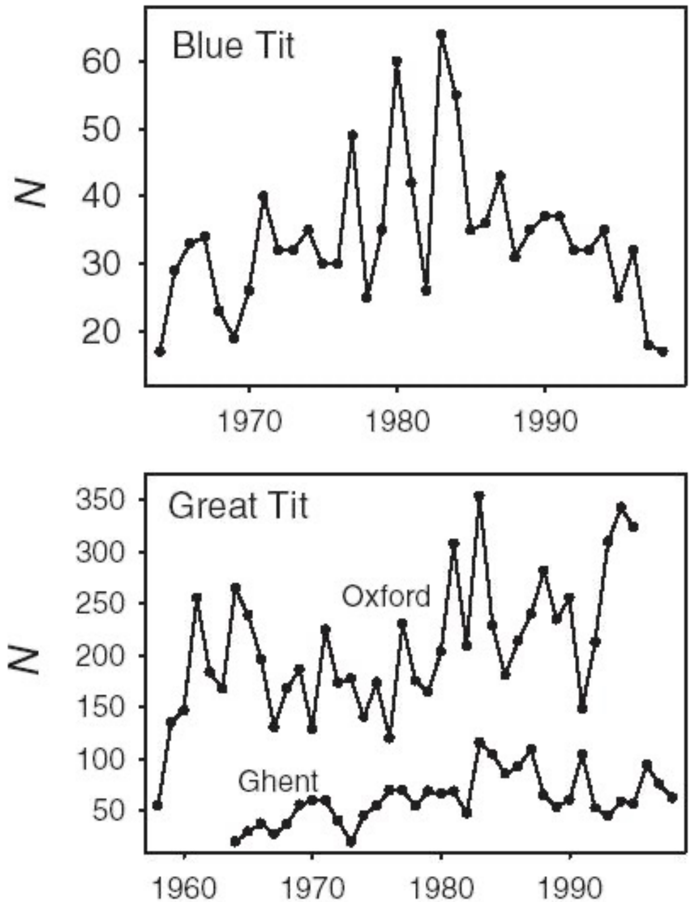
Stochastic fluctuations in population dynamics

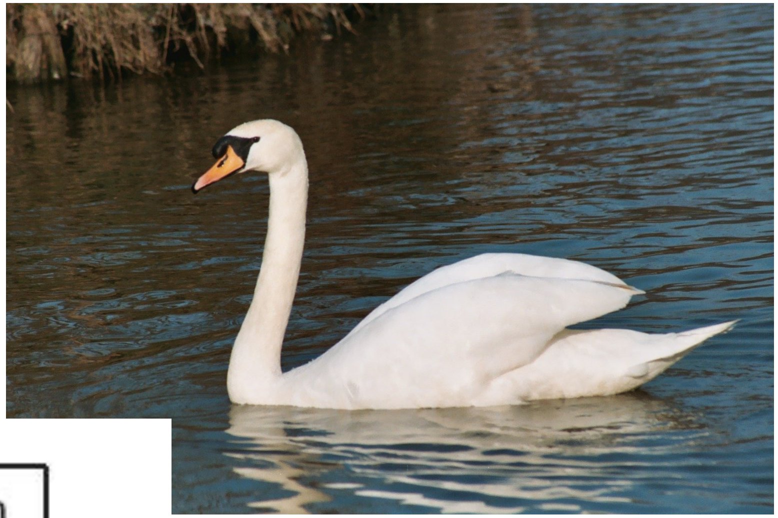


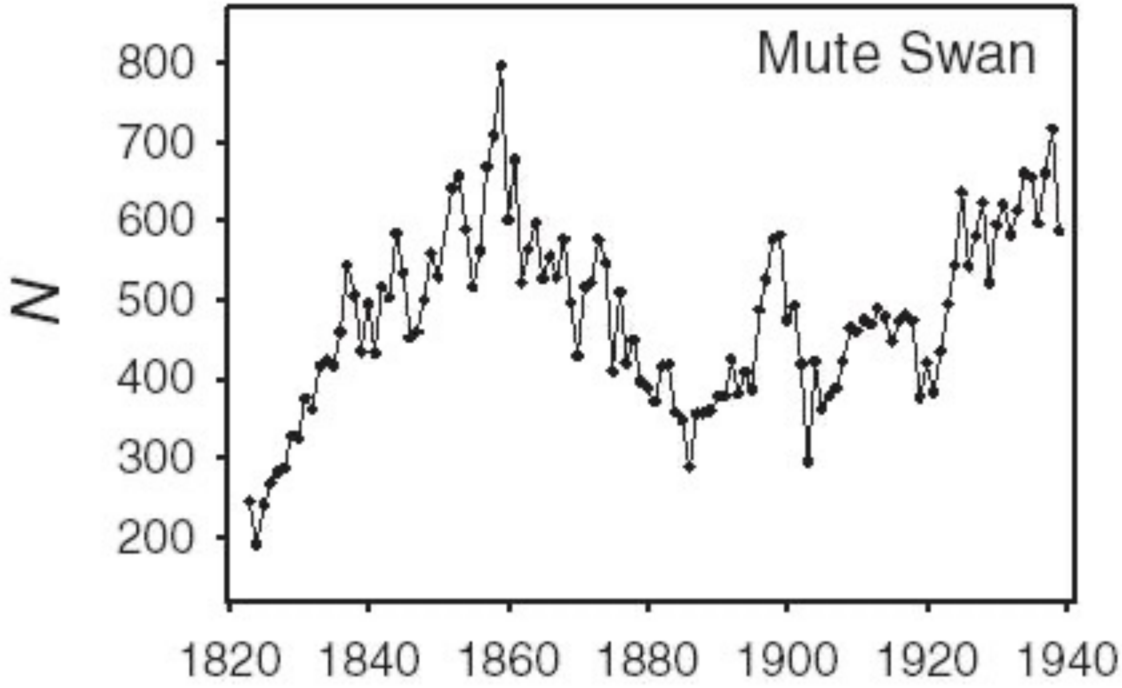
Blue tit
(*Parus caeruleus*)

Great tit
(*Parus maior*)

Fluctuations in population dynamics

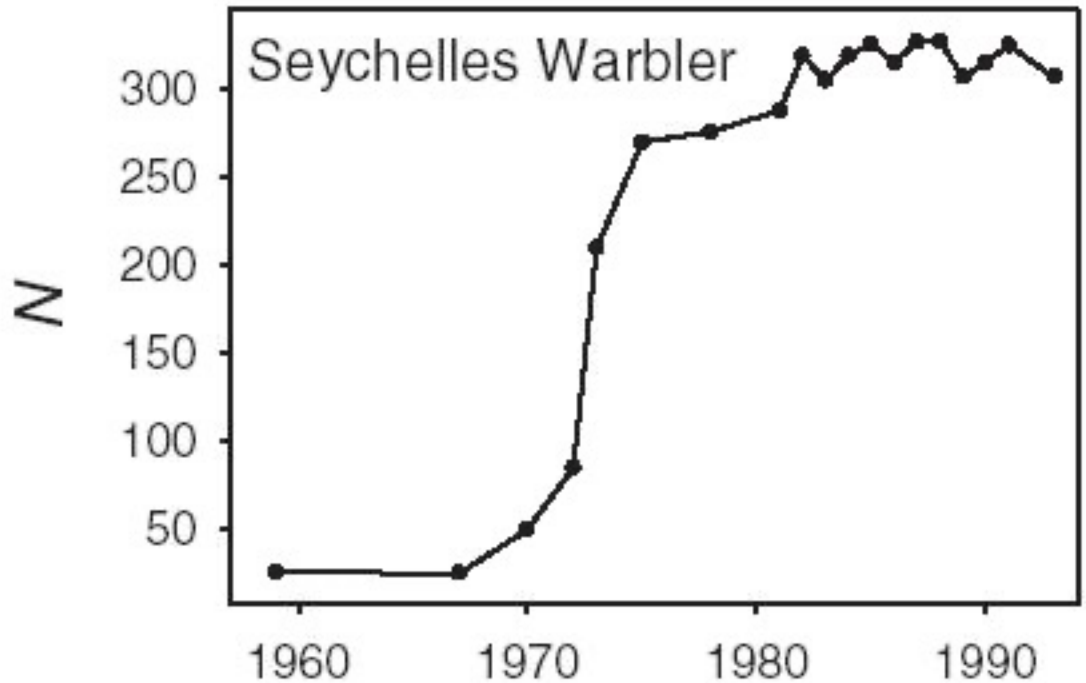
Variation coefficient
$CV = \sigma_N / N_{average}$
$\sigma_{\log N} \cong CV$ if $CV<30\%$





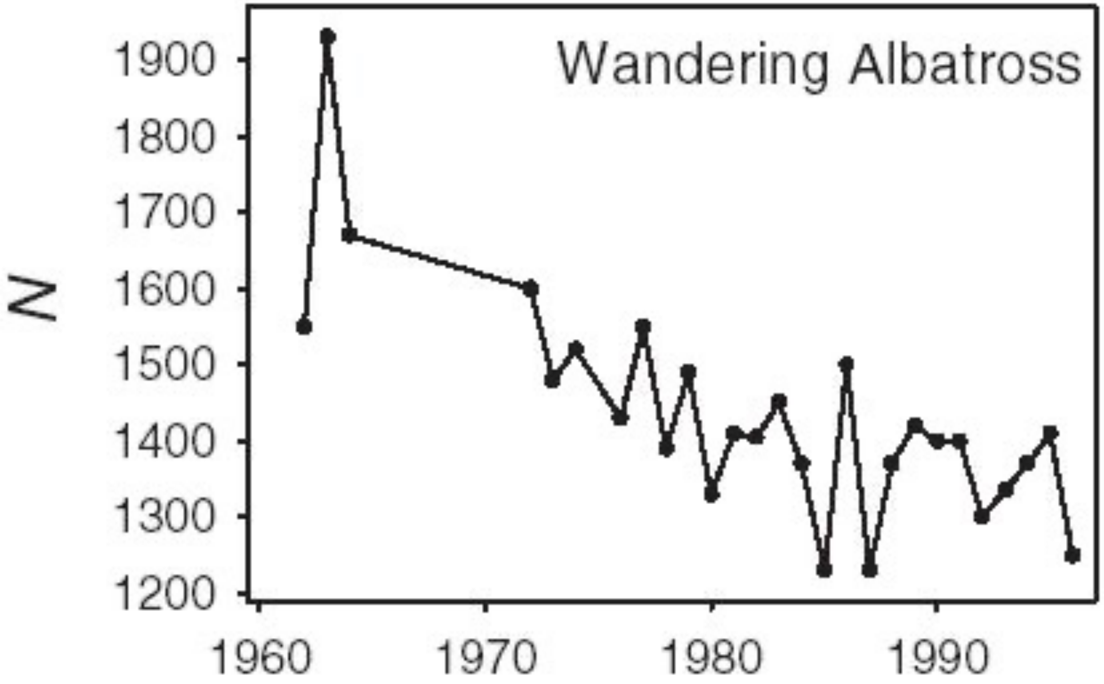
Swan
(*Cygnus olor*)

Fluctuations in population dynamics



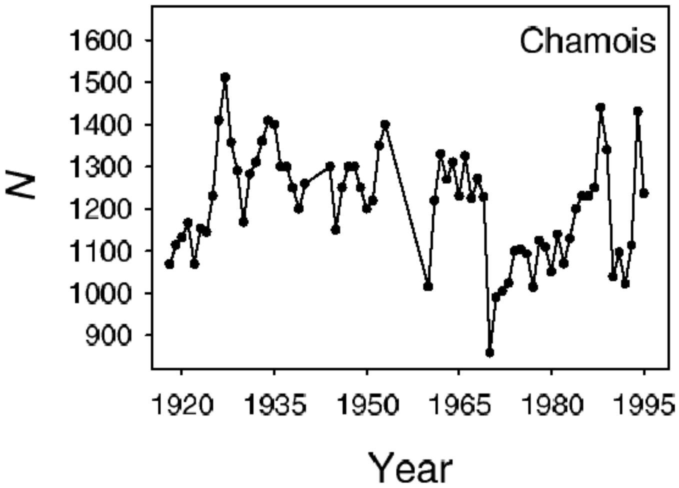
Seychelles warbler
(*Acrocephalus sechellensis*)

Fluctuations in population dynamics

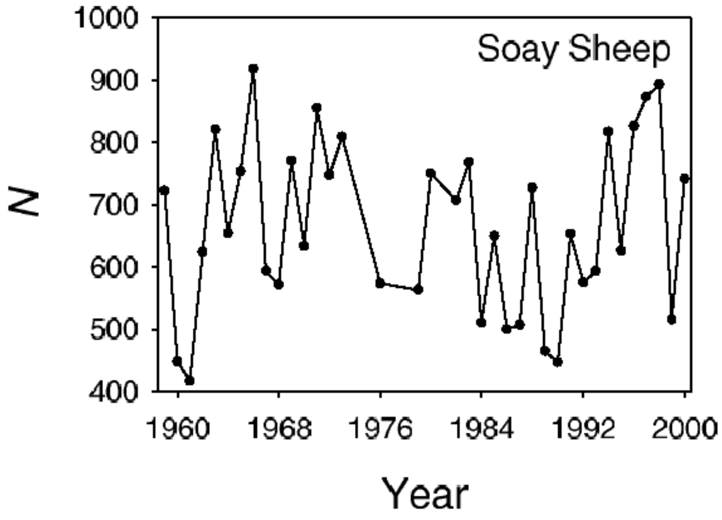


Albatross
(*Diomedea exulans*)

Fluctuations in population dynamics



Chamois
(*Rupicapra rupicapra*)



Soay sheep
(*Ovis aries*)

CV of population fluctuations

CV = coefficient of variation = SD/Mean value

Makes sense for nonnegative variables like population size N

For CV < 30% CV $\simeq$ SD(log N)

Table 1.1 Coefficient of variation (CV) for fluctuations in annual population size in birds. CV is calculated only for the last 20 years of data. α = average age at first breeding of females

Species		α	Locality	Period	CV	Reference
Blue Tit	*Parus caeruleus*	1	Lower Saxony, Germany	1974–93	0.27	Winkel (1996)
Dipper	*Cinclus cinclus*	1	Lygnavassdraget, southern Norway	1978–97	0.46	Sæther *et al.* (2000*b*)
Garganey	*Anas querquedula*	1	Engure Marsh, Latvia	1974–93	0.48	Blums *et al.* (1993)
Great Tit	*Parus major*	1	Lower Saxony, Germany	1974–93	0.17	Winkel (1996)
Great Tit	*Parus major*	1	Wytham Wood, Oxford, England	1974–93	0.27	McCleery (pers. com.)
Northern Shoveler	*Anas clypeata*	1	Engure Marsh, Latvia	1974–93	0.38	Blums *et al.* (1993)
Nuthatch	*Sitta europaea*	1	Lower Saxony, Germany	1974–93	0.31	Winkel (1996)
Pied Flycatcher	*Ficedula hypoleuca*	1	Lower Saxony, Germany	1974–93	0.22	Winkel (1996)
Pied Flycatcher	*Ficedula hypoleuca*	1	Lingen, Germany	1974–93	0.25	Winkel (1998)
Pied Flycatcher	*Ficedula hypoleuca*	1	Kilpisjärvi, northern Finland	1968–87	0.45	Järvinen (1990)
Pochard	*Aythya ferina*	1	Engure Marsh, Latvia	1974–93	0.51	Blums *et al.* (1993)
Seychelles Warbler	*Acrocephalus sechellensis*	1	Cousin Island, Seychelles	1973–93[1]	0.10	Komdeur (1994)
Song Sparrow	*Melospiza melodia*	1	Mandarte Island, British Columbia, Canada	1979–98	0.49	Sæther *et al.* (2000*a*)
Tufted Duck	*Aythya fuligula*	1	Engure Marsh, Latvia	1974–93	0.25	Blums *et al.* (1993)
Avocet	*Recurvirostra avosetta*	2	Havergate, Suffolk, England	1967–86	0.30	Hill (1988)
Grey Heron	*Ardea cinera*	2	Southern England	1979–98	0.09	B.T.O. (pers. com.)
Kentish Plover	*Charadrius alexandrinus*	2	Niedersachsen, Germany	1974–93	0.57	Hälterlein and Südbeck (1996)
Ural Owl	*Strix uralensis*	2	Hämeenlinna, Finland	1969–88	0.50	Saurola (1989)
Common Tern	*Sterna hirundo*	3	Mecklenburg-Vorpommern, Germany	1978–97	0.39	Spretke (1998)
Sandwich Tern	*Sterna sandvicensis*	3	Schleswig-Holstein, Germany	1974–93	0.44	Hälterlein and Südbeck (1996)
Mute Swan	*Cygnus olor*	4	River Thames, England	1920–39	0.15	Cramp (1972)
South Polar Skua	*Catharacta maccormicki*	6	Pointe Géologie, Terre Adélie, Antarctica	1981–2000	0.19	Weimerskirch (pers. com.)
Short-tailed Shearwater	*Puffinus tenuirostris*	7	Fisher Island, Tasmania	1965–84	0.15	Bradley *et al.* (1991)
Northern Fulmar	*Fulmarus glacialis*	9	Eynhallow, Orkney	1958–77	0.27	Dunnet *et al.* (1979)
Wandering Albatross	*Diomedea exulans*	10	Bird Island, South Georgia	1974–93	0.06	Croxall *et al.* (1997)

[1] Only 15 censuses available during the last 20 study years.

Deterministic and stochastic components

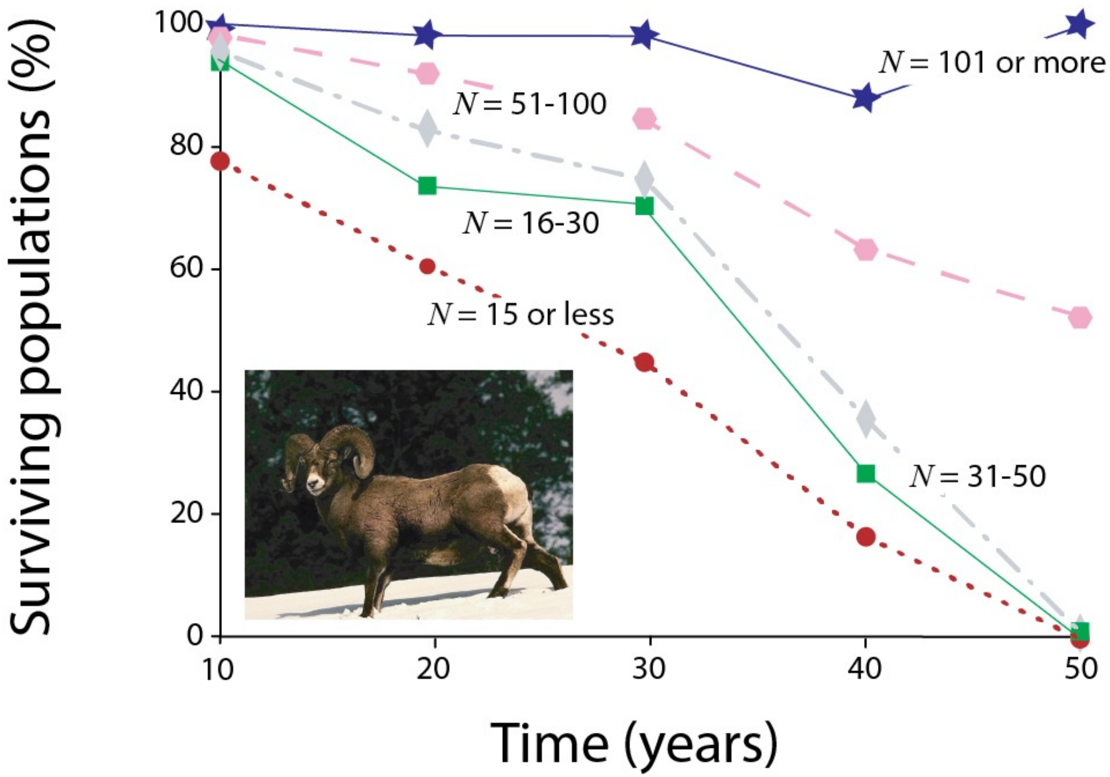
Fluctuations in population dynamics can be due to

- Deterministic drivers:
  - High fertility;
  - Seasonality;
  - Interactions (predation …)

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

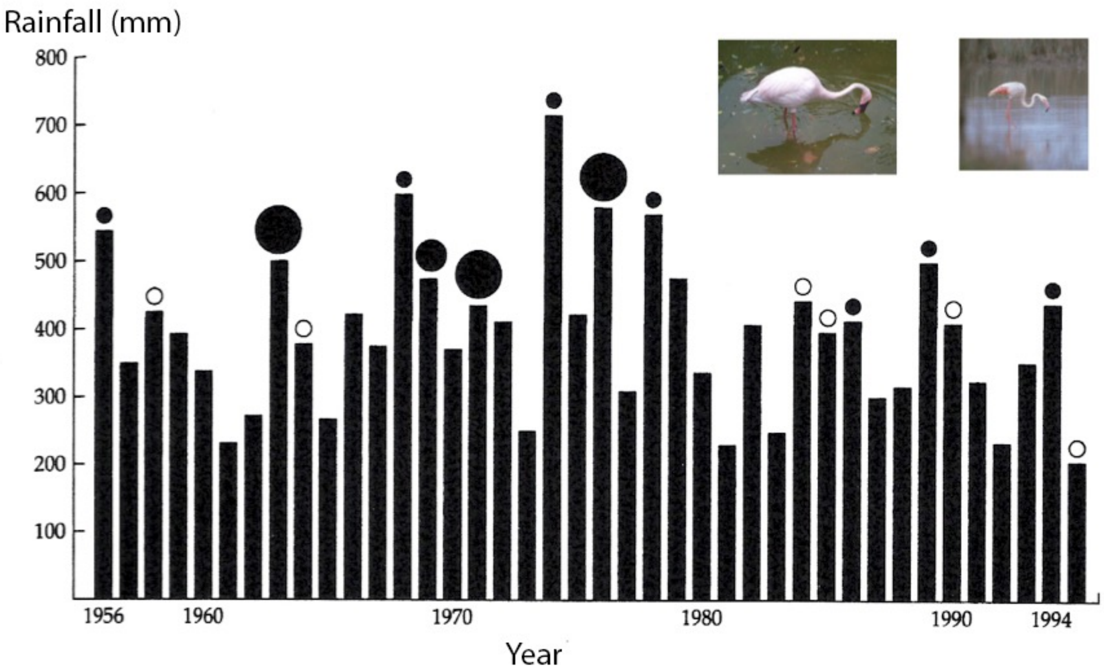
- Stochastic drivers:
  - demographic (Bighorn sheep)
  - environmental (Flamingoes in South Africa);

Examples



Bighorn sheep
(*Ovis canadensis*)

Examples



Circles indicate reproduction success

Flamingo
(*Phoenicopterus ruber*)

Phoeniconaias minor

Extinctions: deterministic or stochastic?

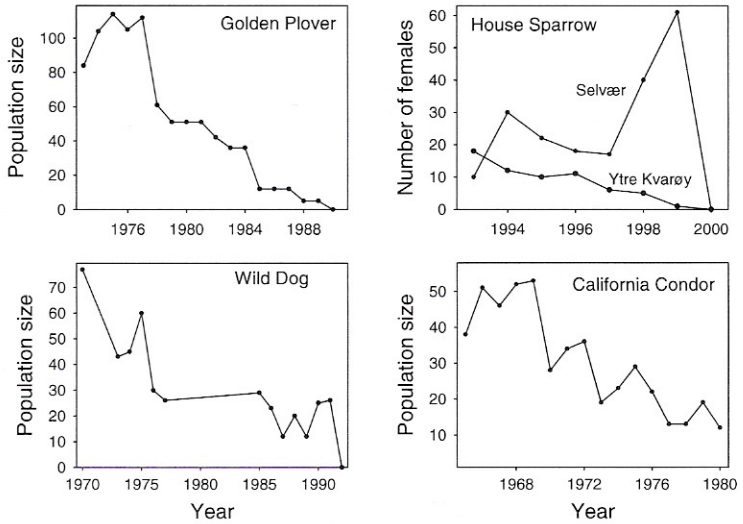


Fig. 2.3 Decline to extinction of a Scottish population of Golden Plover *Pluvialis apricaria* (Parr, 1992), the Wild Dog *Lycaon pictus* in Serengeti National Park, Tanzania (Burrows *et al*., 1995), two populations of House Sparrow *Passer domesticus* at Helgeland, northern Norway (Sæther *et al*., unpubl.), and the California Condor *Gymnogyps californianus* (Dennis *et al*., 1991).

Discrete-time demography

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

Individual fitness

Contribution of individual *i* at time *t* to next generation *t* + 1

$$w_{i,t} \quad \Rightarrow \quad N_{t+1} = \sum_{i=1}^{N_t} w_{i,t}$$

Is there a relationship?

N.B. Better if you always think that N_t is the number of females

Calculating fitnesses

Problem ER10

In 2023 a population of pink finches in the natural reserve of Greybeeches consists of only three adult reproductive females (from now on called A, B, C). They breed in mid spring. You know that:

- Female A produces 7 eggs, of which only 5 hatch; 3 nestlings are female and of them 2 will survive till adulthood and will reproduce in 2024; female A dies in December 2023;
- Female B produces 4 eggs, all of which hatch; 1 nestling is female but will not survive till adulthood; female B is still alive in mid spring 2024;
- Female C produces 9 eggs, of which only 6 hatch; 4 nestlings are female and of them 3 will survive till adulthood and will reproduce in 2024; female C is still alive in mid spring 2024;

Calculate the individual fitnesses of A, B e C and the finite rate of increase of the population between 2023 and 2024.

Female A:2+0 fitness(A)=2; fitness(B)=0+1=1; fitness(C)=3+1=4
N(2024)=2+1+4=7 N(2023)=3 λ_2023=N(2024)/N(2023)=7/3=2.333

Environmental vs. demographic stochasticity

$$N_{t+1} = \lambda_t N_t = \sum_{i=1}^{N_t} w_{i,t} \qquad \lambda_t = \sum_{i=1}^{N_t} w_{i,t} \Big/ N_t$$

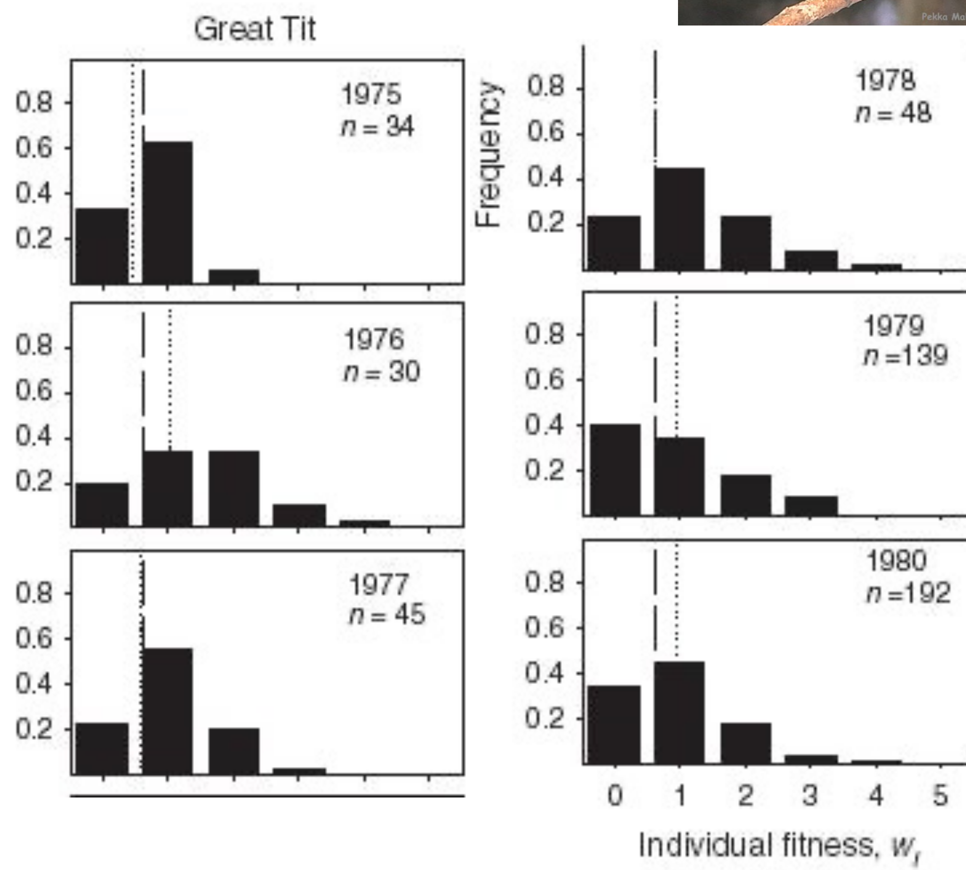
where

$$\boxed{w_{i,t} = \bar{w}_t + \delta_i}$$

$$\begin{cases} E\left[\delta_i\right] = 0 \\ Var\left[\delta_i\right] = \sigma_d^2 \end{cases}$$

$$\begin{cases} E\left[\bar{w}_t\right] = \bar{\bar{w}} \\ Var\left[\bar{w}_t\right] = \sigma_e^2 \end{cases}$$

$$\begin{cases} E\left[\lambda_t \middle| N_t = N\right] = ? \\ Var\left[\lambda_t \middle| N_t = N\right] = ? \end{cases}$$



Environmental vs. demographic stochasticity

$$N_{t+1} = \lambda_t N = \sum_{i=1}^{N_t} w_{i,t}$$

$$\lambda_t = \sum_{i=1}^{N} w_{i,t} \Big/ N = \sum_{i=1}^{N} \frac{\overline{w}_t + \delta_i}{N} = \overline{w}_t + \sum_{i=1}^{N} \frac{\delta_i}{N}$$

$$E[\lambda_t] = \overline{\overline{w}}$$

$$Var[\lambda_t] = Var[\overline{w}_t] + \frac{Var\left[\sum_{i=1}^{N} \delta_i\right]}{N^2} = \sigma_e^2 + \sigma_d^2 \Big/ N$$

Typical values of σ_e^2 and σ_d^2

Table 1.2 Estimated demographic variance, $\hat{\sigma}_d^2$, and environmental variance, $\hat{\sigma}_e^2$, in multiplicative growth rate in populations with different mean age at first breeding of females, α

Species	Locality	α	$\hat{\sigma}_d^2$	$\hat{\sigma}_e^2$	Reference
Barn Swallow, *Hirundo rustica*	Denmark	1	0.18	0.024	Engen *et al.* (2001)
Dipper	Southern Norway	1	0.27	0.21	Sæther *et al.* (2000*b*)
Great Tit	Wytham Wood, U.K.	1	0.57	0.079	Sæther *et al.* (1998*a*)
Pied Flycatcher	Hoge Veluwe, Netherlands	1	0.33	0.036	Sæther *et al.* (2002*a*)
Song Sparrow	Mandarte Island, B.C.	1	0.66	0.41	Sæther *et al.* (2000*a*)
Soay Sheep, *Ovis aries*	Hirta Island, U.K.	1	0.28	0.045	Sæther *et al.* (unpubl.)
Brown Bear, *Ursus arctos*	Southern Sweden	4	0.16	0.003	Sæther *et al.* (1998*b*)
Brown Bear	Northern Sweden	5	0.18	0.000	Sæther *et al.* (1998*b*)

$$N \gg \sigma_d^2 \Big/ \sigma_e^2$$

$$e.g.\ N = 10\,\sigma_d^2 \Big/ \sigma_e^2 = N_c$$

Calculate critical population

Demographic stochasticity

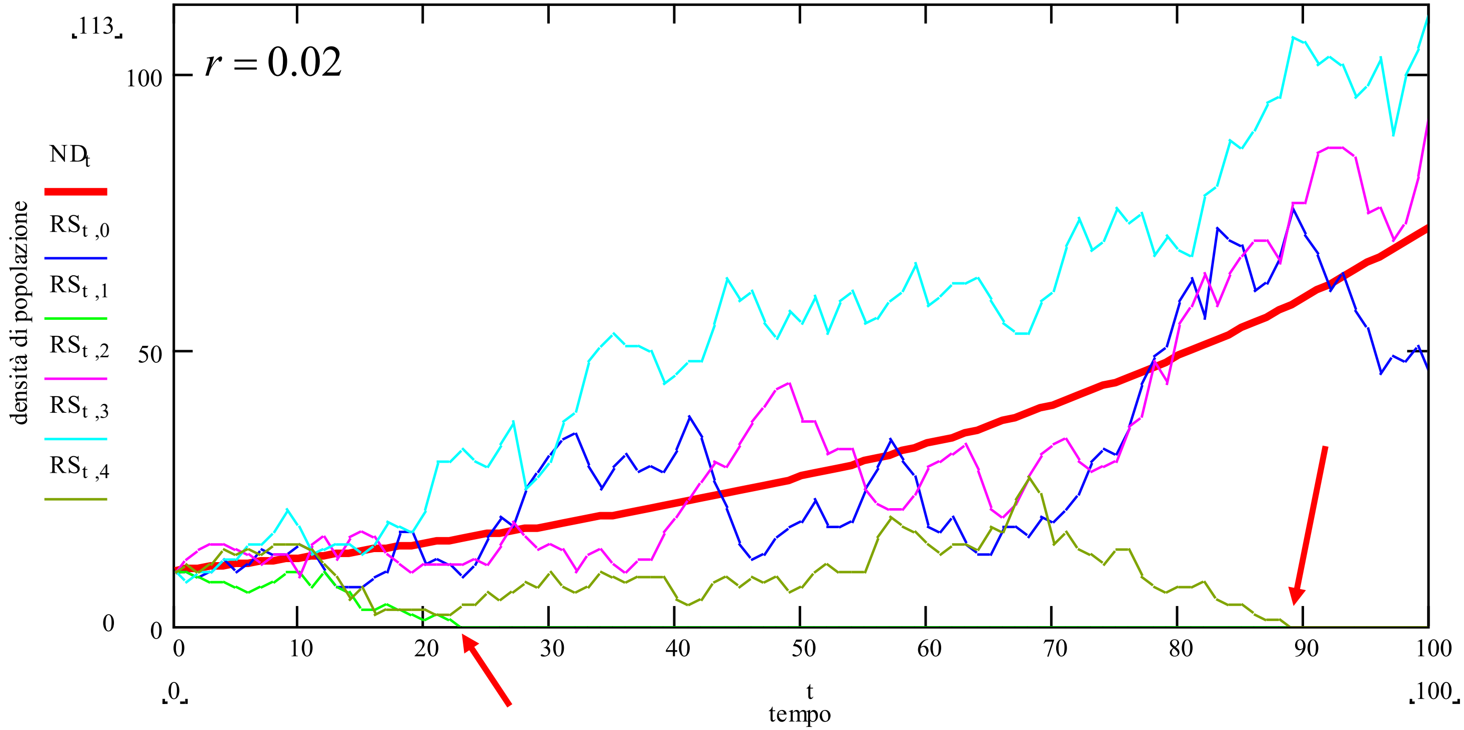
- We use a continuous time model (birth-death process)
- Poisson assumption: in a very short time *dt* at most one event can occur: nothing, one birth, one death
- Malthusian case
  - Variables $p_i(t)$ = probability that population contains *i* individuals at time *t*
  - Demographic parameters (birth rate ν and mortality rate μ are constant)
  - $\nu\, dt$ = probability a mother produces one birth (daughter) between *t* and *t*+*dt*
  - $\mu\, dt$ = probability one mother dies between *t* and *t*+*dt*
  - 1 - $\nu\, dt$ - $\mu\, dt$ = probability no event
  - so-called Kolmogorov equations describe dynamics of $p_i(t)$
- $N(t)$ is a stochastic variable at any time *t* (stochastic process)

Important property of the expected value of $N(t)$ at any time *t*

$$\bar{N}(t) = E\left[N(t)\right] = \sum_{i=0}^{\infty} i p_i(t) \quad \Rightarrow \quad \frac{d\bar{N}(t)}{dt} = (\nu - \mu)\ \bar{N}(t)$$

Realizations of birth-death stochastic process

$$\bar{N}(t) = N(0)\exp(rt) \qquad r = \nu - \mu$$



Variance of total number increases with time

There can be extinctions!

The extinction risk

$p_0(t)$ = probability that population contains 0 individuals at time t = probability of extinction = probability that time of extinction is ≤ t

$$p_0(t) = \left(\frac{\mu \exp(rt) - \mu}{\nu \exp(rt) - \mu} \right)^{N_0} \Rightarrow \begin{cases} \text{if } r < 0, & \lim_{t\to\infty} p_0(t) = \cdots \\ \text{if } r = 0, & \lim_{t\to\infty} p_0(t) = \cdots \\ \text{if } r > 0, & \lim_{t\to\infty} p_0(t) = \cdots \end{cases}$$

N_0 = number of reproductive females

Long-term risk

$$\lim_{t\to\infty} p_0(t) = \left(\frac{-\mu}{-\mu} \right)^{N_0} = 1. \qquad r < 0$$

$$\lim_{t\to\infty} p_0(t) = \lim_{t\to\infty} \left(\frac{\mu \exp(rt) - \mu}{\nu \exp(rt) - \mu} \right)^{N_0} = \left(\frac{\mu}{\nu} \right)^{N_0} = \left(\frac{\mu}{r + \mu} \right)^{N_0}. \qquad r > 0$$

$$\lim_{r\to 0} p_0(t) = \lim_{r\to 0} \left(\frac{\mu t \exp(rt)}{(\mu + r)t \exp(rt) + \exp(rt)} \right)^{N_0} = \left(\frac{\mu t}{1 + \mu t} \right)^{N_0}.$$

$$\lim_{t\to\infty} p_0(t) = \lim_{t\to\infty} \left(\frac{\mu t}{1 + \mu t} \right)^{N_0} = 1. \qquad r = 0$$

Extinction probability (demographic stochasticity)

N_0	Asymptotic Extinct. Prob.	Extinct. 10	Extinct. 50
1	0.909090909	0.8634105	0.908531
5	0.620921323	0.4798291	0.61901
10	0.385543289	0.2302359	0.383174
50	0.008518551	0.0006469	0.00826
100	7.25657E-05	4.185E-07	6.82E-05
500	2.01214E-21	1.284E-32	1.48E-21

Probability of asymptotic extinction and after 10 and 50 generations
$r = 0.05$ and $\mu = 0.5$ time^{-1}
generation time = $1/\mu$

$\nu = 0.55$

	p_0			
N_0	$t = 1/\mu$	$t = 10/\mu$	$t = 100/\mu$	$t = 1000/\mu$
1	0.5	0.909	0.990	0.999
5	0.031	0.621	0.951	0.995
10	0.00097	0.386	0.905	0.990
50	$8.88\ 10^{-6}$	0.0085	0.608	0.951
100	$7.89\ 10^{-31}$	0.000072	0.370	0.905
500	~ 0	$2.01\ 10^{-21}$	0.0069	0.607

Extinction probability in stationary populations ($r = 0$) for varying N_0 at different generations

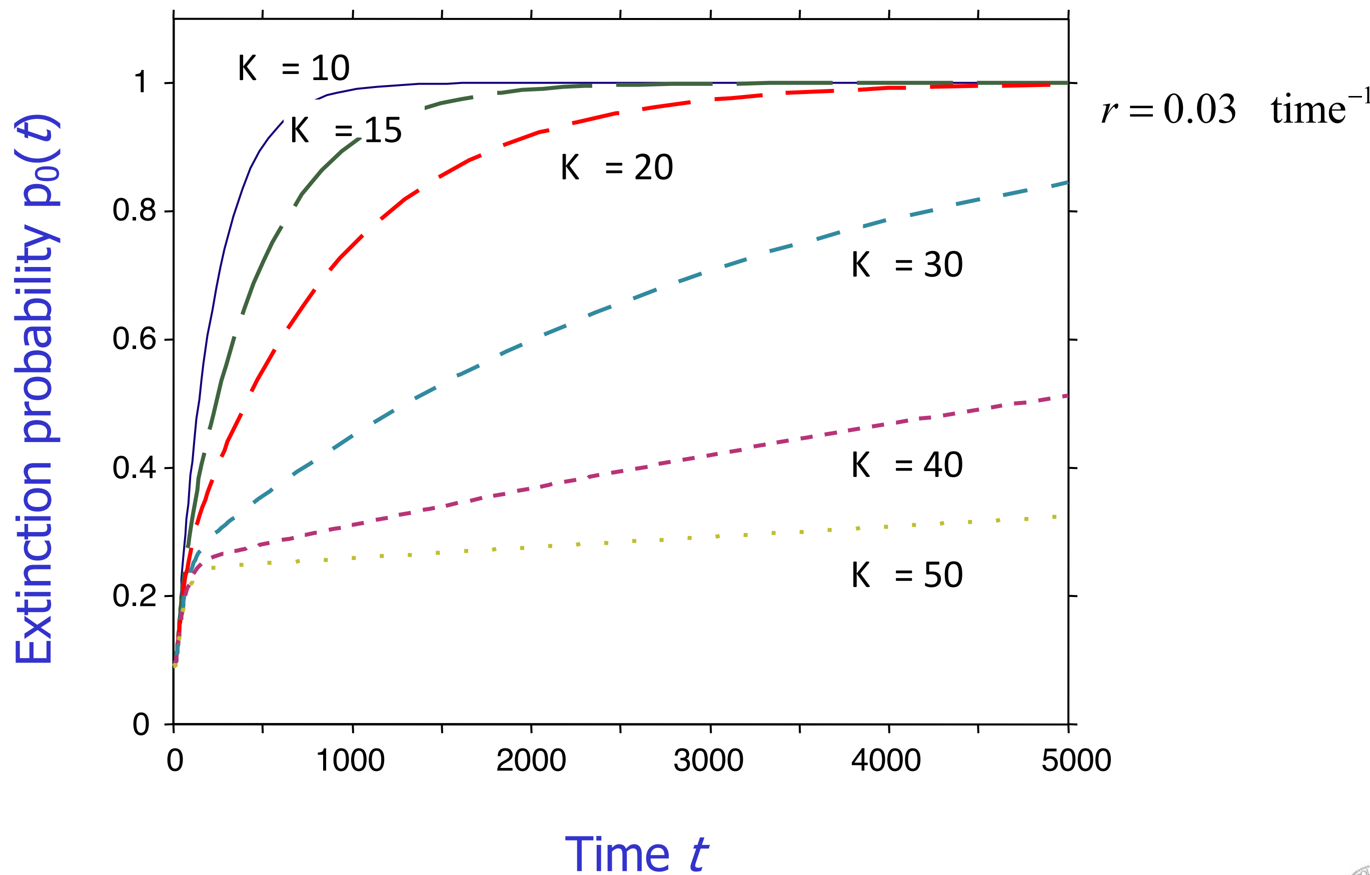
Average and median extinction time (hint: $p_0(t)$ is a cdf)

Demographic stochasticity and density-dependence

In nonMalthusian case

Extinction is certain in the long term, however …

$$\lim_{t \to \infty} p_0(t) = 1$$



Environmental stochasticity

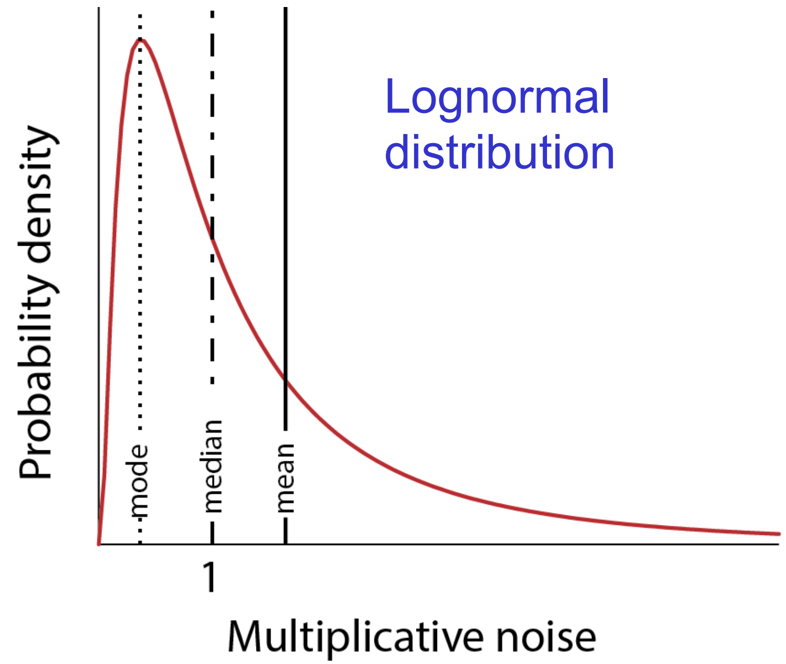
$$N_{t+1} = \sum_{i=1}^{N_t} w_{i,t} = \bar{w}_t N_t = \lambda_t N_t$$

where

$$\boxed{\lambda_t = \delta_t \Lambda(N_t) = \exp(\varepsilon_t)\Lambda(N_t)}$$

White noise

$$\begin{cases} E[\varepsilon_t] = 0 \\ E[\varepsilon_t^2] = Var[\varepsilon_t] = \sigma_\varepsilon^2 \\ E[\varepsilon_t \varepsilon_{t-\tau}] = 0 \end{cases}$$



$$\begin{cases} E[\delta_t] = \exp(\sigma_\varepsilon^2/2) > 1 \\ \mathrm{Median}[\delta_t] = \exp(\mathrm{Median}[\varepsilon_t]) = 1 \\ \mathrm{Mode}[\delta_t] < 1 \end{cases}$$

Environmental stochasticity: the Malthusian case

$$\boxed{\lambda_t = \delta_t \Lambda\left(N_t\right) = \exp\left(\varepsilon_t\right)\lambda}$$

λ = median!

where $N_t = \lambda_{t-1}\lambda_{t-2}\cdots\lambda_0 N_0 = \lambda^t \exp\left(\varepsilon_{t-1} + \varepsilon_{t-2} + \cdots + \varepsilon_0\right) N_0$

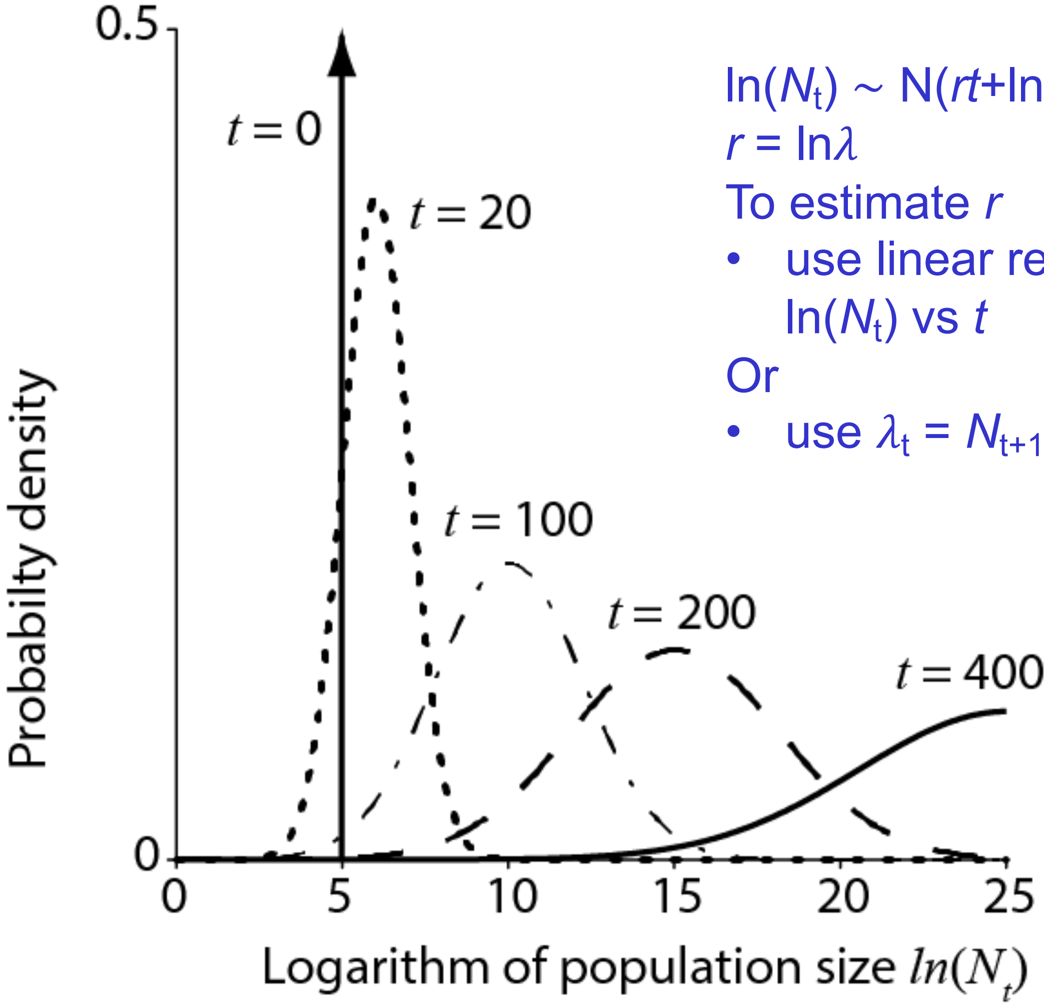
Take logarithms

$$\log\left(N_t\right) = t\log(\lambda) + \log\left(N_0\right) + \sum_{i=0}^{t-1}\varepsilon_i \longrightarrow \begin{cases} E\left[\sum_{i=0}^{t-1}\varepsilon_i\right] = \sum_{i=0}^{t-1} E\left[\varepsilon_i\right] = 0 \\ Var\left[\sum_{i=0}^{t-1}\varepsilon_i\right] = \sum_{i=0}^{t-1} Var\left[\varepsilon_i\right] = t\sigma_\varepsilon^2 \end{cases}$$

Result: log(N_t) is distributed as a Normal with

$$\begin{cases} E\left[\log\left(N_t\right)\right] = t\log\left(\lambda\right) + \log\left(N_0\right) + \sum_{i=0}^{t-1} E\left[\varepsilon_i\right] = rt + \log\left(N_0\right) \\ Var\left[\log\left(N_t\right)\right] = E\left[\left(\log\left(N_t\right) - E\left[\log\left(N_t\right)\right]\right)^2\right] = E\left[\sum_{i=0}^{t-1}\varepsilon_i^2\right] = \sum_{i=0}^{t-1} Var\left[\varepsilon_i\right] = t\sigma_\varepsilon^2 \end{cases}$$

Environmental stochasticity: the Malthusian case



$\ln(N_t) \sim N(rt + \ln(N_0), t\sigma_\varepsilon^2)$

$r = \ln\lambda$

To estimate r

- use linear regression of $\ln(N_t)$ vs t

Or

- use $\lambda_t = N_{t+1}/N_t$, however…

Environmental stochasticity: the Malthusian case

If

$$\boxed{\log(\lambda) = r > 0}$$

then population increases.
Remark: logarithm of median must be positive not logarithm of average!

In fact, with lognormal noise

$$E[\lambda_t] = E[\lambda\delta_t] = \lambda E[\delta_t] = \lambda \exp\left(\frac{\sigma_\varepsilon^2}{2}\right) > \lambda$$

Therefore, using the average of λ_t's can be misleading and produce an overestimation of the population growth rate

Example

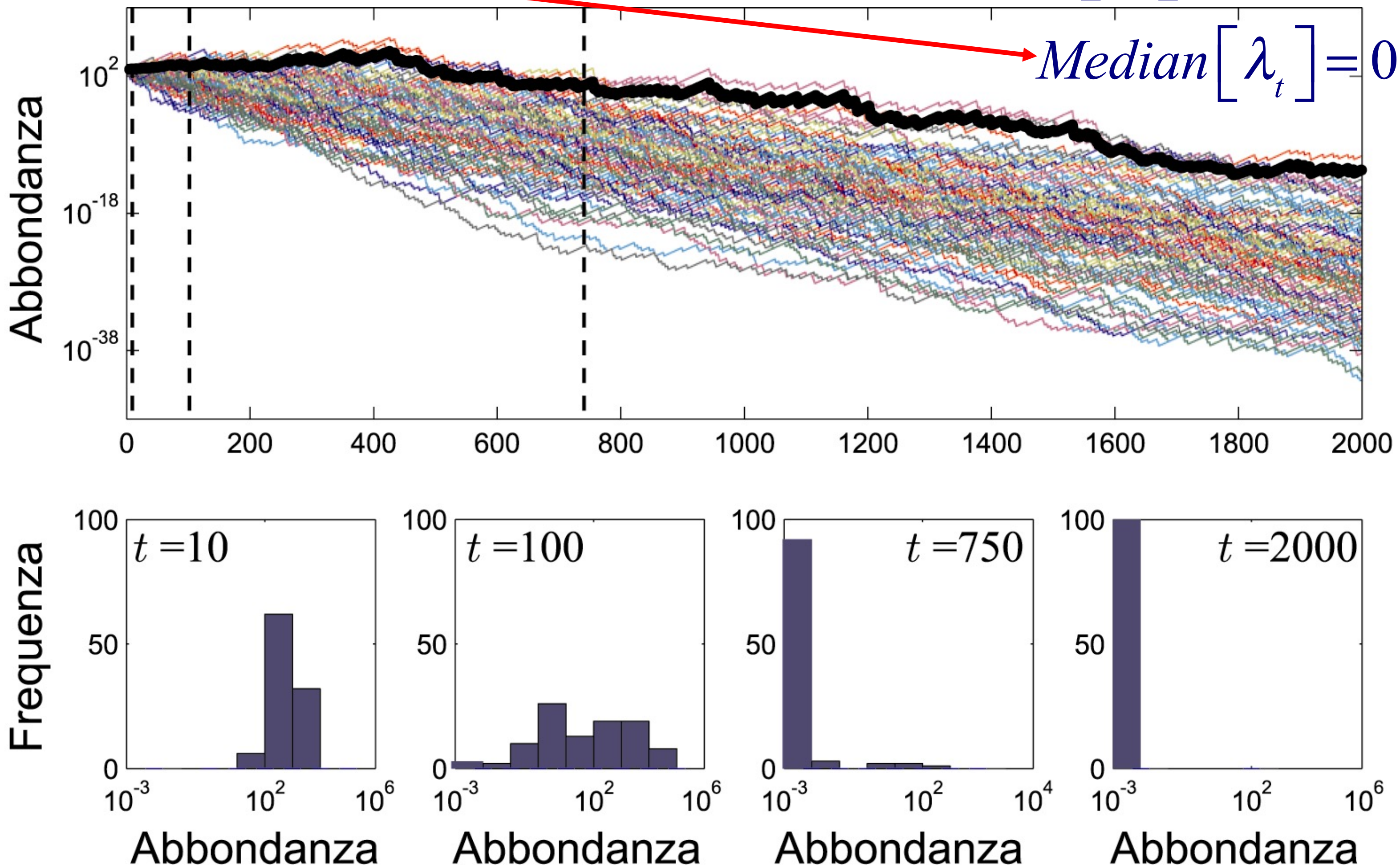
Annual population with finite rate of increase equal to 1.1 in normal years and 0.3 in critical years that occur once in a decade. What is the fate of the population?

Environmental stochasticity: the Malthusian case

ln(1.1)*0.9+ln(0.3)*0.1=ln(lambda)

0.9*1.1+0.1*0.3 → $E\left[\lambda_t\right]=1.02$

$Median\left[\lambda_t\right]=0.966$

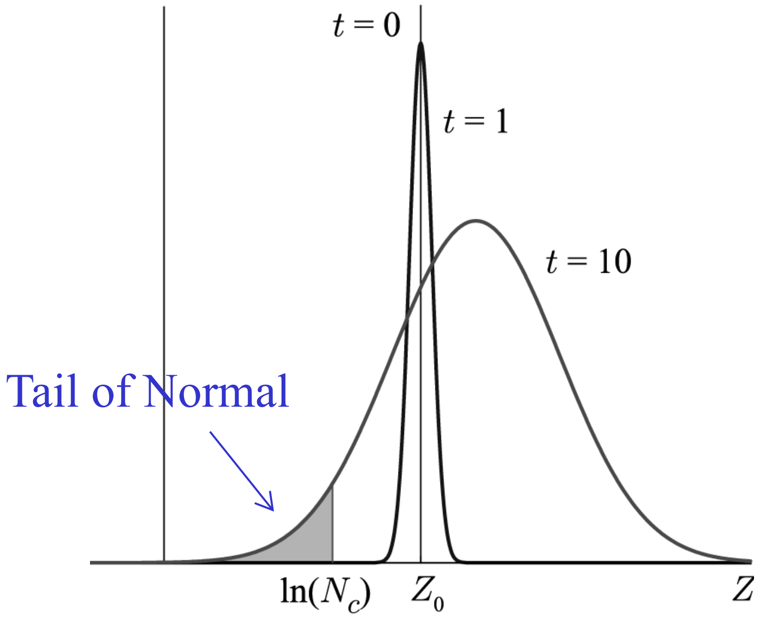


Extinction risk and environmental stochasticity

Whenever environmental stochasticity brings population below a critical threshold it can be captured by an extinction “vortex”:

$$N < N_c \qquad \Rightarrow \qquad \text{quasiextinction}$$

How to estimate quasiextinction probability? Based on *r* and σ^2_ε …



How to estimate σ^2_ε ?

$$\log\left(N_{t+1}/N_t\right) = r + \varepsilon_t$$

Use estimate of *r*

$$\hat{\varepsilon}_t = \log\left(N_{t+1}/N_t\right) - \hat{r}$$

$$\hat{\sigma}_\varepsilon^2 = \frac{1}{m-2}\sum_{i=1}^{m-1}\hat{\varepsilon}_i^{\,2}$$

Normal distribution table

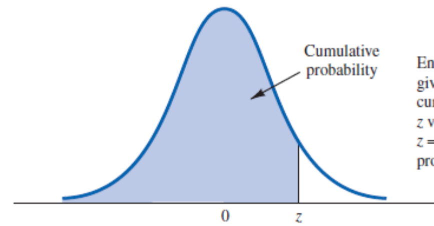
Prob{$N_t < N_c$} = Prob{lnN_t < lnN_c} = Introduce standard Normal

$$Z_t = \frac{\ln(N_t) - rt - \ln(N_0)}{\sqrt{t}\sigma_\varepsilon}$$

$$Z_c = \frac{\ln(N_c) - rt - \ln(N_0)}{\sqrt{t}\sigma_\varepsilon}$$

Prob{lnN_t < lnN_c} = Prob{standard normal < Z_c}

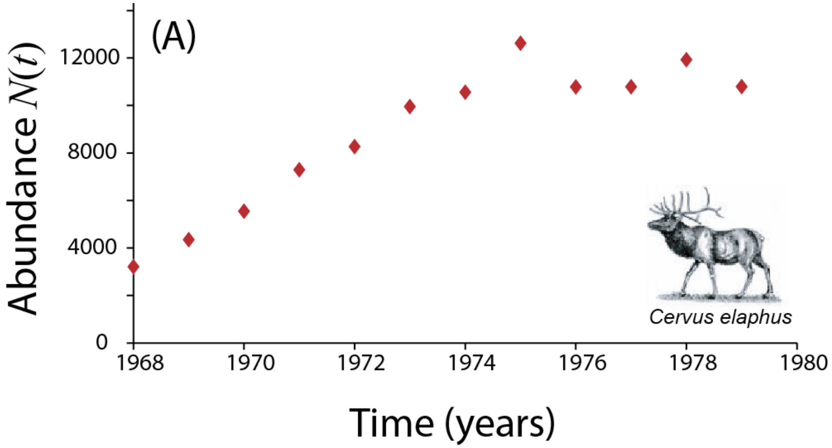
TABLE 1 CUMULATIVE PROBABILITIES FOR THE STANDARD NORMAL DISTRIBUTION (*Continued*)

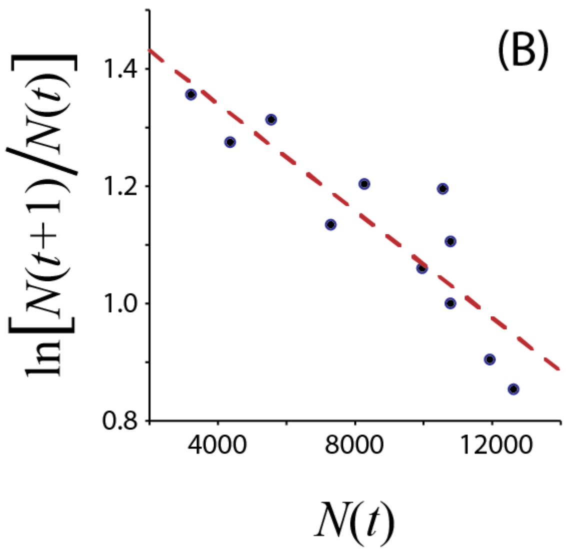


Entries in the table give the area under the curve to the left of the z value. For example, for $z = 1.25$, the cumulative probability is .8944.

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990

Environmental stochasticity and density dependence





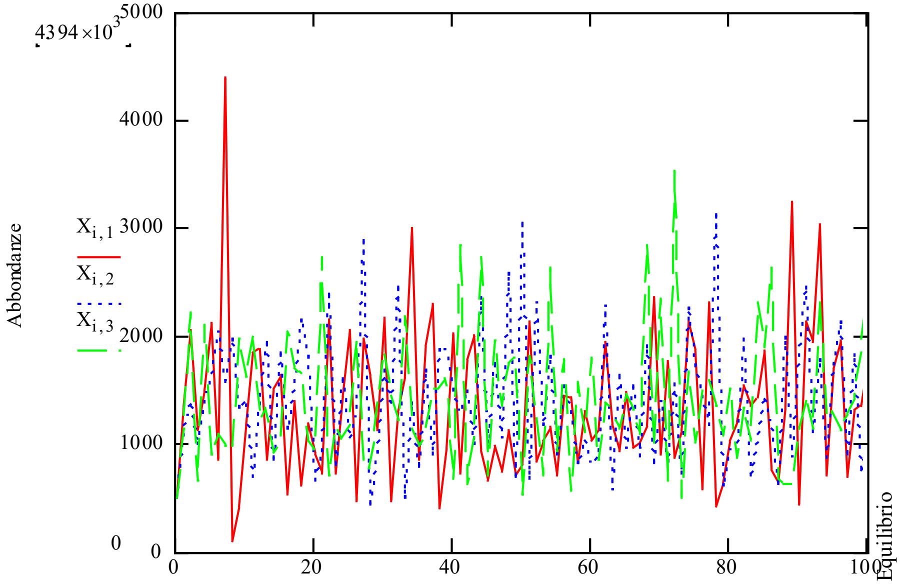
Stochastic Ricker model

$$N_t = \lambda N_t exp(-\beta N_t + \epsilon_t)$$

$$\ln\left(\frac{N_{t+1}}{N_t}\right) = \log\lambda - \beta N_t + \varepsilon_t$$

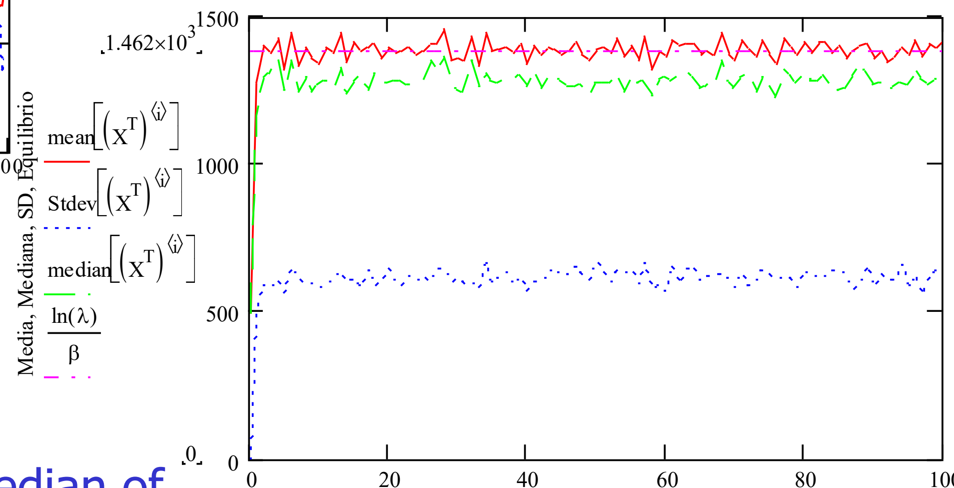
Red Deer abundance in Yellowstone Park, and logarithmic rate of increase vs deer abundane (data and linear regression)

Environmental stochasticity and density dependence



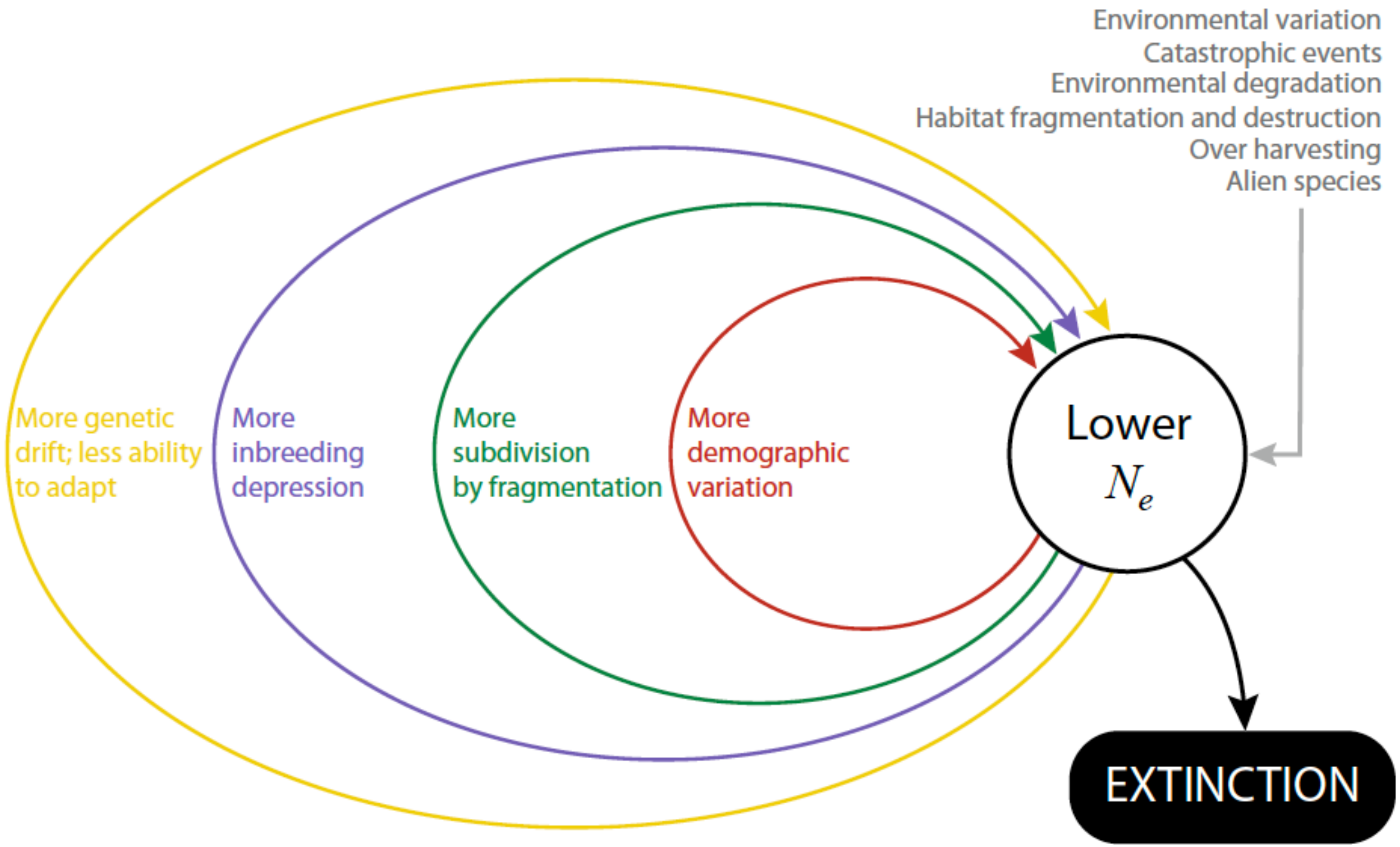
$$N_{t+1} = \lambda\, N_t \exp(-\beta\, N_t + \varepsilon_t)$$

$\lambda = 4$, $\beta = 0.001$, $\sigma_\varepsilon = 0.385$

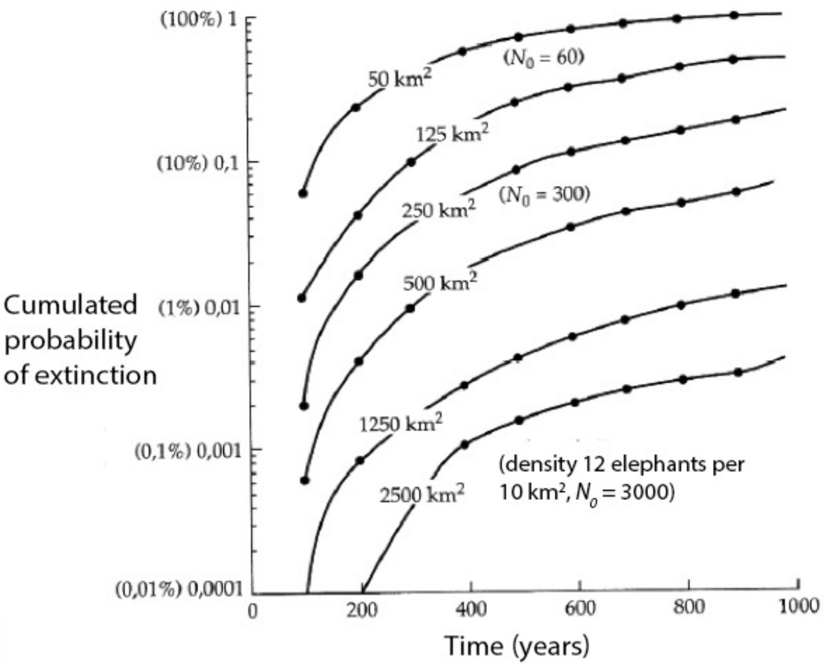


- average, standard deviation and median of population abundance;
- extinction probability vs time;
- average and median extinction time

Extinction vortices



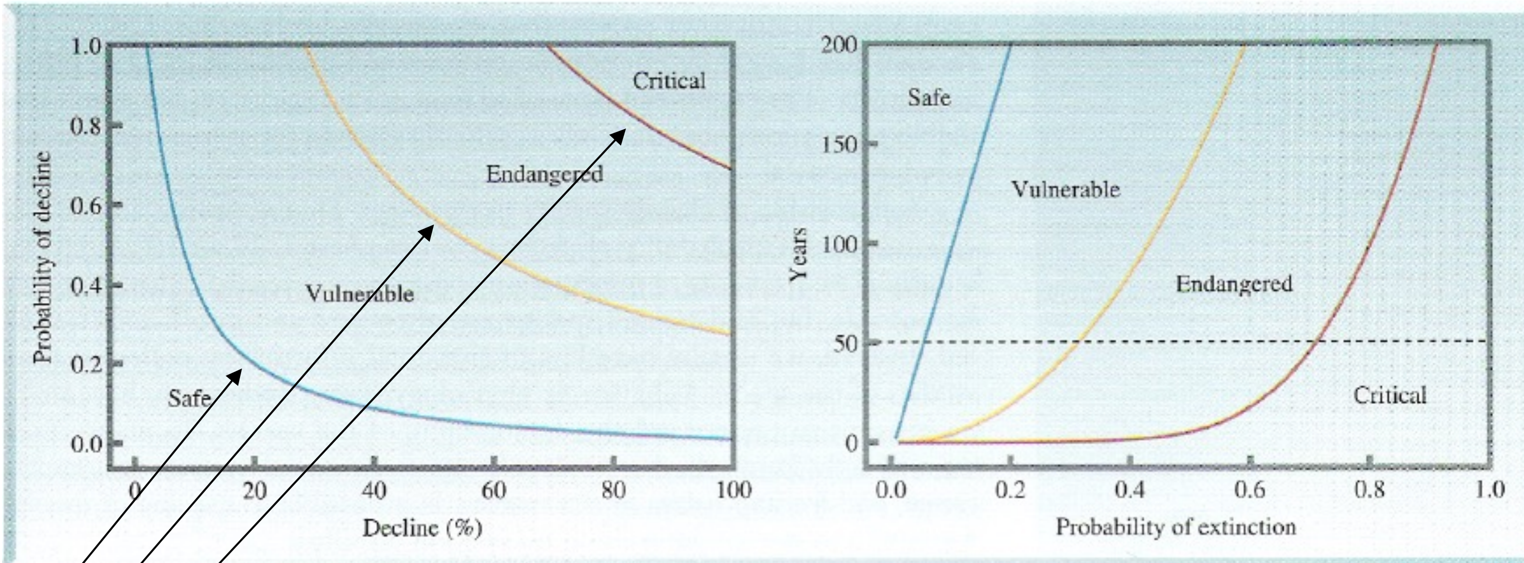
Population Viability Analysis (PVA)



African elephants

Software: VORTEX, RAMAS, ALEX …

http://www.ramas.com



Equal risk curves

Risk=Decline × ProbDecline

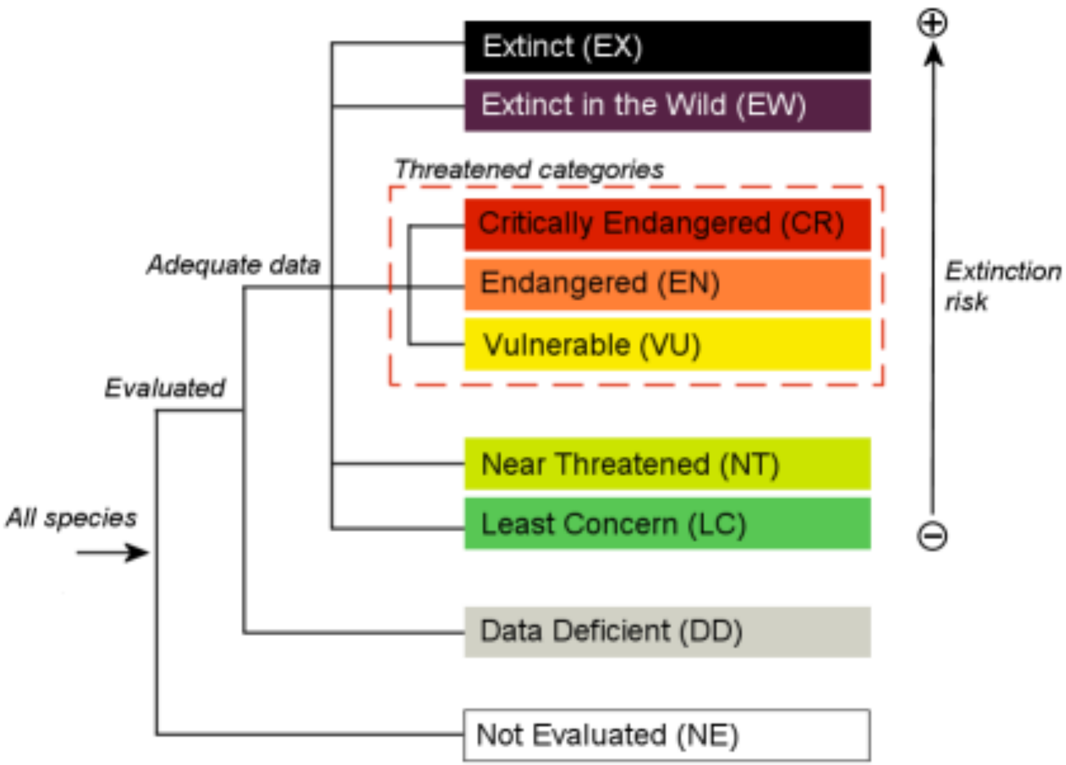
How to classify threatened species

Mace and Lande's Criteria for Threatened Species (1991)

	Population Trait	*Critical*	*Endangered*	*Vulnerable*
A	Observed decline	80% in 10 years or 3 generations	50% in 10 years or 3 generations	20% in 10 years or 3 generations
B	Geographical range	< 100 km^2 single location	< 5000 km^2 < 5 locations	< 20,000 km^2 < 10 locations
C	Total population	$N <$ 250 $N_s <$ 50	$N <$ 2,500 $N_s <$ 250	$N <$ 10,000 $N_s <$ 1000
D	Projected decline	> 25% in 3 years or 1 generation	> 20% in 5 years or 2 generations	> 20% in 10 years or 3 generations
E	Extinction probability	> 50% in 10 years or 3 generations	> 20% in 20 years or 5 generations	> 10% in 100 years

Note: N_s refers to the sizes of subpopulations that are found in different parts of the total range occupied by the species.

IUCN (International Union for Conservation of Nature) classification: Mace and Lande slightly modified



Ex. Category CR

- Criterion D: Population size of mature individuals N < 50
- Criterion E: Extinct. Probab. ≥ 50%within next 10 years or next 3 generations

http://www.iucn.org/

https://www.iucnredlist.org/

Tabella 1. Categorie di minaccia delle piante vascolari italiane valutate secondo i criteri IUCN (2001).

Categoria *Red List* IUCN	*Policy species*	*Non Policy species*	Totale
Estinta (EX)	0	2	2
Estinta a livello regionale (RE)	1	0	1
Estinta in Natura (EW)	0	1	1
Probabilmente Estinta CR (PE)	7	4	11
Probabilmente Estinta in natura CR (PEW)	0	1	1
Gravemente minacciata (CR)	18	78	96
Minacciata (EN)	35	41	76
Vulnerabile (VU)	10	12	22
Quasi Minacciata (NT)	24	7	31
A Minor Rischio (LC)	40	0	40

Endangered vascular plants in Italy

Tabella 4. Categorie di minaccia dei vertebrati italiani

Categoria Red List IUCN	Specie terrestri	Specie marine
Estinto nella regione (RE)	6	0
In Pericolo Critico (CR)	17	12
In Pericolo (EN)	42	7
Vulnerabile (VU)	79	4
Quasi minacciata (NT)	50	3
Minor Preoccupazione (LC)	254	17
Dati Insufficienti (DD)	27	38
Non Applicabile (NA)	101	15
Totale	**576**	**96**

Endangered vertebrates in Italy