GATE ECOLOGY AND EVOLUTION
QUICK ACHIEVER COURSE

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GATE (Ecology and Evolution) 2016: AIR 08

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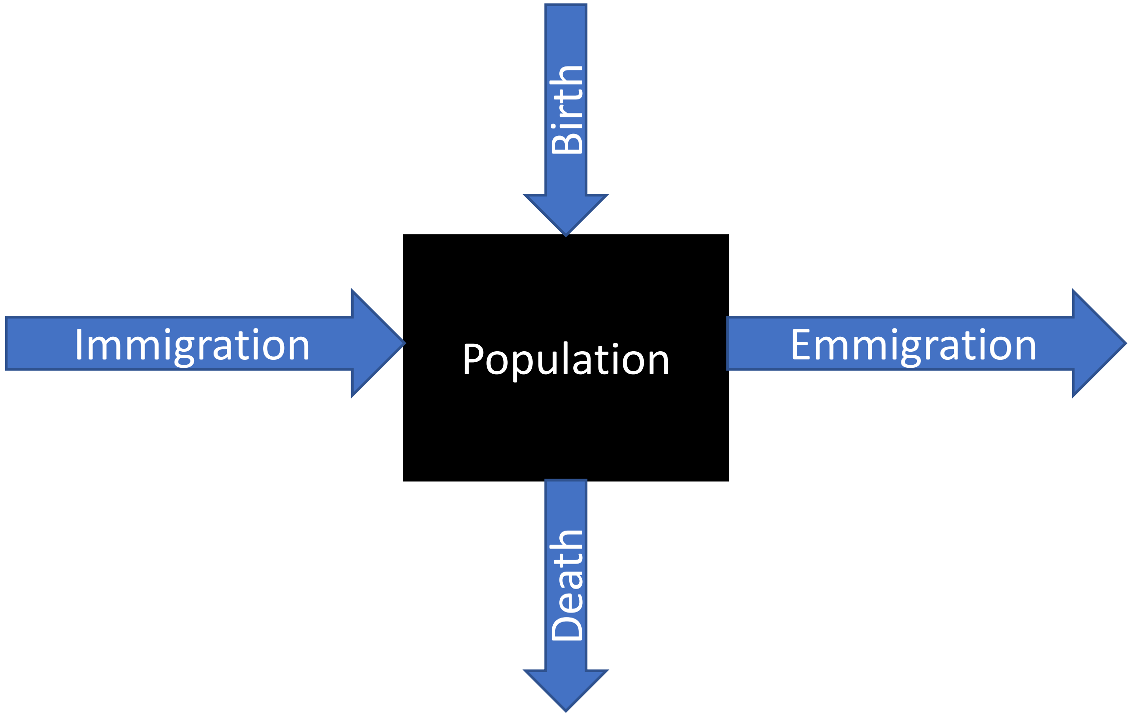
CLASS-2
POPULATION ECOLOGY

POPULATION

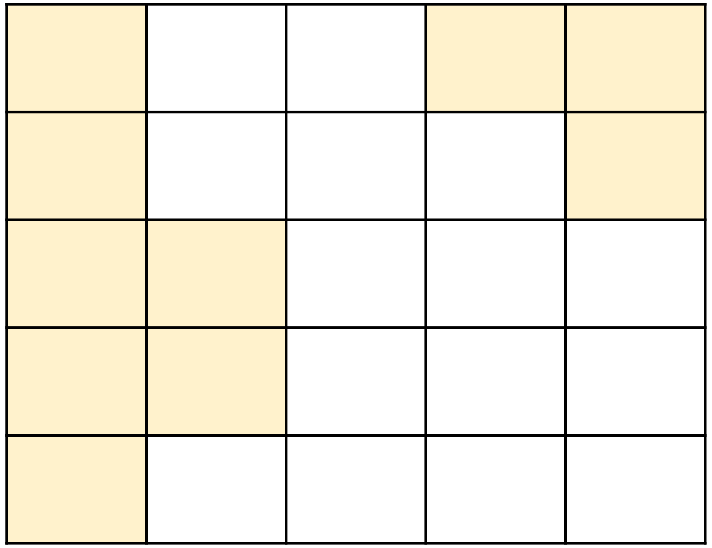
- **Population:** Any group of organism of the same species which occupies a given area and functions as a part of a biotic community.
- Population is different from individuals in several aspects:

Individual	Population
Born and dies	Continues
male/female, old/young	Sex ratio, age structure
Individual born, ages and dies	Birth rates, death rates, age ratio, genetic fitness and growth form


Birth
Immigration
Population
Emmigration
Death

Population density

- **Definition:** Size of the population (number of individual) in relation to a definite unit of space.
  Example: 50 trees/ha
- **Crude density:** Number of individuals (N) (or biomass) per unit area (A)
  $$N/A$$
- **Ecological density:** Number of individuals (or biomass) per habitat space (h)
  $$N/H$$
- **Relative abundance:** Used to understand changing population density with respect to time.
  Ex: Number of birds seen per hour
- **Frequency of occurrence:** Percentage of sample plot occupied by a species.



$$f = \frac{10}{25} \times 100$$

Methods to estimate population density: Lincoln Index (Mark-recapture method)

- This method relies on capturing and marking some fraction of a population and using this fraction to estimate total density
- It is simple!
- Suppose, **M** is the individual captured, marked and released initially
- In the subsequent sampling effort after a sufficient time interval, **n** individual recaptured.
- Out of **n** total **x** individual found marked
- So, what is the expected population size??

x marked individuals found in **n** number of individuals

1 marked individual can be found in **n/x** number of individuals

M marked individual can be found in **nM/x** number of individuals

Methods to estimate population density: Lincoln Index (Mark-recapture method)

The validity of this method depends on the following assumptions:

- that the marking technique has no negative effect on the survivility of marked individuals.
- that the marked individuals are released at the original site of capture and allowed to mix with the population based on natural behaviour.
- that the marking technique does not affect the probability of being recaptured.
- that the marks (such as ear tags) are not lost or overlooked.
- that there is no significant immigration or emigration of marked or unmarked individuals in the interval between mark and recapture.
- that there is no significant mortality or natality in the interval between mark and recapture.

Methods to estimate population density: Other methods

- Transect method
- Quadrat method
- Plotless sampling method
- Total count method

Natality

- It is ability of a population to increase by reproduction
- **Maximum natality:** Theoretical maximum possible natality under ideal condition without any biological limitation. It is constant for a population.
- **Ecological or realised natality:** Actual natality under field condition. It is not constant which changes with population size, age composition etc.
- **Absolute/crude natality:** Number of new individual per unit time.
- **Specific natality:** Number of new individual per unit time per unit population.

Mortality

- It refers to death of individuals in a population.
- **Minimum mortality:** Loss due to death under ideal or non-limiting condition. It is constant.
- **Ecological or realized mortality:** Loss of individuals due to death under actual environmental conditions. It is not constant.
- **Absolute and specific mortality:** same like natality.
- **Vital index:** birth to death ration as percentage. (birth*100/death)

Survival rate, longevity & life expectancy

- **Survival rate:** Converse to mortality

$$S = 1 - M$$

Where, S is survival rate, M is mortality expressed in fraction

- **Longevity:** Average life span of individuals in a population
- **Potential (physiological) and realized (ecological) longevity?**
- **Life expectancy:** average number of years to be lived in the future by population members of a certain age.
- **Age structure:** Number of individuals of a population at different age classes.
- **Cohort:** The individuals from birth (born approximately at same time) to death form a group called cohort.

Life table

- Tabular representation of age specific summary of mortality and life expectancy called Life table.

Age (x)	Survivorship (l_x)	Death (d_x)	Mortality rate (q_x)	Life expectancy (e_x)
0	100	55	0.55	1.15
1	45	30	0.67	0.94
2	15	10	0.67	0.83
3	5	5	1	0.5
4	0	-	-	-

Life table

Age (x)	Survivorship (l_x)	Death (d_x)	Mortality rate (q_x)	Life expectancy (e_x)
0	100	55	0.55	1.15
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4	0	-	-	-

- l_x= number of survivors at start of age interval x.
- d_x= number dying between age interval x to x+1
- $l_{x+1}= l_x-d_x$
- q_x= mortality rate between age interval x to x+1 = d_x/l_x
- e_x is complex
- It is calculated from average number alive between each age interval (L_x).

Life table

Age (x)	Survivorship (l_x)	Death (d_x)	Mortality rate (q_x)	Life expectancy (e_x)
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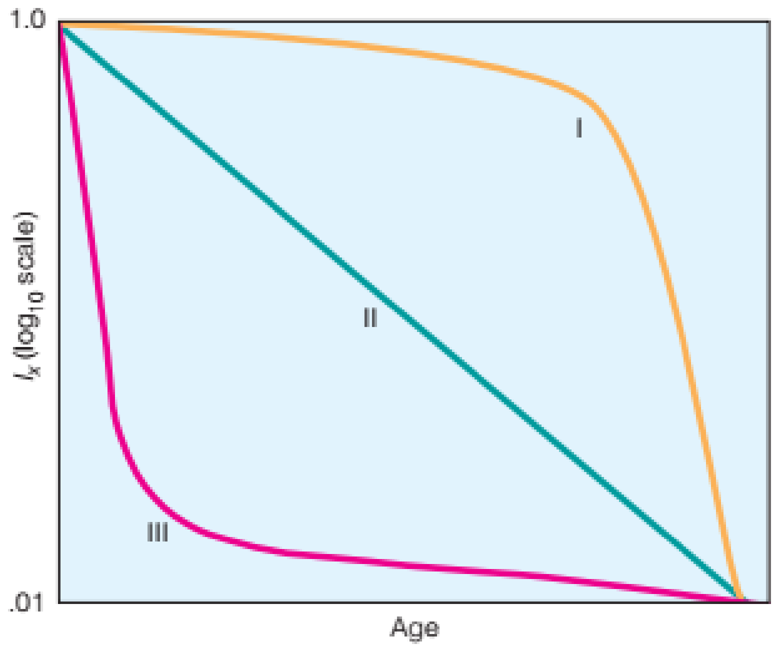
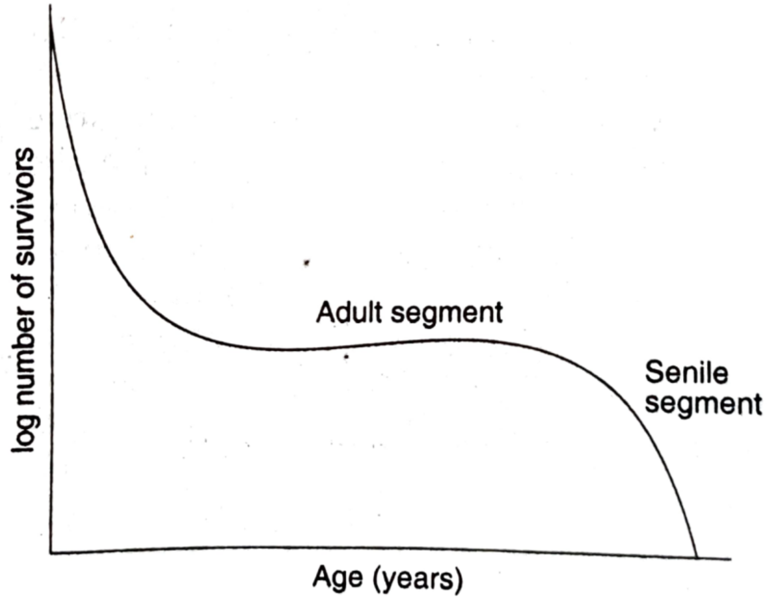
4	0	-	-	-

- $L_x=(l_x+l_{x+1})/2$
  - $L_1=(45+15)/2 = 30$
- $T_x = \sum_x^\infty L_x$
  - $T_1= L_1+L_2+L_3+L_4=30+10+2.5=42.5$
- $e_x=T_x/l_x$
  - $e_1=42.5/45 = 0.94$
- $T_0=L_0+T_1=(100+45)/2 + 42.5 = 115$
- $e_0= T_0/l_0 = 115/100 = 1.15$
- e_0 is mean natural longevity

Survivorship curve

- It is obtained by plotting survivorship (l_x) on a logarithmic scale (*hence* log l_x) on y-axis and age (x) on the x-axis.
- It is of 3 types:
  - Type I: Highly convex curve. Mortality is low until the end of the life span. Ex. Human, many large mammal, some plant species.
  - Type II: Diagonal curve. Steady mortality throughout the life. Ex. Birds, rodents, rabbit, deer, many perennial plants
  - Type III: Highly concave. Mortality rate is extremely high at early life. Ex. Most trees, fishes, many invertebrates.
- Shape of the survivorship curve depends on degrees of parental care, density etc.





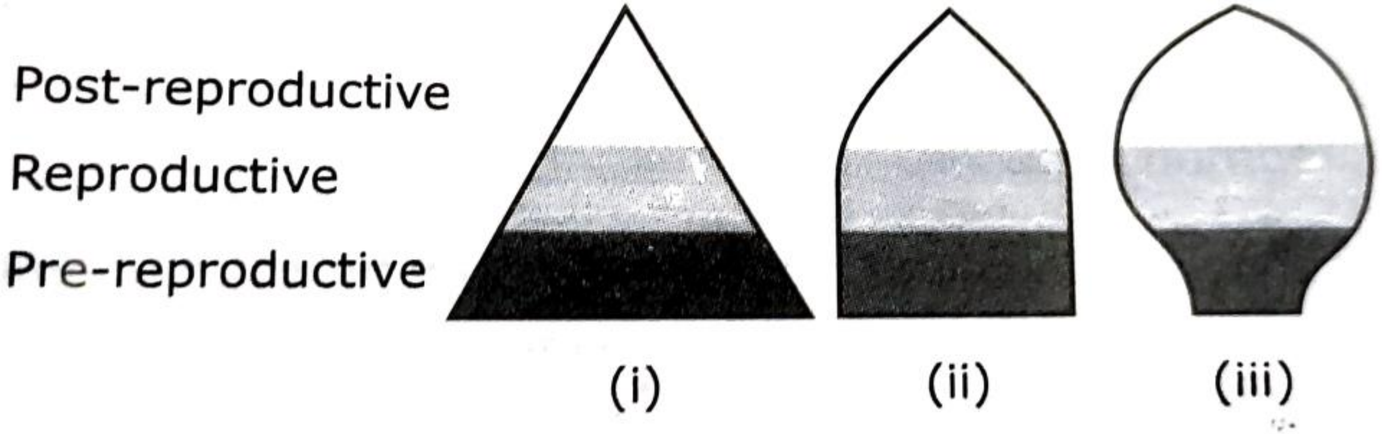
Age distribution

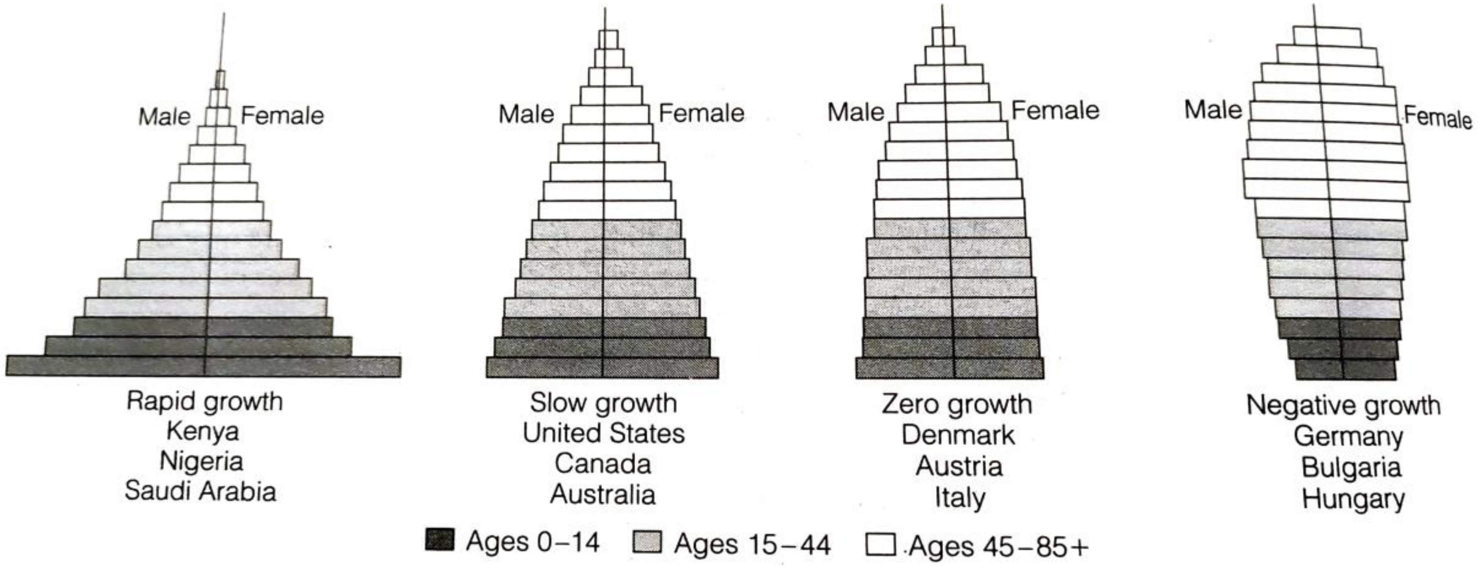
- **Age structure:** It is the proportion of individual at various age classes in a population.
- There are 3 main ecological age classes:
  - Pre-reproductive
  - Reproductive
  - Post-reproductive

  The relative duration of this age classes varies between organism to organism
- Age structure affects both natality and mortality
- **Age pyramid:** A model, representing geometrically the proportions of different age groups in a population in the form of vertical bar graph.

Age distribution

- There are 3 kinds of hypothetical age pyramids:
    - Expanding population
    - Stable population
    - Diminishing population
- **Stage structure?**





Patterns of distribution

- Measurement:

Quadrat count of 9 samples: 2, 5, 7, 0, 3, 6, 4, 2, 5

Mean $(\bar{X}) = \frac{2+5+7+0+3+6+4+2+5}{9} = 3.78$

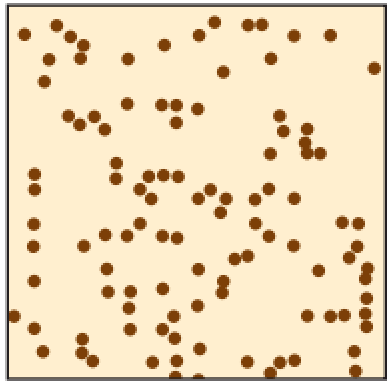
Variance (S^2)$= \frac{\sum(X-\bar{X})^2}{n-1} = \frac{40}{9-1} = 5$

X	X-$\bar{X}$	$(X-\bar{X})^2$
2	-1.78	3.17
5	1.22	1.49
7	3.22	10.37
0	-3.78	14.29
3	-0.78	0.61
6	2.22	4.93
4	0.22	0.48
2	-1.78	3.17
5	1.22	1.49
	Total	40

$\frac{S^2}{\bar{X}} = \frac{5}{3.78} = 1.32$

$\frac{S^2}{\bar{X}}$ is called **index of dispersion**

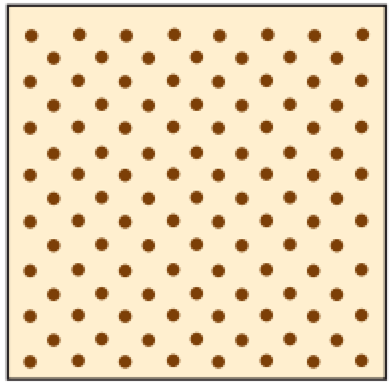
$\frac{S^2}{\bar{X}} = 1$



Random

Environment is uniform and there are no tendency between individuals to aggregate. Ex. Lone parasites or predators

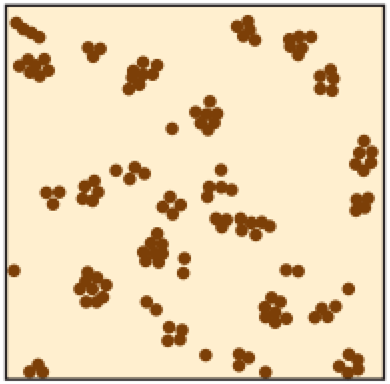
$\frac{S^2}{\bar{X}} < 1$



Uniform

Each individual maintains a more or less equal distance than others due to negative feedback. Ex. Trees in a forest, territorial animals, plantation

$\frac{S^2}{\bar{X}} > 1$



Clumped

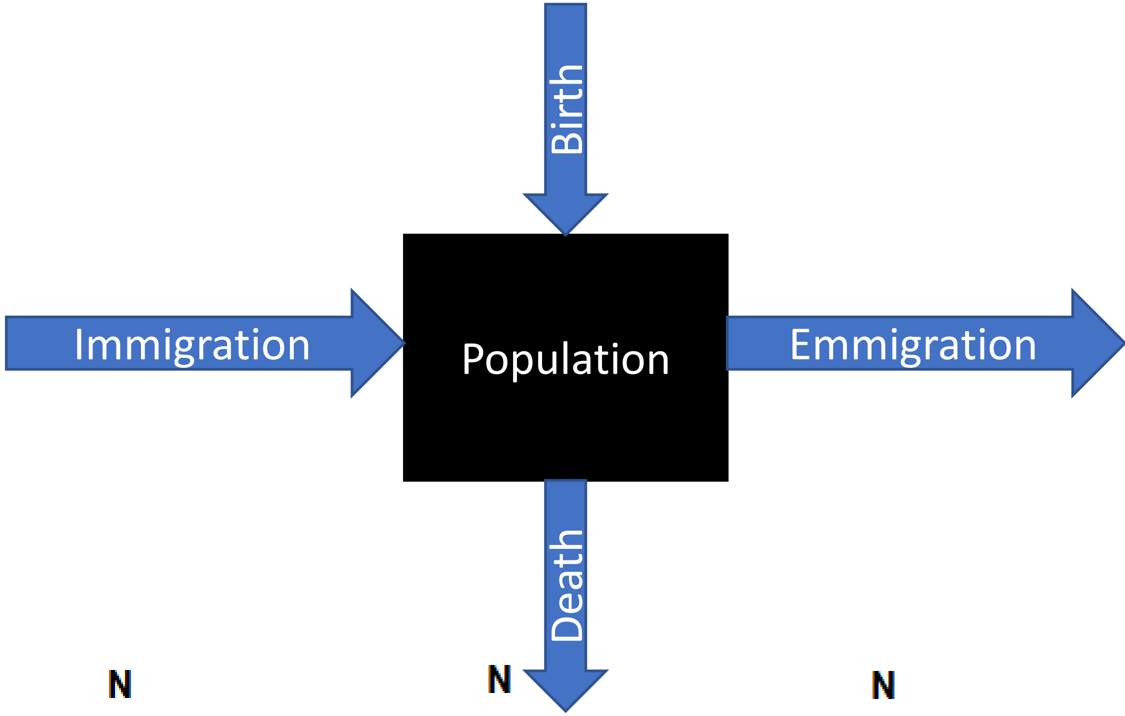
Most common. It occurs due to sociality, resource availability etc.

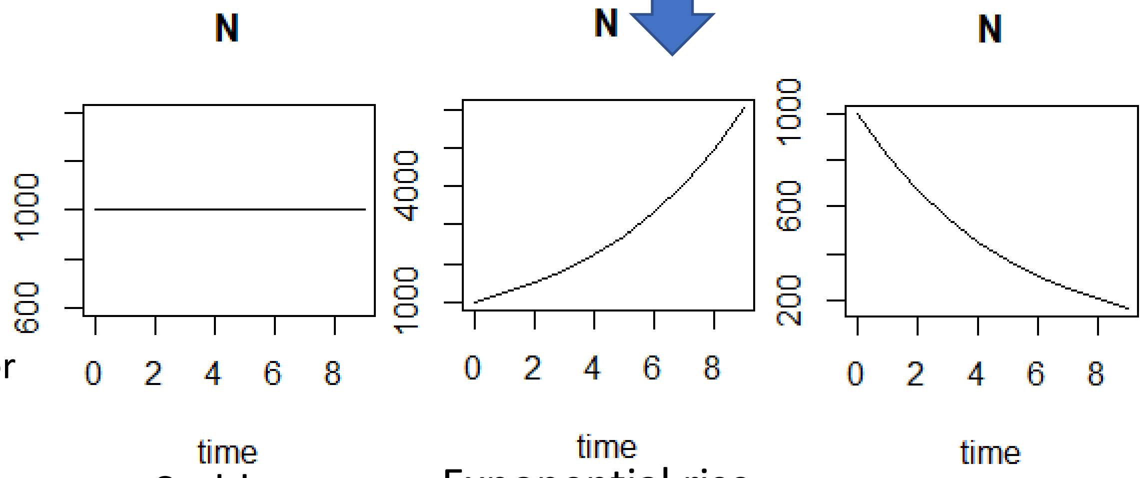
Population growth

- **Population dynamics:** The study of changes in the relative numbers of organisms in population and the factor explaining these changes.
- *Calculus* is used to study the population dynamics.
- **Rate:** Change in some quantity by the period of *time.*
- **Δ** is used to denote change in some quantity.
- **ΔN** is change in number of organisms
- **$\Delta N/ \Delta t$** is average change in number of organisms per time
- **$\Delta N/ N\Delta t$** specific growth rate
- **dN/dt** is instantaneous growth rate. (dt is very close to zero)

Population growth

- $\Delta N = B + I - D - E$ [**open population**]
- $\Delta N = B - D$ [**closed population**]
- $\frac{\Delta N}{\Delta t} = N_{t+1} - N_t = B - D$ [**discrete growth**]
- $dN/dt = B - D$ [**continuous growth**, dN is the change in the population at a very small time dt≈0]
- $dN/dt = bN - dN$ [here, b is instantaneous rate of birth and d is instantaneous rate of death]
- $dN/dt = (b - d)N = rN$
  here, r is instantaneous coefficient of population growth/intrinsic rate of natural increase
- r varies with the natural conditions and age structure of the populations
- The r reached its maximum value (r_{max}), when a stable age distribution exists in a population, it is also called **biotic potential** or **reproductive potential**.
- Difference between r and r_{max} called **environmental resistance**.





Stable
$r = 0$
$b = d$

Exponential rise
$r > 0$
$b > d$

Exponential decline
$r < 0$
$b < d$

Exponential growth

- $dN/dt = rN$

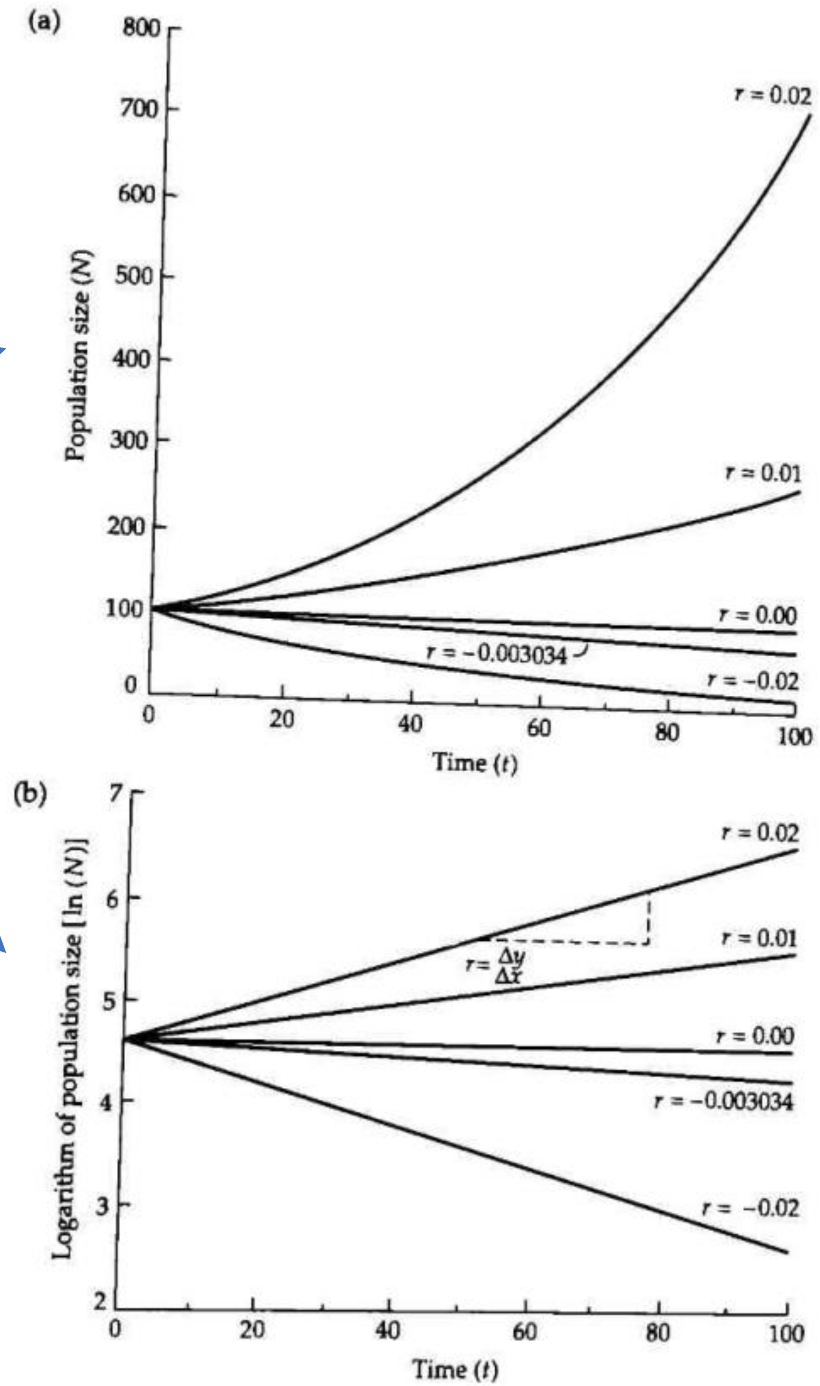
Or, $N_t = N_0 e^{rt}$ [Exponential curve]

Or, $\ln N_t = \ln N_0 + rt$ [linear curve]

- Calculating doubling time:

$$\frac{N_t}{N_0} = e^{rt} = 2$$

Or, $\ln 2 = rt$ or, t=0.693/r



Assumptions of exponential growth model

- No immigration or emigration
- Constant birth and death rate
- No genetic structure
- No age or size structure
- No time lag

Exponential model for discrete population growth

Continuous population	Discrete population
This kind of population has overlapping generations.	This kind of populations has non-overlapping generation.
Individuals of one generation can mate with the individuals of another generations.	Individuals of one generation can only mate with individuals of the same generation.
Growth of this kind of population is modelled with differential equations.	Growth of this kind of population is modelled with difference equations.
Ex: Human population.	Ex. Butterfly population

- $N_{t+1} = N_t + r_d N_t$ [here r_d is discrete growth factor]

or, $N_{t+1} = N_t(1 + r_d)$

or, $N_{t+1} = N_t \lambda$ [λ is finite rate of increase]

$e^r = \lambda$ or, $r = \ln \lambda$

r	λ
r>0	λ>0
r=0	λ=1
r<0	0<λ<1

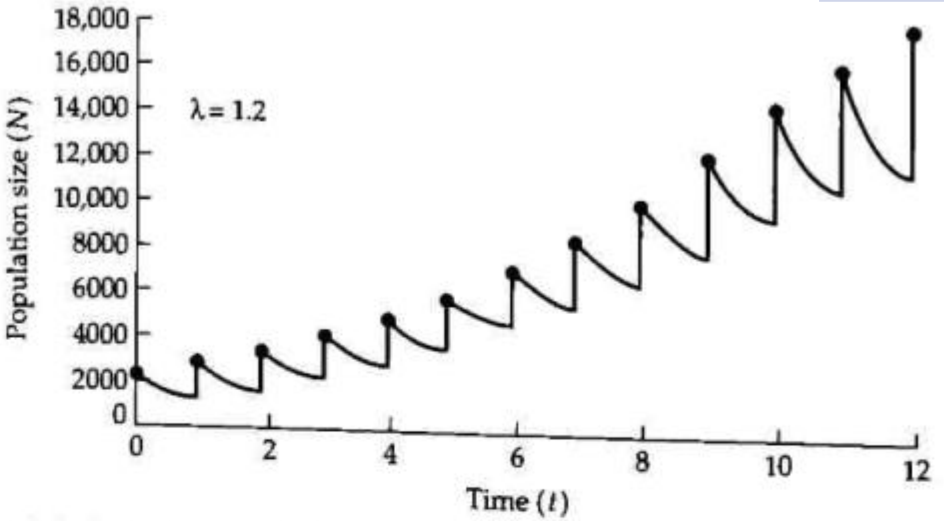


Figure 1.2 Discrete population growth. In this example, births are pulsed at the beginning of the year, and deaths occur continuously.

Population regulation

- The population cannot growth indefinitely as shown in exponential growth.
- The population growth is regulated in primarily two manner:
  - Density-independent (extrinsic)
  - Density-dependent (intrinsic)

Density-independent population regulation	Density-dependent population regulation
This kind of factor causes drastic variations in population density, which sometime results in shifting of carrying capacity	This kind of factor tends to maintain a stable population density
In physically stressed ecosystem, this kind of factor plays a greater role.	In favourable condition, these kinds factors play a greater role
It involves interactions with the rest of the community	It is populations's own response to the density
Ex: Predation, parasitism, interspecific competition, natural calamities	Intra-specific competition, contaminative disease, migration, behavioural and physical changes.

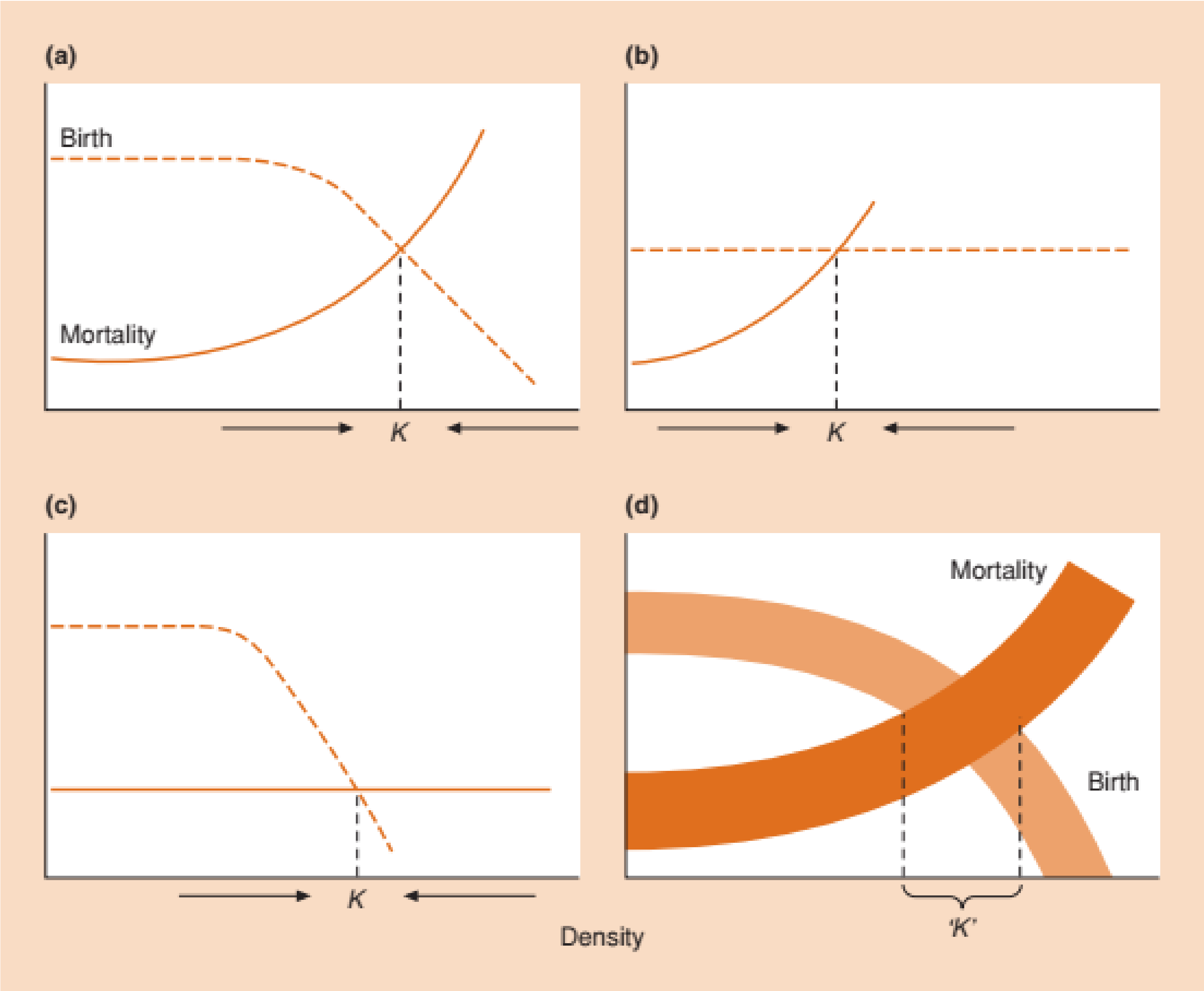
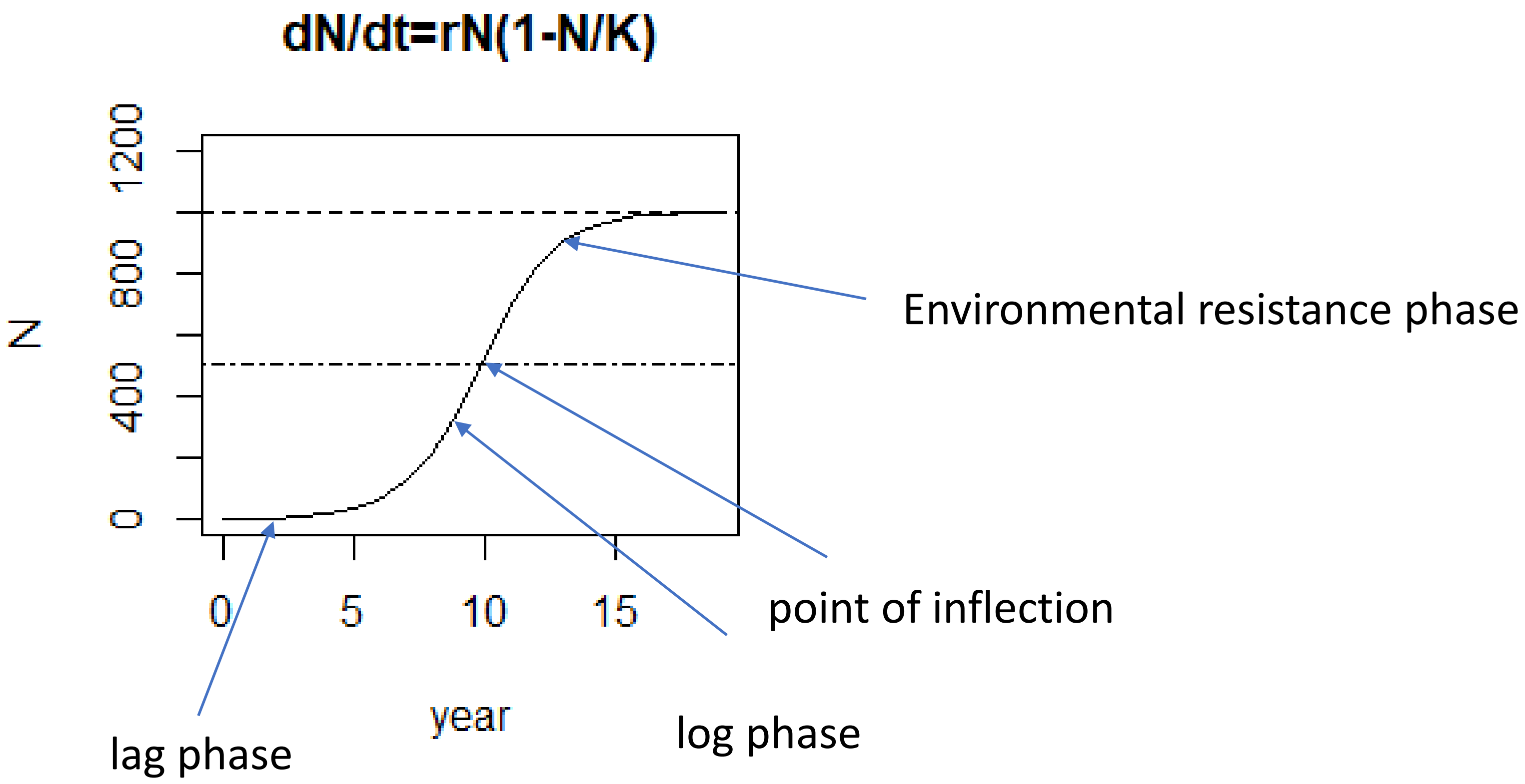


Figure 5.7 Density-dependent birth and mortality rates lead to the regulation of population size. When both are density dependent (a), or when either of them is (b, c), their two curves cross. The density at which they do so is called the carrying capacity (K). Below this the population increases, above it the population decreases: K is a stable equilibrium. However, these figures are the grossest of caricatures. The situation is closer to that shown in (d), where mortality rate broadly increases, and birth rate broadly decreases, with density. It is possible, therefore, for the two rates to balance not at just one density, but over a broad range of densities, and it is towards this broad range that other densities tend to move.

Logistic growth and carrying capacity

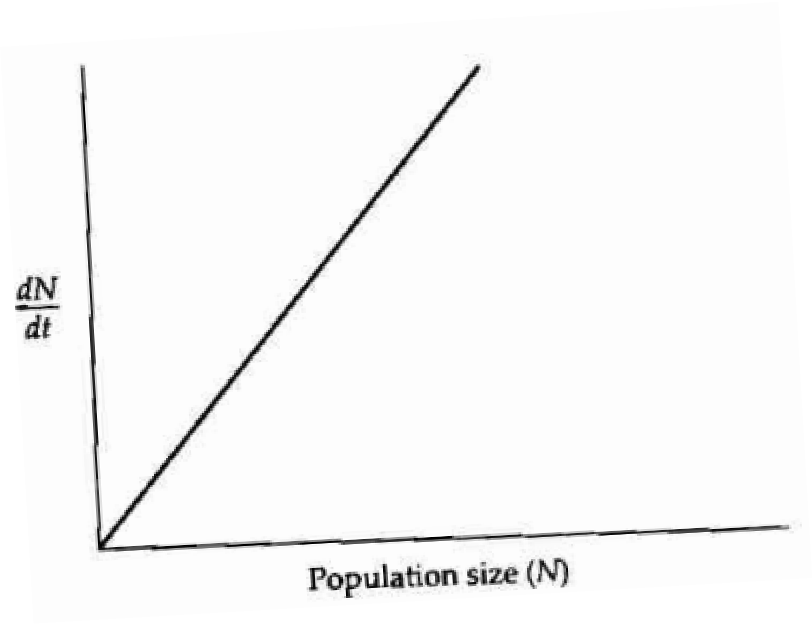
- $r = r_{max}(1 - \frac{N}{K})$
- $\frac{dN}{dt} = r_{max}N(1 - \frac{N}{K})$ or $r_{max}N(\frac{K-N}{K})$ or $r_{max}N - \left(\frac{r}{k}\right)N^2$
- Integrated form:

$$N_t = \frac{K}{1 + e^{a - r_{max}t}}$$



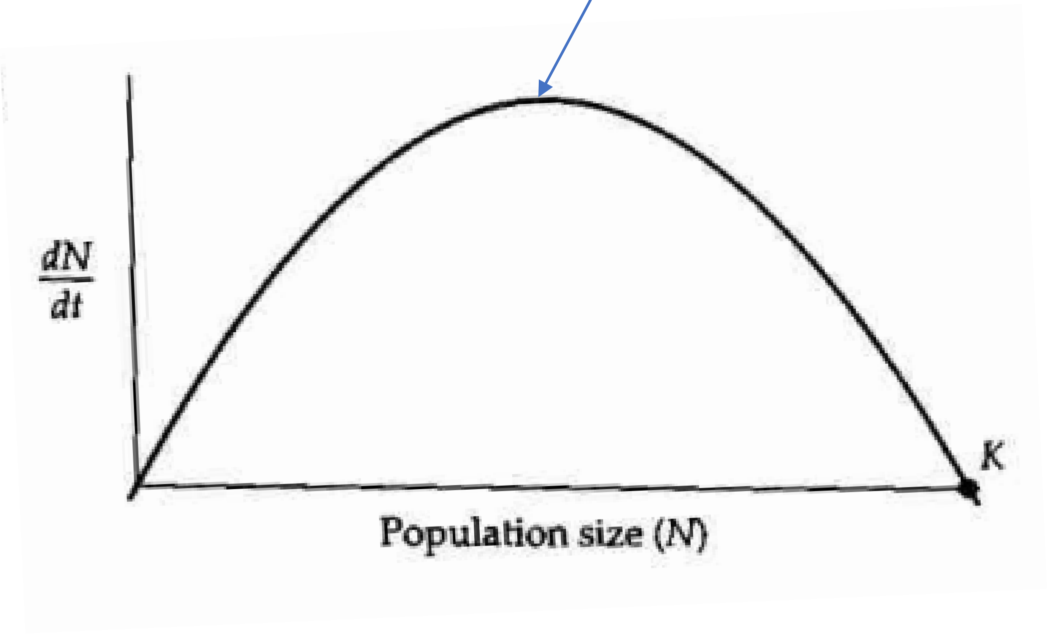
The maximum number of individuals of a given species that the resources available in a given environment can sustainably support, is called **carrying capacity (K).**

Population growth rate as a function of population size



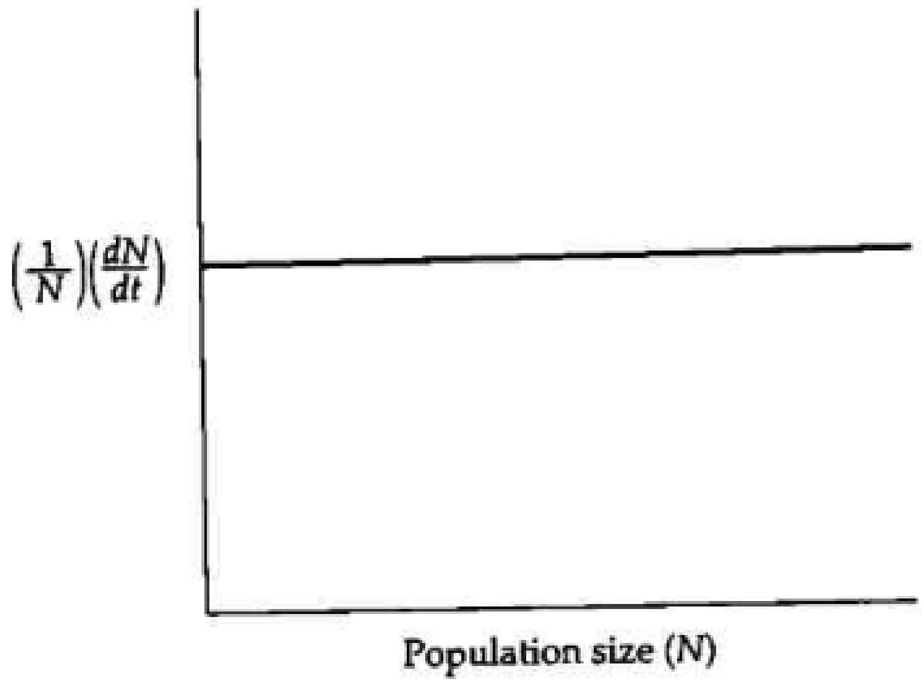
Exponential growth

Maximum at K/2

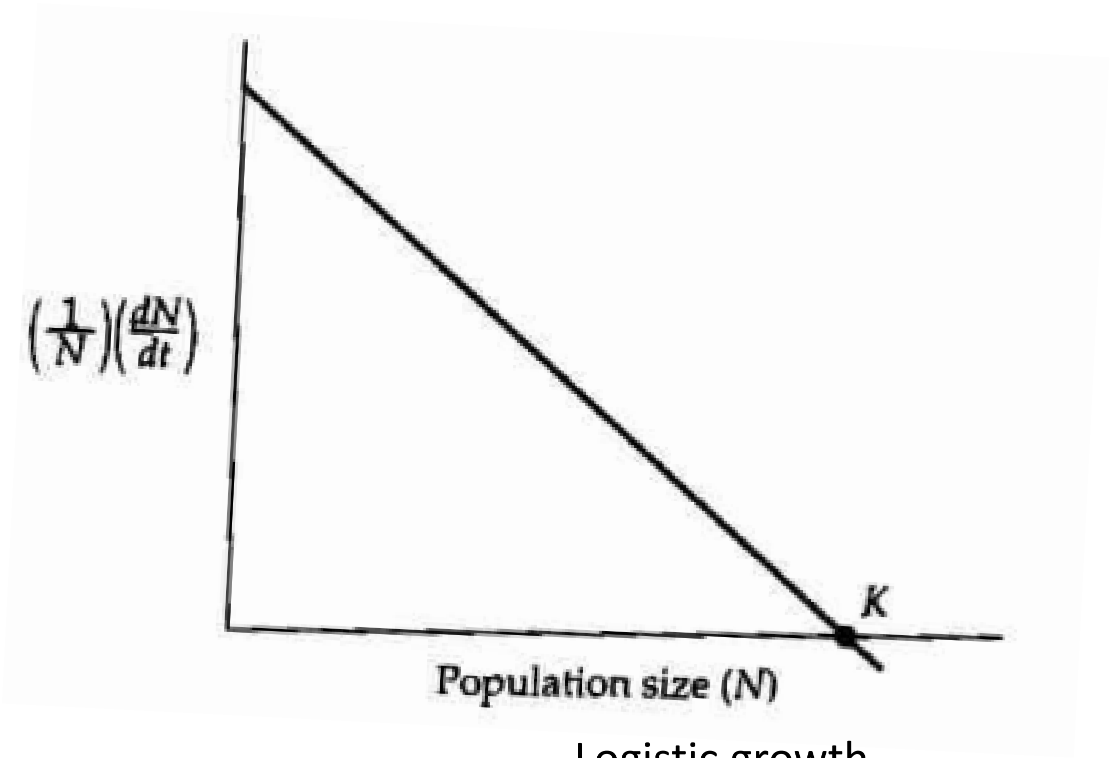


Logistic growth

Per-capita growth rate as a function of population size



Exponential growth



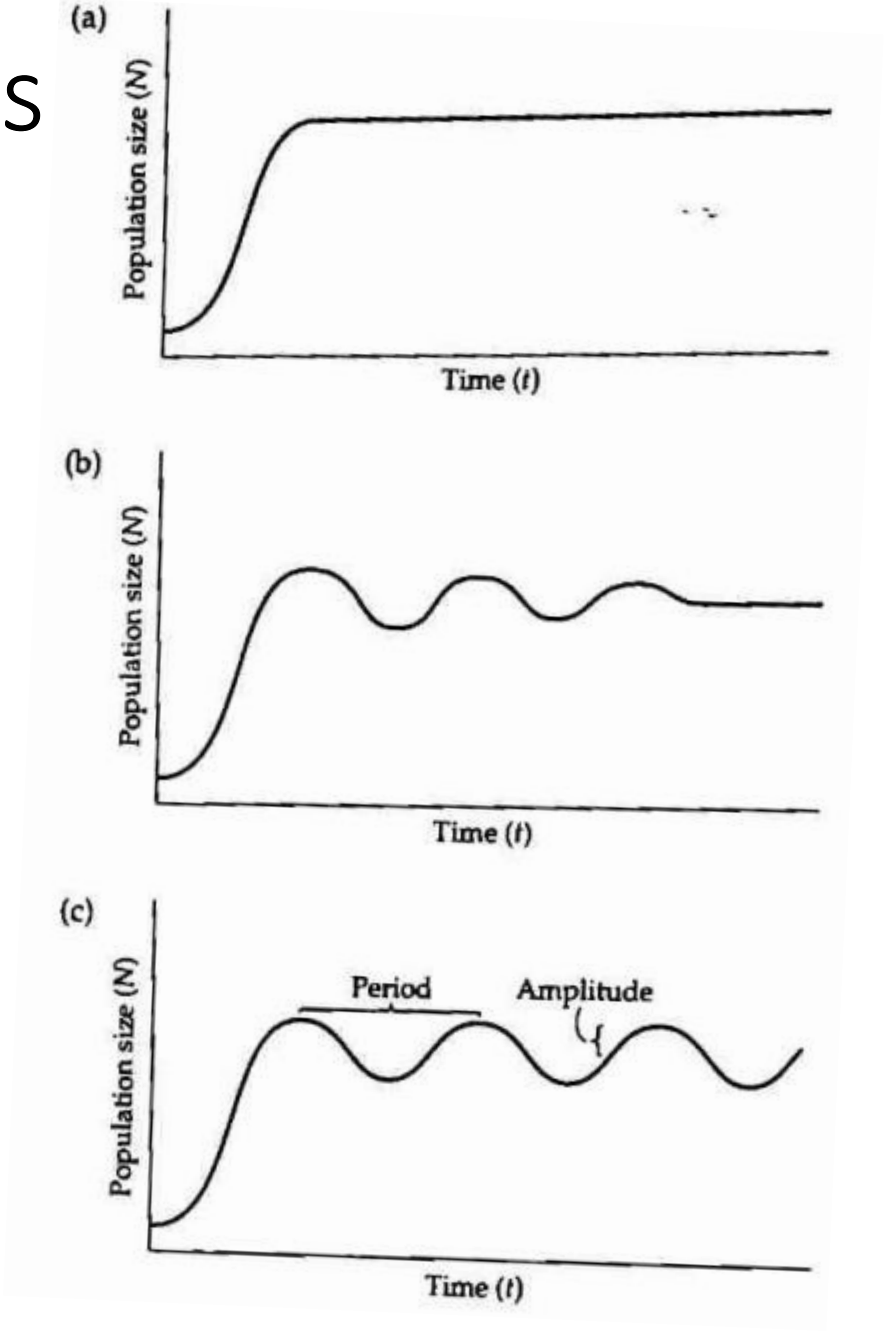
Logistic growth

Model assumptions of logistic growth

- No immigration or emigration
- No genetic structure
- No age or size structure
- No time lag
- Constant carrying capacity
- Linear density dependence

Inclusion of time lag, oscillations population

- $\frac{dN}{dt} = rN(1 - \frac{N_{t-\tau}}{K})$ [Delay differential equation]
- The behaviour of the growth curve depends on:
  - Time lag (τ)
  - Response time (1/r)
- The growth is controlled by ratio between τ and 1/r or simply rτ.
  a) For small values of rτ (0 < rτ < 0.368) population smoothly reaches the K
  b) For moderate values (0.368 < rτ < 1.570), convergent oscillations
  c) For high values (rτ>1.57), limit cycle

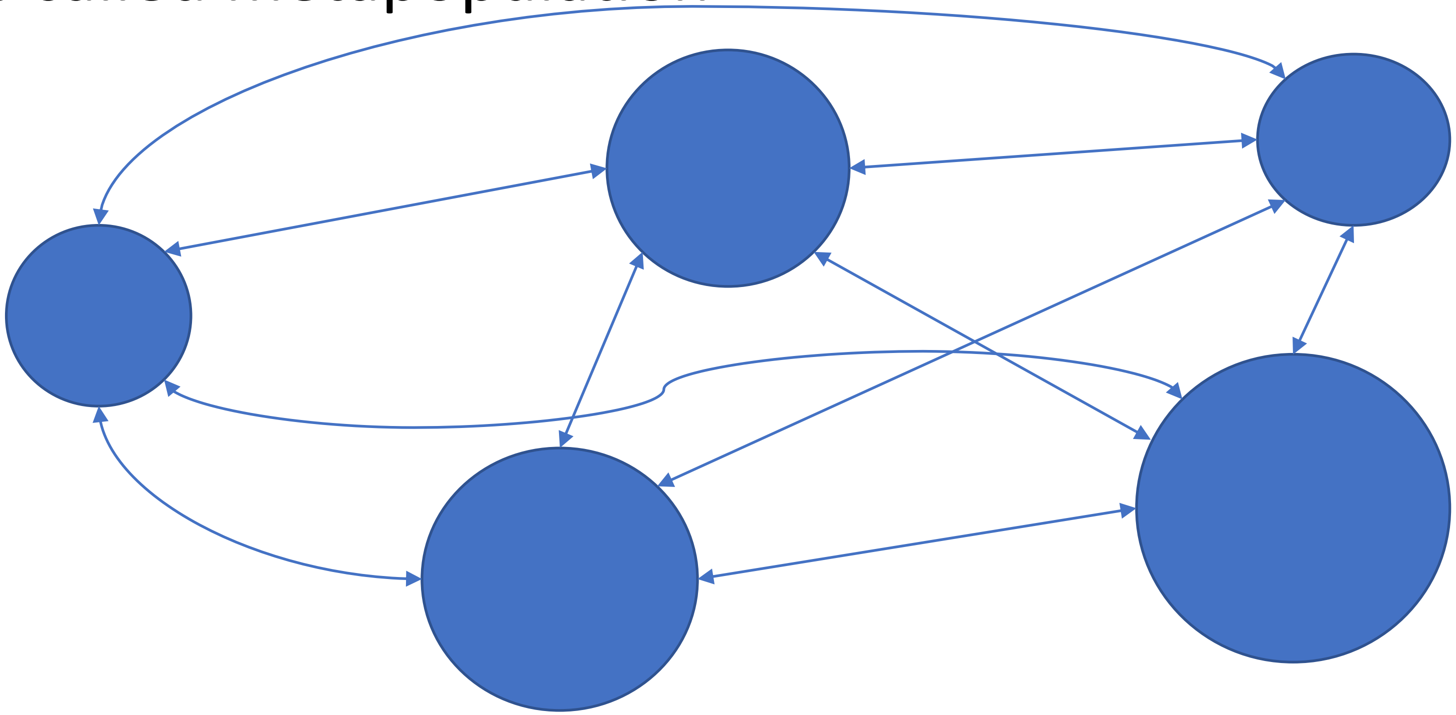


Life history pattern (r and K selection) (McAurthur and Wilson,1967)

Chatacters	r-selection	K-selection
Population size	Variable	Constant
	Usually below K	Close to K
	Emmigration and recolonisation high	Emmigration and recolonisation uncommon
Mortality	Variable & unpredictable	More constant and predictable
	Not density-dependent	Density-dependent
Intra/inter-specific competition	Variable, often weak	Usually strong
Survivorship curve	Type III	Type I or II
Selection favours	Rapid development	Slow development
	Early reproduction	Delayed reproduction
	Small body size	Large body size
	Semelparity	Iteroparity
Lifespan	Usually shorter	Longer, usually >1year
Leads to	Higher productivity	Higher efficiency

Metapopulation concept

- A set of local populations occupied an array of habitat patches and connected to one another by the movement of individuals among them is called metapopulation



Metapopulation concept

- **Habitat patches:** Areas of habitat that contains necessary resources and conditions for a population to persist
- **Local population:** The individuals of a species that lives in a habitat patch
- **Turnover event:** When a habitat patch becomes vacant through local extinction and then again recolonised by individuals from other populations, then an extinction-colonisation turnover event occurs
- **Metapopulation persistence time:** The length of time until all populations become extinct

Patch metapopulation model (Levins 1969)

- The metapopulation is conceptualised as a group of local population each having a density of either 0 (extinct) or <u>K</u> (equilibrium density)
- At some time, some proportion, p, of the total number of patches in the metapopulation will be occupied and the remaining fraction will remained unoccupied $(1-p)$.
- The rate of change of p is given by:

$$\frac{dp}{dt} = mp(1-p) - ep$$

Where, m is the rate of patch colonisation and e is the rate of patch extinction

Now in equilibrium state, $\frac{dp}{dt} = 0$, or, $mp(1-p) - ep = 0$, or $mp(1-p) = ep$, or $m(1-p) = e$ or, $p_{eq} = 1 - \frac{e}{m}$

- So, metapopulation will persist if $\frac{e}{m} < 1$

Assumptions

- Process of population growth is not considered
- Time to recolonisation is neglected
- Area and distance between all patches are considered equal
- Variations in movement between patches were not considered

Inclusion of patch size and density (Hanski 1991)

- It is modification of Levin's metapopulation model
- Here the migration rate (m) to another patches is inversely related to patch distance (D):

$$m = m_0 e^{-aD}$$

Here, m_0 and a are parameter

- Similarly, chances of extinction (e) is considered as inversely related to patch size (A)

$$e = e_0 e^{-bA}$$

Here, e_0 and b are parameters

Inclusion of patch size and density (Hanski 1991)

- Now the equilibrium patch density will be

$$p_{eq} = 1 - \frac{e_0 e^{-bA}}{m_0 e^{-aD}}, \text{ or, } p_{eq} = 1 - \frac{e_0}{m_0} e^{aD-bA}$$

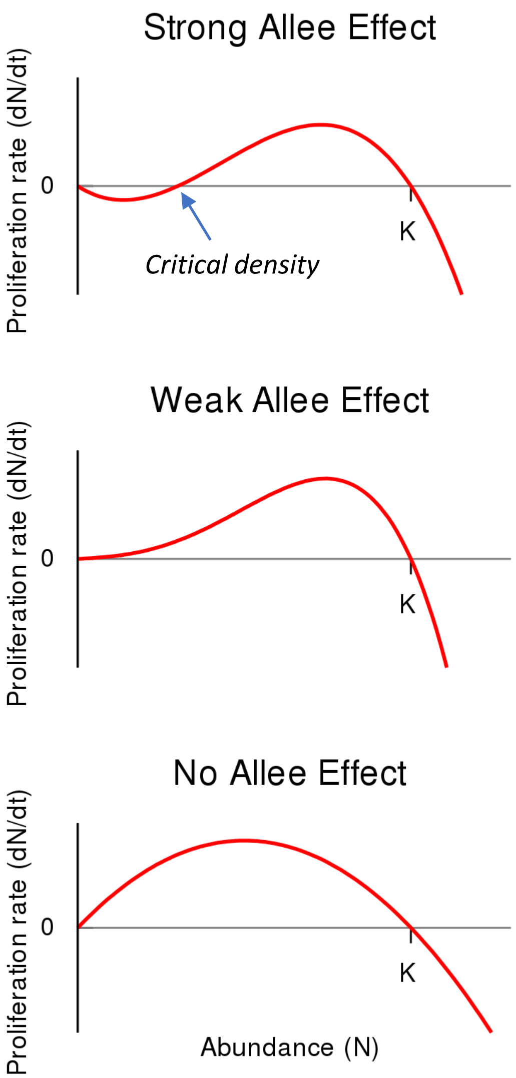
If we consider, e_0/m_0 is constant (0.07 in example), then the effect of patch size and distance can be understood by examining the term e^{aD-bA}. If a=b=1:

A	D	e^{D-A}	p_{eq}
1	1	$e^{1-1} = 1$	0.993
1	2	$e^{2-1} = 2.718$	0.81
1	3	$e^{3-1} = 7.39$	0.48
2	3	$e^{3-2} = 2.718$	0.81

Allee effect

Warder Clyde Allee
1885-1955

- Proposed by WC Allee in 1930
- It is the positive effect of density dependence on population growth.
- **Component Allee effect:** It is the positive relationship between any measurable component of individual fitness and population density.
- **Demographic Allee effect:** It is the positive relationship between the overall individual fitness and population density.
- **Strong Allee effect:** It is a demographic Allee effect with a critical population size or density.
- **Weak Allee effect:** It is a demographic Allee effect without a critical population size or density.



Mathematical model of Allee effect

$$\frac{dN}{dt} = rN\left(\frac{N}{A} - 1\right)\left(1 - \frac{N}{K}\right)$$

Where, A is the critical density.

- Population has a negative growth rate if $0 < N < A$
- Population has a positive growth rate if $A < N < K$, where $0 < A < K$

Ecological Mechanism of Alee Effect

- Mate limitation
- Cooperation
- Environmental conditioning/habitat alteration
- Inbreeding depression and Genetic drift