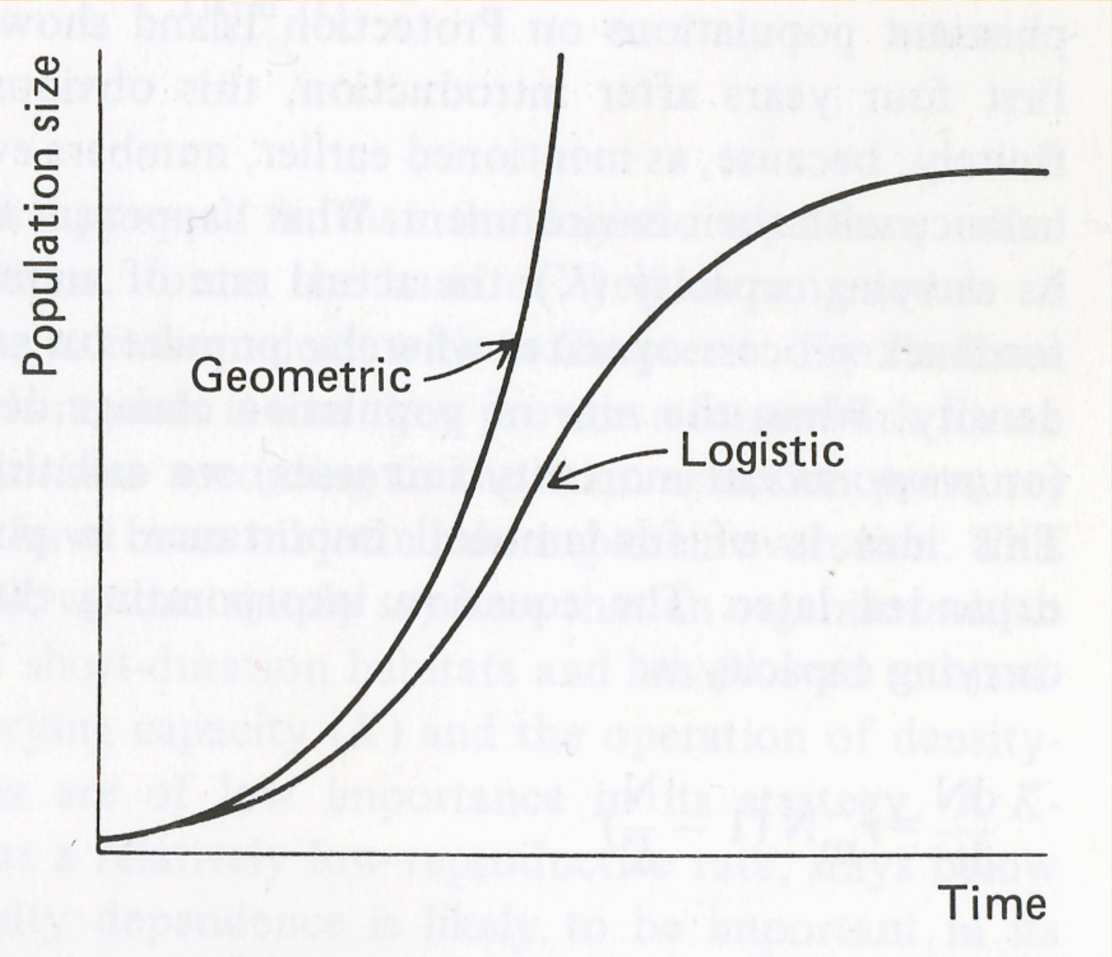
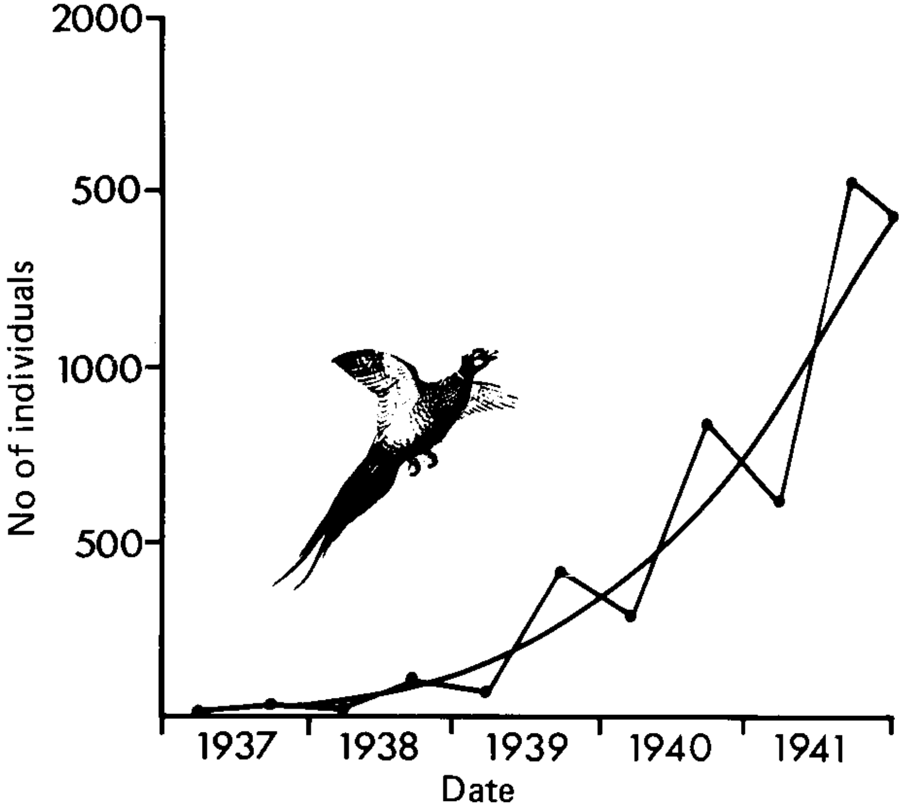
Population Models Part II

Review: Continuous Generations

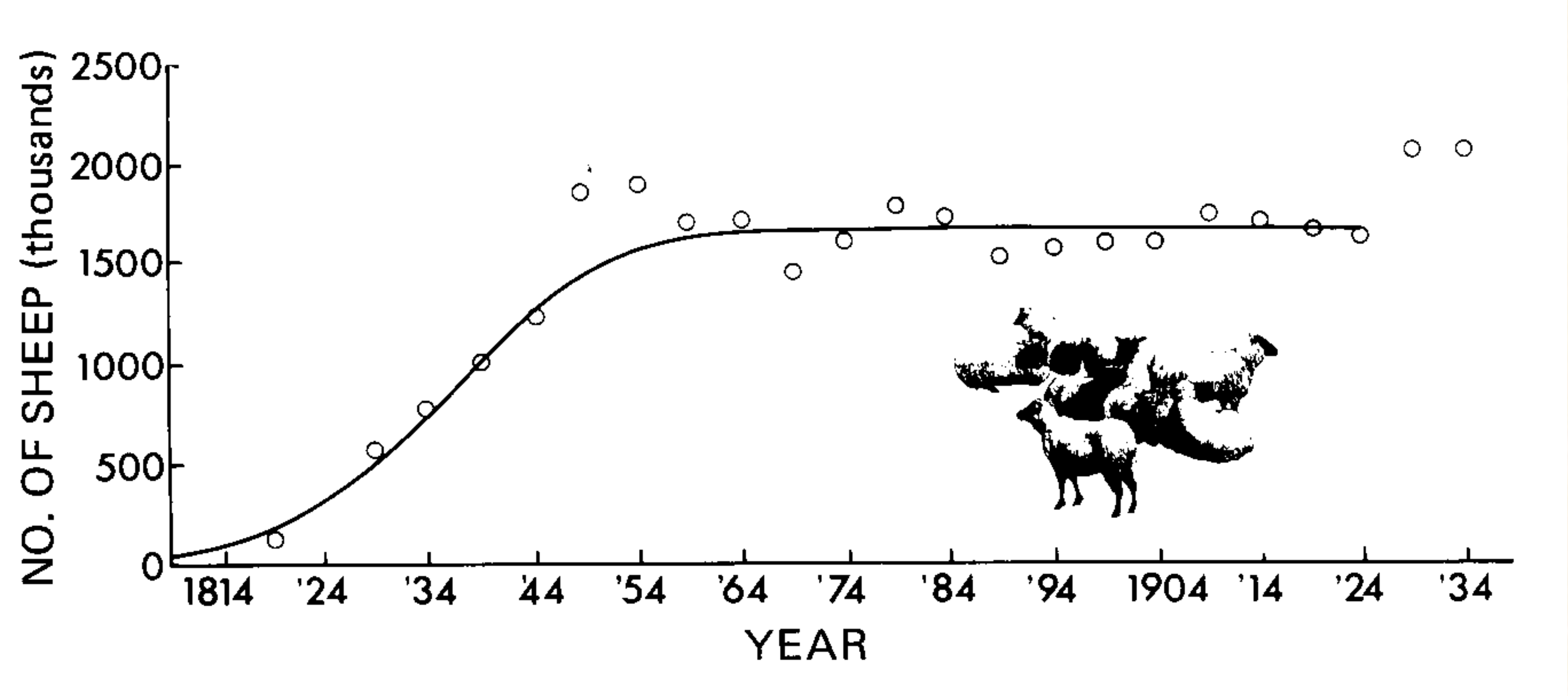


Review: Continuous Generations



Pheasants introduced to Protection Island, WA

Review: Continuous Generations



Sheep in Tasmainia

Discrete Generations

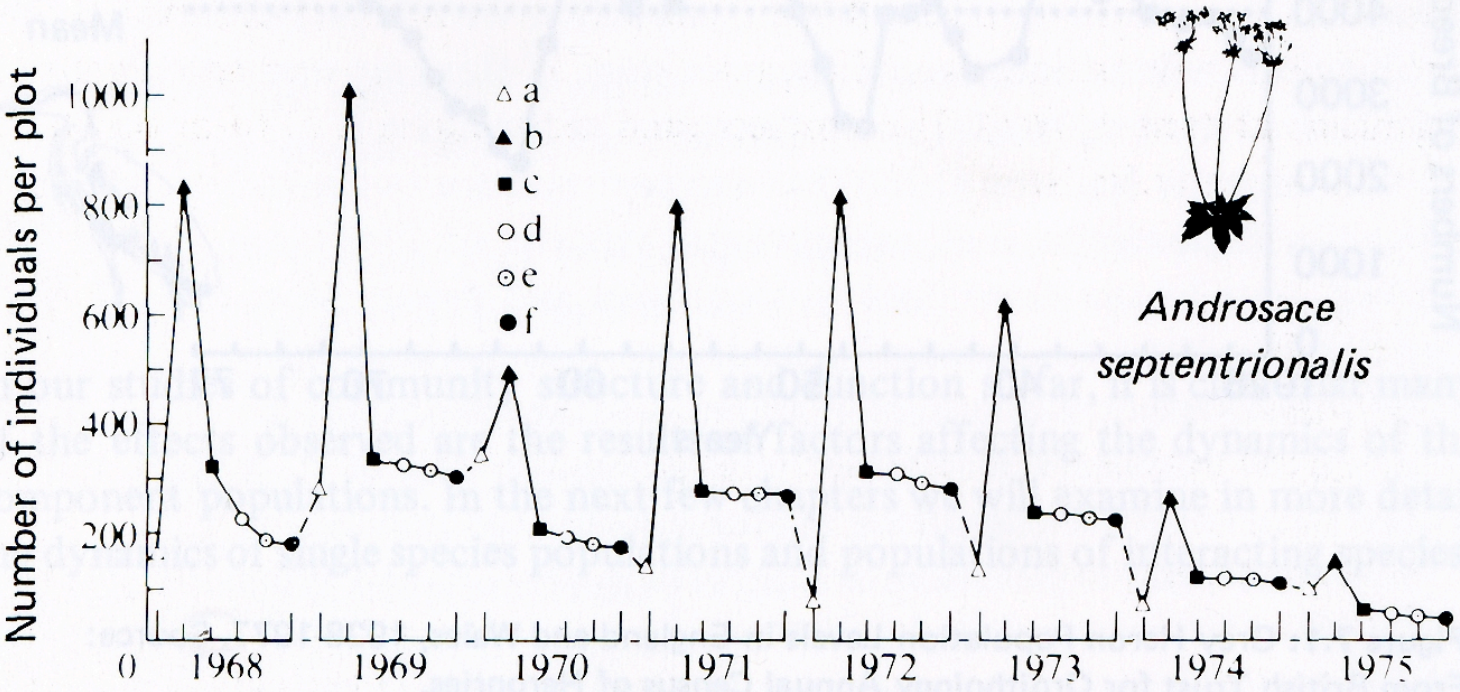


Figure 7.3: The Population Dynamics of *Androsace septentrionalis* Over an 8-Year Period. (a) Beginning of germination; (b) maximum germination; (c) end of seedling phase; (d) period of vegetative growth; (e) flowering; (f) fruiting. Source: From Symonides, 1979 and Silvertown, 1982.

The Equations for Discrete Generations

- The population size is a function of the previous generation *only,* so
- $N_{(t+1)} = F(N_t)$
- In practice…
- $N_{t+1} = \lambda \cdot N_t$

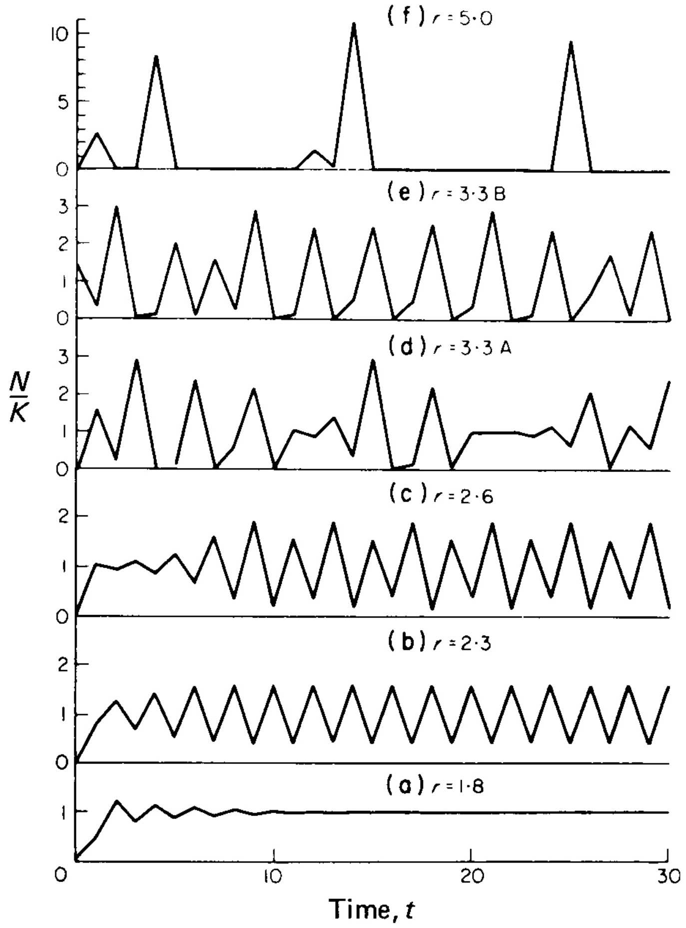
Then, Individuals at time ‘t’

- $N_{@}t = \lambda_t \cdot No$
  - λ = Finite rate of increase
  - t = Number of times the population multiplies itself/generation
- Note that
- $r = \ln \lambda$
- This allows us to determine an effictive ‘r’ by linear regression
- This equation also results in geometric growth.

Modifying the solution to include logistic growth

$$N_{t+1} = N_t e^{r\left(1-\frac{N}{k}\right)}$$

This can lead to a variety of solutions



What is wrong with these equations?

- *Ignore competitors.*
- *Ignore predators.*
- *Ignore abiotic environment.*
- *Ignore interactions between populations in community.*
- *Ignore age effects in the population.*

Note the age effects

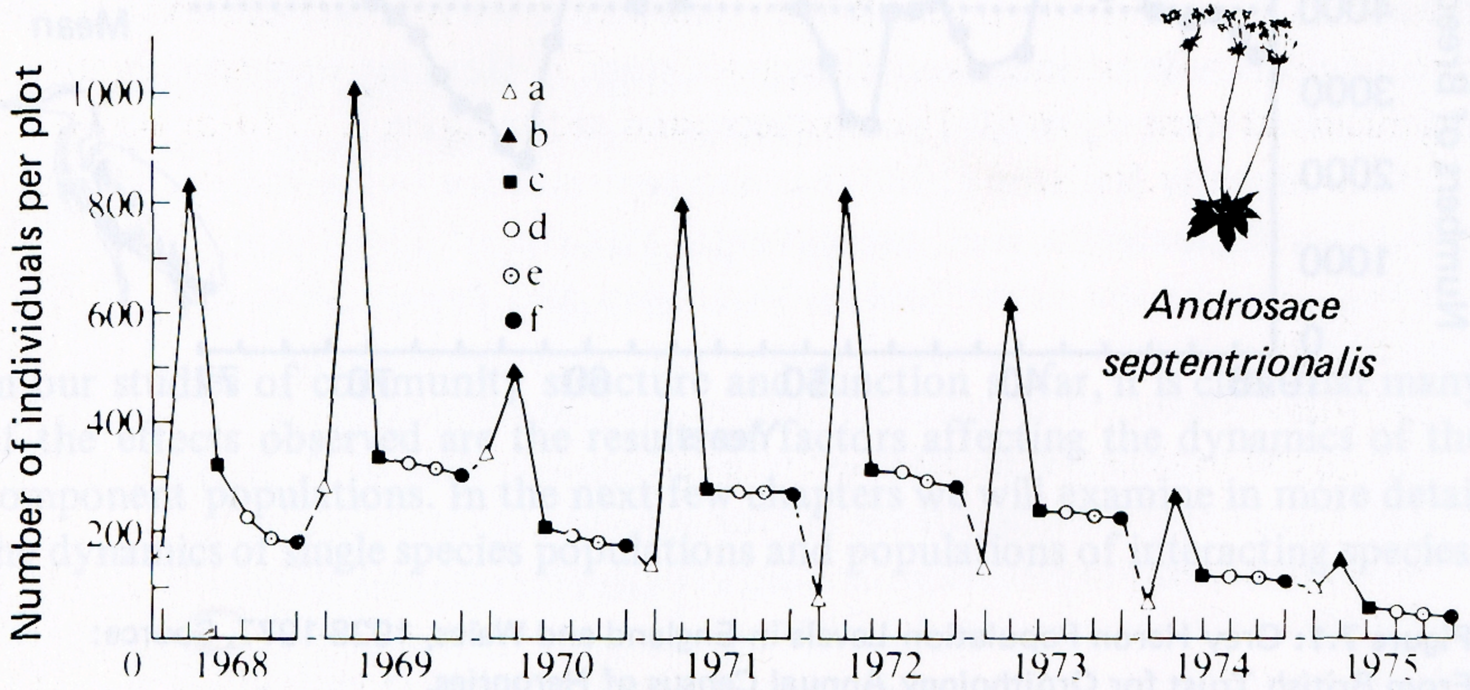


Figure 7.3: The Population Dynamics of *Androsace septentrionalis* Over an 8-Year Period. (a) Beginning of germination; (b) maximum germination; (c) end of seedling phase; (d) period of vegetative growth; (e) flowering; (f) fruiting. Source: From Symonides, 1979 and Silvertown, 1982.

Life Table Approach

- Used only for overlapping generations.
- Contains age distribution information.
- Used most effectively for a relatively constant population.
- Requires mortality information.

Life Table Approach

- Start by defining a pivotal age group size.
  - Man - 10 Years
  - Insects - Days or Weeks
  - Bacteria - Hours
- Tradition requires starting at 1000 or normalizing to 1000 initial population.
- Death rates are determined by
  - aging a sample population
  - studying remains. (more subject to sampling bias)

A Life Table

x	l_x	log l_x	d_x	q_x	e_x	L_x	T_x
1	1000	3.0	550	550	1.21	725	1210
2	450	2.7	250	556	1.08	325	485
3	200	2.3	150	750	0.80	125	160
4	50	1.7	40	800	0.70	30	35
5	10	1.0	10	1000	0.50	5	5

- x = Pivotal age class
- l_x = Number of the 1000 surviving at start of age class
- d_x = Number dying during interval
- q_x= (fraction dying) x 1000 [e.g. at start of age class 2, q_x = (250/450) x 100]

A Life Table

x	l_x	$\log l_x$	d_x	q_x	e_x	L_x	T_x
1	1000	3.0	550	550	1.21	725	1210
2	450	2.7	250	556	1.08	325	485
3	200	2.3	150	750	0.80	125	160
4	50	1.7	40	800	0.70	30	35
5	10	1.0	10	1000	0.50	5	5

- L_x = Average number of individuals between age x and age x+1 (i.e. $L_x = (l_x + l_{x+1})/2$)
- T_x = Total number of individuals of aged x and beyond (determined by adding midpoints from bottom up to point)
- e_x = Life expectancy for individuals attaining age x
- $= T_x/l_x$

Survivorship

Survivorship data showing a constant death rate.

l_x	log l_x	d_x
1000	3.0	300
500	2.7	250
250	2.4	125
125	2.1	63
63	1.8	

Plotted Data

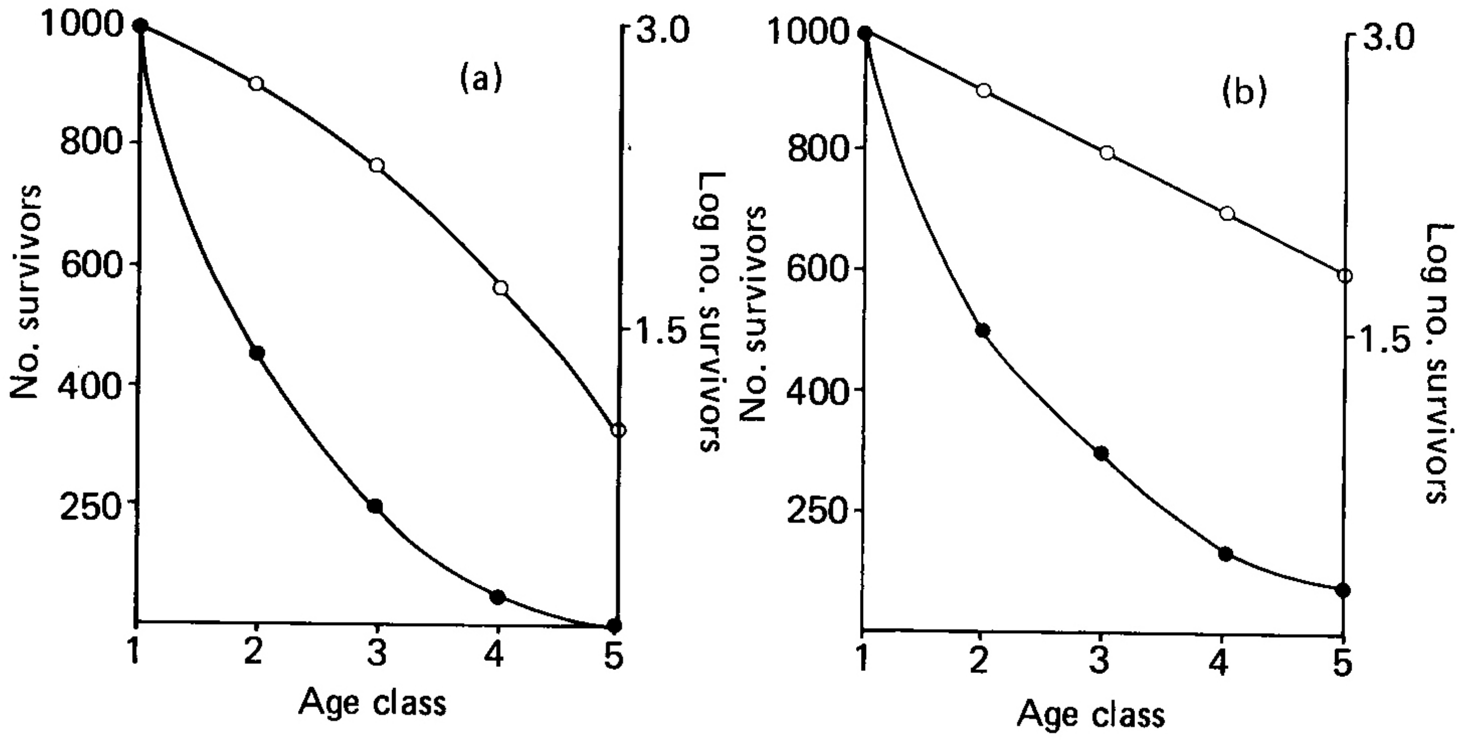
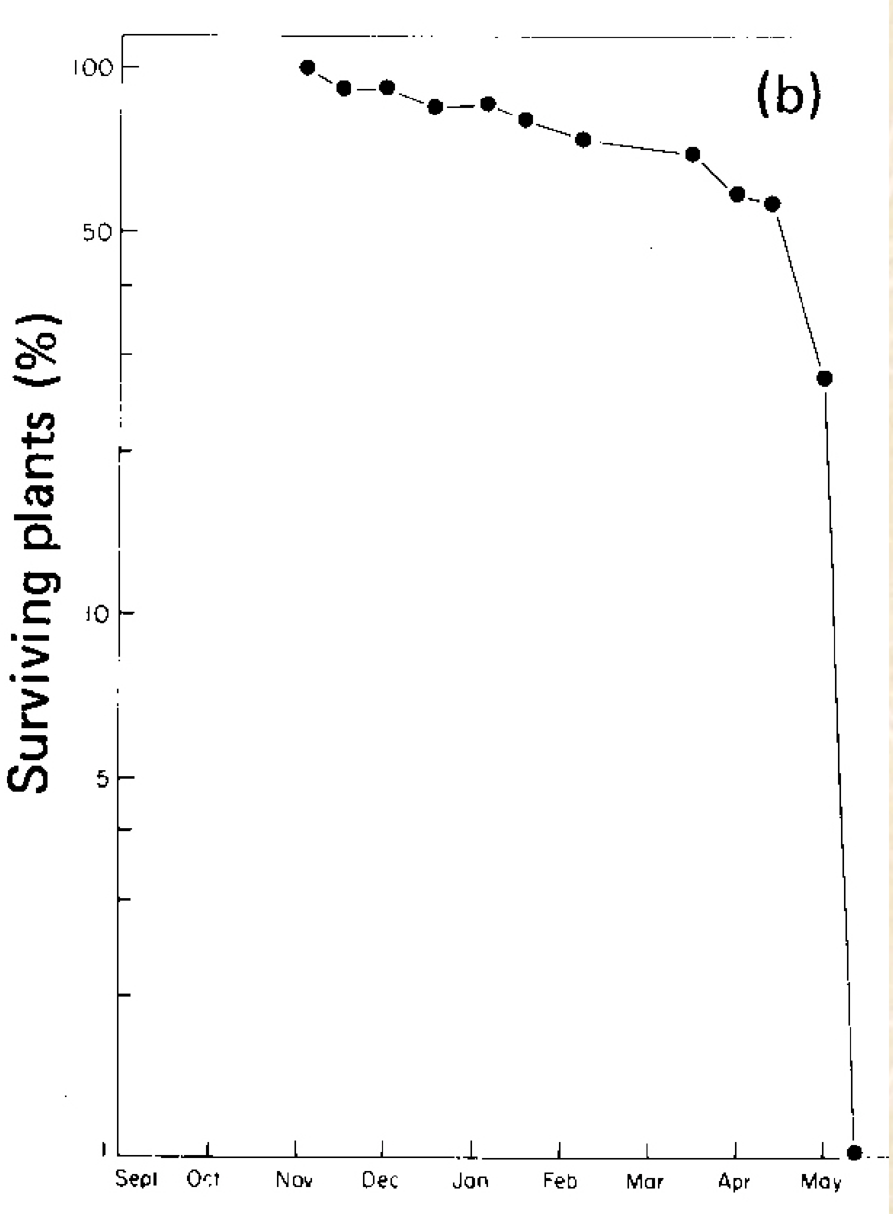


Figure 7.7: Survivorship Curves on Arithmetical and Log Axes for the Data in (a) Table 7.2 and (b) Table 7.3.

Chickweed on fixed dunes

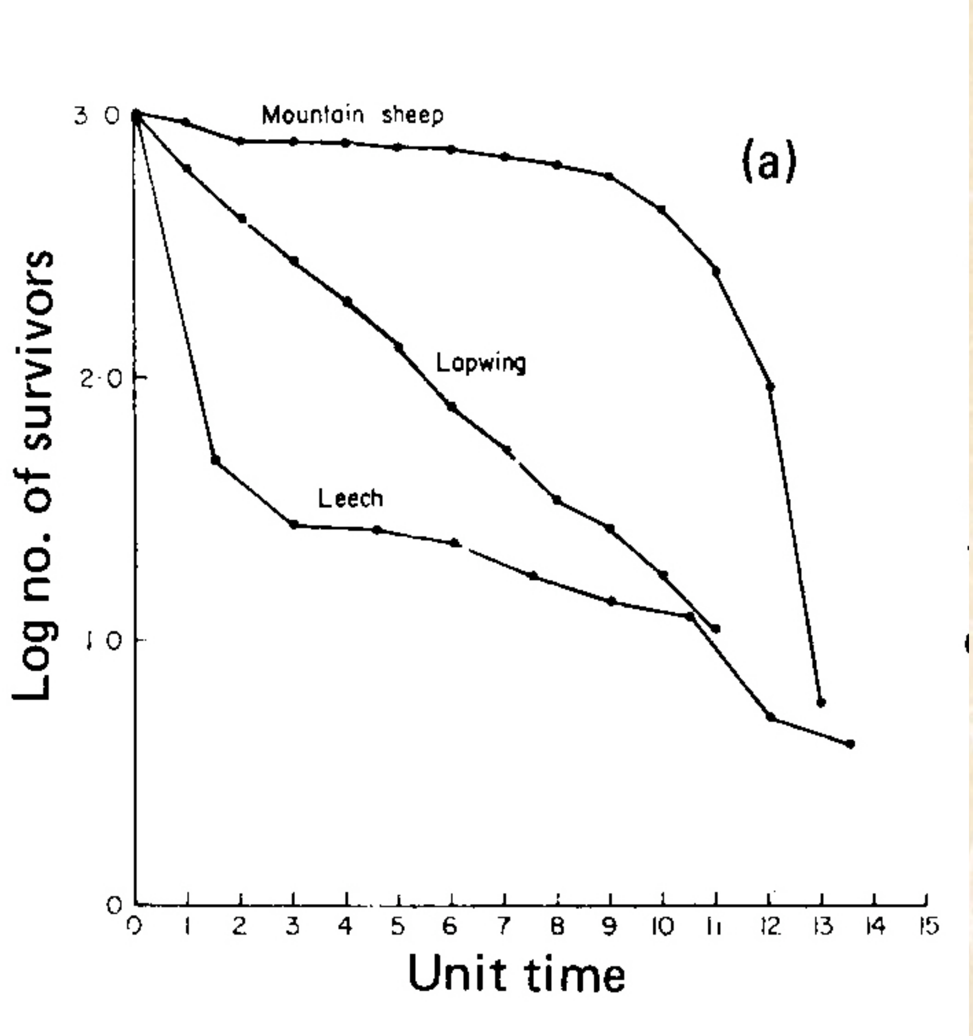


‘r’ and ‘k’ Selected Organisms

- “r-Selected”
  - Exploits short duration habitats.
  - Maximizes r while staying below k.
  - Density dependence is low.
- “k-Selected”
  - Relatively low reproduction rate.
  - Density dependence is important in population processes.
  - Exhibit parental care

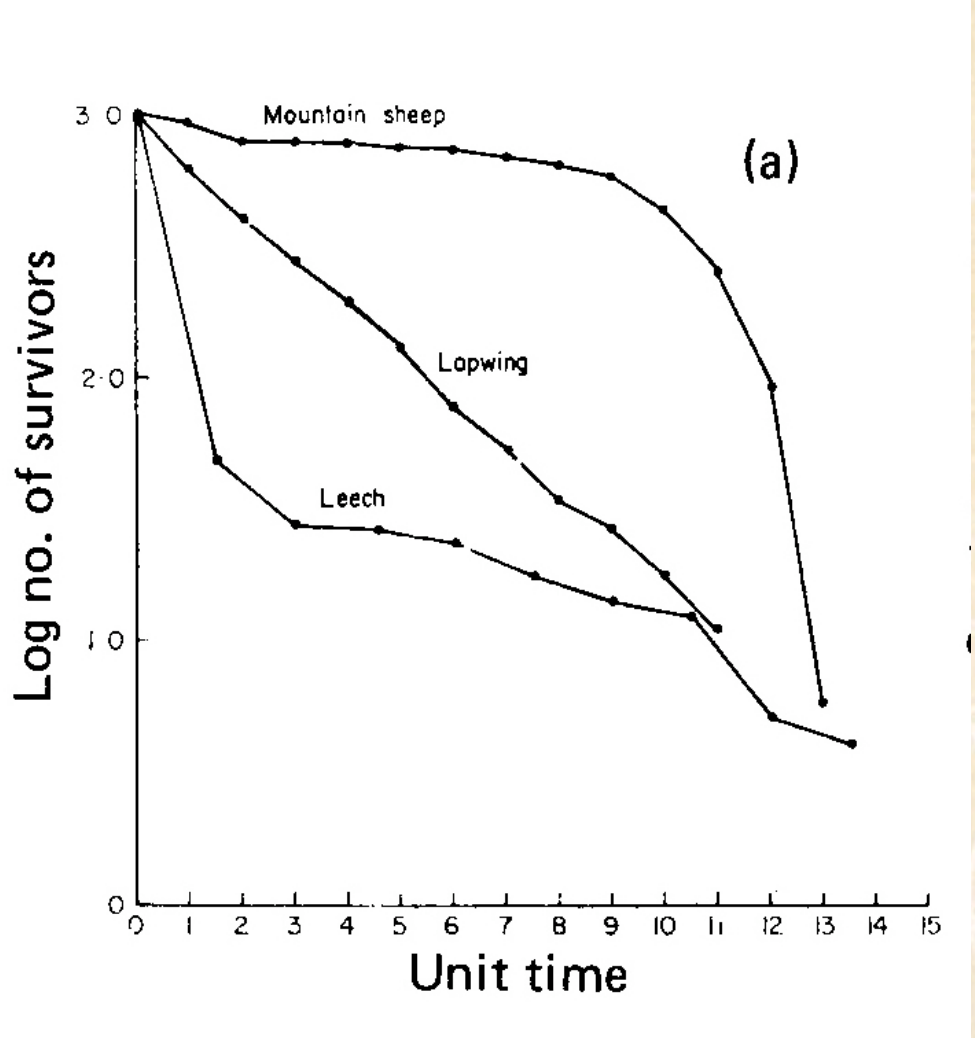
Plotting Life Tables - Type 1

- k-Selected
  - Exhibit parental care
  - Mammals
  - Mountain Sheep



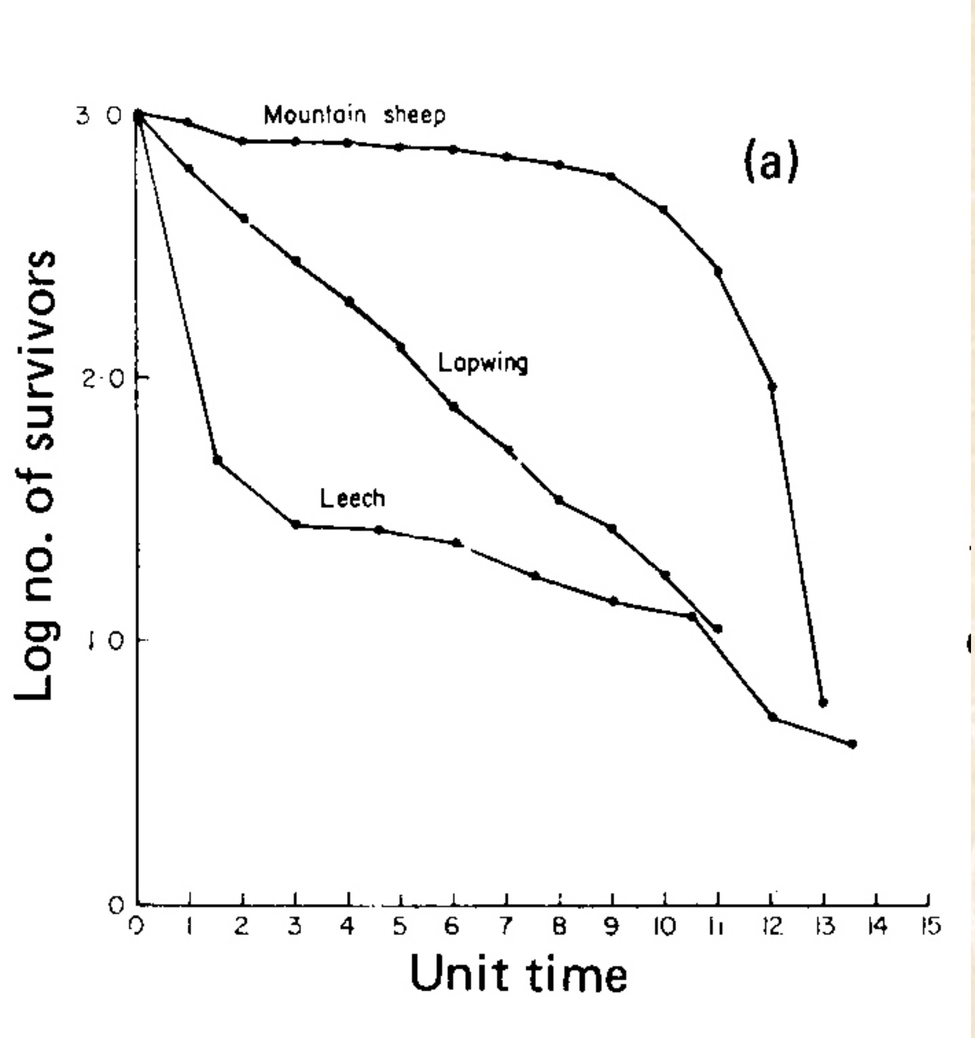
Plotting Life Tables - Type 2

- Constant Survivorship
  - Lapwing
  - Obtained from banded birds
  - Omits infant mortality
  - Reality is between types 2 and 3
  - Die before they are old



Plotting Life Tables - Type 3

- r-Selected Organisms
  - Insects
  - Fish
  - Parasites
  - Annual Plants
  - Leech



Explain this curve

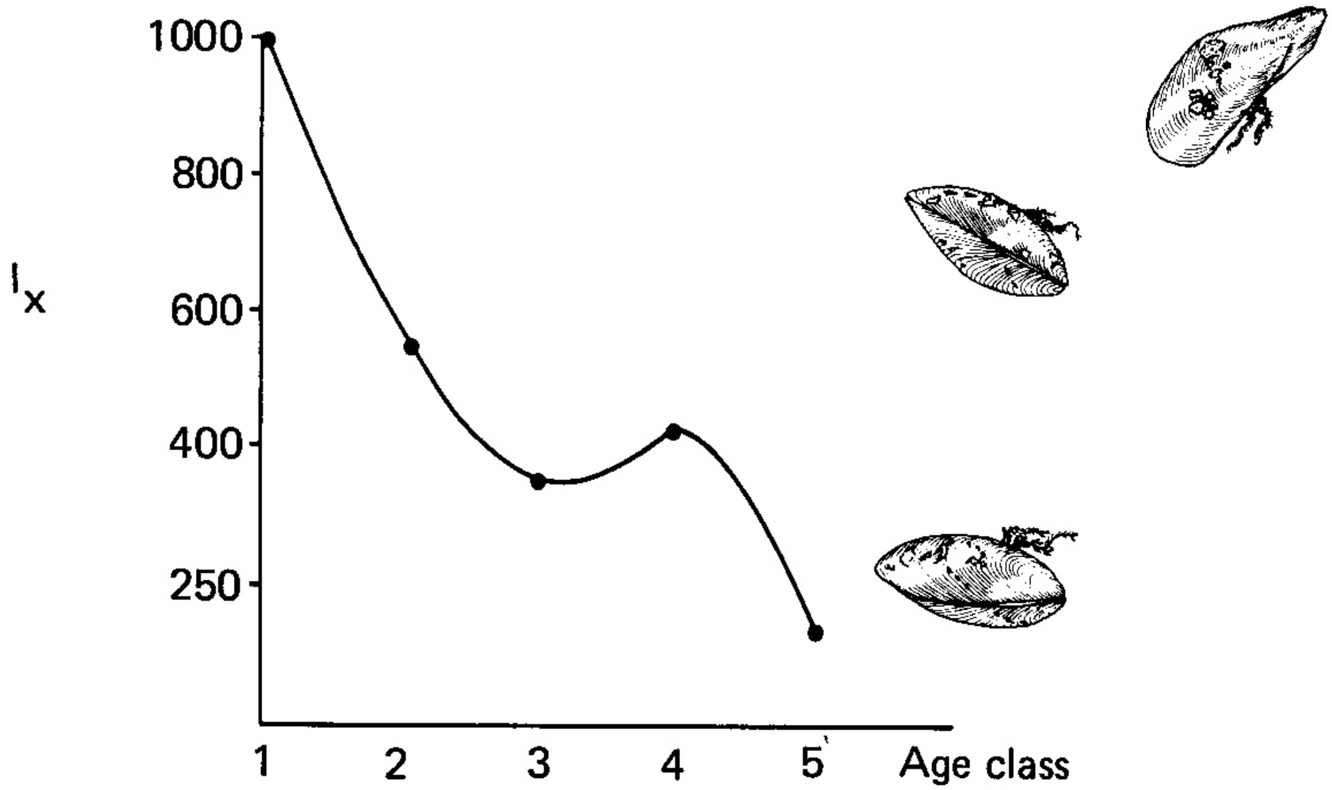


Figure 7.9: A Survivorship Curve for a Population of Mussels (*Mytilus edulis*) Which did not Exhibit a Constant Age Structure.

Multi-Species Considerations - Competition

- When 2 organisms occupy the same ecological niche, they influence each other through competition.
- 2 types of competition:
  - Intraspecific Competition - Same species
  - Interspecific Competition - Different species
- Competitors must require the same resource ***and*** that resource must be limiting or potentially limiting. If this is not the case, then there is no competition.

Multi-Species Considerations - Competition

- Competition occurs by either or both of the following:
    - Interference Competition - Direct interactions of competitors for the same resource, thus interfering with each other's uninterrupted access to and use of that resource; e.g. plants & space or light.
    - Exploitation Competition - One individual affects another's uninterrupted use of a resource through prior exploitation. Competitors do not meet, but use by one diminishes the amount of the resource available for the other.

Multi-Species Considerations - Competition

- Use of one resource by ‘A’ that affects the use of another by ‘B’ that is not used by ‘A’ is *not* competition.
- Intraspecific competition leads to diversity/variation in the population and ‘broadens’ the niche occupied. This may lead to new species.
- Both inter- and intraspecific competition are mechanisms used to regulate population size.
- Intense interspecific competition results in: 1) Extinction of one competitor or 2) Movement of one competitor into a new niche.

Intraspecific Competition

- Remember that:

$$\frac{dN}{dt} = r \bullet N \bullet \left(1 - \frac{N}{k}\right)$$

- In this equation the “1 – N/k” term is a compensation for intraspecific competition

Interspecific Competition

- We must compensate for the effects of the second species.
- This requires the inclusion of an additional term (for Species 2 or Species 1).
- This term needs to:
  - be negative in sign,
  - include the carrying capacity for Species 1, and
  - include a competition coefficient $\alpha_{1,2}$
- A second equation is needed to handle the second species

For Species 1…

$$\frac{dN_1}{dt} = r_1 \bullet N_1 \bullet \left(1 - \frac{N_1}{k_1}\right) - r_1 \bullet N_1 \bullet \left(\alpha_{1,2} \bullet \frac{N_2}{k_1}\right)$$

This simplifies to…

$$\frac{dN_1}{dt} = r_1 \bullet N_1 \bullet \left(1 - \frac{N_1}{k_1} - \alpha_{1,2} \bullet \frac{N_2}{k_1}\right)$$

Geometric
Growth

Effect of
Species 1
on itself

Effect of
Species 2 on
Species 1

For Species 2…

$$\frac{dN_2}{dt} = r_2 \bullet N_2 \bullet \left(1 - \frac{N_2}{k_2} - \alpha_{2,1} \bullet \frac{N_1}{k_2}\right)$$

Geometric Growth

Effect of Species 2 on itself

Effect of Species 1 on Species 2

An Aside - 3 Species Competition

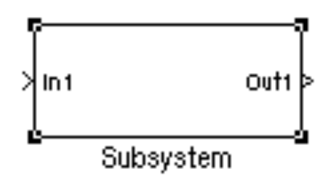
The equation becomes…

$$\frac{dN_2}{dt} = r_2 \bullet N_2 \bullet \left(1 - \frac{N_2}{k_2} - \alpha_{2,1} \bullet \frac{N_1}{k_2} - \alpha_{2,3} \bullet \frac{N_3}{k_2}\right)$$

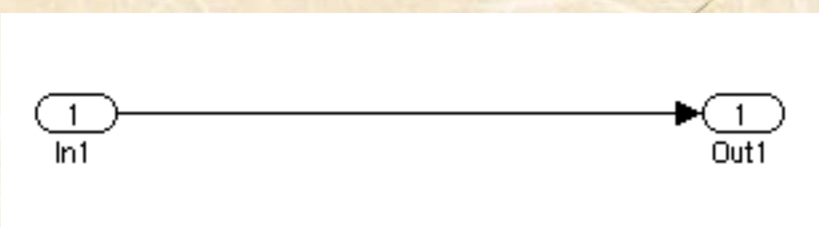
etc.

A Simulink Aside…

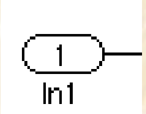
Using the *Subsystems block*



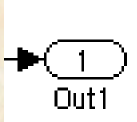
When opened the block becomes



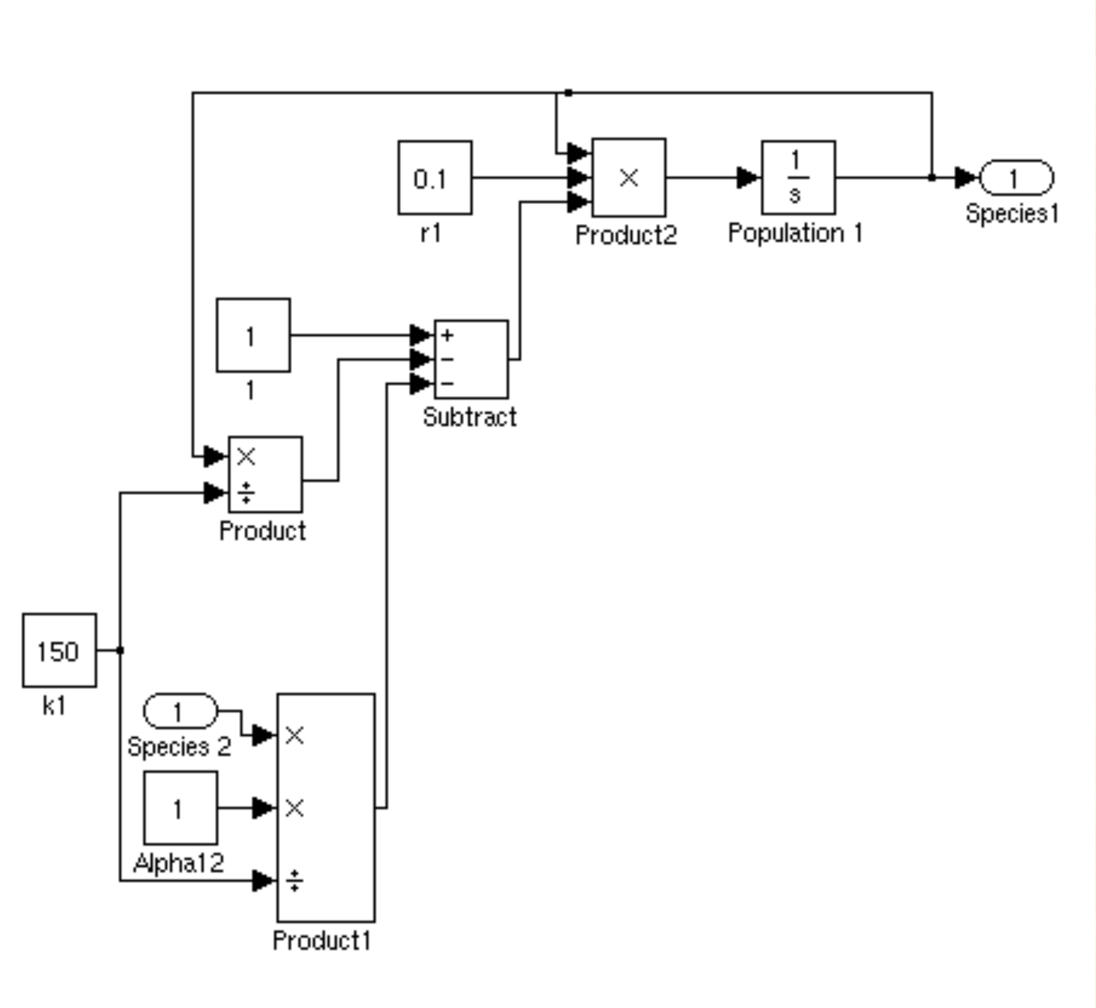
Your program replaces the signal between



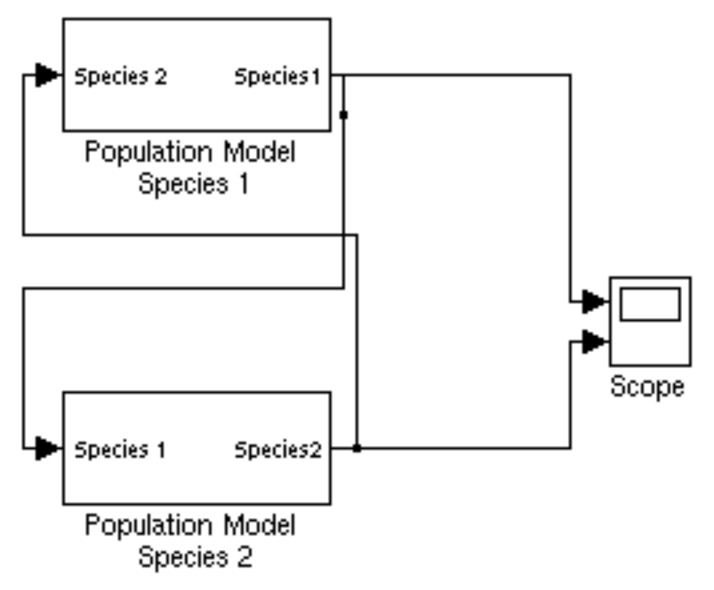
and



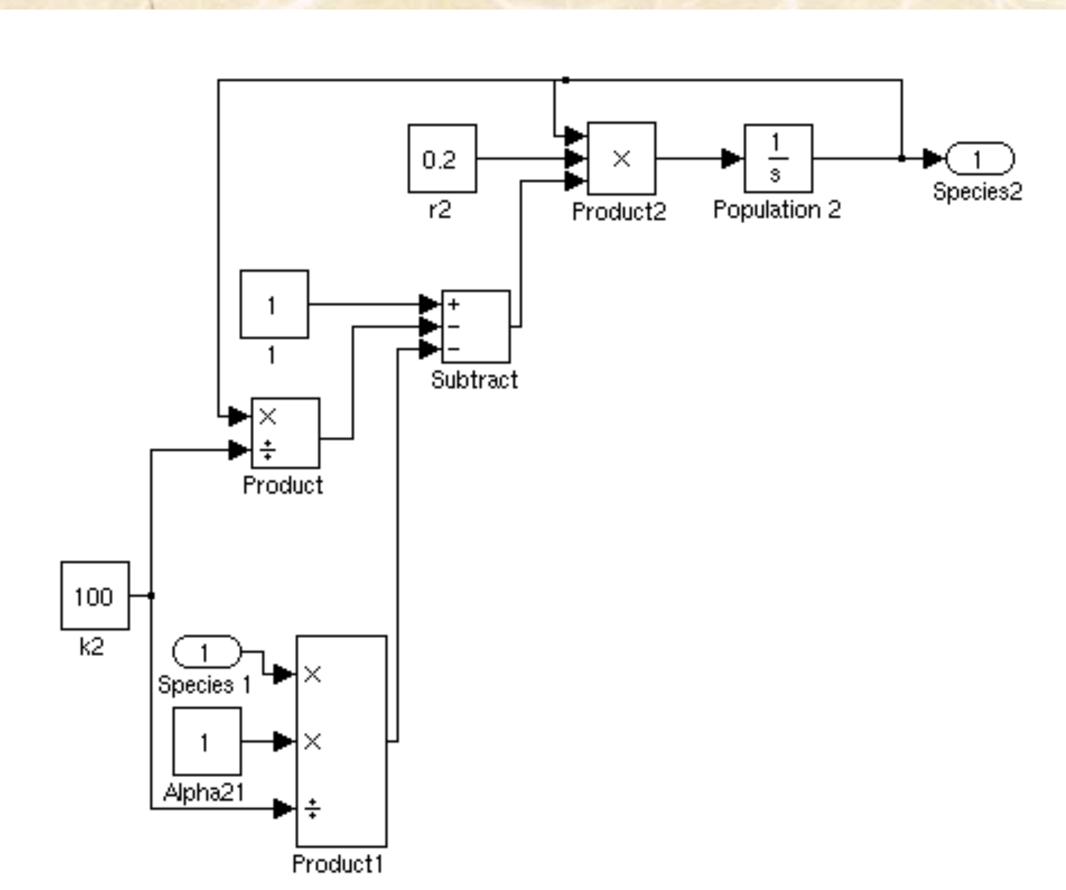
Then you build a model for species 1



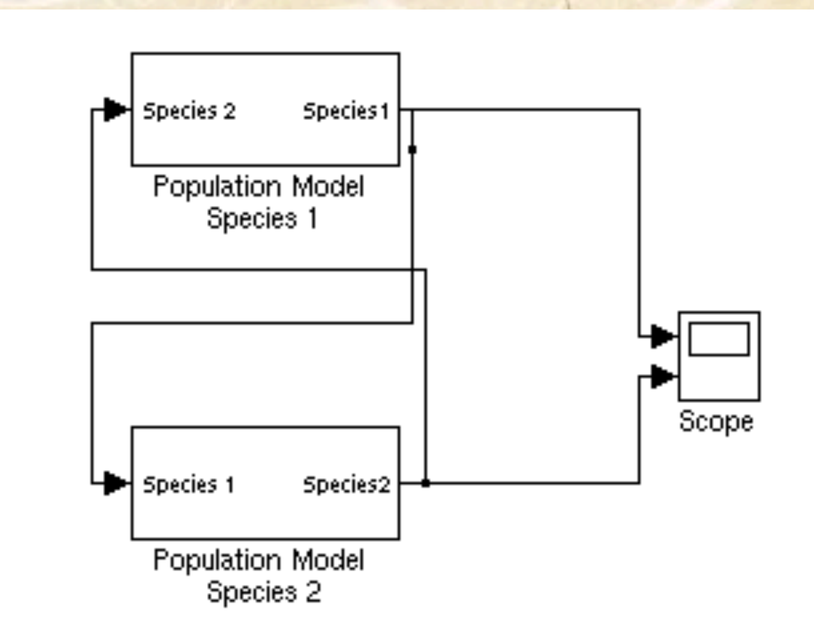
Close the subsustem, cut and paste, and connect in block 2

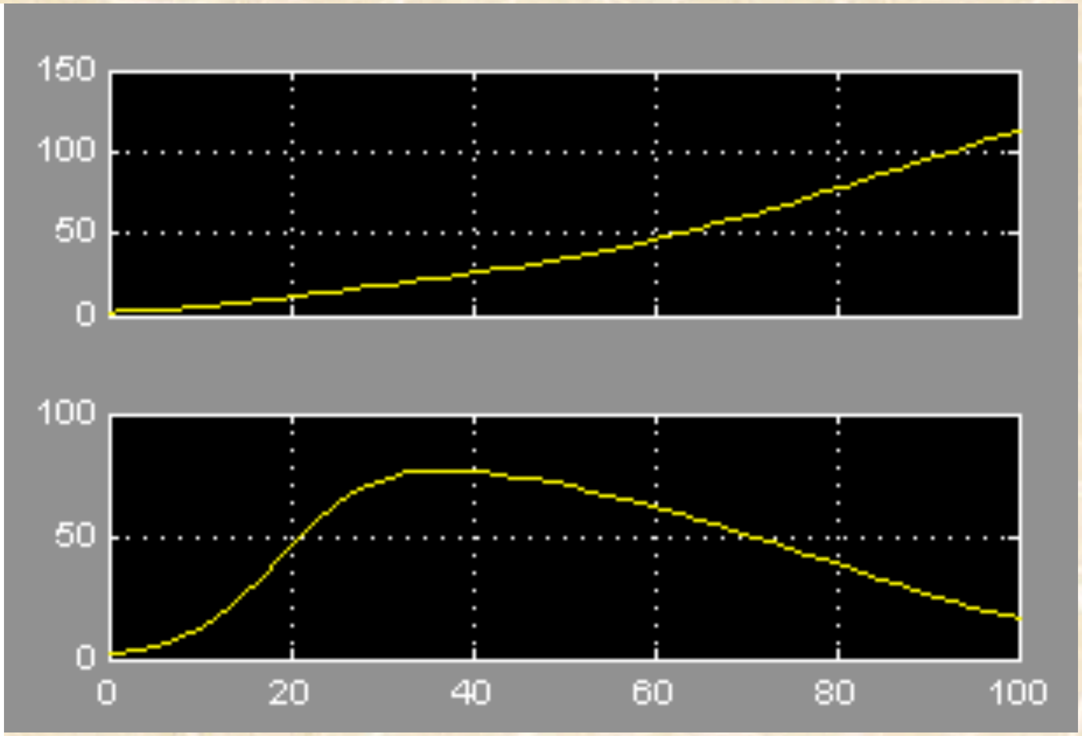


And alter the second subsystem to yield



Then run…


Species 2
Species1
Population Model
Species 1
Species 1
Species2
Population Model
Species 2
Scope

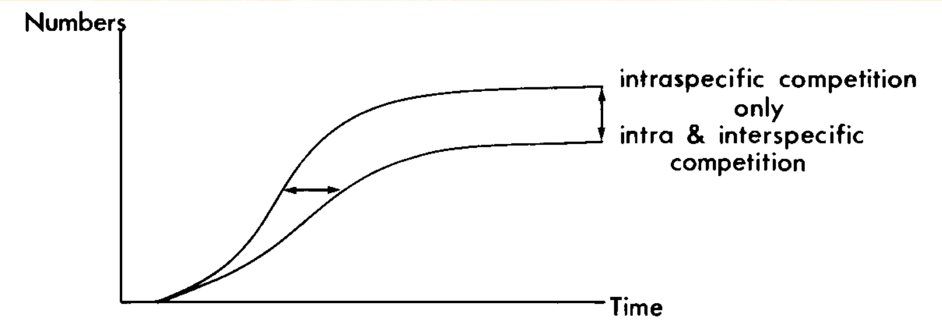

150
100
50
0
100
50
0
0
20
40
60
80
100

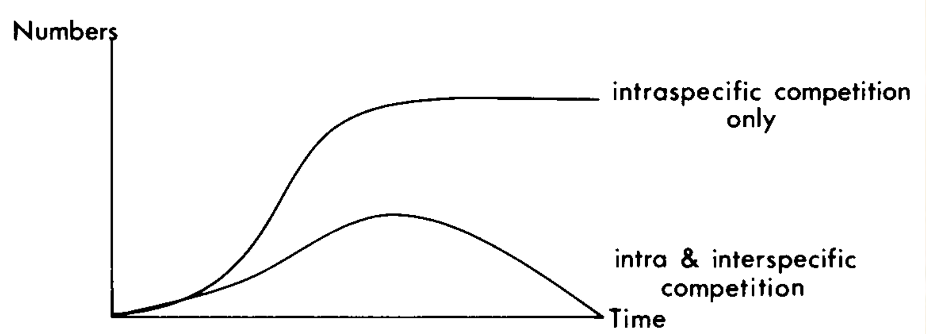
By changing sign on the species 2 term…

- -,- Competition
- -,+ Parasitism
- +,+ Mutualism, Symbiosis
- +,0 Use of one organism as the host for another
- -,0 Incidental damage, e.g. trampling of plants

Multispecies Niches

- It has been said that 2 species with the same ecologies (or niche) can not coexist in the same environment.
- Theory, however, gives two possibilities.
- These possibilities are:





An example…

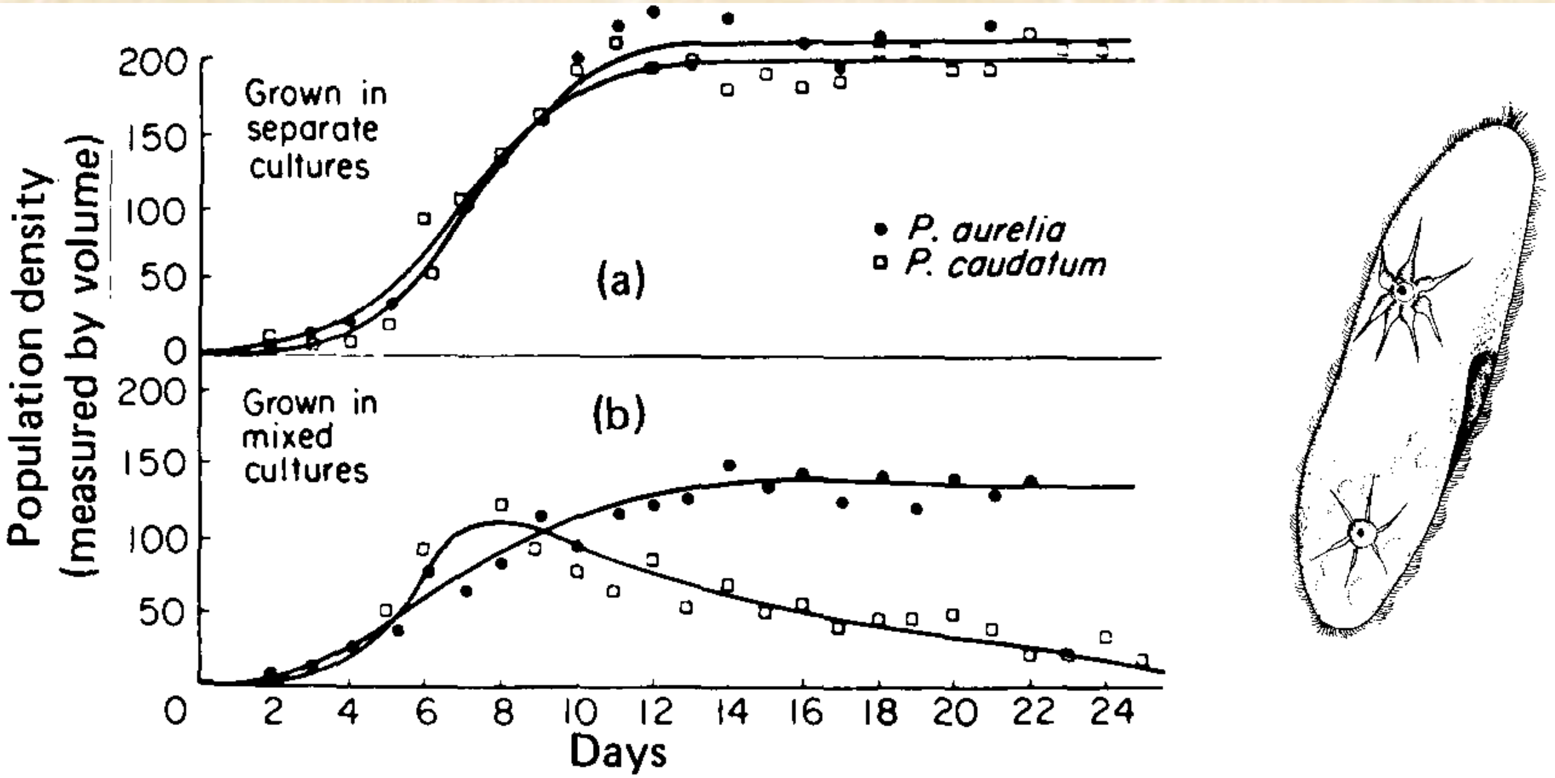


Figure 6.5: Growth of *Paramecium* Populations (*P. caudatum*, *P. aurelia*) in Separate Culture (a) and in Mixed Culture (b). Source: After Gause, 1934.

The exclusion rule is *not* always true

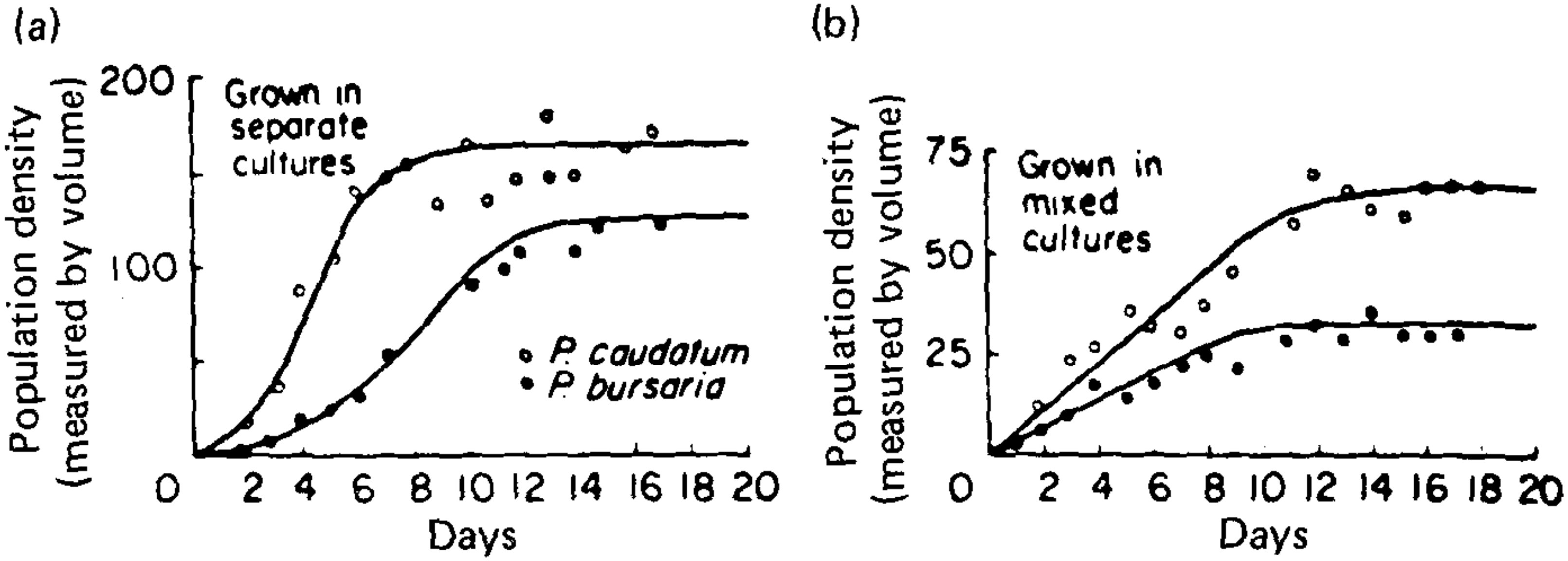


Figure 6.7: Coexistence of *Paramecium caudatum* and *P. bursaria* in Mixed Culture (b). Population curves for the two species in separate culture are shown in (a).

The outcome is dependant on…

- The outcome is dependent on:
  - Initial population densities
  - Environmental conditions
  - Genetic constitution of the strains of the competing species.

An example of external effects…

- An example of environmental effects considering
  - *Drosophila pseudo obscura*
  - *Drosophila serrata*
- At 23^{o}C - the 2 species exist in competition.
- At 25^{o}C - *D. serrata* out competes *D pseudo obscura*.
- At 22^{o}C - *D. pseudo obscura* wins.

“Patchy” external effects…

- Competition may also exist in a “patchy” environment
- Spatial heterogeneity gives each of 2 species a local advantage in an area.
- The victor is also a function of the period by which the environment favors one organism over another (where time is in terms of generational length).

The effect of time frame…

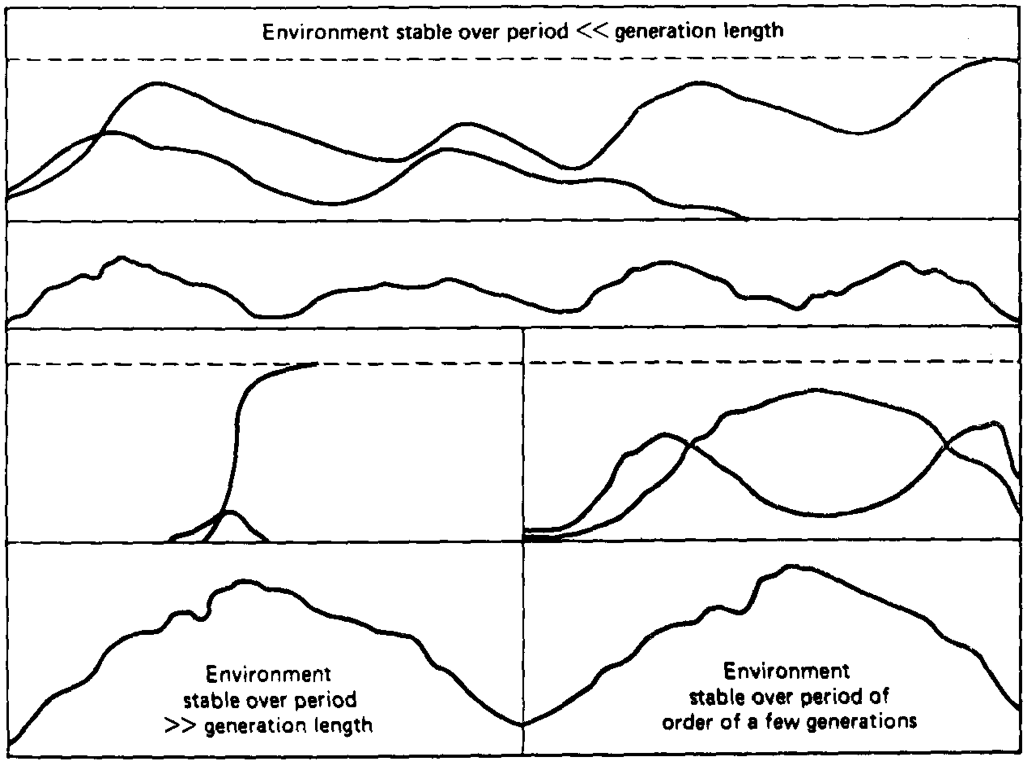


Figure 6.8: Ideal Course of Competition Between Two Species as Regulated by the Relation Between Generation Length and the Period over which the Environment may be Taken to be Stable. Source: From Hutchinson, 1953 after Collier *et al*., 1973.

Indirect Competition

- Note also that competition does not need to be direct. (Indirect competition))
  - e.g. 2 Species which do not occupy the same dietary niche may share a predator. If one species becomes scarce the predator may switch species.
  - e.g. 2 predatory species which do not eat the same prey, but whose prey species compete. If one prey species outcompetes the other, the predators will be affected.

A Summary of Competition Rules

Criteria for establishing the existence of competition

- 1) The comparative distribution and/or relative abundance of the two potentially competing species should be amenable to explanation based on competition.
- 2) It is necessary to show that the competing species are utilizing a common resource which may provide the basis of competition.

A Summary of Competition Rules

- 3) There should be evidence from the performance of the particular species populations in the field that intraspecific competition is occurring. This may relate to fecundity, survival growth rate of individuals or some other appropriate parameter. This criterion assumes that if persistent interspecific competition is occurring then intraspecific competition must also be taking place.

A Summary of Competition Rules

- 4) Both the resource which is being competed for and the population should be manipulated separately in the field with predictable results based on the hypothesis that competition is occurring. It is insufficient to manipulate only the absolute amounts of a resource since its availability may be altered irrespective of the competition process. For example, many populations are likely to respond to an increase in food whether or not competition is occurring because the same amount (or more) may be obtained with less expenditure of energy.

A Summary of Competition Rules

- 5) Events following the introduction or removal (or reduction) of a competing species should be consistent with the competition hypothesis. This criterion differs from criterion 4 since it concerns interspecific events only. Criteria 4 and 5 are clearly the most crucial to observe: results or criterion 5 enable the empirical determination of the competition coefficients α.