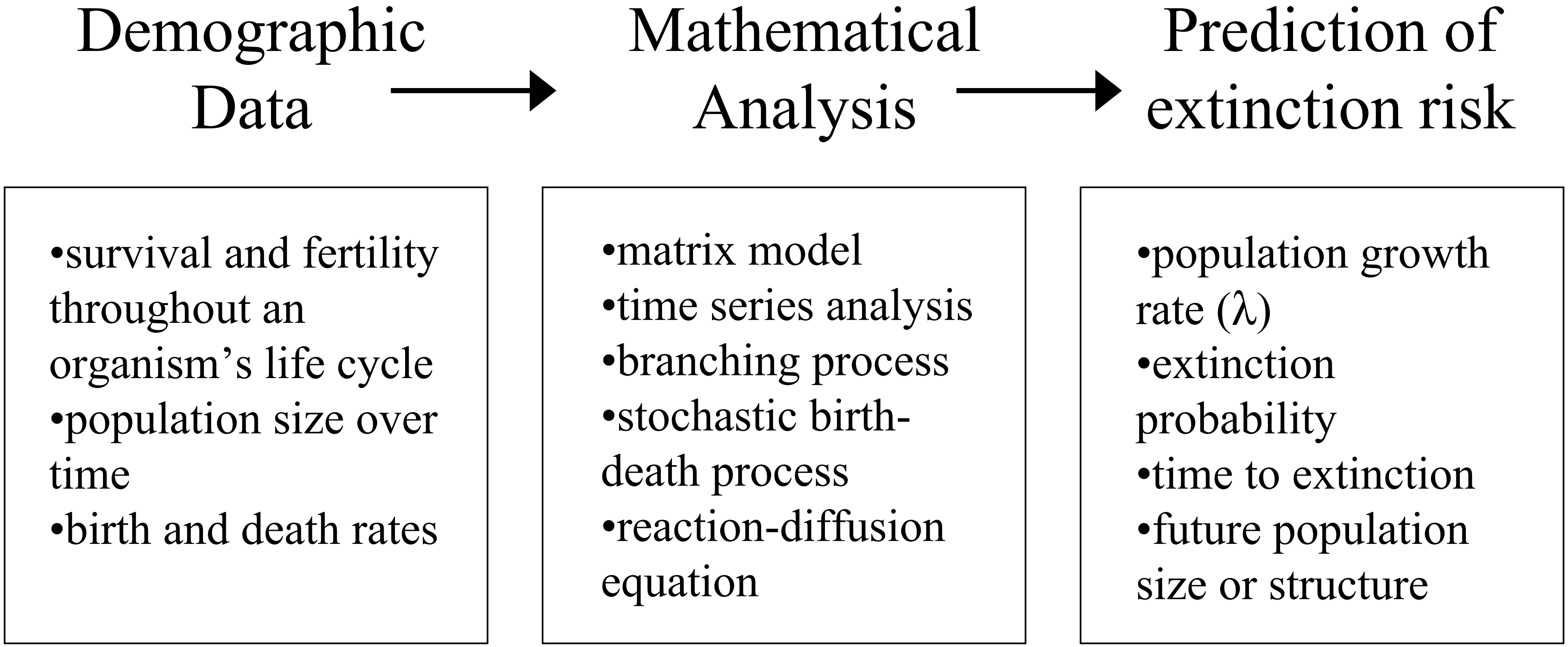
What is population viability analysis? (PVA)

Population viability analysis is

a quantitative analysis of population dynamics with the goal of assessing extinction risk



Demographic Data → **Mathematical Analysis** → **Prediction of extinction risk**

- survival and fertility throughout an organism’s life cycle
- population size over time
- birth and death rates

- matrix model
- time series analysis
- branching process
- stochastic birth-death process
- reaction-diffusion equation

- population growth rate (λ)
- extinction probability
- time to extinction
- future population size or structure

Table 1.1 Potential uses of PVA "products"

Category of Use	*Specific Use*	*Examples*
Assessment of extinction risk	Assessing the extinction risk of a single population	Shaffer 1981, Shaffer and Samson 1985, Lande 1988a
	Comparing relative risks of two or more populations	Menges 1990, Forsman et al. 1996, Allendorf et al. 1997
	Analyzing and synthesizing monitoring data	Menges and Gordon 1996, Gerber et al. 1999,
Guiding management	Identifying key life stages or demographic processes as management targets	Crouse et al. 1987
	Determining how large a reserve needs to be to gain a desired level of protection from extinction	Shaffer 1981, Armbruster and Lande 1993
	Determining how many individuals to release to establish a new population	Bustamante 1996, Howells and Edwards Jones 1997, Marshall and Edwards Jones 1998, South et al. 2000
	Setting limits on the harvest (or take) from a population that are compatible with its continued existence	Nantel et al. 1996, Ratsirarson et al. 1996, Caswell et al. 1998, Tufto et al. 1999
	Deciding how many populations are needed to protect a species from regional or global extinction	Menges 1990, Lindenmayer and Possingham 1996

Why do we do population "viability" analysis?

U. S. Endangered Species Act (1973)

codifies in law a national policy of avoiding the extinction of species

U. S. National Forest Management Act (1976)

"[f]ish and wildlife habitat shall be managed to maintain viable populations of existing native and desired nonnative vertebrate species in the planning area…In order to insure that viable populations will be maintained, habitat must be provided to support at least a minimum number of reproductive individuals and the habitat must be well distributed so that those individuals can interact with others in the planning area"

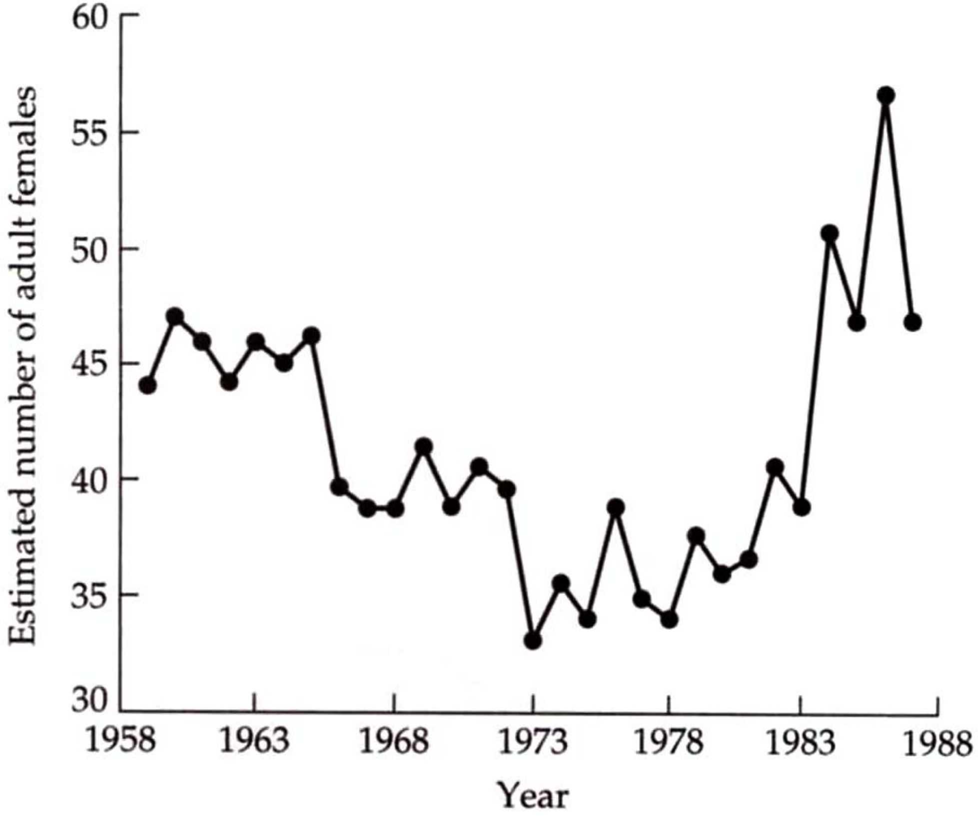
U. S. Marine Mammal Protection Act (1994 amendments)

stock assessment process

What do I mean by "population dynamics"?

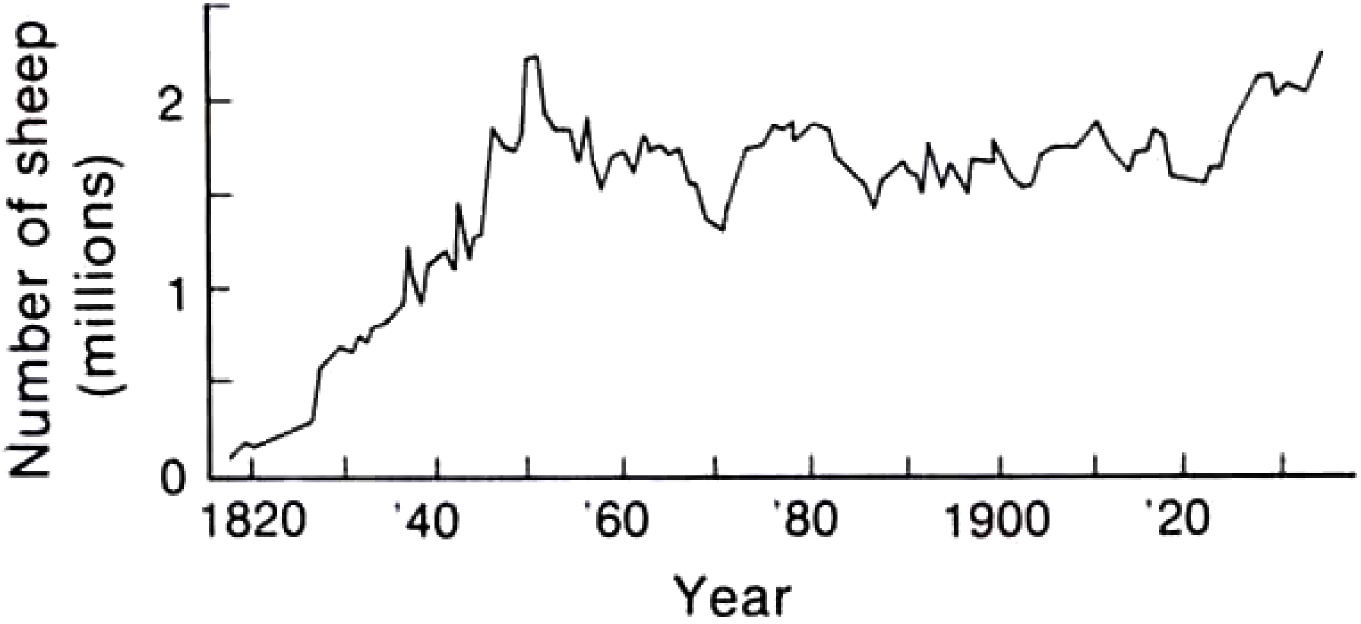
populations are dynamic, not static

Grizzly
bears
in Yellowstone
National Park

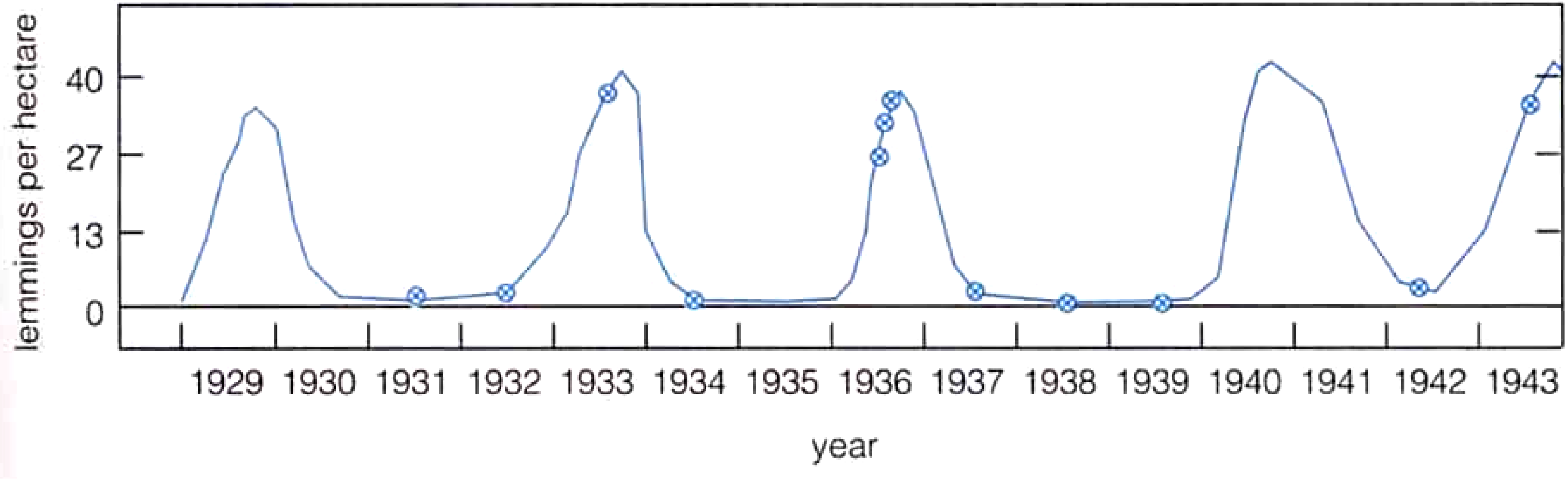


populations are dynamic, not static

Sheep on the island of Tasmania

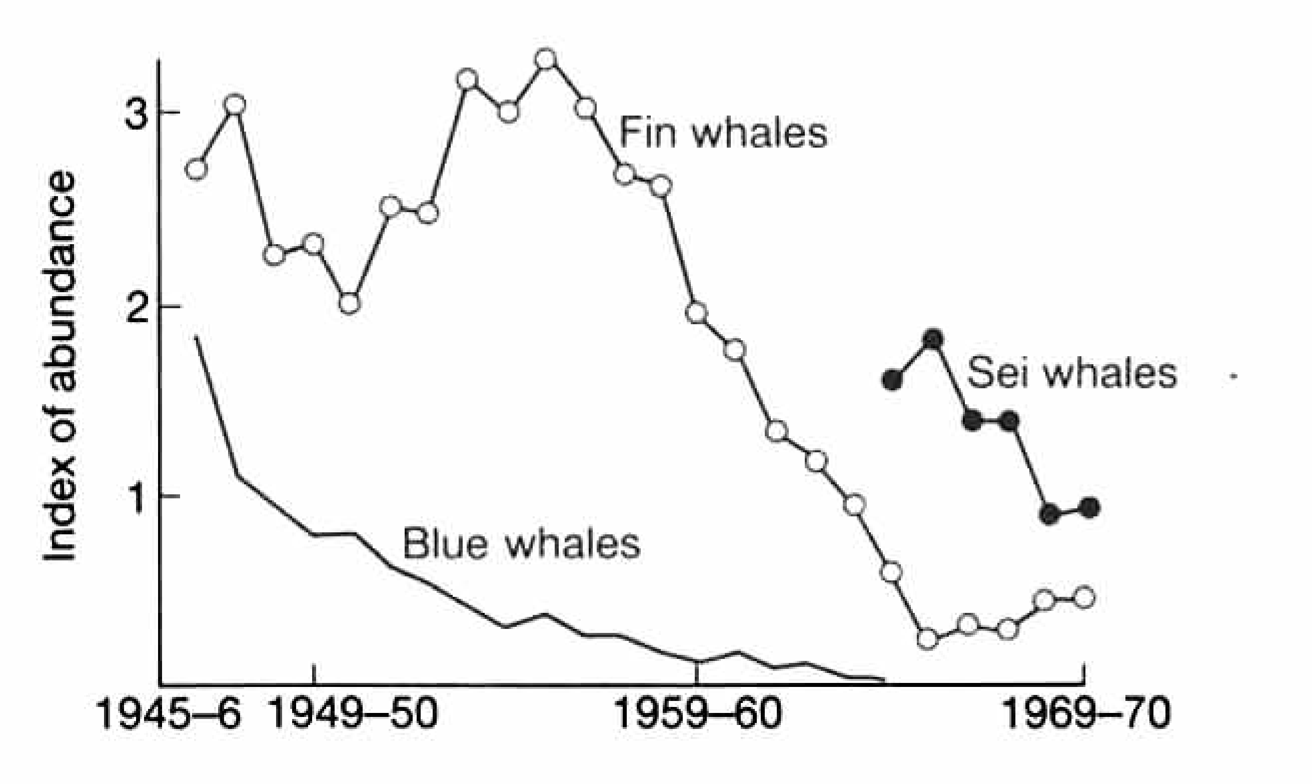


populations are dynamic, not static



populations are dynamic, not static

Whales in the Antarctic

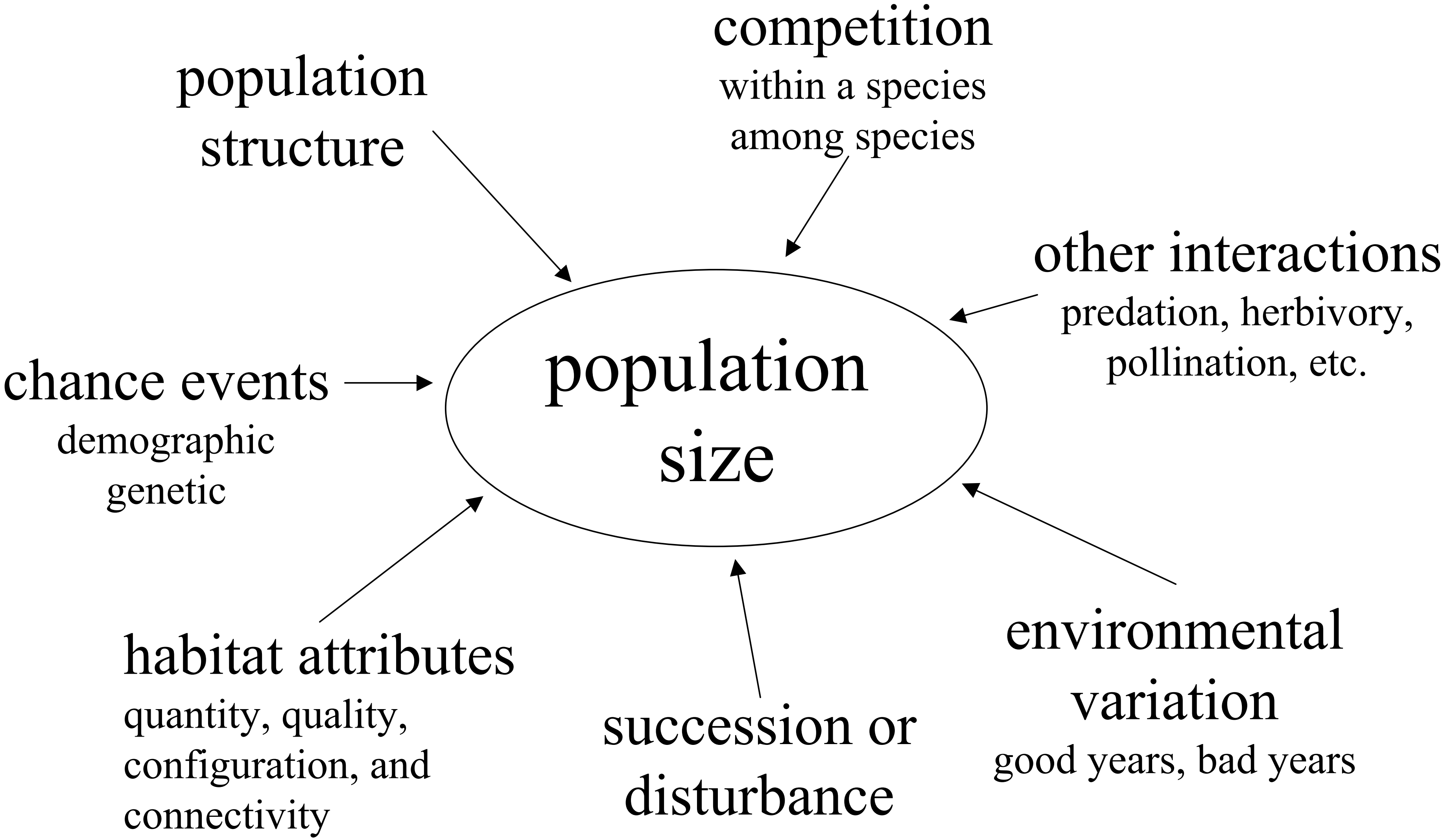


Population sizes change over time

Why?
What causes change in population size?
What regulates population size?

If we can answer these questions, we might be able to make changes that increase populations of declining (endangered) species

Many things affect population size



population size

population structure

competition
within a species
among species

other interactions
predation, herbivory, pollination, etc.

chance events
demographic
genetic

environmental variation
good years, bad years

succession or disturbance

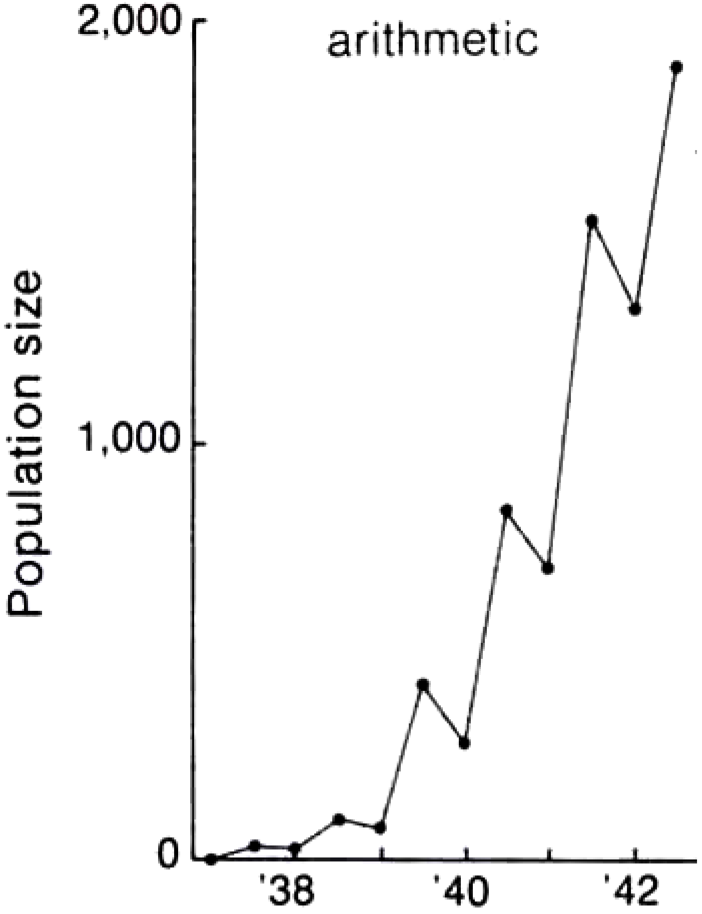
habitat attributes
quantity, quality, configuration, and connectivity

• Exponential growth

density-independent, deterministic

In a closed population (no immigration or emigration), population growth is a function of birth and death rates

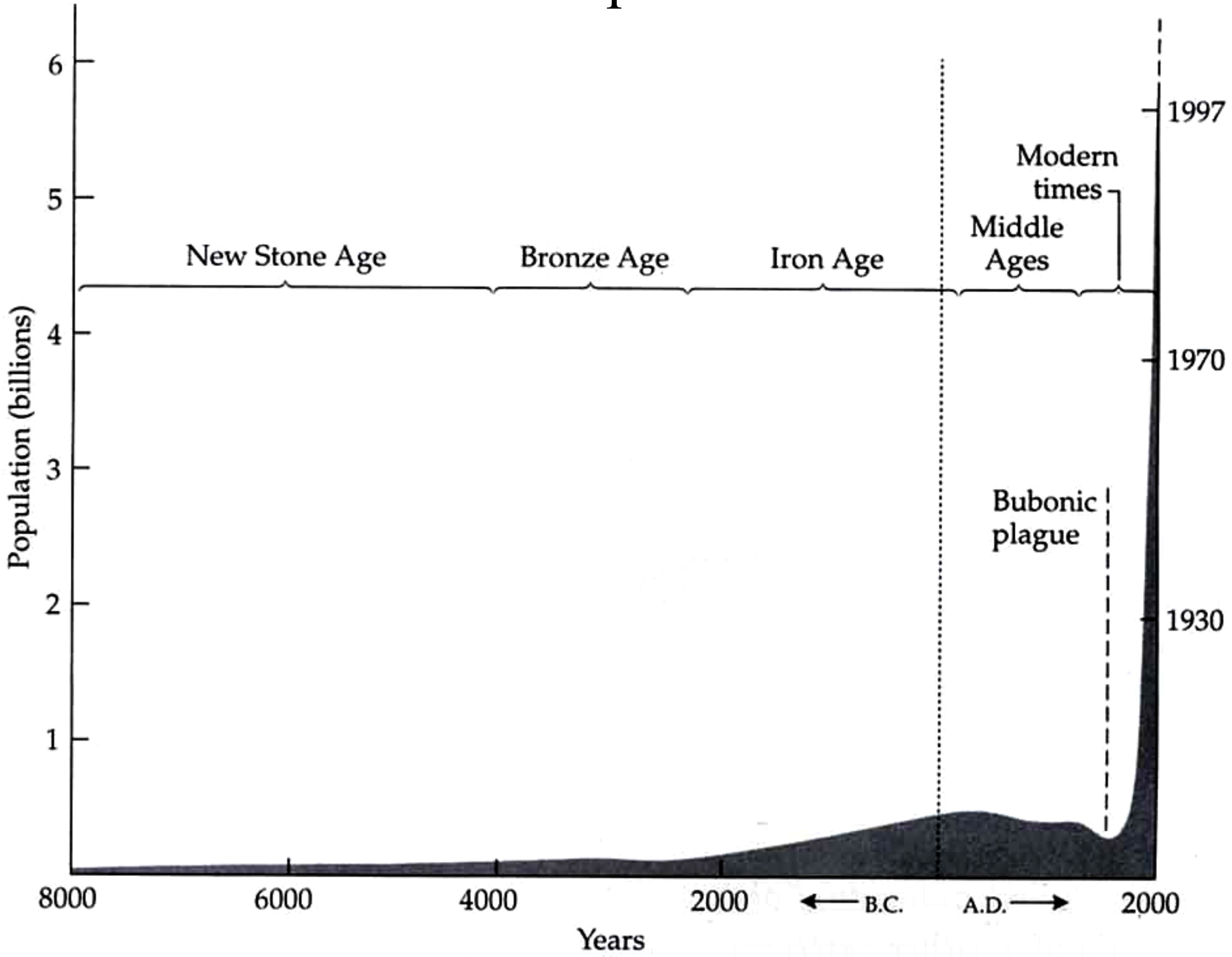
$$\frac{dN}{dt} = (b-d)N$$



Ring-necked pheasant
on Protection Island

exponential growth: an unrealistic model?

Humans on planet Earth



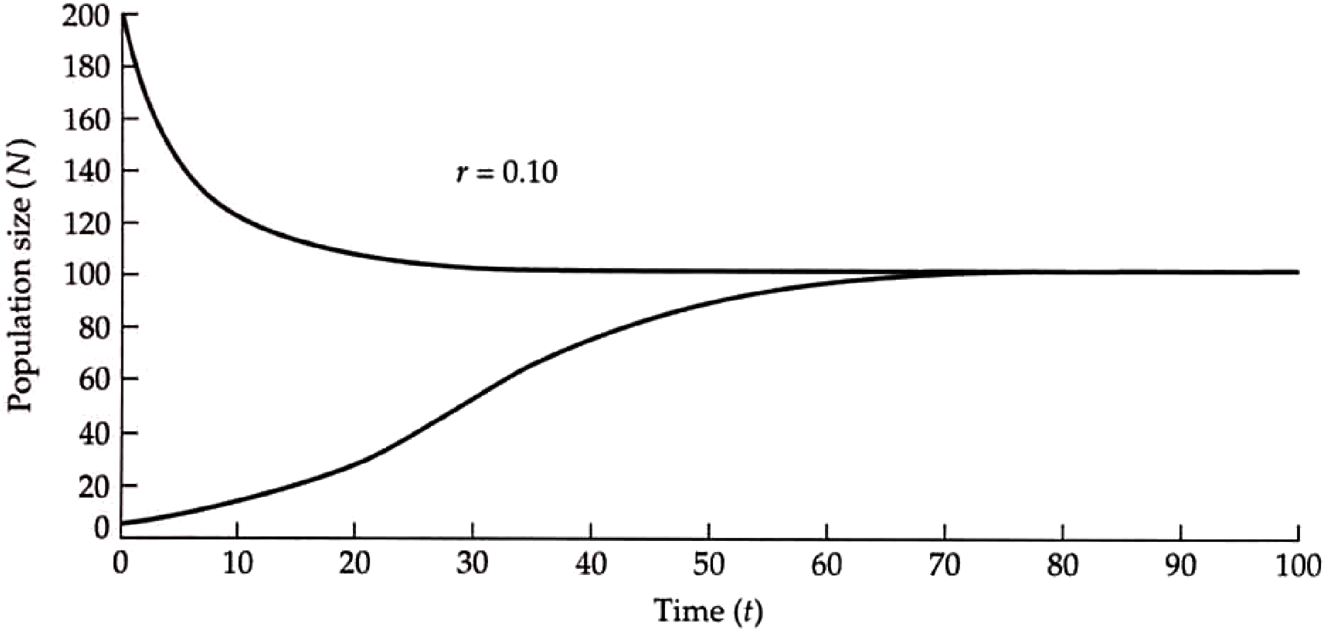
2. Logistic growth

density-dependent, deterministic

$$\frac{dN}{dt} = rN\left(\frac{K-N}{K}\right)$$

intraspecific competition stabilizes population size

birth rates go down and/or death rates go up with increasing population size

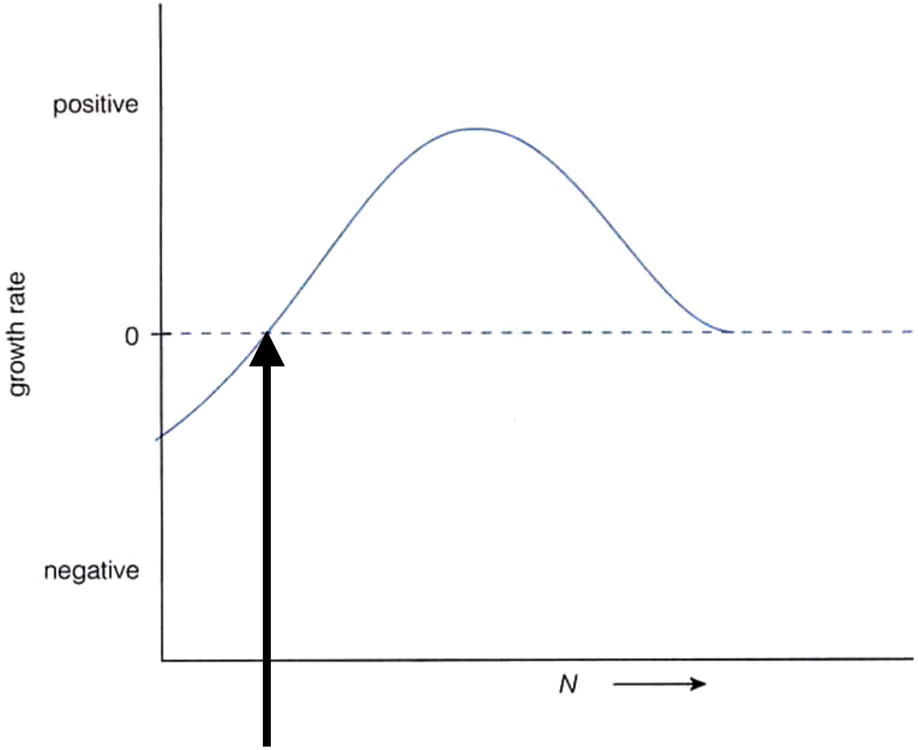


carrying capacity (K)

Alternatively,

The population growth rate may increase with population size (positive density-dependence)

Allee effect



minimum viable population size

Allee effect

How?

group defense against predators

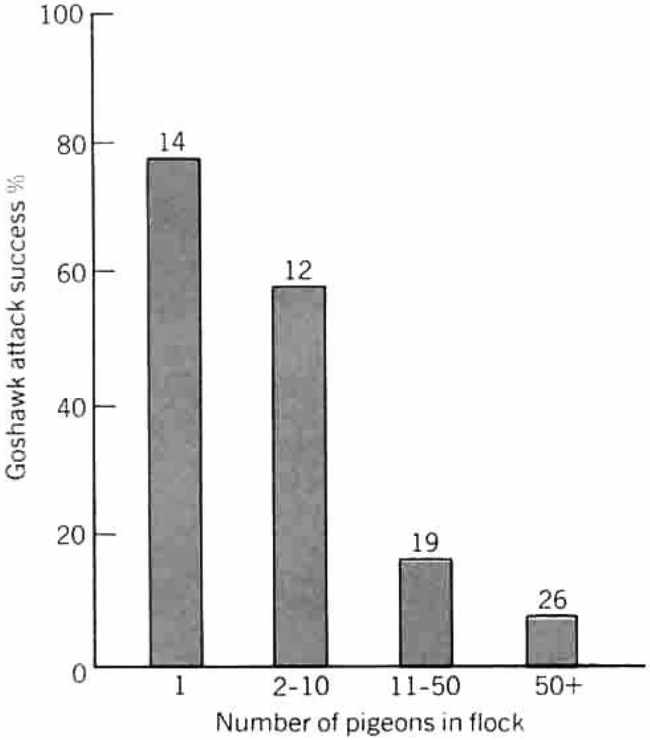


FIGURE 13.17

Success rate of goshawk attacking pigeons in flocks.

Attack by a trained goshawk rarely resulted in capture of a pigeon from a large flock, although most attacks on single pigeons were successful.

Allee effect

How?

In animals:

group defense against predators
group attack of prey
mates difficult to find
critical number to stimulate breeding behavior

In plants:

pollinator limitation
self-incompatibility
inbreeding depression

37 Passenger Pigeon (adult male).

The two categories of models we have considered thus far assume that

all individuals in a population have the same birth and death rates

no genetic, developmental, or physiological differences among individuals

under some circumstances, this might cause us to inaccurately predict population size

3. Structured population models

density-independent, deterministic

This is the type of model most often used in population viability analysis

What is meant by “structure”?

A population is **unstructured** if all individuals have the same rates of survival and fertility.

A population is **structured** if differences among individuals in **age**, developmental **stage**, or **size** cause them to have different survival or fertility rates.

TABLE 6.3 Survival data for red-cockaded woodpeckers in different reproductive stages, from Walters (1990)

Stage	Total number of bird-years	Fate at the end of a one-year interval		Proportion surviving one year
		Dead	Alive	
Fledglings	616	345	271	0.44
Solitary males	131	50	81	0.62
Helpers-at-the-nest	273	60	213	0.78
Breeding males	838	201	637	0.76
Floaters	29	11	18	0.62

Loggerhead turtles

3. Density-independent, deterministic, structured population growth

What can structured population models tell us?

1. Eigenvalues

The dominant eigenvalue (λ) will eventually govern population growth

3. Density-independent, deterministic, structured population growth

What else can structured population models tell us?

2. Sensitivity

The sensitivity of λ to each matrix element quantifies how much λ will be affected by a change in that transition probability

3. Density-independent, deterministic, structured population growth

What else can structured population models tell us?

2. Sensitivity

The sensitivity of λ to each matrix element describes how much λ will be affected by a change in that transition probability

Would it be better to focus conservation efforts on improving the survival of hatchlings or large juveniles or adults???

3. Density-independent, deterministic, structured population growth

What else can structured population models tell us?

3. Elasticity

Elasticities quantify the proportional change (1%) in the asymptotic growth rate that can be expected given a particular proportional change (1%) in each life history transition.

Many things affect population size

population size

population structure

competition
within a species
among species

other interactions
predation, herbivory,
pollination, etc.

chance events
demographic
genetic

habitat attributes
quantity, quality,
configuration, and
connectivity

succession or disturbance

environmental variation
good years, bad years

Two possible predictions given a single transition matrix:

exponential growth (λ>1)
extinction probability = 0

or

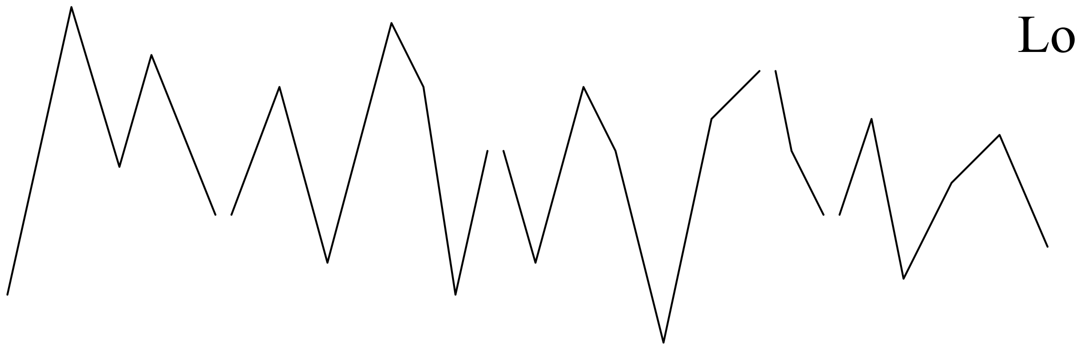
exponential decline (λ<1)
extinction probability = 1.0

Two possible predictions given a single transition matrix:

exponential growth ($\lambda>1$)
extinction probability = 0

or

exponential decline ($\lambda<1$)
extinction probability = 1.0



Long-term average?

4. Stochastic models

A. Environmental stochasticity

The environment varies from one year to the next

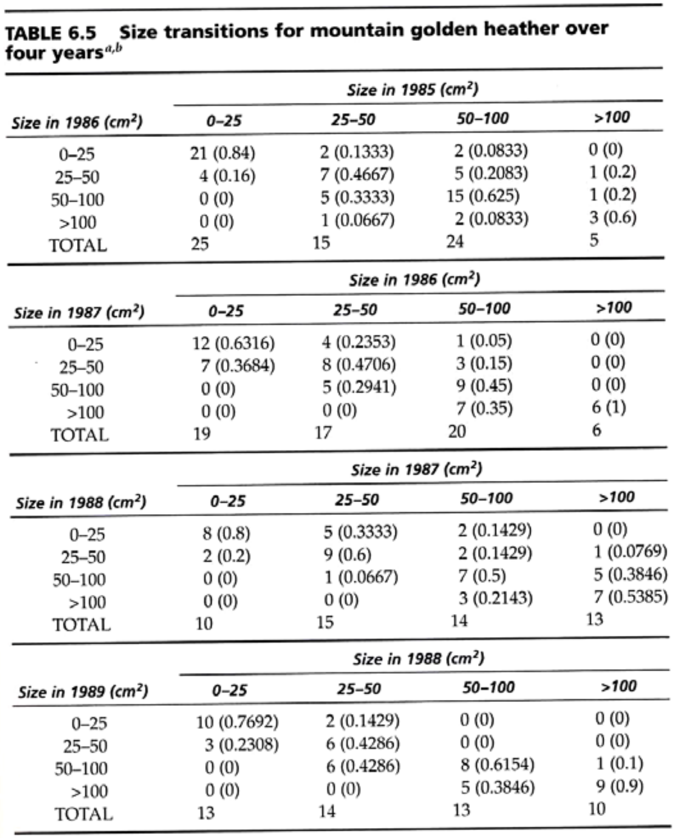


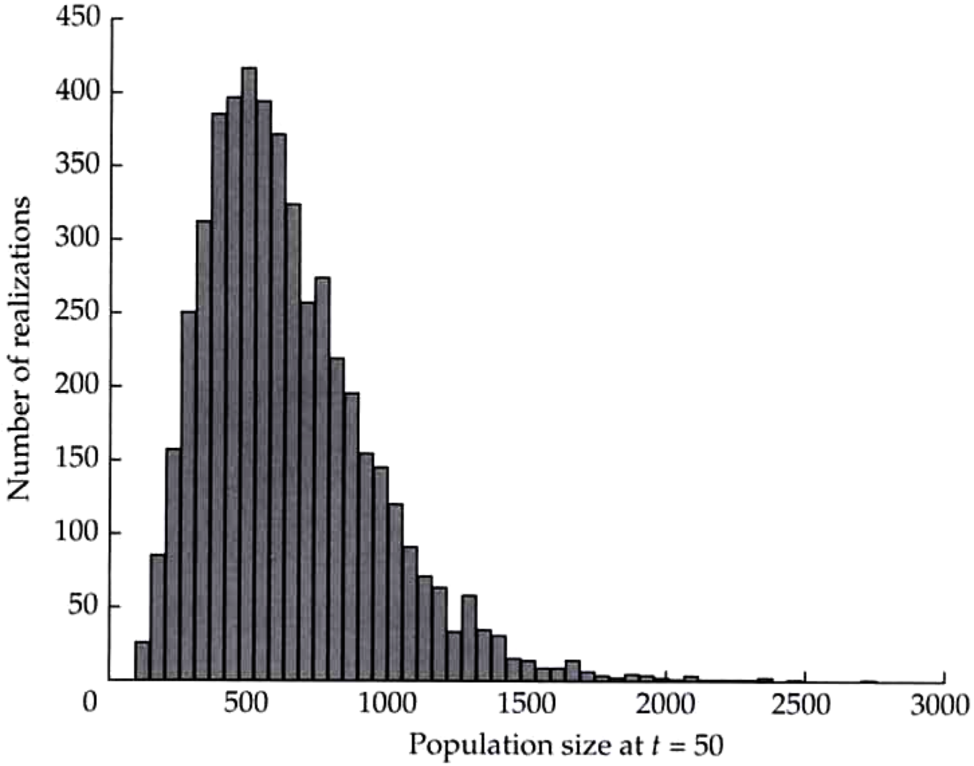
TABLE 6.5 Size transitions for mountain golden heather over four years[a,b]

	Size in 1985 (cm^2)			
Size in 1986 (cm^2)	***0–25***	***25–50***	***50–100***	***>100***
0–25	21 (0.84)	2 (0.1333)	2 (0.0833)	0 (0)
25–50	4 (0.16)	7 (0.4667)	5 (0.2083)	1 (0.2)
50–100	0 (0)	5 (0.3333)	15 (0.625)	1 (0.2)
>100	0 (0)	1 (0.0667)	2 (0.0833)	3 (0.6)
TOTAL	25	15	24	5

	Size in 1986 (cm^2)			
Size in 1987 (cm^2)	***0–25***	***25–50***	***50–100***	***>100***
0–25	12 (0.6316)	4 (0.2353)	1 (0.05)	0 (0)
25–50	7 (0.3684)	8 (0.4706)	3 (0.15)	0 (0)
50–100	0 (0)	5 (0.2941)	9 (0.45)	0 (0)
>100	0 (0)	0 (0)	7 (0.35)	6 (1)
TOTAL	19	17	20	6

	Size in 1987 (cm^2)			
Size in 1988 (cm^2)	***0–25***	***25–50***	***50–100***	***>100***
0–25	8 (0.8)	5 (0.3333)	2 (0.1429)	0 (0)
25–50	2 (0.2)	9 (0.6)	2 (0.1429)	1 (0.0769)
50–100	0 (0)	1 (0.0667)	7 (0.5)	5 (0.3846)
>100	0 (0)	0 (0)	3 (0.2143)	7 (0.5385)
TOTAL	10	15	14	13

	Size in 1988 (cm^2)			
Size in 1989 (cm^2)	***0–25***	***25–50***	***50–100***	***>100***
0–25	10 (0.7692)	2 (0.1429)	0 (0)	0 (0)
25–50	3 (0.2308)	6 (0.4286)	0 (0)	0 (0)
50–100	0 (0)	6 (0.4286)	8 (0.6154)	1 (0.1)
>100	0 (0)	0 (0)	5 (0.3846)	9 (0.9)
TOTAL	13	14	13	10



initial population
size = 4,343

4. Stochastic models

A. Disturbance and succession

The environment varies from one year to the next in a cyclical or predictable manner

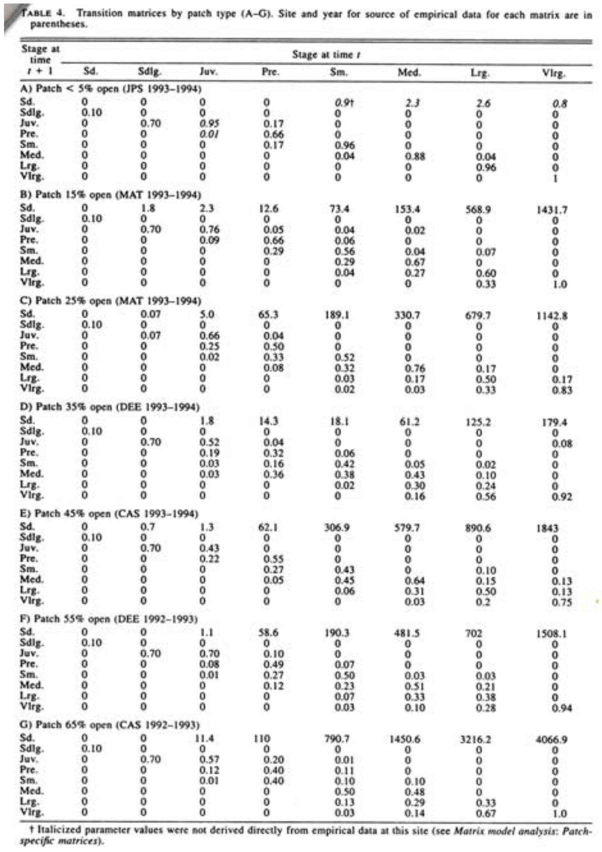
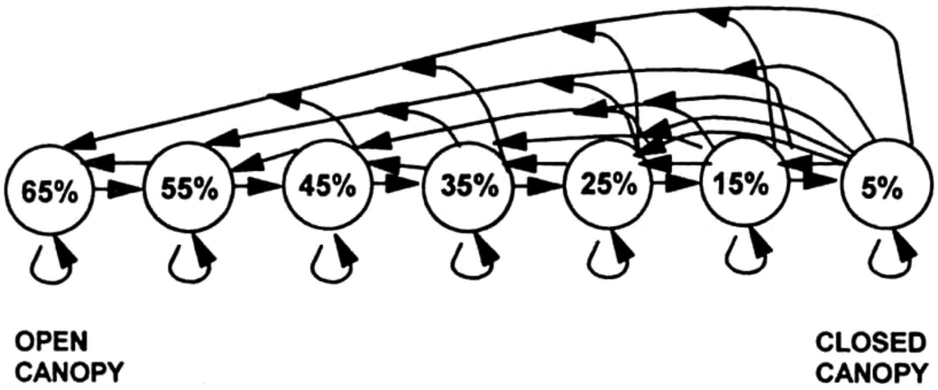


TABLE 4. Transition matrices by patch type (A–G). Site and year for source of empirical data for each matrix are in parentheses.

Stage at time $t + 1$	Stage at time t							
	Sd.	Sdlg.	Juv.	Pre.	Sm.	Med.	Lrg.	Vlrg.
A) Patch < 5% open (JPS 1993–1994)								
Sd.	0	0	0	0	*0.9*†	*2.3*	*2.6*	*0.8*
Sdlg.	0.10	0	0	0	0	0	0	0
Juv.	0	0.70	*0.95*	0.17	0	0	0	0
Pre.	0	0	*0.01*	0.66	0	0	0	0
Sm.	0	0	0	0.17	0.96	0	0	0
Med.	0	0	0	0	0.04	0.88	0.04	0
Lrg.	0	0	0	0	0	0	0.96	0
Vlrg.	0	0	0	0	0	0	0	1
B) Patch 15% open (MAT 1993–1994)								
Sd.	0	1.8	2.3	12.6	73.4	153.4	568.9	1431.7
Sdlg.	0.10	0	0	0	0	0	0	0
Juv.	0	0.70	0.76	0.05	0.04	0.02	0	0
Pre.	0	0	0.09	0.66	0.06	0	0	0
Sm.	0	0	0	0.29	0.56	0.04	0.07	0
Med.	0	0	0	0	0.29	0.67	0	0
Lrg.	0	0	0	0	0.04	0.27	0.60	0
Vlrg.	0	0	0	0	0	0	0.33	1.0
C) Patch 25% open (MAT 1993–1994)								
Sd.	0	0.07	5.0	65.3	189.1	330.7	679.7	1142.8
Sdlg.	0.10	0	0	0	0	0	0	0
Juv.	0	0.07	0.66	0.04	0	0	0	0
Pre.	0	0	0.25	0.50	0	0	0	0
Sm.	0	0	0.02	0.33	0.52	0	0	0
Med.	0	0	0	0.08	0.32	0.76	0.17	0
Lrg.	0	0	0	0	0.03	0.17	0.50	0.17
Vlrg.	0	0	0	0	0.02	0.03	0.33	0.83
D) Patch 35% open (DEE 1993–1994)								
Sd.	0	0	1.8	14.3	18.1	61.2	125.2	179.4
Sdlg.	0.10	0	0	0	0	0	0	0
Juv.	0	0.70	0.52	0.04	0	0	0	0.08
Pre.	0	0	0.19	0.32	0.06	0	0	0
Sm.	0	0	0.03	0.16	0.42	0.05	0.02	0
Med.	0	0	0.03	0.36	0.38	0.43	0.10	0
Lrg.	0	0	0	0	0.02	0.30	0.24	0
Vlrg.	0	0	0	0	0	0.16	0.56	0.92
E) Patch 45% open (CAS 1993–1994)								
Sd.	0	0.7	1.3	62.1	306.9	579.7	890.6	1843
Sdlg.	0.10	0	0	0	0	0	0	0
Juv.	0	0.70	0.43	0	0	0	0	0
Pre.	0	0	0.22	0.55	0	0	0	0
Sm.	0	0	0	0.27	0.43	0	0.10	0
Med.	0	0	0	0.05	0.45	0.64	0.15	0.13
Lrg.	0	0	0	0	0.06	0.31	0.50	0.13
Vlrg.	0	0	0	0	0	0.03	0.2	0.75
F) Patch 55% open (DEE 1992–1993)								
Sd.	0	0	1.1	58.6	190.3	481.5	702	1508.1
Sdlg.	0.10	0	0	0	0	0	0	0
Juv.	0	0.70	0.70	0.10	0	0	0	0
Pre.	0	0	0.08	0.49	0.07	0	0	0
Sm.	0	0	0.01	0.27	0.50	0.03	0.03	0
Med.	0	0	0	0.12	0.23	0.51	0.21	0
Lrg.	0	0	0	0	0.07	0.33	0.38	0
Vlrg.	0	0	0	0	0.03	0.10	0.28	0.94
G) Patch 65% open (CAS 1992–1993)								
Sd.	0	0	11.4	110	790.7	1450.6	3216.2	4066.9
Sdlg.	0.10	0	0	0	0	0	0	0
Juv.	0	0.70	0.57	0.20	0.01	0	0	0
Pre.	0	0	0.12	0.40	0.11	0	0	0
Sm.	0	0	0.01	0.40	0.10	0.10	0	0
Med.	0	0	0	0	0.50	0.48	0	0
Lrg.	0	0	0	0	0.13	0.29	0.33	0
Vlrg.	0	0	0	0	0.03	0.14	0.67	1.0

† Italicized parameter values were not derived directly from empirical data at this site (see *Matrix model analysis: Patch-specific matrices*).



4. Stochastic models

B. Demographic stochasticity

Tossing a coin

sex ratio
survival

Rolling a dice

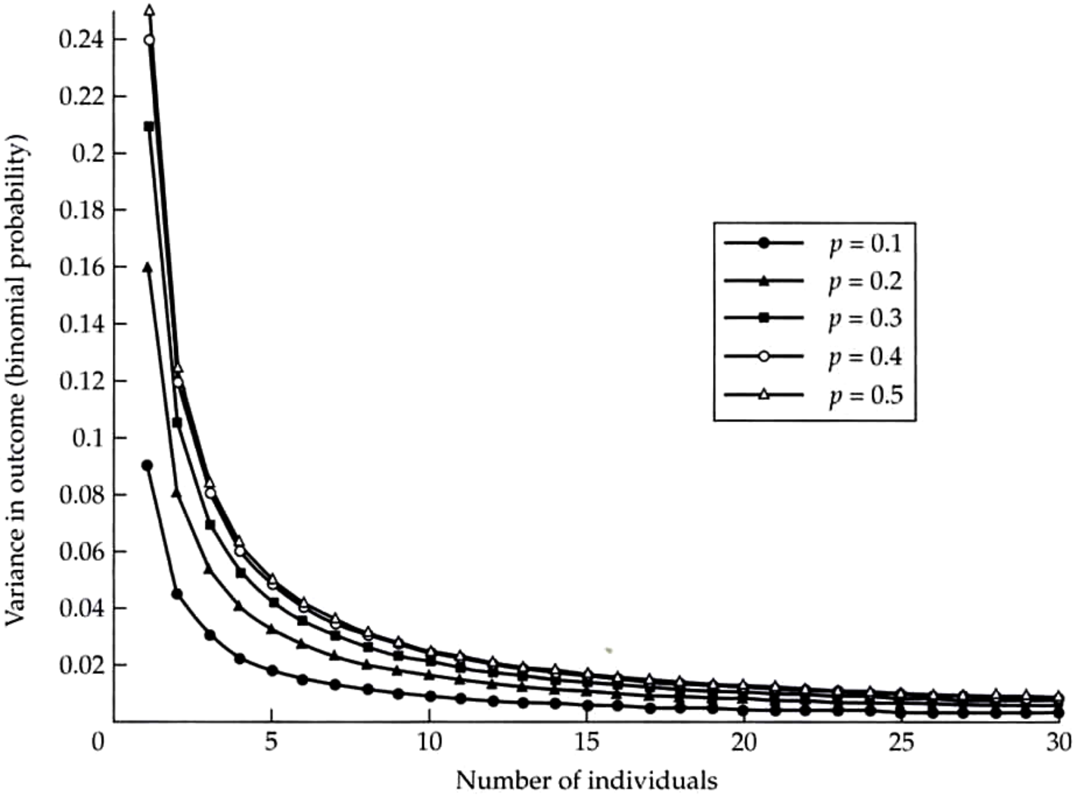
clutch size

4. Stochastic models

B. Demographic stochasticity

Tossing a coin
sex ratio
survival

Rolling a dice
clutch size



4. Stochastic models

C. Genetic stochasticity

Small populations tend to lose genetic diversity (heterozygosity, allelic diversity) via inbreeding, drift, or combinations of the two. This may have fitness consequences.

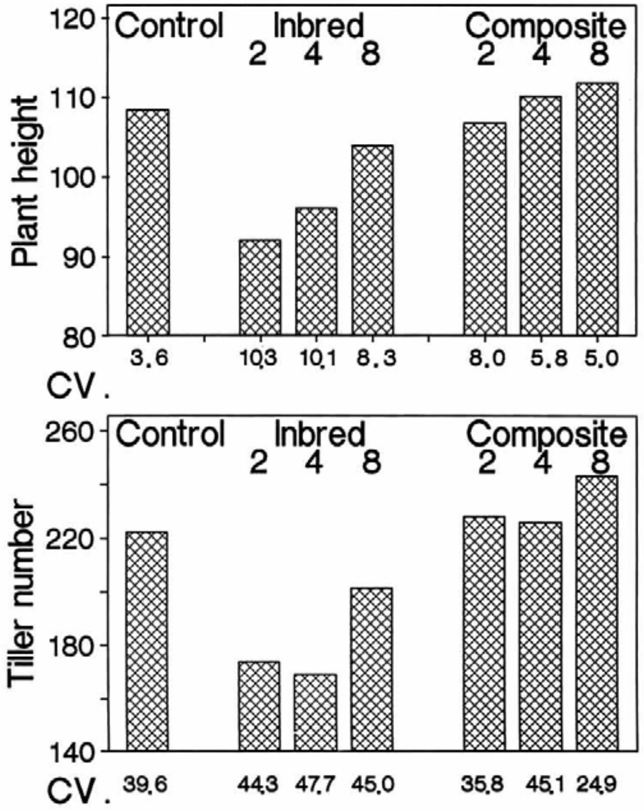


Figure 1.4. The effect of experimental bottlenecks on plant height (cm) and tiller number in *Lolium multiflorum*. Experimental populations of restricted size (2, 4, and 8) were maintained for three generations and then grown in a common garden with a control treatment and composite mixture of genotypes from the inbred treatments. The mean and coefficient of variation for each treatment are illustrated. (After Polans and Allard 1989)

Rule of thumb

genetic and demographic stochasticity important in populations < 50

environmental stochasticity still important in populations > 50

5. Landscape-scale or metapopulation models

- amount of habitat
- quality of habitat
- distribution or configuration of habitat
- connectivity of habitat

5. Landscape-scale or metapopulation models

Patch size matters

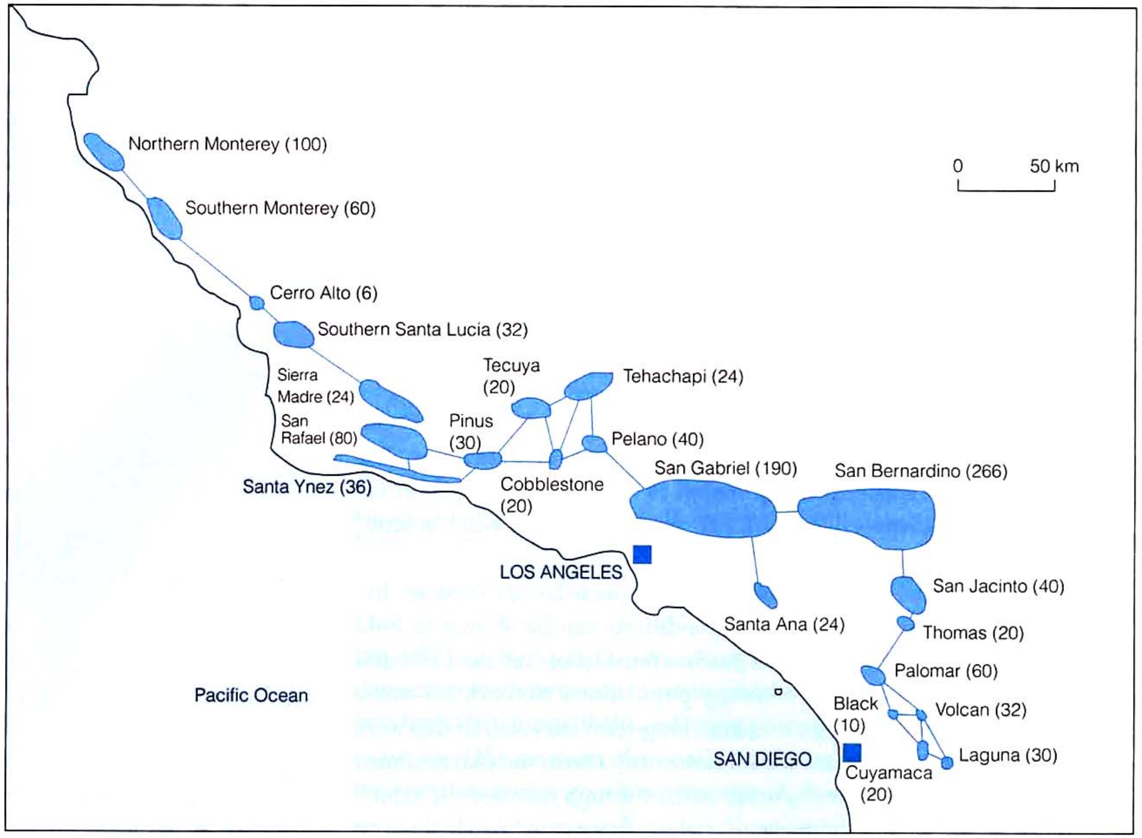
populations in smaller habitat patches (‘islands”) are more likely to go extinct than populations in larger habitat patches

Patch isolation matters

the more isolated an unoccupied habitat patch is from occupied habitat patches, the less likely that it will be colonized

The Theory of Island Biogeography (MacArthur and Wilson 1967)
Metapopulation Theory (Levins 1969 and others)

5. Landscape-scale or metapopulation models



Which population is most/least likely to go extinct?

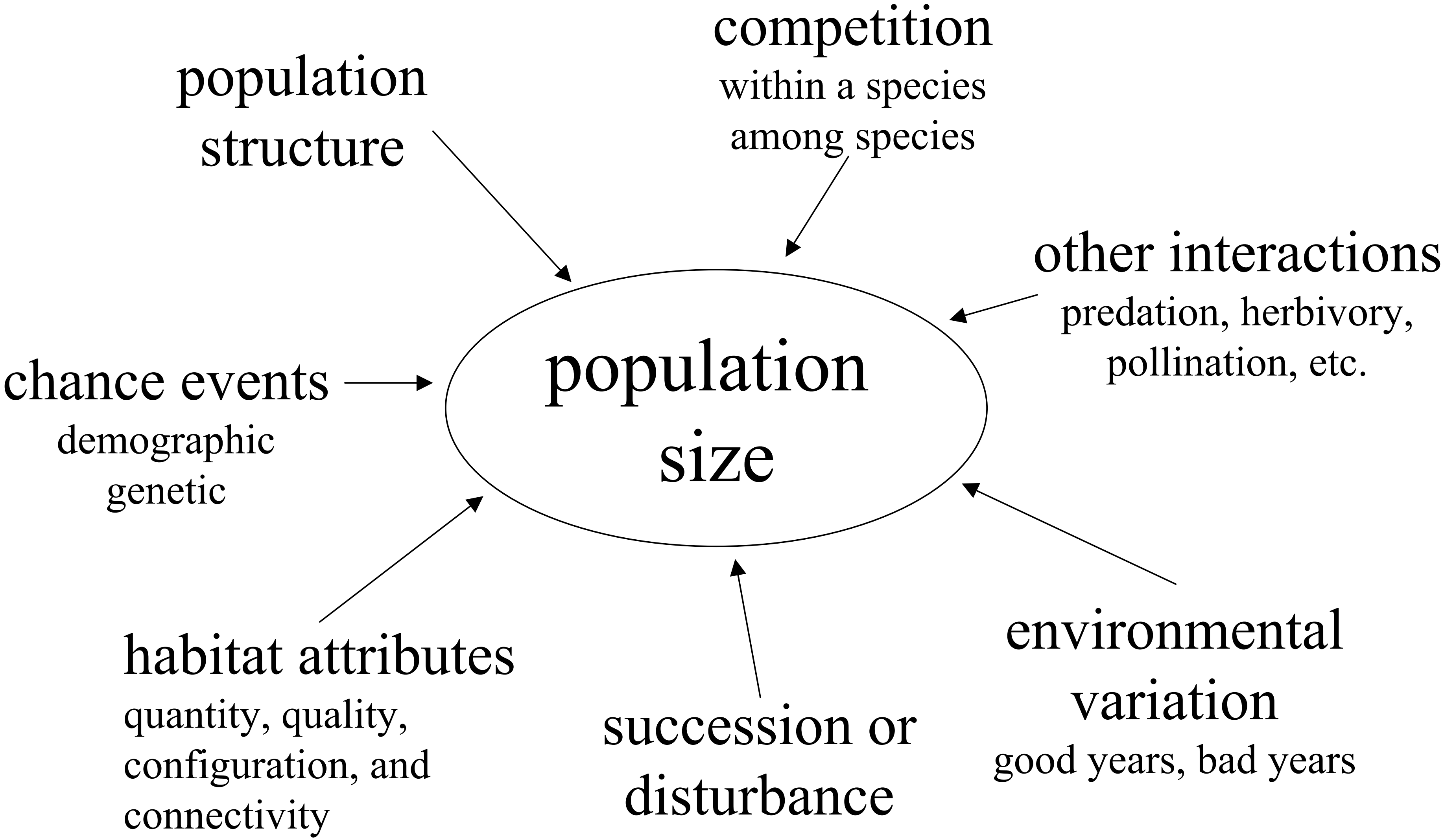
5. Landscape-scale or metapopulation models

Patch quality matters
populations in habitat patches of higher quality are less likely to go extinct than populations in patches of lower quality

A "**source**" is an area where b>d. Excess individuals may emigrate from a "source" patch.

A "**sink**" is an area where d>b. Populations in sink patches are certain to go extinct. Sink populations may be "rescued" by immigration from source populations (the **rescue effect**).

Many things affect population size



population structure

competition
within a species
among species

other interactions
predation, herbivory, pollination, etc.

chance events
demographic
genetic

population size

habitat attributes
quantity, quality, configuration, and connectivity

succession or disturbance

environmental variation
good years, bad years

Last thoughts on PVA

PVA requires lots of data, which takes time, work, and money, whereas managers want answers (predictions about extinction) now. Few species will get thorough PVA. When should PVA be used and what type of PVA (how complex)?

Predictions from PVA can only be as good as the data that go into the analysis. We can only have degrees of confidence in the predictions from PVA. Populations should not be managed to their "minimum viable population" size.

One of the greatest strengths of PVA is the ability to play "what if" games with the model. That is, what if management were to increase patch sizes or connectivity? What if adult survival were improved?