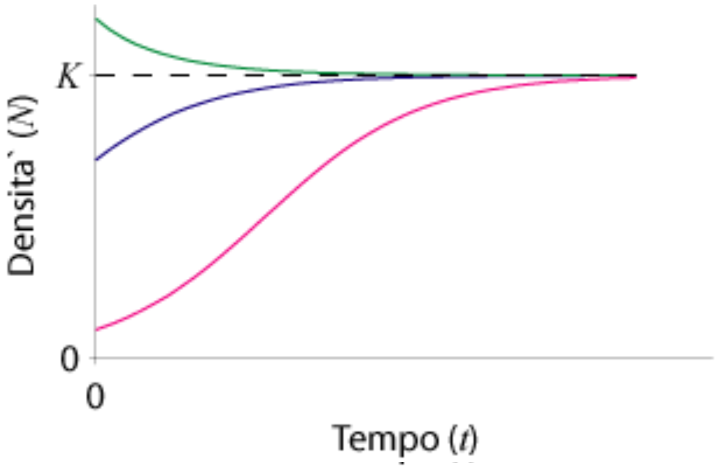
r = intrinsic instantaneous growth rate

Solutions of the logistic equation

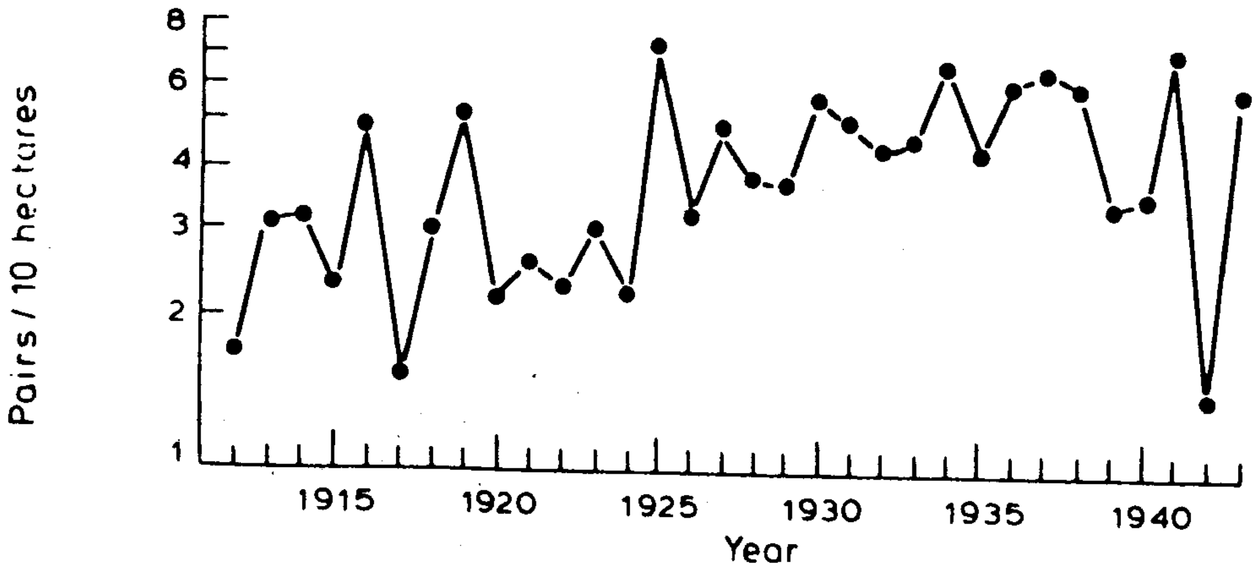


$$\frac{dN}{dt} = \text{Population rate of increase}$$

$$N(t) = \frac{N_0 K \exp(rt)}{K - N_0 + N_0 \exp(rt)} = \frac{N_0 \exp(rt)}{1 + \frac{\exp(rt) - 1}{K} N_0}$$

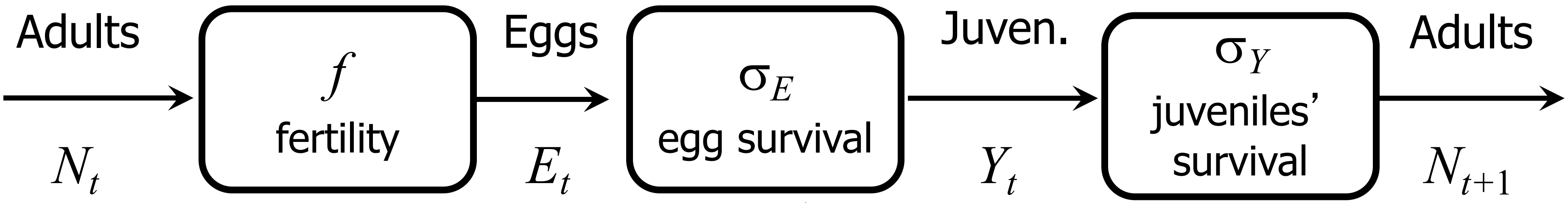


Discrete reproduction



Great tit (*Parus major*)

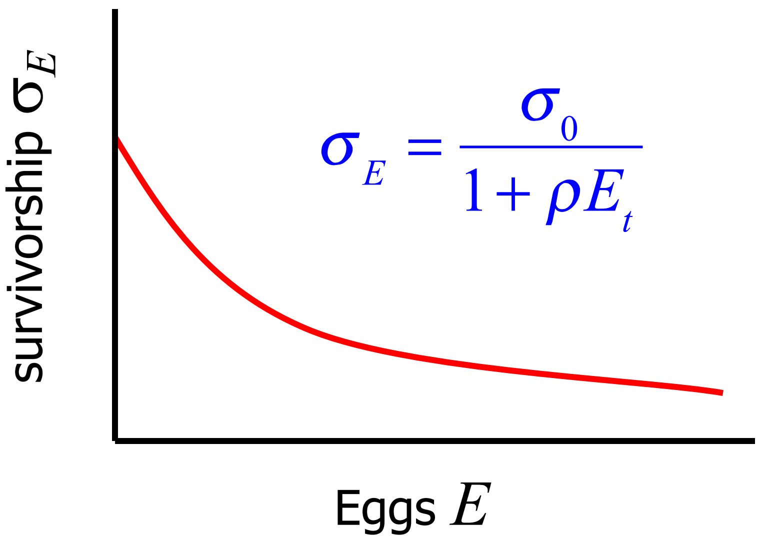
Beverton-Holt model



all adults die

$$N_{t+1} = \sigma_Y Y_t = \sigma_Y \sigma_E E_t = \frac{\sigma_Y \sigma_0 f N_t}{1 + \rho f N_t}$$

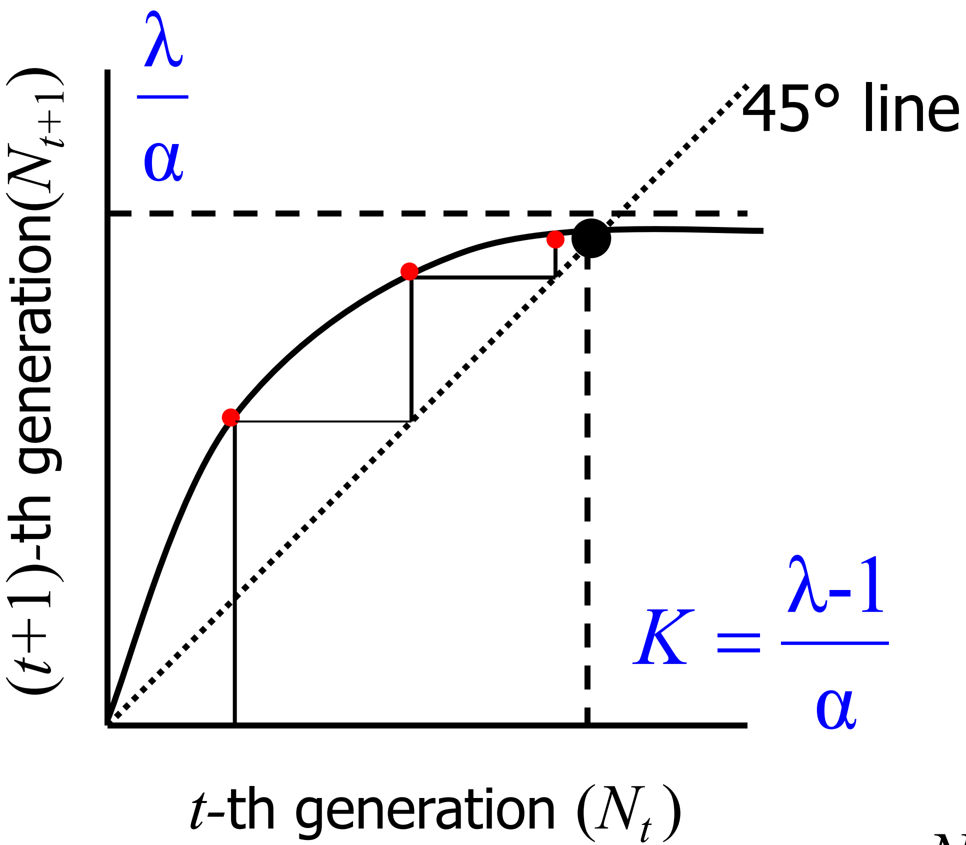
Density dependent



$$\sigma_E = \frac{\sigma_0}{1 + \rho E_t}$$

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

...and its behavior

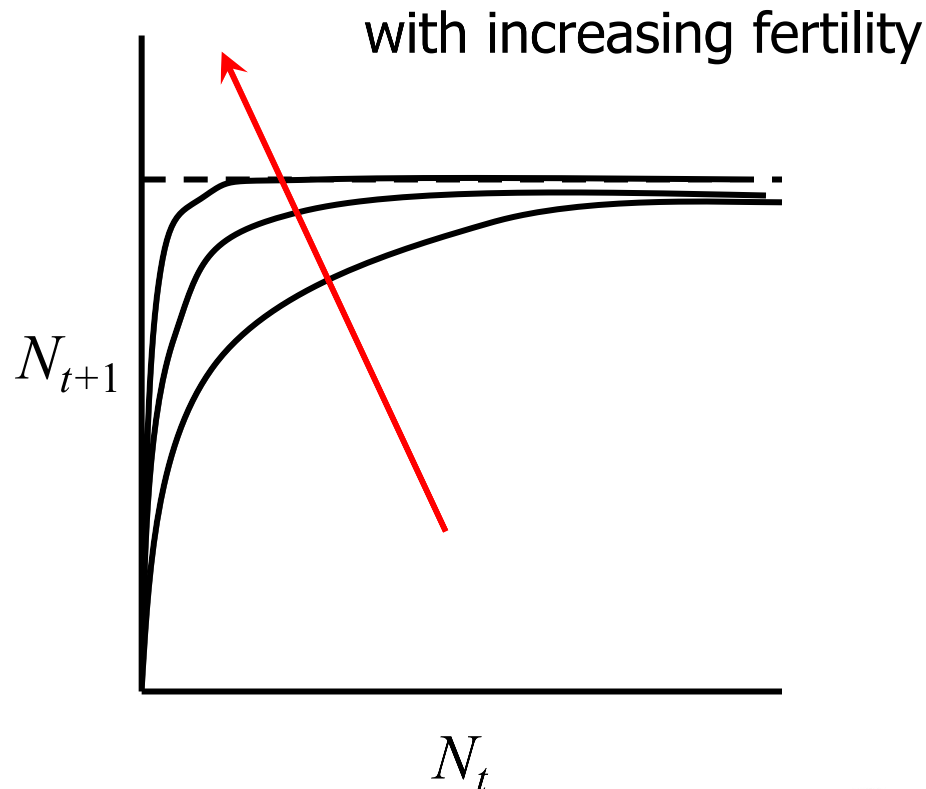


$$K = \frac{\lambda - 1}{\alpha}$$

$N_{t+1}=N_t=N$

N=lambda*N/(1+alfa*N)

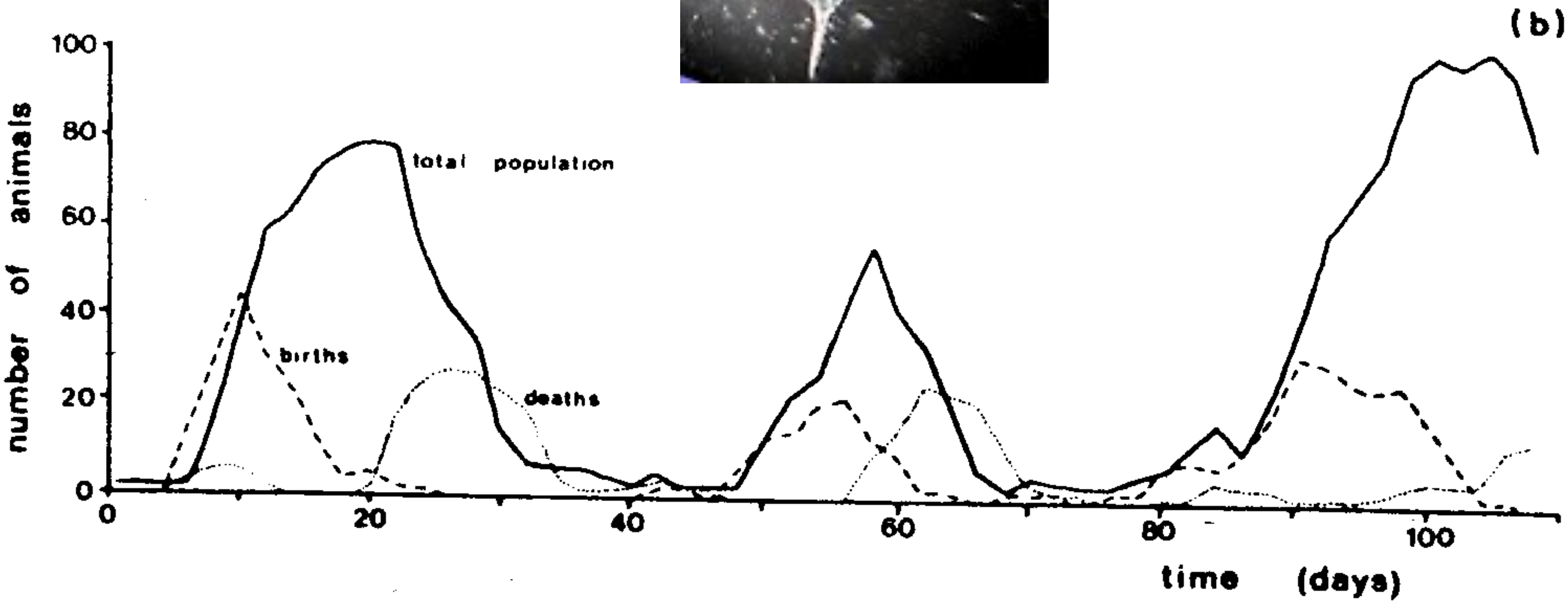
1=lambda/(1+alfa*N)



In extremely fertile species, recruitment is independent of the parental stock

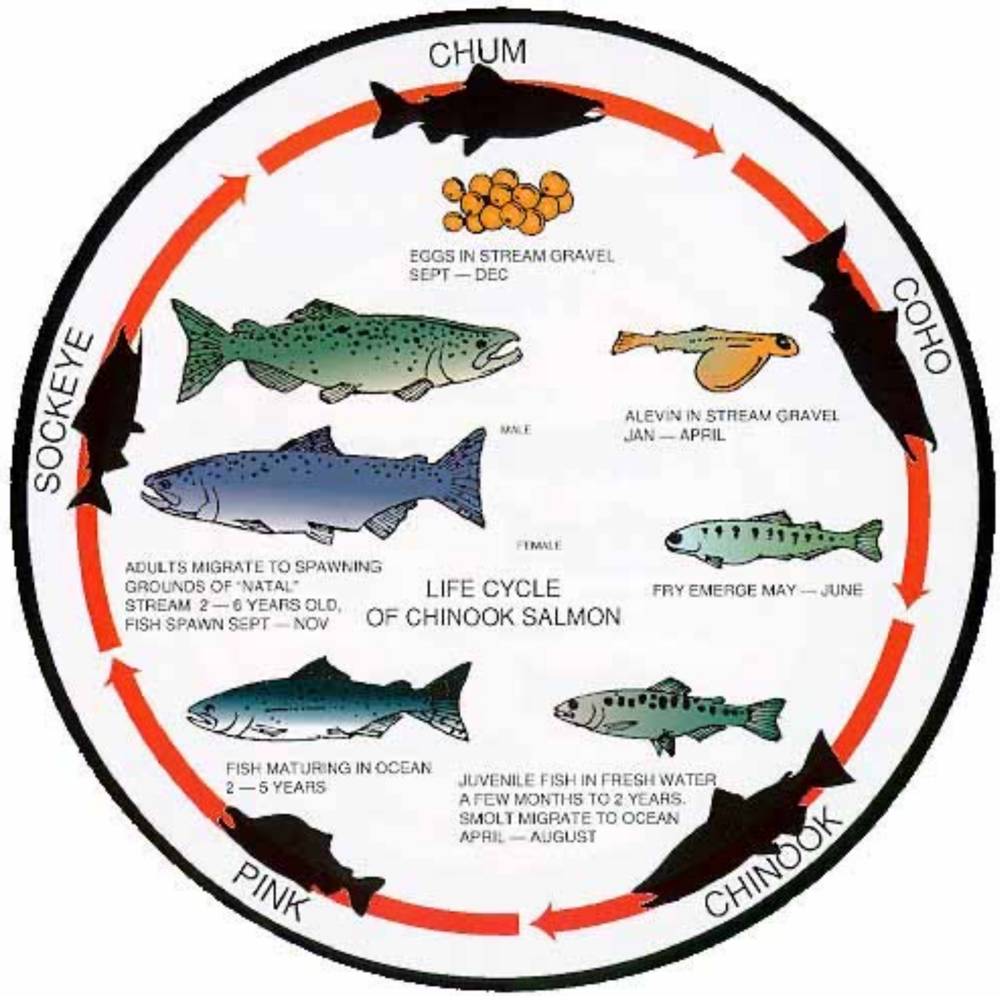
Oscillatory dynamics

Water flea
(*Daphnia magna*)

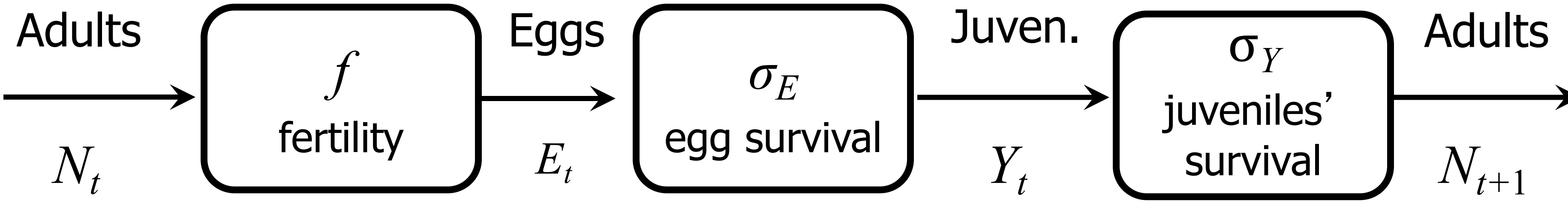


Pacific salmon

Fish ladder at Ice Harbor Lock and Dam North on the Lower Snake River, WA. (Photo: US Army Corps of Engineers)

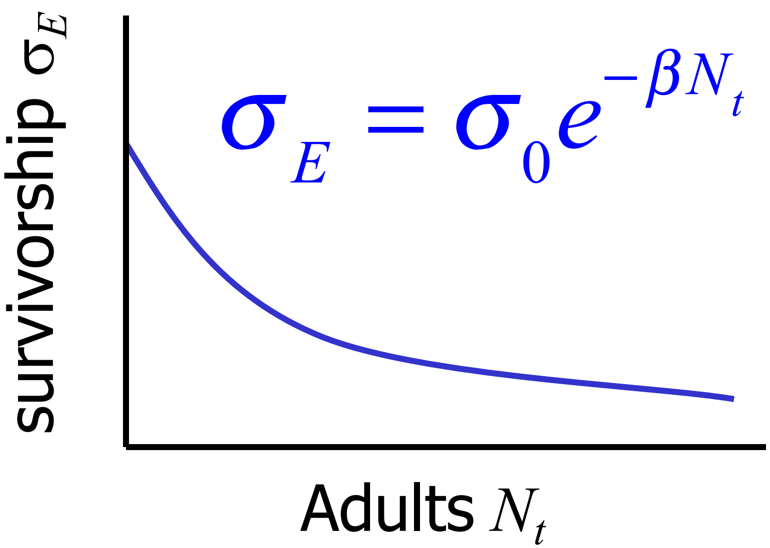


Ricker model (1954)



Dependence from parental density

all adults die

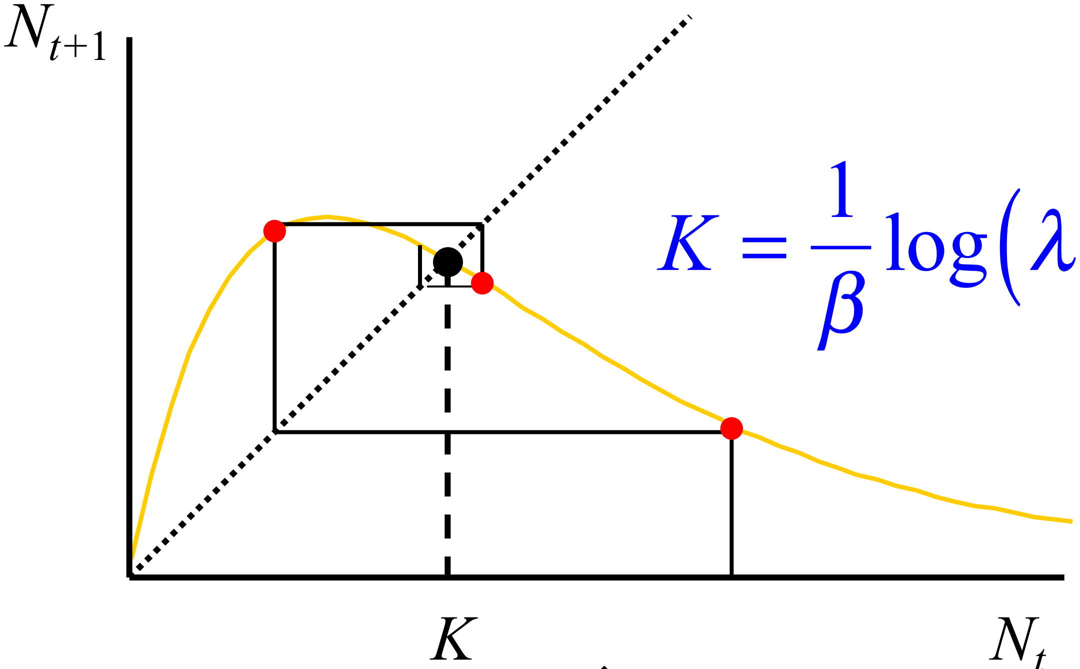


$$\sigma_E = \sigma_0 e^{-\beta N_t}$$

$$N_{t+1} = \sigma_Y \sigma_E f N_t = N_t \sigma_Y \sigma_0 f e^{-\beta N_t}$$

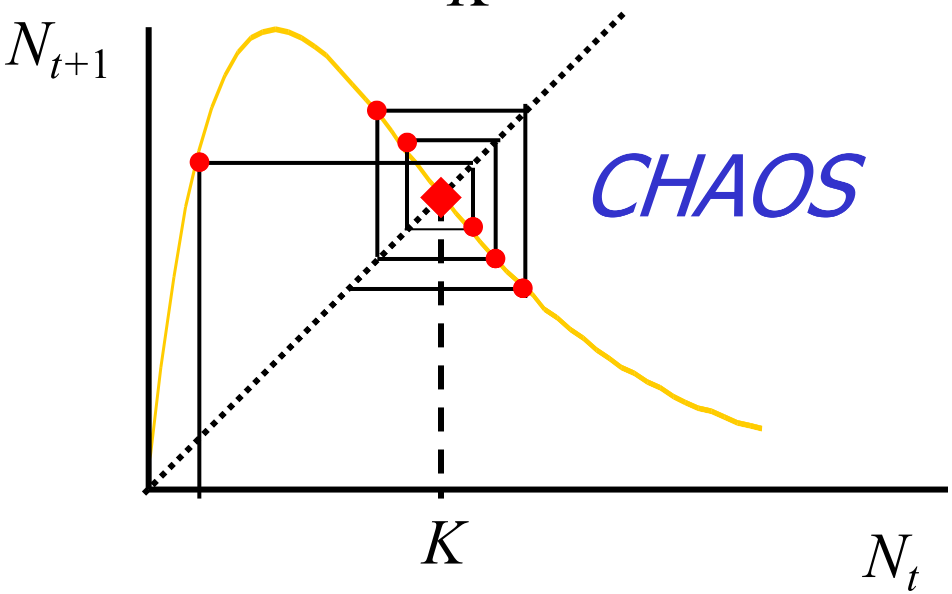
$$N_{t+1} = \lambda N_t e^{-\beta N_t}$$

...and its behavior



$$K = \frac{1}{\beta}\log(\lambda)$$

Overcompensation



CHAOS

For very fertile species...

... dynamics becomes unstable

Phenomena contributing to extinction risk and vulnerability of populations

1. Inverse density dependence(Allee effect)
   - Sociality
   - Defense against predators

2. Loss of genetic diversity
   - Random genetic drift
   - Inbreeding and outbreeding depression
   - Bottleneck and founder effects

3. Demographic and environmental stochasticity
4. Extinction vortices and PVA

- Program Populus 5.5: freely available at http://www.cbs.umn.edu/populus
- Professor Steve Stearns lectures at Yale http://oyc.yale.edu/ecology-and-evolutionary-biology/eeb-122#sessions

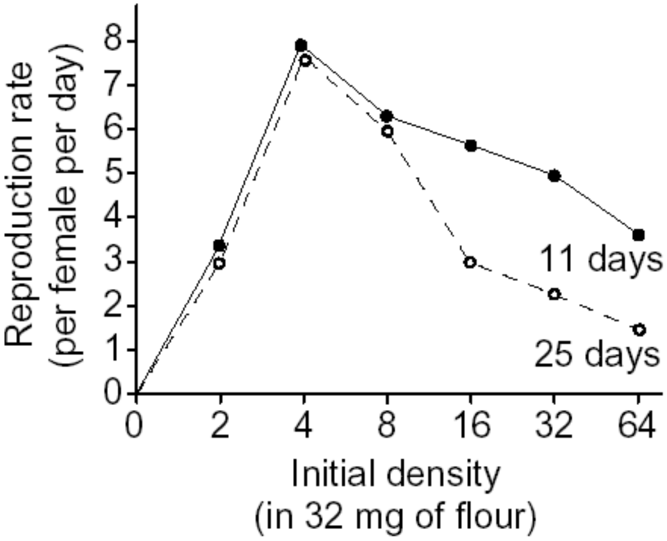
Allee effect (depensation)

- Sociality
- Defense against predators
- Pollination
- Perimeter/area or surface/volume ratio
- Finding a mate

Tribolium confusum

Box 1. The floury little world of the *Tribolium*

One of the earliest illustrations of Allee's ideas of the existence of an optimal population size concerns his analysis of the laboratory work of three different researchers on the flour beetle, *Tribolium confusum*[35]. This species showed the 'most rapid population growth at an intermediate population size rather than with too few or too many present', as shown in his figure, reproduced below.



Trends in Ecology & Evolution

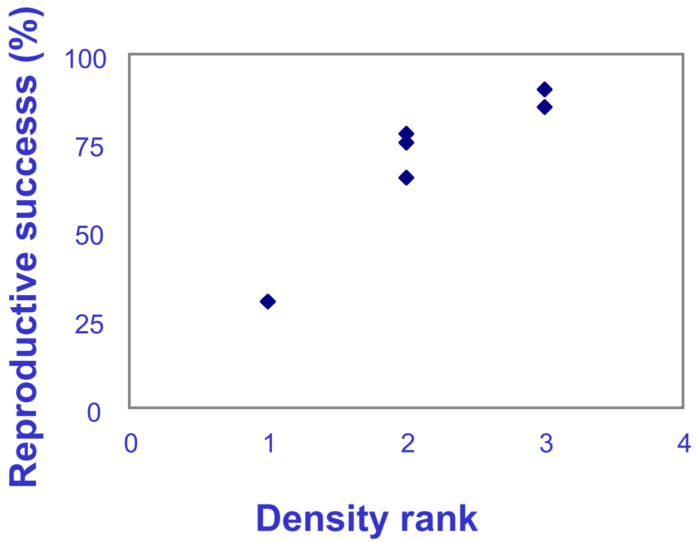
(Online: Fig. I)

Sociality mechanisms

A group of wild dogs

Lycaon pictus

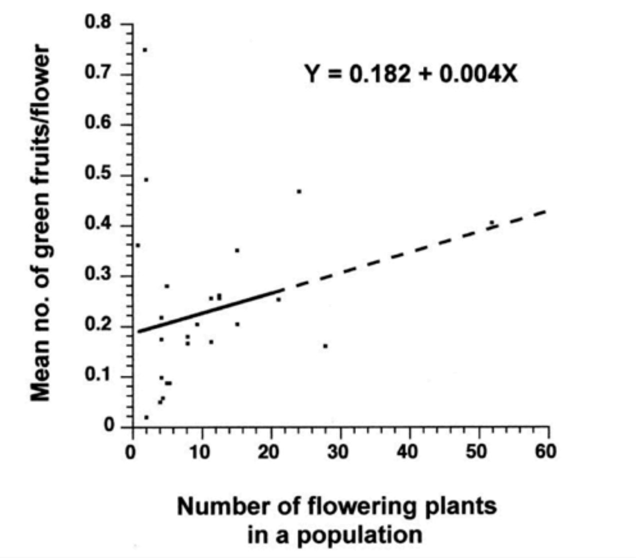
Defense against predators

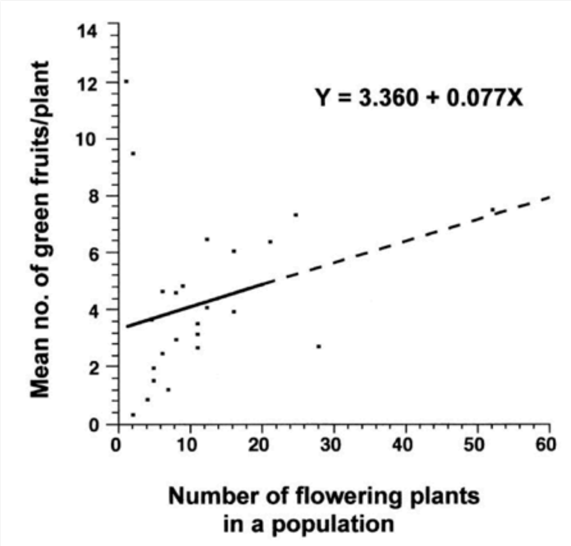


Uria aalge

Positive influence of density on fraction of reproducing individuals in common guillemot

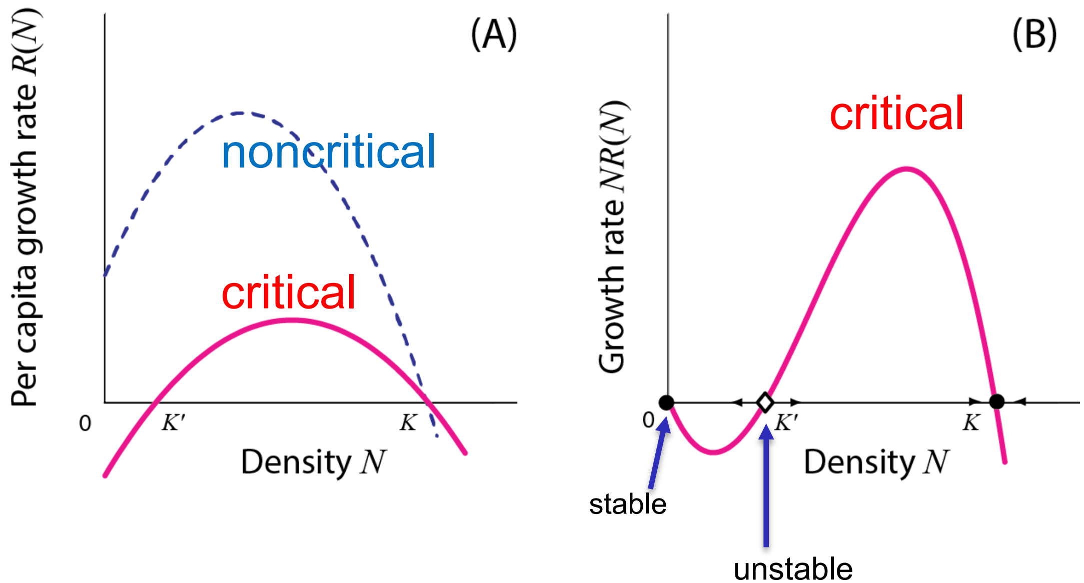
Pollination





Reproductive success
as a function of density
in American ginseng
(*Panax quinquefolium* L.)

Depensation models



Per capita growth rate

$$\dot{N} = R(N)N$$

Population growth rate

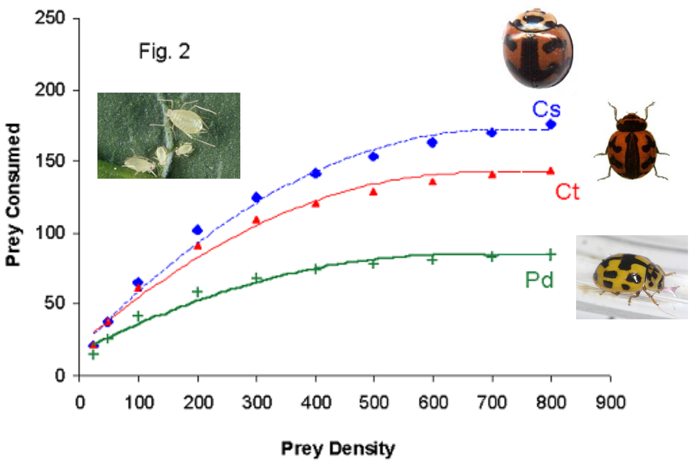
$R(N)$ = birth rate - death rate

Critical: death rate > birth rate at low density

$$\frac{dN}{dt} < 0 \text{ if } N < K' \text{ or } N > K$$

$$\frac{dN}{dt} > 0 \text{ if } K' < N < K.$$

Allee effect due to nonselective predators

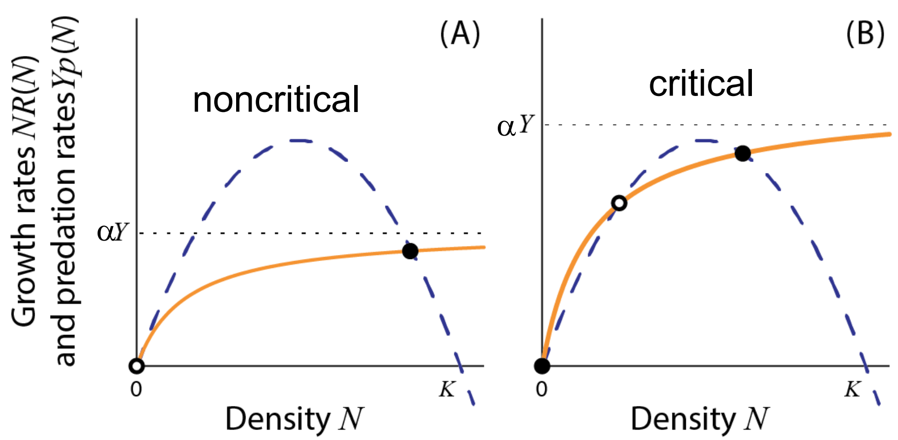


Type II functional response of ladybirds, *Cheilomenes sexmaculata* (*Cs*), *Coccinella transversalis* (*Ct*), and *Propylea dissecta* (*Pd*) at different densities of the aphid *Myzus persicae*

Type II functional response

$$\dot{N} = rN\left(1 - \frac{N}{K}\right) - Y\frac{\alpha N}{N + \beta}$$

$$Y = \text{No. of predators}$$



$$\dot{N} = NR^*(N) - Yp(N)$$