Population

"*Populus*" in Latin means people from which the term population has been derived. In 1954, Clarke suggested two kind of population:

1. **Mixed or Poly-specific population:** sometimes even called as**Community** where group of different species constitutes a population.
2. **Mono-specific population:** is where grouping of same species constitute a population.

Population characteristics

An organism can never live in absolute isolation therefore, interacts and form groups. Even if an individual lives an isolated life, at some time point it may interacts with other species during his entire life cycle. Thus each species at some time point exist as population. All individuals constituting the population get a chance to reproduce with other group members of same species. Thus, a population can be interpreted as a group of species occupying a particular space at certain time where each species is potentially interbreeding with other members of the group belonging to same species.

Local population

Several demes or sub-populations constitute the organism population termed as local population. The smallest and interbreeding group of animal population is termed as "**Deme"**. Each interbreeding individual in a local population carries certain genetic combinations and share a common gene pool called as genetic unit of a population. Between different populations the genetic information is exchanged through certain group characteristics called immigration or emigration.

When the local population accumulates genetic variations it leads to genetic differentiation and further support a phenomenon called **evolution**.

Unitary organism is an eminent single unit of organism such as fish, cat, dog etc. but some organisms are called **modular organisms**, for instance, some grasses, suckers where many suckers are attached together with their root extensions (just like adventitious roots of one plant will give rise to another plant nearby). The individual and a population have different set of characteristics thus, the group characteristic of a population, "density" is a basic feature highly influencing by the rate of emigration, immigration, mortality and natality. Additionally, dispersal and dispersion as a pattern distribution and age distribution are the secondary characteristics of collective group of individuals constituting population.

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The group characteristics of population such as growth forms, age distribution, density, dispersion, dispersal, mortality and biotic potentials are explained below.

1. Population Density

In a given population at a particular time the total number of organisms per unit area represents the Population Density. The unit of population density differs a sin case of number of organism per unit area (in Kilometres) = N/Km^2, and in case of number of organisms per unit volume (in Litres) = N/L

Population density has defined limits maintained by certain homeostasis mechanisms instead of which the characteristic varies according to the climate change, season and even by food supply. The size and tropic levels highly influence the limit of population density. The smaller the organism, the higher the density of organism in population is expected per unit area.

It also depends on the productivity of the population, for example the higher the productivity or fecundity rate of population the higher the expected density. Energy flow utilization and resource availability influence the population density, higher the resources available i.e. more resources to sustain the demands of population, higher will be the density.

Dispersal and physiological stress also have higher impact on the population density. The higher the physiological stress the lower population density expected. Other important factors are emigration, and mortality leading to decrease in population density while immigration and natality leads to increase in population density.

The density of population is influenced by several factors such as energy flow, dispersal, resource availability, stress etc. and categorized into- Specific/ Ecological density and Crude density.

i. Ecological density

Ecological density is defined as the number of individuals per unit of available habitat area. The individuals will colonize only if the prevailing conditions are favourable on the land or area. So, out of the geographical area of population only that part of the land is utilized by the individuals where the resource availability is high along with the other optimum conditions and it is denned as ecological or specific density.

ii. Crude density

The total number of individuals per unit of total land area or volume. For example total number of tigers in Jim Corbett National Park. The crude density vary due to non uniform distribution of individuals on the total land area as the habitat conditions are not favourable over the geographical range of population. Only at the places with favourable conditions the density is high.

In 1964, Karl revealed that the two densities crude and ecological vary according to the number of fishes, season and depth of water in the pond. He observed that as the summer season reaches the depth of water steep down leading to decrease in the total geographical area hence decrease in the crude density (as it depends on geographical area) while at the same time the ecological density increases as by now the fishes are more crowded in pond due to low depth of water, thus the density of fishes is high in that suitable area leading to high specific/ecological density. At the time of winters, the depth of water is high, thus, the total geographical areas increase and hence, the crude density also increases but the ecological density decreases as by now the fishes are more randomly distributed in the total volume of pond.

Thus, the two densities are inversely proportional to each other depending on the climatic/seasonal variations.

Methods of measuring Population density

There are three different techniques of measuring population density:

a. **Arithmetic density:** or real density. It’s the number of individuals divided by total land.
b. **Physiological density:** is the number of individual in its suitable area.
c. **Agricultural density:** the number of people involved in agriculture (agriculturist) divided by arable area.
d. **Residential density:** the number of individuals divided by the residential area
e. **Urban density:** number of individuals living in a urban area divided by total urban area.

f. **Ecological optimum:** the number of individuals supported by the available natural resources.

2. Natality

In a given population the total number of new born offspring produced either by fission, germination or hatching per unit time defines **Natality**. It has been categorized into Ecological/Realized Natality and Physiological/Absolute/Crude Natality.

a. Ecological Natality

Under actual environment conditions offspring produced and leads to enhancement in population size termed as Ecological Natality also known as Realized Natality. For a given population, realized Natality is over variable and depends on size, composition, age and physical surrounding condition.

b. Crude or Physiological Natality

Under idealistic conditions the maximum number of offspring's produced by the organisms in its physiological limits is termed as physiological Natality. It's a constant component of population statistical characteristic and also known as Absolute Natality. Although in a wild population, it near to impossible to achieve Physiological Natality. But under favourable conditions with no limiting factor small population of bacterial culture in nutrient broth under all optimal conditions, maximum reproduction is achievable, thus, indicating maximum Natality. It is important as it's used in calculating equations of increase in rate of population growth and also act as standard for realized natality comparison.

Natality can be expressed in terms of offspring's produced per unit time per unit population,

i.e. $\Delta Nn/N\Delta t$= Natlity/rate of birth.

or

Absolute or crude natality/rate of birth=$Nn/\Delta t$.

3. Mortality

In a given population, mortality can be defined as the rate of organism's deaths. Mortality is majorly categorized into two types:

a. Minimum mortality

Under idealistic condition, the death rate is termed as Minimum or Theoretical mortality. It's a constant component of population statistical factors. Under ideal conditions also organism dies because of natural process of senescence or ageing.

b. Realized mortality

Under realistic or non idealistic conditions, the rate of death is defined as Realized or ecological mortality. It varies with the prevailing conditions of population and environment, eg. epidemic, predation etc.

Mortality generally expressed as death rate at a given time difference is the number of deaths divided by average population. For instance at the beginning of the time 400 people constitute the population size but at the end of time period only 350 people are alive, means total 50 are dead. Thus, the average size of population is 400+350/2= 375 and the death rate will be 50/375=0.133

Death rate=Dead people/ Average population

To calculate the probability of people dying divided the "dead people" at a given time with the alive people present at the beginning of time intervals. For example by assuming above data, probability of dying= 500/400=0.125. Probability of dying is complementary to probability of surviving given by = 350/400=0.875 i.e. people alive at a given time divided by population size at the beginning of time interval. Here, we do not consider average population size as in case of calculated death rate.

Life Expectancy

An average number of years a member of a given age is expected to live in future in a population define **Life expectancy**.

In 1921, under laboratory conditions, Raymond Pearl was the first who introduced and used life table for Drosophila population.

Life stable is a set of records of mortality and survival at a given time intervals in a population. It gives a systematic order to population characteristics recorded overtime varying with size, developmental stages and with age. Ecologist found the applicability of life table in natural population for understanding the cause and pattern of mortality and predicting the possibility of survival and future growth of population. A life table describes an age specific mortality aspects of people and represented in a form of subsequent columns.

"**Cohort**" is group of people born at the same time. It's the life expectancy and reproductive rate on which the increase or decrease in population size depend on. Reproductive rate specially depends on the female age at which she starts producing young one and also possible age of female to which she can reproduce in future.

Applications of life tables

1. The rate of premium by life insurance companies was determined by using life tables to determine the possibility of client survivorship.
2. Life tables are used to predict wildlife population growth decline and management.
3. Conservation biologists use life tables in species conservation.
4. Comparing the life history trends within and between populations.

Three types of life stable are there:

1. Cohort/ Horizontal/Dynamic life tables

Use of this life tables is for short lived species and short generation time. This table records the survival and reproduction of cohort of individuals from birth to death. Cohort is group of individuals born and hatched together during a defined time interval. Dynamic/ Cohort life tables start with 1000 initial members of cohort and they are followed till the population is exhausted.

Cohort can be defined on daily, weekly, monthly or annual basis such as *Ursus americanus*, all black bear cubs born in Ozarks in 2014. The cohort life table record two important aspects (A) fecundity schedules and (B) survivorship schedules.

2. Static/ Vertical/Time specific life tables

Static life table is based on assumption that the population is stable and the Natality and mortality fecundity rate etc characteristic of population are constant too. It measure all the individuals each age and reproduction in a population and ages at death. In short, all living members of each age counted at a given time.

3. Dynamic composite life tables

In 1986, Begon and Mortimur define this form of life table. It is similar to cohort life table but here the members of cohort are counted on annual basis rather than birth timings. It’s a time specific technique allowing natural variability in survival rates.

Life tables whether static or cohort if classified the members on age basis are termed as **age based life tables**. Representation of **age** is by “**x**” and age specific **life expectancy** as “e_x” for each age. Life tables classifying the members on the basis of size and developmental stages are termed as**size-based life tables** and **stage based life tables** respectively.

To determine ecological life tables, the following type of data have been used:

1. Laboratory animals

Laboratory animals are used to prepare life tables as their specific stages are known to us. We observe the number of animals/members at regular intervals and record their death arte till the population dies off.

2. Direct observation of Survivorship

In 1961, Connell constructed life table of *Chthamalus stellatus*growing on rocks in autumn season in Scotland. He observed and recorded the mortality at regular intervals. Hence, survival data of cohort at regular intervals were followed till its existence.

3. Direct observation of Age structure

By observing several physiological features of individual, the age structure information can be observed. For example observation of the annular rings on fish scales, horns of sheep, growth rings in trees etc. Although, this type of data is not preferred for table construction yet some age structure ecological information can be collected.

Table 1: Different columns of life table are:

S. no	Abbreviation	Meaning
1	**x**	Age interval
2	$\mathbf{n_x}$	Number of survivors at start of age interval x
3	$\mathbf{l_x}$	Proportion of organisms surviving to start age interval x
4	$\mathbf{d_x}$	Number dying during age interval x to x+1
5	$\mathbf{q_x}$	Rate of mortality during age interval x to x+1
6	$\mathbf{L_x}$	Average number of live individuals during age interval x to x+1
7	$\mathbf{T_x}$	Total years lived by individuals of age x
8	$\mathbf{e_x}$	Life expectancy for individuals alive at age x

Table 2: Life table of *Baranus glandula* (Barnacle) on pile points at the upper shore levels, San Juan Island, Washington (Connell 1970).

Age (yr) (x)	Observed No. Barnacles Alive Each Year (n_x)	Proportion Surviving at start of age interval x (l_x)	No. dying within age interval x to x+1 (d_x)	Range of mortality (q_x)	Average Live individuals within age interval x to x+1 (L_x)	Total years lived by individual of age x(T_x)	Mean expectation of further life for animals alive at start of age x($T_x/l_x=e_x$)
0	1000000	1	999938.0	0.9999	0.500031	0.500153	0.5002
1	62	0.00006	28.0	0.4516	0.000048	0.000122	1.9613
2	34	0.00003	14.0	0.4118	0.000027	0.000074	2.1647
3	20	0.00002	4.9	0.2450	0.000018	0.000047	2.3300
4	15.1	0.00002	4.1	0.2715	0.000013	0.000029	1.9238
5	11	0.00001	4.5	0.4091	0.000009	0.000016	1.4545
6	6.5	0.00001	4.5	0.6923	0.000004	0.000007	1.1154
7	2	0.00000	0.0	0.0000	0.000002	0.000003	1.5000
8	2	0.00000	2.0	1.0000	0.000001	0.000001	0.5000
9	0	0.00000	0	0.0000	0.0000	0.0000	0.0000

Calculations

Life expectancy is calculated in following steps.

Step 1: We first calculate (l_x) as:

(i) For the first age group its always 1.

For example for the age (x)=0, and n_x =1,000,000 the (l_x)=1.

(ii) For the next interval, (x) =1, and n_{x+1}= 62, the (l_{x+1}) is calculated by unitary method, i.e. if 142 individuals are 1 in proportion, 62 will have how many?

(l_x) for 1000000 = 1

(l_{x+1}) for 62…..??

(l_{x+1}) for 62 = 1x62/1000000 = 0.00006

Step 2: Now we calculate d_x as: [n_x-(n_{x+1})]

For example, (x) =0, and n_x =1000000; and (x) =1, and n_{x+1}= 62

d_x as: [n_x-(n_{x+1})] = 100000-62= 999938.0.

Step 3: Now we calculate q_x as: {$d_{x/}$ n_x}

For example, (x) =0, and n_x =1000000; d_x = 999938.0,

q_x = 999938.0/1000000= 0.9999

Step 4: Now we calculate L_x as: $\{l_x + l_{x+1}/2\}$

For example, (x) =0, and n_x =1000000; (l_x) for 1000000 = 1

(x) =1, and n_{x+1} =62, (l_{x+1}) for 62= 0.00006,

Therefore, $L_x = \{l_x + l_{x+1}/2\} = \{(1+0.00006)/2\}= 0.500031$

and, $L_{x+1} = \{l_{x+1} + l_{x+2}/2\} = \{(0.00006+0.00003)/2\}= 0.000048$

Step 4: Now we calculate T_x as: $\{T_{x(n)} + L_{x(n-1)}\}$

To calculate T_x, start from bottom,

for (x_9)=9, n_{x+8} =0, T_x is also 0, i.e. T_{x9}=0

For (x_8) =8, n_{x8} =2, T_{x8} = $\{T_{x9} + L_{x8}\}$

i.e. T_{x8} = (0 + 0.00001) = 0.00001

Let's take another reading,

For (x_7) =7, n_{x7} =2, T_{x7} = $\{T_{x8} + L_{x7}\}$

i.e. T_{x8} = (0.00001 + 0.00002) = 0.00003 and so on.

Step 5: Calculate life expectancy as $e_x = (T_x / l_x)$

For example for the age (x) =0, (l_x) =1 and T_{x1}= 0.5015

$e_x = (T_x / l_x) = (0.5015/1) = 0.502$

Step 6: Proceed further for calculations similar to this and then draw survivorship curve graph on the semi-log graph by plotting Age (years) on X-axis and l_x on Y-axis.

The graph plotted against the lifespan (Age or Years) and l_x on X-axis and Y-axis respectively has represented the life table of Barnacle and depicted a Type III or Concave type curve. Hence, by using the data of life tables we can predict the history pattern, size or developmental stages of the species.

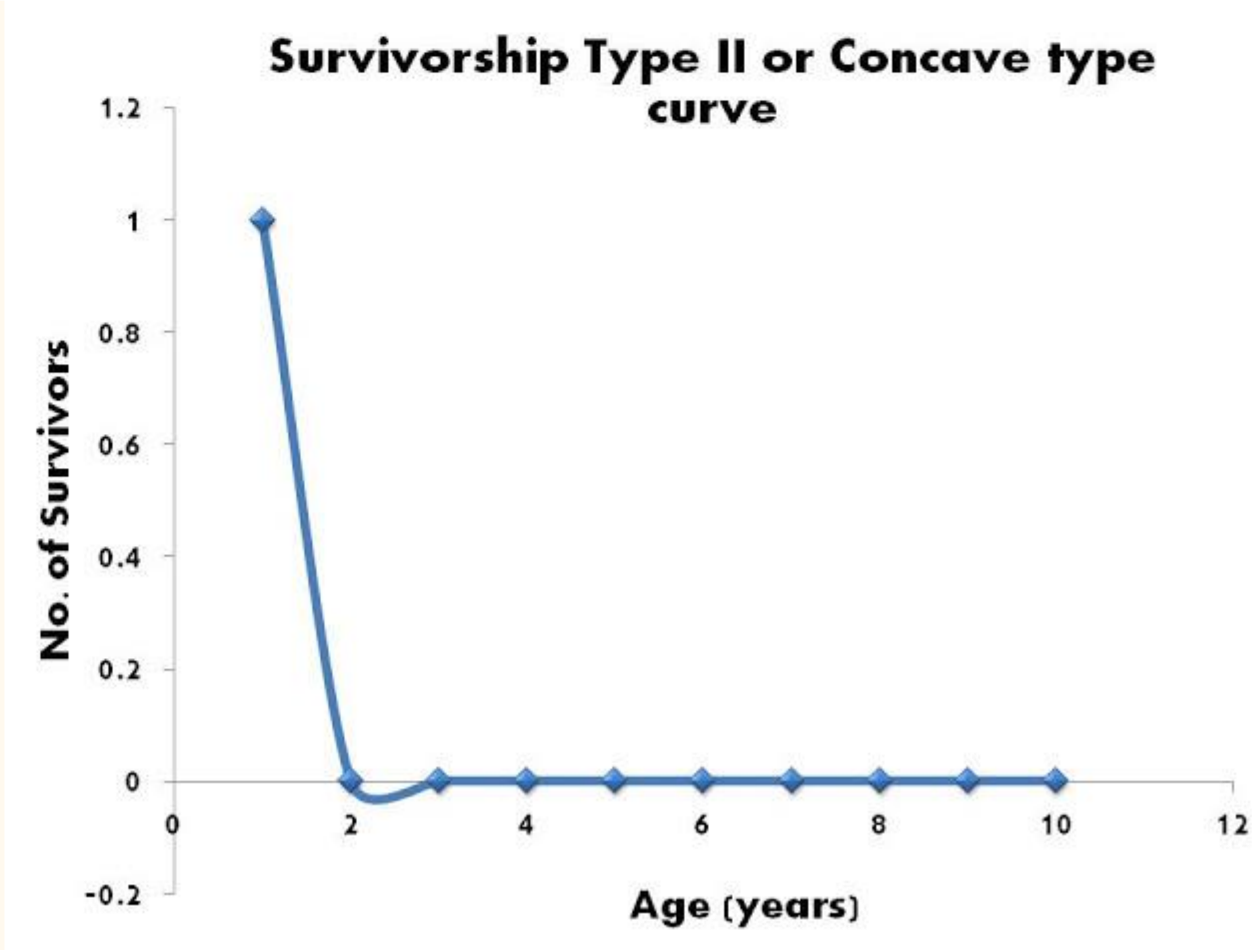


Figure 1: Survivorship curve obtained from the life table data between age (x) and (l_x).

Life insurance companies and state government municipal communities collect birth and death records of humans and with the collected data construct the Human life tables.

A very potential application of life table is the comparison of history trends between the population and within the population is possible.

Life tables illustrate three types of survivorship curves which help in understanding the mortality, pattern of survival in the observed population and also the growth and decline of future population.

Survivorship curve

Survivorship curves are generally produced from the data of cohort life tables for a particular population and these curves depicts the age specific mortality. These curves represent that in each phase of life cycle what are the number of surviving individuals per thousand of a population.

Survival curves are drawn on semi-log graph where X and Y axis represents the Lifespan (age, years) and number of surviving individuals per thousand of population on algorithm scale respectively. Generally these survivorship curves are in frequent use by ecologists- Type I, Type II and Type III. These curves are standards and used to compare with the real life survivorship curves of different organisms: (a) Convex type curve, (b) linear curve and (c) Concave type curve.

a. Convex type curve or Type I

Populations capable of living their physiological life span are Type I or convex type of curve. They show high survivorship rate throughout life and low survivorship curve in later stages when upto 75% of life span is complete i.e. high mortality in old ages. It's a characteristic pattern in many mammals, like humans, and sheep.

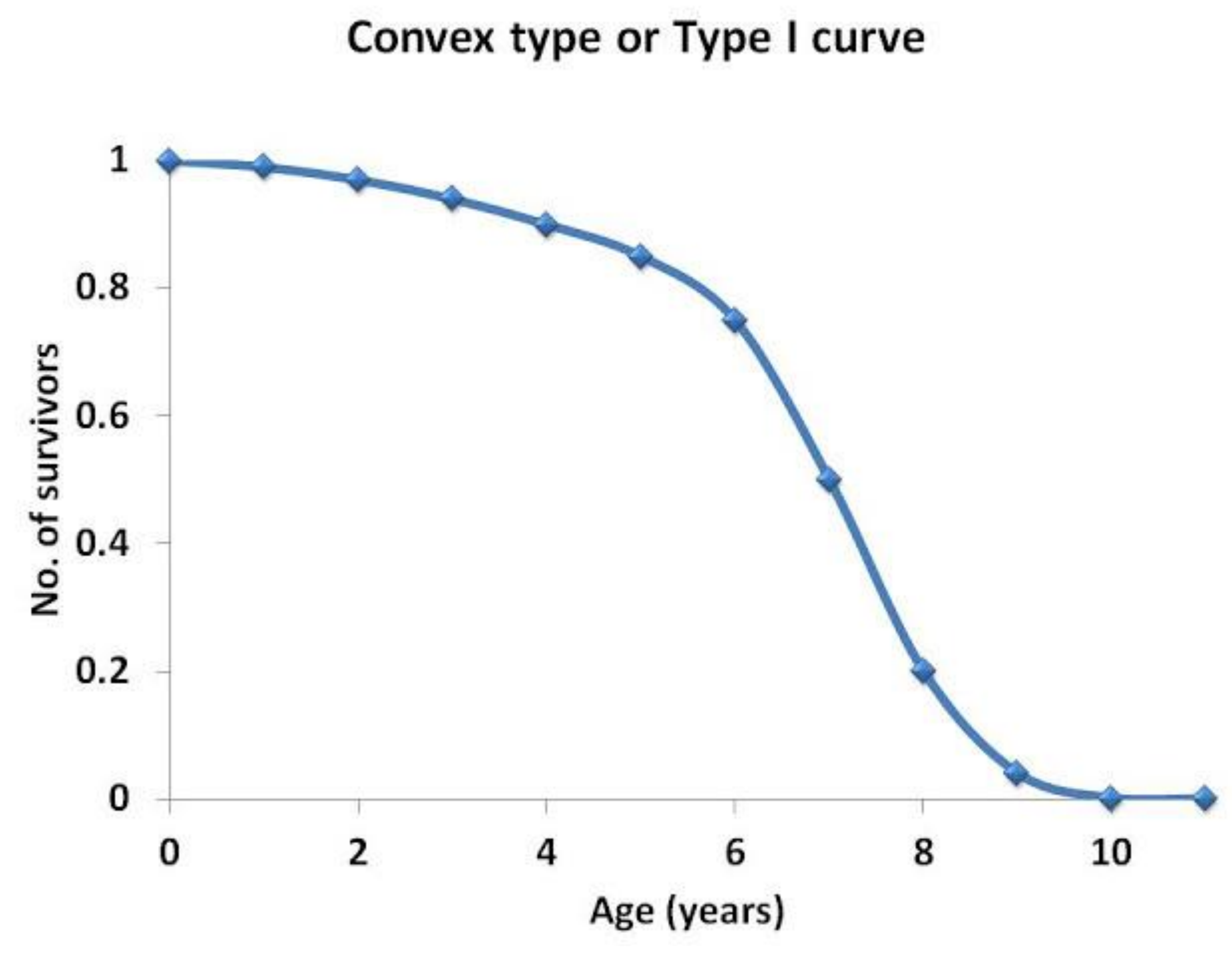


Figure 2: Convex type or Type I survivorship curve obtained from the life table data between age (x) and (l_x).

b. Linear curve or Type II curve

These curves represent uniform age specific survival throughout life in organism. Adult stages of many birds and rodents show this type of curve. In mice, rabbits and many birds the high mortality rate in young one but constant rate in adults attributed to slightly sigmoid or slightly concave curve. A staircase survivorship curve is an indication of different survival rates at different stages by homometabolous insects.

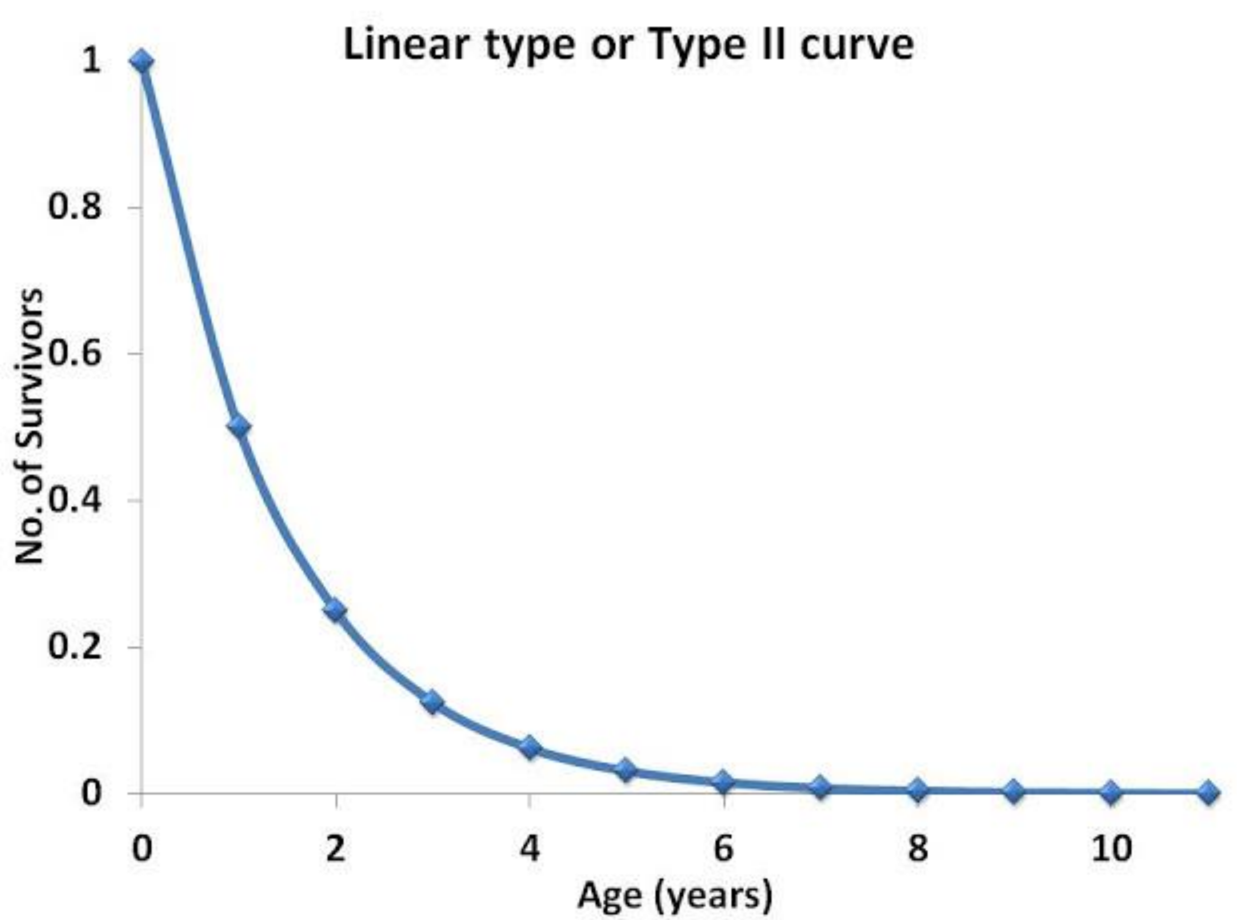


Figure 3: Linear type or Type II survivorship curve obtained from the life table data between age (x) and (l_x).

c. Concave type curve or Type III curve

Concave curve is a survivorship curve represented by many organisms such as fishes, oysters, many insects and shellfishes. It is curve for organisms with high reproduction rate in early life and dies off quickly after reproduction. Those individuals who sustain 25% of their lifespan tend to have slow death rate. For example in oyster, the early larval stages are more prone to predation therefore high mortality rate is there initially but those who survived reaches their adult stages and live longer.

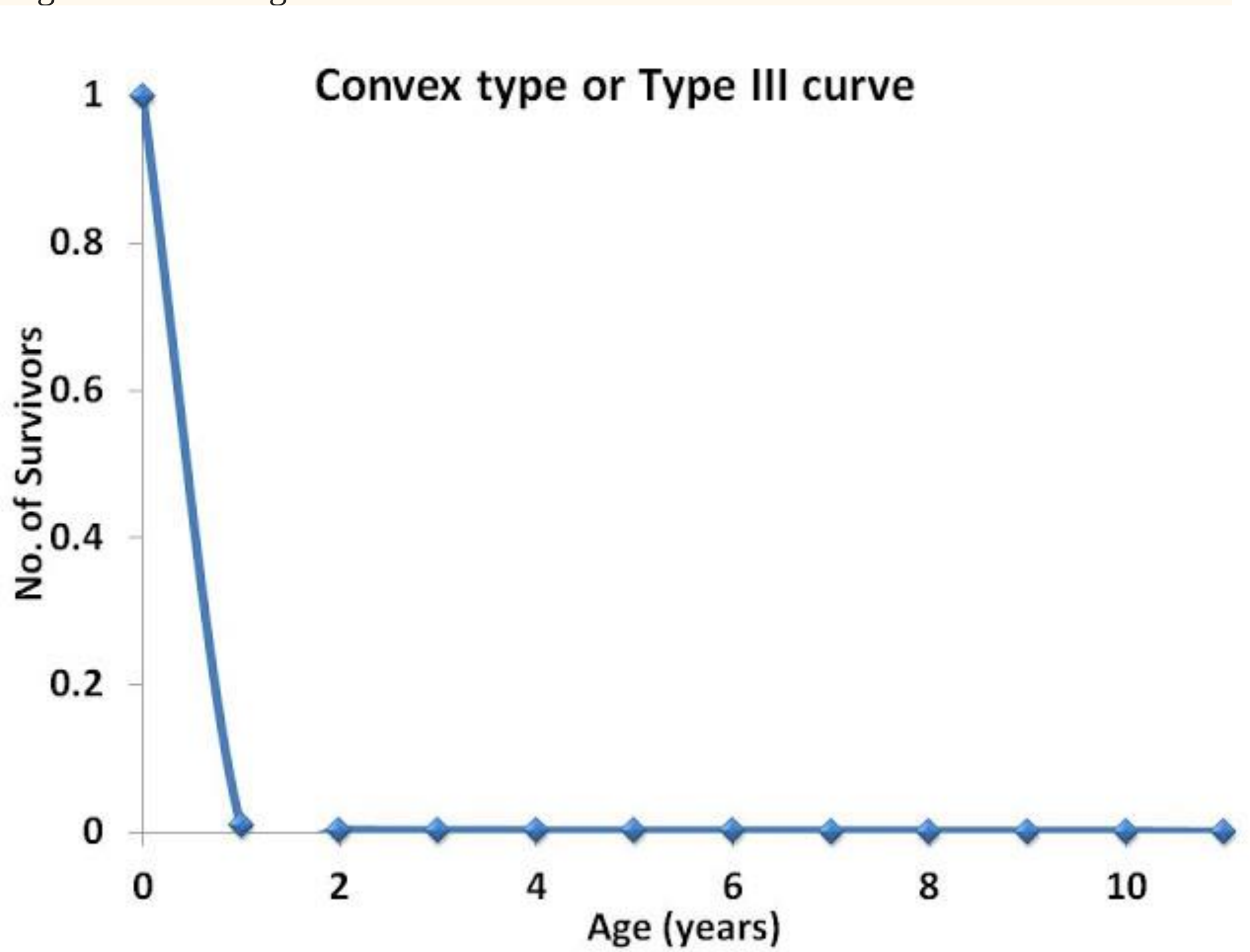


Figure 4: Concave type or Type III survivorship curve obtained from the life table data between age (x) and (l_x).

Mortality curve

The rate of mortality plotted against age during age intervals gives mortality curve. Plotted graph has time/year/age on X-axis and "q_x" on Y-axis. It has two phrases in Type I a high mortality phase or juvenile phase and a post juvenile phase where rate of mortality first decreases as age increase and then increases with age. It forms a J-shaped curve.

Figure 5: J-shaped Mortality curve obtained from the life table data between age (x) and (q_x).

4. Age distribution

Age distribution of a given population can be defined as the total number of organisms distributed in different age groups. It influences other population characteristics such as natality, mortality and reproductive rate. Age can be expressed in terms of pre- and post-reproductive or else in terms of years, months or even days. By understanding the age structure or distribution we can predict about the future population and categories into expanding population, stable and declining population. If individual are more distributed in reproductive phase than post-reproductive phase, the population is termed as expanding population. If the individuals are distributed almost equally in both reproductive and post reproductive phase, the given population is stable while if the distribution is more in post-reproductive phase, the population is considered as declining population.

Age pyramids

Age polygons or pyramids are representing model to depict the age distribution in population where the relative width of successive bar represent the number of individuals distributed in different age groups at a particular time. The age pyramids are hypothetically categorized into three types:

i. **Bell shaped Age Pyramids**

It's a representative form of expanding population. The broad horizontal base of polygon represent the higher distribution of young organisms and thus, expanding population. It is characterized by exponential growth and high birth rate in a population at a particular time.

ii. **Dome shaped Age Pyramid**

It represent a stable population where the distribution of young to old is in equal proportion depicted by the equal width of horizontal zones of pre-Reproductive and reproductive phase. The post-reproductive phase is smallest in this form of representation.

iii. **Urn shaped Age Pyramid**

It represents a declining population where the smallest distribution of organism is in pre-reproductive phase.

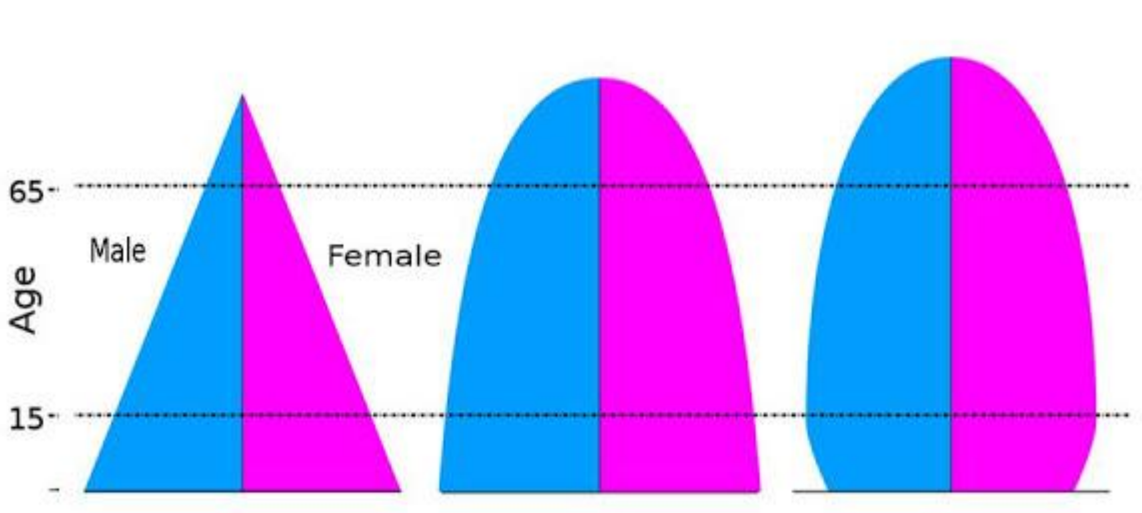


Figure 7: Age distribution in Age pyramids, (a) Bell shaped, (b) Dome shaped and (c) Urn shaped age pyramids.

5. Sex ratio

In a given population the ratio of female and male organisms defined sex ratio. It is majorly categorized into primary and secondary sex ratio

a. Primary sex ratio

At conception the female to male ration represent the primary sex ratio which usually tends to be 1:1.

b. Secondary sex ratio

During the birth time the ratio of female to male represents the secondary sex ratio and in humans it is generally biased towards male organisms.

6. Dispersal

Geographical differentiation does not allow organisms to freely reach their potential range of total land area as various biological and physical factors prevent their distribution to differential areas.

Although when an organism dispersed to a new area and colonize there by adapting to the external environment conditions, create a new species and thus support evolution.

Hence, dispersal is an ecological process of organism distribution in a habitat. It's a self made distribution of organism which requires several mechanisms to move across the geographically differentiated habitats.

Plants and immobile animals show a low dispersal rate as a means of transportation. Active process of distribution is adopted by movable animals depicting high dispersal rate. Among all living organisms, human has played a prominent role in worldwide dispersal and redistribution of species. Dispersal is influenced and stimulated by many factors such as food supply, food quality, change in temperature, high reproduction and photoperiod and operates when organism leave their native place where they were born.

Thus, by dispersal, organisms change the area of habitat. The first movement of individual animal towards its first breeding attempt from its birth site is denned as **Natality Dispersal**. When an adult changes its location and settle to a new place it's called **Adult Dispersal**.

The modes of dispersal are:

i. Migration

It's a two way regular movement of animals during different seasons, usually for feeding and breeding purposes. For example Roebuck Bay is a migratory bird, Western Australia.

Figure 8: Migratory Roebuck Bay, Western Australia.

Some species aimlessly do regular movements and never settle down to one habitat called as **Nomadism,** while mostly all other migratory animals return back to their original place after this seasonal movement. **Nomadism** exhibiting species have unpredictable possibility of food availability from years to years and thus, wandering without settling.

Migration and Nomadism are not the actual dispersal mechanisms.

ii. Emigration

It’s a unidirectional outward movement of organism from present population to a new population. These outward movements occurred because of scarcity of food/natural resources, high fecundity rate and many more unfavourable conditions. The migrated organisms never return back to the population where it was born.

Figure 9: Emmigration of birds

iii. Immigration

A unidirectional inward movement of organism into a new population from its native population for reproduction and feeding purposes is termed as Immigration.

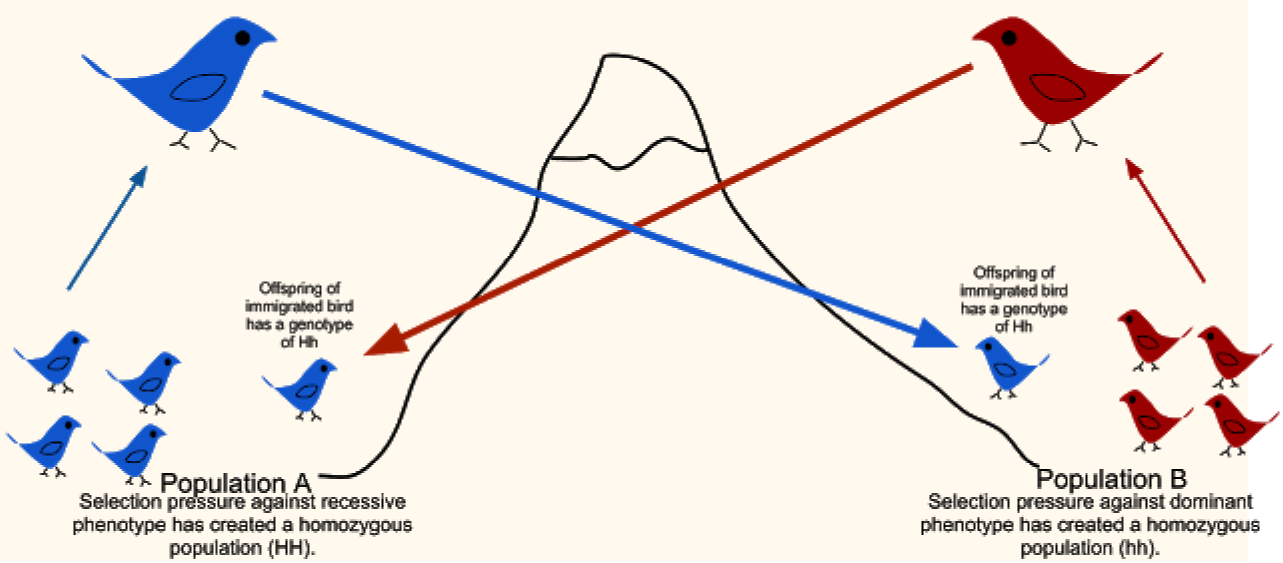


Figure 10: Immigration of Birds

7. Dispersion

Dispersion is the distribution of individuals within its geographical area. The pattern of dispersion by individual defines their relative spacing. Different population of same species and different species can have different pattern of dispersion. The social behaviour or other traits of organism's resource utilization, and other conditions influence the pattern of organism dispersion.

The general patterns followed by organisms are of two types: **Temporal and spatial dispersion**

a. Temporal Dispersion

When the dispersion pattern of organism is regulated by time, it is termed as temporal dispersion. For example some insects are dispersed according to the circadian cycle, while some are regulated by lunar and some by tidal cycle.

b. Spatial Dispersion

Spatial dispersion is majorly classified into three types of dispersal: a. Clumped (contignous/ aggregated), b. Random and c. Uniform (even spaced).

i. Clumped Dispersion

A population disperse in large geographical area as tightly packed "clumps" or clusters exhibit clumped dispersion.

These clusters are apart and between them nearly no organism can be found. Some organisms form clusters to attain protection from predators and some for the resource utilization.

ii. Uniform Dispersion

When the organisms are uniformly or evenly distributed in their habitat, the mode of dispersion is called Uniform dispersion. This tendency is among those species which can survive anywhere.

iii. Random dispersion

When the organism is distributed unevenly and randomly, it's known as random dispersion. Random dispersion is possible under uniform conditions where each organism has an equal chance to habitat place. It does not involve aggregation.

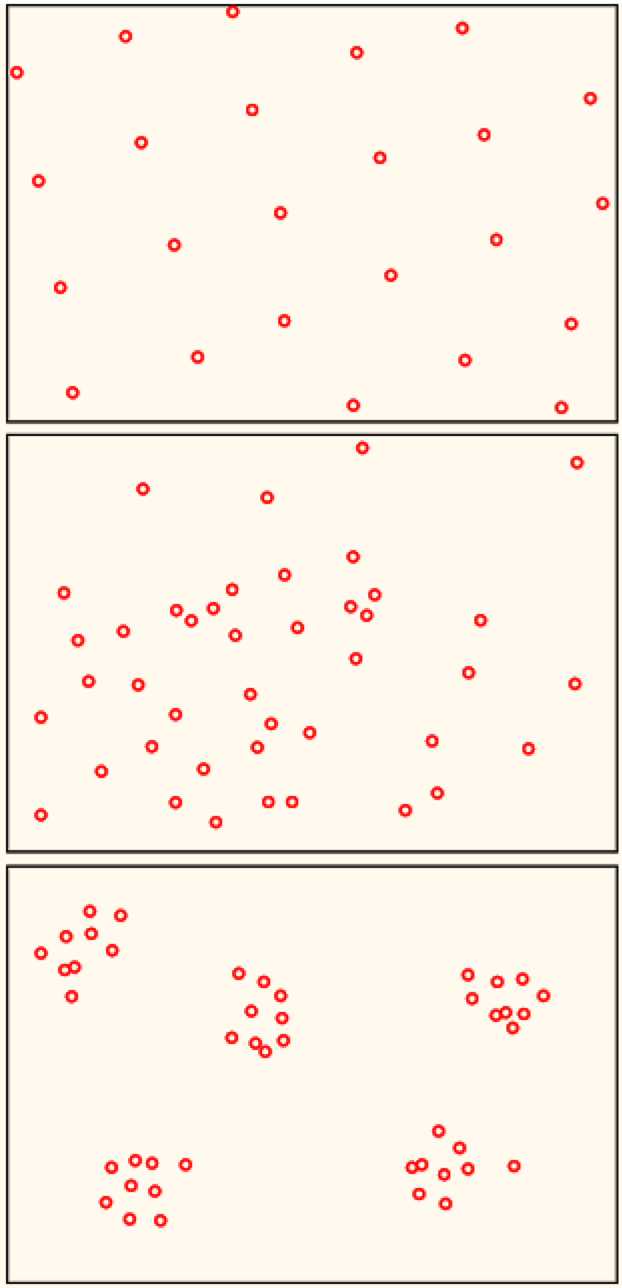


Figure 11: Dispersion; (a) Uniform dispersion (b) random dispersion and

Population Regulation

The population is influenced and regulated by various abiotic and biotic factors including population size. The regulation can be density dependent or density independent.

Density dependent

The factors involved in density dependent regulation are generally biotic (biological). Density dependent regulation affects the birth and death rate of population *via* factors such as predation and competition. Other factors are diseases (especially caused by parasitism), waste accumulation and both type of negative interaction i.e. interspecific and intraspecific competition. The high density population usually depicts high mortality rates.

Predation affects regulates the density of population by regulating the prey population density. As the population density of prey increases the predation increases and thus regulates the density.

Competitions either intraspecific or interspecific influence the fecundity rate of population and also limit the availability of food resources thereby limiting the growth in population density.

Independent dependent factor

This type of regulation is independent on population size and affects the whole population in similar way and mainly involves chemical or physical factors (abiotic). Density independent factors affecting the death and birth rate of population are regulated by environmental factors such as climatic conditions (weather), natural disaster such as fire, and pollution in air, water, land and Human interference such as deforestation.

Population Interactions

Population is a group of species living independently of other species. Ecosystems consist of group of different species population where the interacting species of one population has major effects on other populations. Various interactions are affecting growth of interacting populations. Among all the three major interactions are Competition, mutualism and predation.

Competition is when members of population limit the growth of same or different species and the members belong to same trophic levels. Mutualism and predation involves members of adjacent trophic levels. One species affects the other in either negative way or positive ways and sometimes has no effect on each other. These interactions can be presented in signs of "+" or "-"or "0" means positive effect, negative effect and no effect of one population on another.

Competition: Competition can be between individuals of same species or different species and termed as **intraspecific competition** and **interspecific competition** respectively. In this type of interaction both the interacting population has negative effect on each other and thus, inhibits each other's growth. Hence, it's a -/- type of interaction.

Figure 13: Interspecific competition for food between Lion and hynae

Figure 14: Intraspecific competition for territory

Mutualism: Mutualism is a type of interaction where both the interacting populations benefit each other and there is no negative effect. It’s a +/+ type of interaction between populations. For example lichens, Mycorrhizae etc.

Figure 15: Lichens as an example of mutualism

Predation: Predation is an interaction between prey and predation population constituting a prey-predator system. The predator has negative effect on prey population while prey has no effect on predator population density. Thus, it’s a +/- type of interaction. For example grazing, browsing etc.

Figure 16: Grazing by cows showing predation (Herbivory)

Other types of interactions are Amensalism, parasitism, commensalism, cleaning symbiosis etc.

In **Amensalism** one population secrete some allelochemicals inhibiting the growth of others while other population has no effect on it. It's a -/0 type of interaction. For example bacteria, fungi etc.

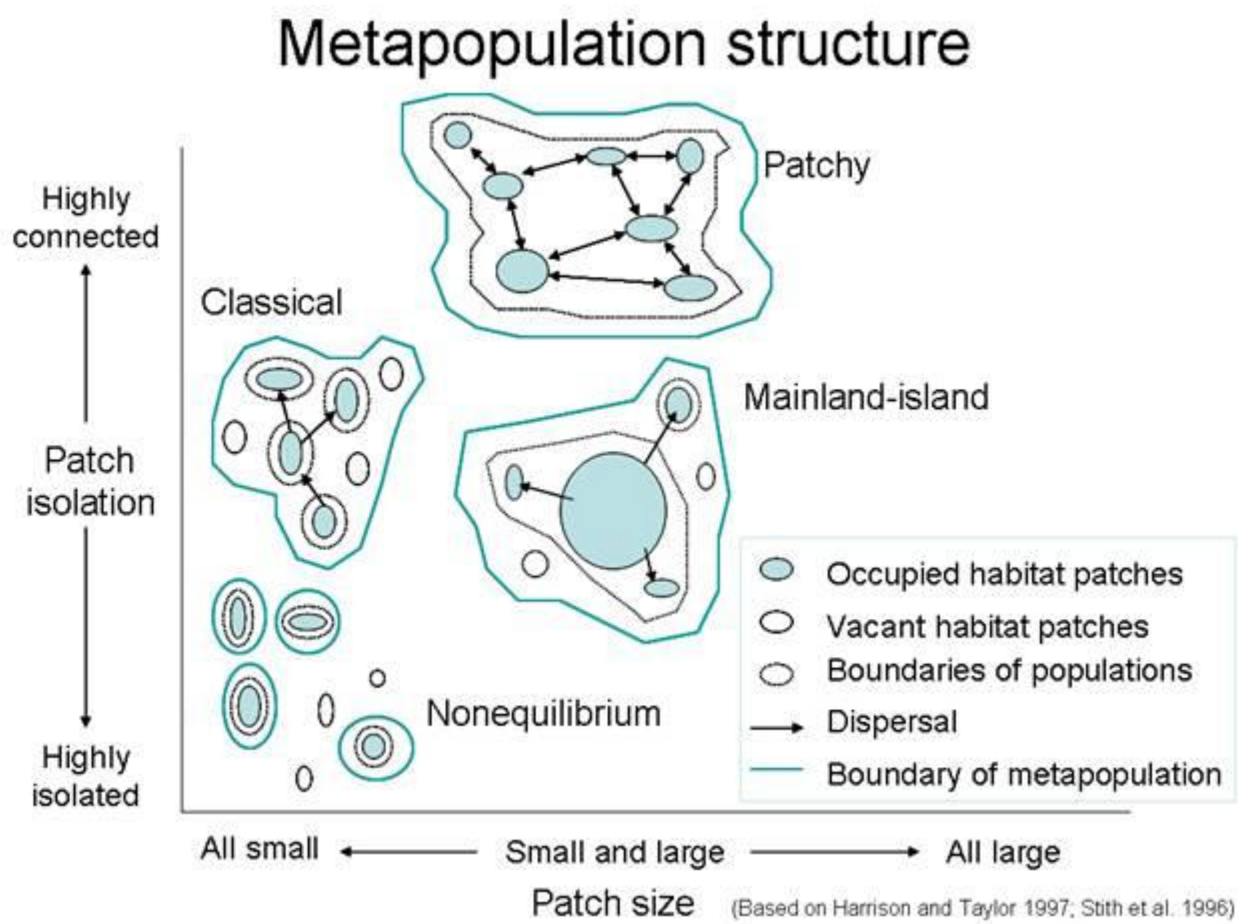
In **Commensalism** type of interaction one population is benefitted while the other is unaffected. It's a +/0 type of interaction. For example lianas, Epiphytes etc.

The interspecific competition that is the competition between different species of population relates to a classical mathematical model called as Lotka-Volterra equations. If the population dynamics follow logistic model the outcomes of **Lotka-Volterra** equations will be:

a. When the intraspecific competition is more intense than interspecific competition the **species may coexist**. Neither population reaches their intrinsic growth rate.
b. The species with intense negative effect on its competition species will survive and other is eliminated.
c. When both the interacting species have equal negative effects and when the interspecific competition is more intense than intraspecific competition than the species with high density of population persist while the other is eliminated.

Metapopulation: set of local populations occupying various habitat patches and connected to one another by the movement of individuals among them (Ricklefs and Miller 2000) . Subdivided populations with demographically significant exchange among them (Gutierrez and Harrison 1996). A 'population of populations'.

Populations of species like Mountain Sheep occupy patches of high quality habitat and they move from one patch to another only due to some factors of attraction. These species are distributed to a number of populations that are either isolated or have some exchange of individuals. Such a collection of populations and its dynamics is called metapopulation dynamics. Each local habitat in a metapopulation is referred as subpopulations.



Exponential or J-shaped growth curve and Sigmoid Growth curve

In a new environment population follow a J-shaped curve when the density increases exponential in a logarithmic form and then due to environment resistance halt abruptly. It is summarised as: dN/dt= r (r=constant for organism's biotic potential)

Number of population show characteristic great fluctuations. It's a density independent population growth curve i.e. the population growth is independent of density until the final crash.

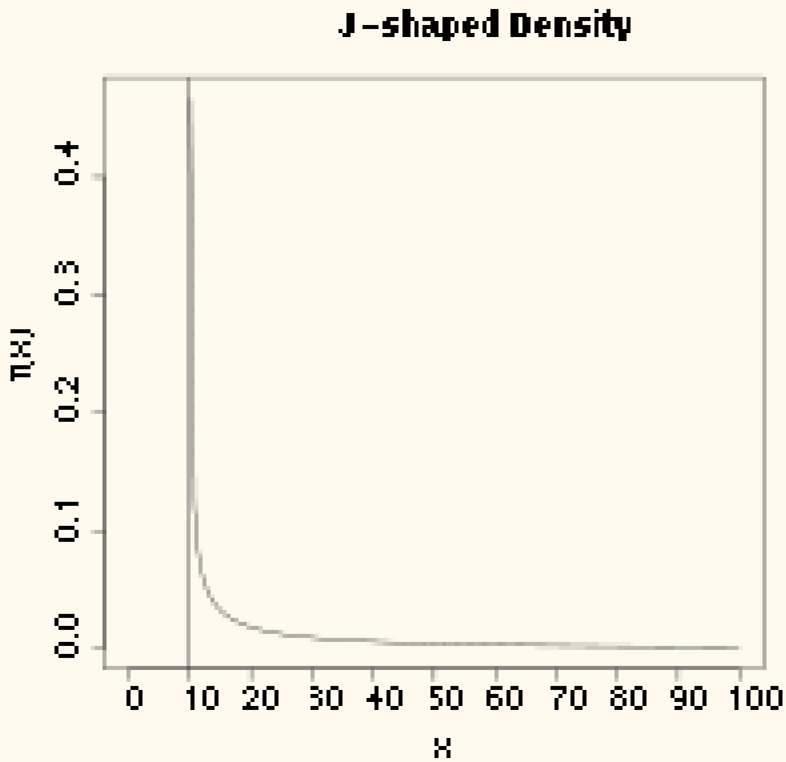


Figure 20: J-shaped or exponential growth curve.

Sigmoid Growth curve

Sigmoid or S-shaped curve is a population growth pattern where initially density of population accelerated slowly and then rapidly at an exponential growth rate. Further, the population stabilizes at zero growth rates due to environmental resistance at higher population density. Hence, it's a density dependent population growth. The stabilized zero population growth rates are called as "carrying capacity" (K) or saturation value. It's a graph plotted against time and change in number of population.

When the biotic potential interacts with environment resources the population shows an S-shaped growth curve and summarised as:

$$dN/dt = rN (K-N)/K$$

Table 6: Difference between exponential and Logistic Growth curve

S.No.	Exponential or J-shaped growth	Sigmoid or Logistic or S-shaped growth curve
1.	Abundance of resources	Limited resources (strong intraspecific competition)
2.	Population exceeds carrying capacity	Population never reaches carrying capacity
3.	Seldom reaches steady phase	Reaches a stationary phase
4.	Mass mortality leads to population decline	Seldom decline in population
5.	Two phase curve: lag and log phase	Four phase curve: lag phase, log phase, deceleration and steady phase.
6.	Eg. algal bloom. Lemming and other few organisms	Common curve eg. members of wildlife

Living organism differ from non living things by means of reproduction. Thus, population dynamics is majorly discussed under two models of population growth; (a) exponential and (b) logistic model, to answer some basic questions as how long a population will take to reach certain density and the expected duration in non favourable environment the population can withdraw and also what will be the generation time of population.

a. Exponential Model

Exponential model of population growth is applicable in fishery to predict the fish population dynamics, for predicting the yield of insect rearing, conservation biology, in predicting the population growth of introduced species i.e. insect quarantine and in microbiology for predicting the growth kinetics of multiplying bacteria.

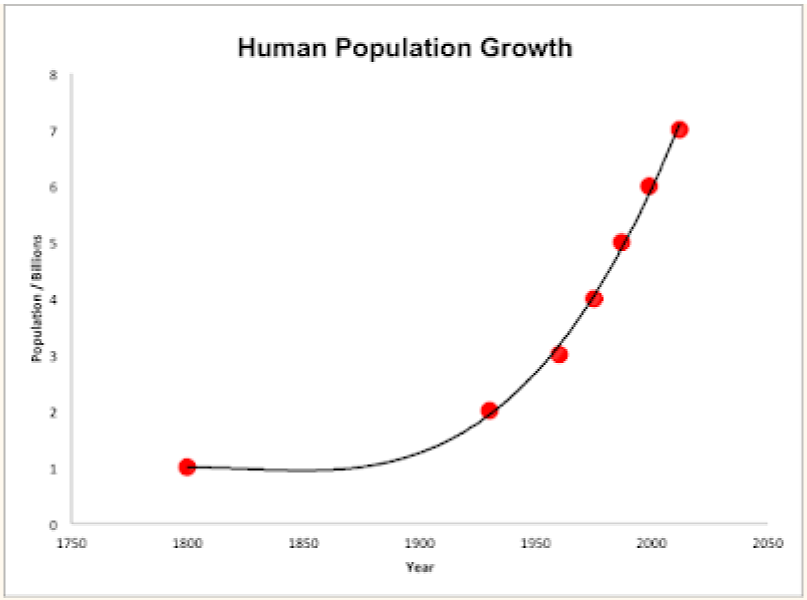


Figure 21: Exponential growth curve of Human population

Thomas was the first who suggested that the size of population increases in a geometric series. For example, in an annual plant, suppose each species produces R offspring, the population size a number after generation 0 (zero) will be:

$$N_0 = N_0R_0$$

$$N_1 = N_1R_1$$

After time "t"; $N_t = N_0R$

But when the generation time is large, the population size became an exponential function.

$$\mathbf{N_t = N_0 \exp (r*t) = N_0 e^{rt}}$$

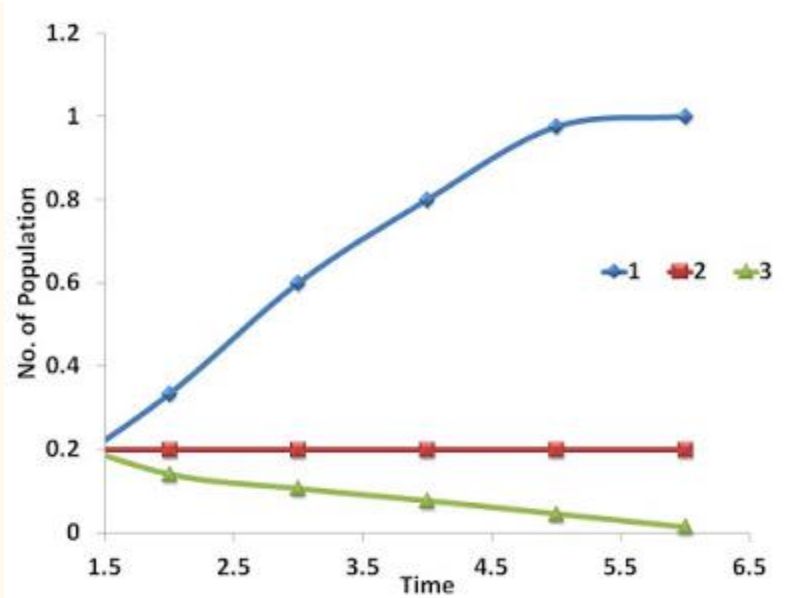


Figure 22: Three outcomes of Population growth rate

1. **Population declines exponentially (r<0)**
2. **Increases exponentially (r>0)**
3. **No change (r=0)**

This "**r**" is called "**population growth rate**", sometimes called as "**Intrinsic rate of increase**" or Malthusian parameter or instantaneous rate of natural increase.

Assumptions of Exponential model

The exponential growth curve is based on the assumptions that the fecundity rate is constant i.e. continuous reproduction and the age structure of all individuals is identical and constant environment (no environmental resistance, unlimited resource availability).

However, even if the following assumptions are unmet (such as age, mortality and survival rate are different among organisms) due to large population size, average birth and death rate gives a reasonable precision.

In the exponential model of population dynamics, the fecundity rate and death rate can be differentiated by parameter "r" analysis.

$$r = (b-m)$$

$$dN/dt = (b-m)N = rN$$

b= birth rate, one organism producing number of offsprings per unit time in a population.

m= death rate, probable number of organisms dying in a population.

When the death rate (m) is subtracted from the birth rate (b) it gives the population growth rate (r).

b. Logistic Model

In 1838, Pierre Verhulst developed logistic method and depicted the population density dependent population growth i.e. the increase in population growth rate is dependent on the density of population.

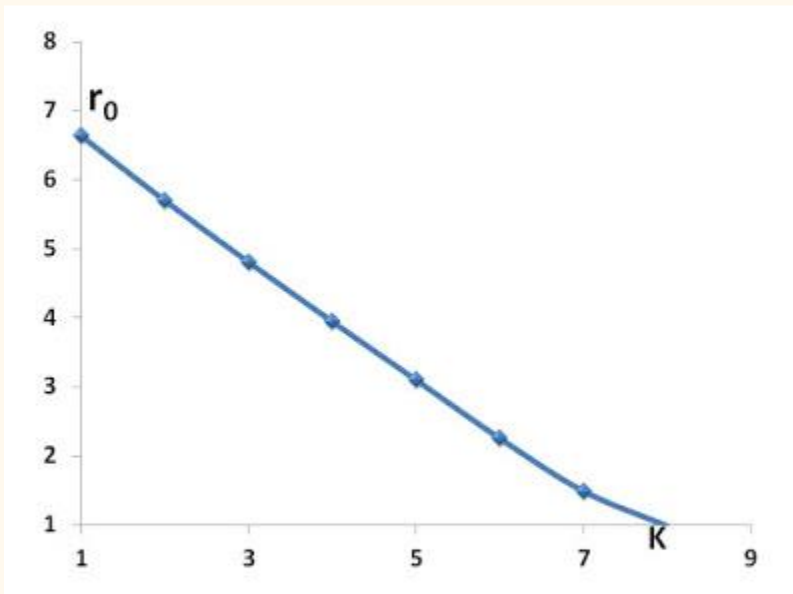


Figure 23: Population growth rate curve

$$r = r_0 (1 - N/K)$$

In this model the resources are limited; hence, a maximum population size is set which can be supported by the environment.

According to this model, the rate of population growth at low density of population (N<<K) and at this point it is equal to “r_0” i.e. the rate of population growth when the intraspecific competition is no more.

The growth rate of population is directly proportional to N but become “0” when N=K. so as the “N” i.e. population size declines the growth rate also decreases. “K” is a parameter called as “carrying capacity” which is the upper limit of population growth. The amount of resources available to support certain number of organisms can be expressed in terms of carrying capacity. In simple terms it is the maximum number of organism an environment can support.

A population growth declines and become negative if exceeds K. the differential equation for population dynamics.

$$dN/dt= rN=r_0N (1- N/K)$$

$$Nt= N_0K / N_0 + (K+N_0) \exp (-r_0t)$$

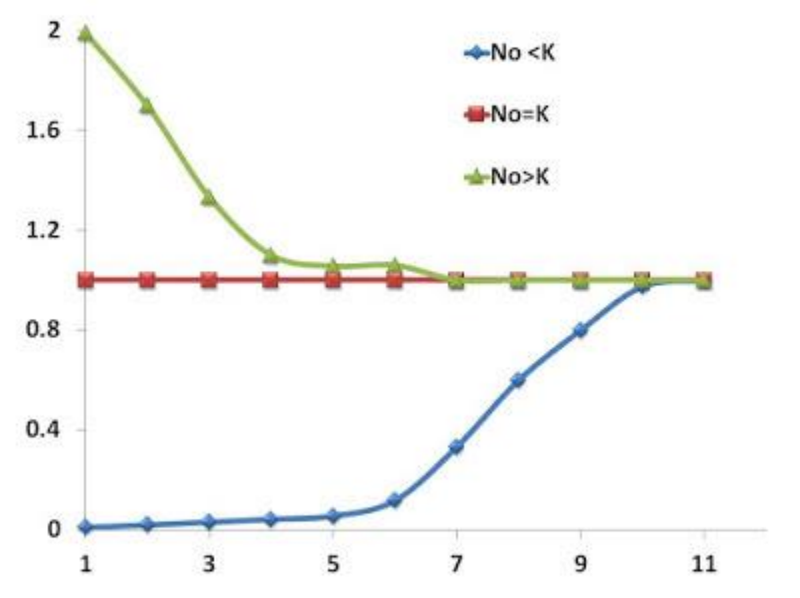


Figure 24: Three outcomes of population growth curves

Outcomes of model

1. **$N_0 < K$; increase in population**
2. **$N_0 > K$; declining population**
3. **$N_0 = 0 = K$; no change in population**

The logistic model for population growth resulted into two equilibrium states, one stable and one unstable. The stable equilibrium is when N=K, any small fluctuations in population is buffered and the population reaches the equilibrium state.

The unstable equilibrium is when N=0, where even a small fluctuation will leads to population growth.

The density dependent factors, reproduction and competition in combination are the ecological process affecting logistic model.

Parameters

a. “K”: carrying capacity is a intrinsic biological which regulate reproduction and population size. It is the maximum number of population size supported by the environment.
   Intraspecific competition becomes intense when the resources become limited as the population size increases.
b. “r_0” is a maximum population growth rate and is directly proportional to the fecundity rate and is a combined result of both mortality and fecundity. For example pest insects have high r_0 as they are rapidly reproducing while low r_0 is depicted in slow reproducing Elephants.
   r_0 regulate both population decline (N>K) as well as population growth rate.
   Logistic model does not work when the mortality is high and reproductively is slow.

r and K strategy

R. Mac Arthur and Wilson study on island biogeography coined the term r/k selection.

In an organism the selected combination of traits decides the quality and quantity of new individuals produced and this relates to r/k selection theory.

For successful living in a particular environment the r strategy focus upon the investment of parent to produce large number of offspring i.e. quantity matters while in K strategy few offspring are produced with increase parental care.

Verhulst model of population dynamics illustrated an ecological algebra from where these terms have evolved- r and k.

It was hypothesized that the evolution is drawn to any of the two ways i.e. either r selection or K selection under the influence of selection pressure.

The algebra equation of Verhault model is

$$dN/dt = rN\,(1 - N/K)$$

This equation of population dynamics represented, K as the carrying capacity, r as maximum growth rate and N as the population.

a. r-selection

r-selected or r-strategists are those organisms whose life history is regulated by r-selection.

Various Semelparous cephalopods, bacteria, grasses, diatoms, insects and mammals (especially small rodents) are all subject to r-selection and exhibit r-selection triats.

The r-selection traits are:

a. Generation time is short
b. Small body size
c. Produce high number offsprings i.e. high fecundity rate
d. Onset of early maturity and
e. The dispersal is high for offsprings.

Hence, r-selected species are also termed as "**opportunistic**" and are characterized by high "r" and low "K" as they have higher growth rate (r), they predominate in a low density niche for producing high number of offspring with less survival probability. Dandelion *Taraxacum* genus is a typical example of r-species.

Figure 25: Mice giving birth to many offspring's is an example of r selected species.

As the r-selected species has high fecundity rate therefore, it is easier for them to sustain and predominant under unstable and changing environmental conditions. Hence, offer low competition as the environment is ever changing there is no need to waste energy in adapting into it, so does not permit competition with other organisms.

b. K-selection

K-selection species are occasionally referred to as “equilibrium” exhibiting traits such as:

a. Longer generation time
b. Large body size
c. Low fecundity rate
d. High parental care requires to reach maturity

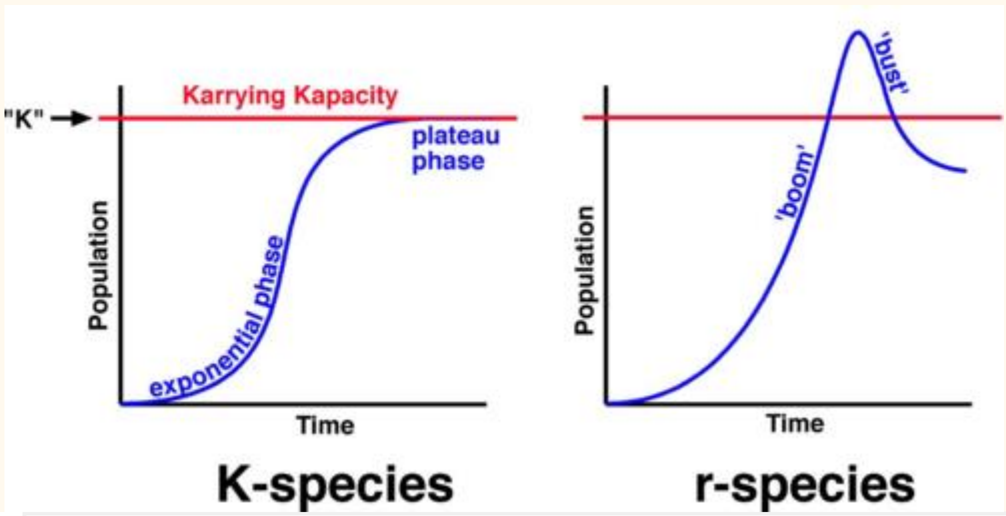
They are characterized by low “r” i.e. growth rate while high “K” as the density of organism is very much close to carrying capacity with higher life expectancy. Parents invest in fewer offspring for their survival in crowded niche with strong competition between organisms.

Figure 26: Elephant and Whales are K selected species.

K-strategists are organism characterized with K-selected traits. For example whales, humans, Elephant and Arctic terns (exceptional as small but they are long lived). Unlike r-strategists whose population size is controlled by the unstable environment, the K-strategists populate much stable environment and offer strong competition for limited resources. The population density reaches maximum the niche can tolerate and is very much constant.

c. r/K dichotomy or continuous organisms

Some organisms share traits common to both r-selected as well as K-selected patterns. For example reptiles like sea turtle and trees. Sea turtle are large body size with high life expectancy (K-selected traits) organisms but produce number of un-nurtured offspring (r-selected traits). Similarly trees are long lived and strong competitors (K-selected) but also produce thousands of offspring supporting s-selected traits.



Characteristics of r- and K-selected organisms	
r-organisms	**K-organisms**
short-lived	long-lived
small	large
weak	strong or well-protected
waste a lot of enrgey	energy efficient
less intelligent	more intelligent
have large litters	have small litters
reproduce at an early age	reproduce at a late age
fast maturation	slow maturation
little care for offspring	much care for offspring
strong sex drive	weak sex drive
small size at birth	large size at birth

Comparison of r & k selected organisms

r selected	k selected
Unstable environment	Stable environment
Small size of organisms	Large size of organisms
Energy used to make individuals is low	Energy used to make individuals is high
Many offspring are produced, early maturity	less offspring are produced, late maturity
Short life expectancy	long life expectancy
Each individual reproduce only once.	Each individual reproduce more than once.
Density independent	Density dependent
Follow type III survivorship curve	Follow type I OR II survivorship curve

Difference Between r selection vs K selection

Features	r- Selection	K-Selection
Example	Bacteria, insects	Primates, including humans
Development	Rapid	Slow
Reproduction rate	High	Low
Reproductive age	Early	Late
Body size	Small	Large
Reproductive type	Single reproduction (Semelparous)	Repeated reproduction (Iteroparous)
Length of life	short	Long
Competitive ability	weak	Strong

Gause’s Principle,Resource Partitioning and Character Displacement

Gause’s Principle

Gause's principle suggests that the two competing species can coexist.
In 1960, Hardin based on Gause's principle restated that complete competitors affecting each other with equal magnitude cannot coexit and called it as **Competitive exclusion principle**.

The population growth effected by the competition between two species of*Paramecium* depicts the more intense negative effecting population survives at the expense of other. *P. aurelia* and *P.caudatum* reaches there carrying capacity when culture alone in laboratory but when these two cultures are mixed and grown together *P.aurelia* survives while *P.caudatum*is eliminated.

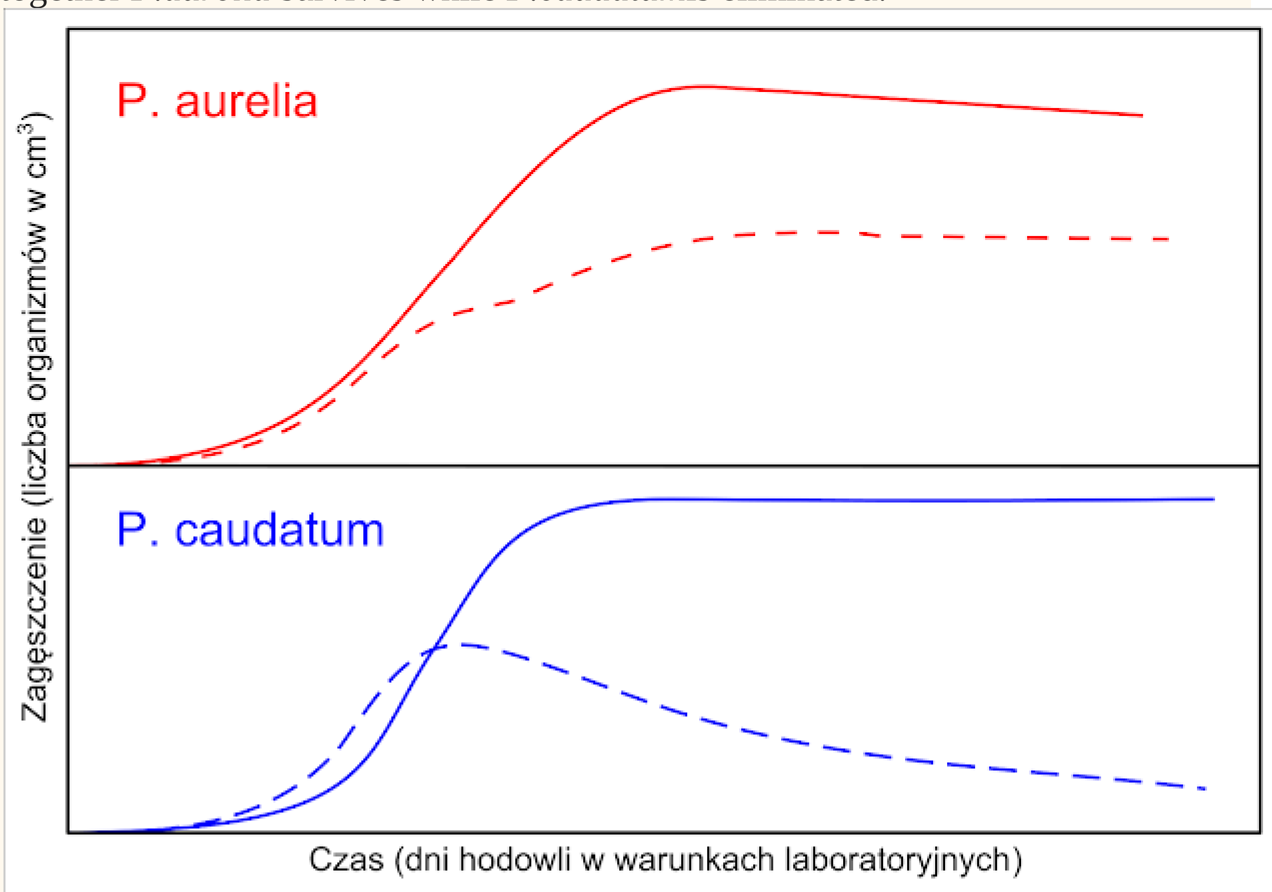


Figure 17: Graph illustrating growth inhibition in one species of paramecium on co-culturing them in laboratory.

The species can coexist by reducing the competition *via* **ecological segregation** or **resource partitioning.** In this hypothesis it was suggested that when two species share common resources than they may coexist by partitioning their resources such as food, space etc (figure 18).

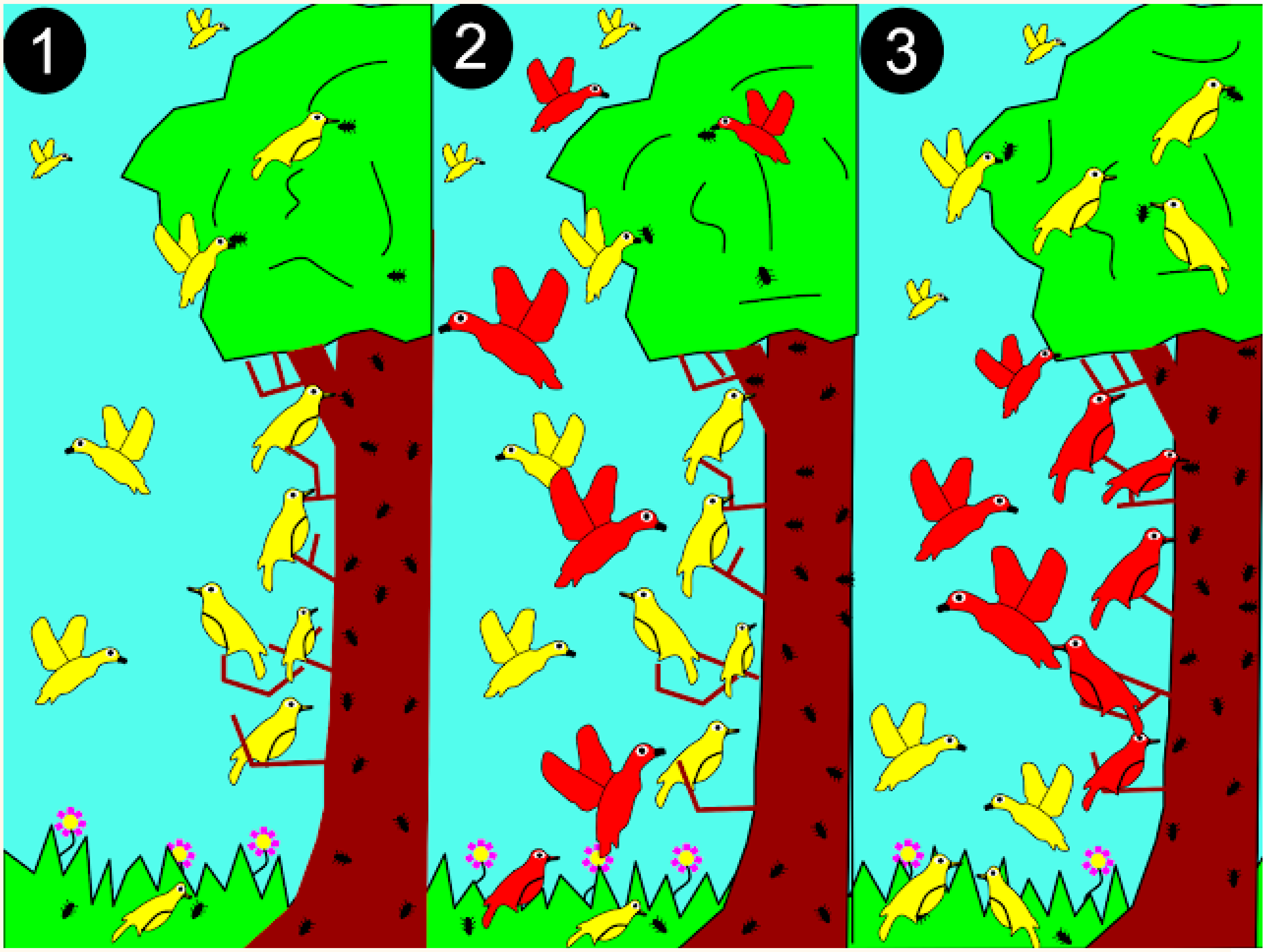


Figure 18: The illustration of Competitive exclusion principle. (1) Small yellow birds utilize the resources all over the tree. (2) On invasion of large red colour birds the competition increases and (3) leads to competition exclusion/resource partitioning between two birds species, thus, the large red birds utilize resource abundant middle part of the tree while small yellow birds consume rest of the resources.

In field some lizards and many insects like ants depicts the coexistence of species through Resource partitioning or ecological segregation.

Character Displacement: Different species develop traits under the influence of competition and can coexist. The best and classical example is set by **Finches of Galapagos Island** where the Darwin observed that the size and shape of the bird's beak vary according the vegetation in the Galapagos Island.

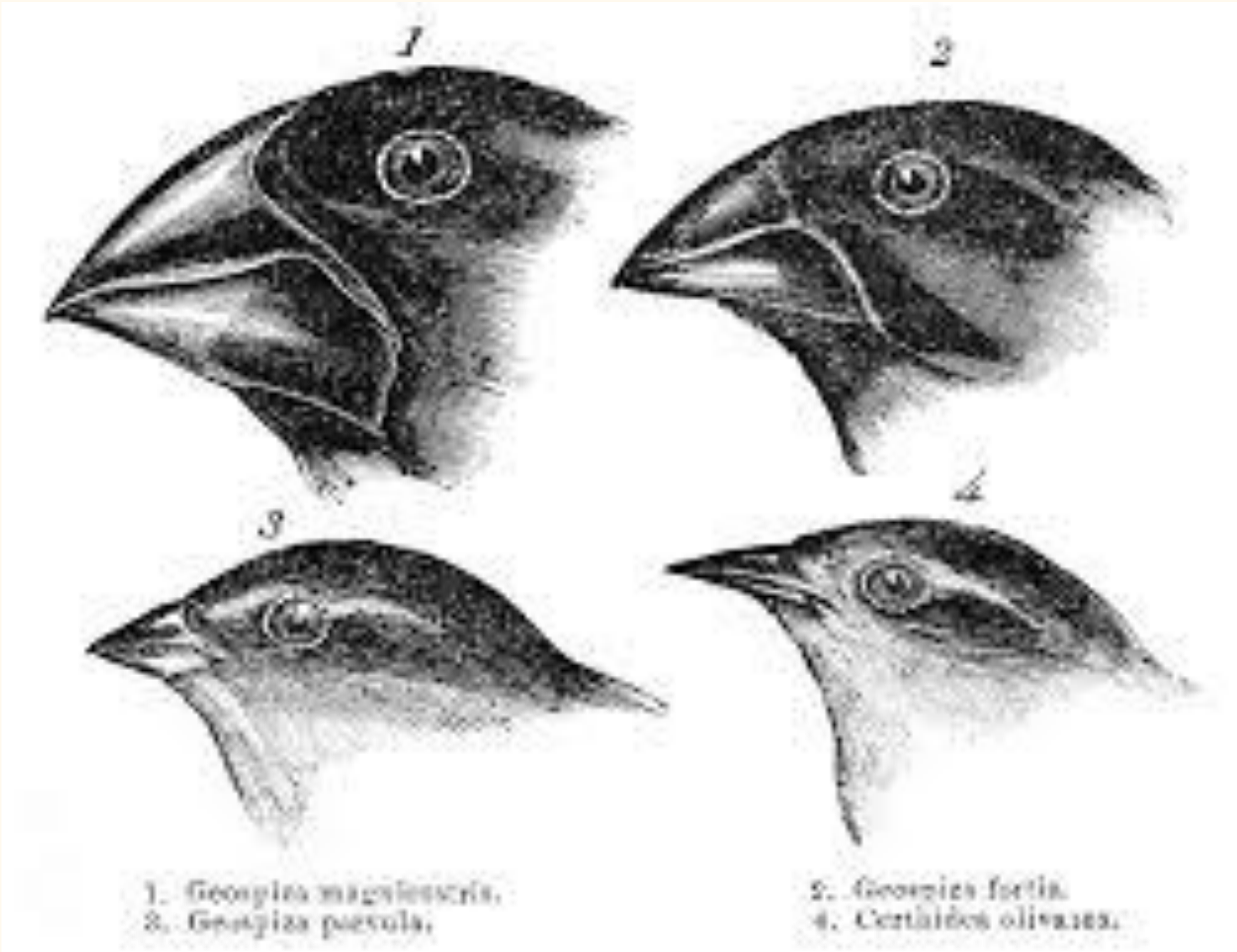


Figure 19: Darwin’s Finches

Lotka Volterra equation for competition and Predation

The Lotka Volterra equation are used to interpret the population dynamics in which two organisms interact in one of the two ways, (a) either compete for common resources or (b) associated in a prey-predator system.
The equation for first type of interaction i.e. competing for common resources is termed as the Competitive Lotka-Volterra equations while another type of interaction is described by predator-prey equation.

1. Competitive Lotka-Volterra equations

The Lotka-Volterra equation for competition is based on the logistic equation. This equation is similar to Predation prey equation of Lotka-Volterra where species interact with others by one term and to itself by another term but this equation follows exponential mode rather than logistic model.

Ecologists used the equation for logistic model is given as:

$$dN/dt = rN\ (1 - N/K)$$

- N= population size
- r=growth rate of population
- K=carrying capacity

For competition between two species

In the Lotka-Volterra equation two additional terms were added to depict the species interactions between two given population N_1 and N_2 related logistic dynamics.

The equation is given as:

$$dN_1/dt = r_1N_1\ [1-(N_1+a_{12}N_1/K_1)] \text{ for species 1}$$

$$dN_2/dt = r_2N_2\ [1-(N_2+a_{21}N_2/K_2)] \text{ for species 2}$$

We all know that each organism has its own carrying capacity (K_1 and $K_2$are different) and growth rate (r_1 and r_2 are different). As this equation for population dynamics is associated with interaction (competition) which are harmful to interesting species, in equation all a values are positive. In this equation $\mathbf{a_{12}}$ termed as **competition coefficient** depicts the **competitive effect on population one (N_1) by another population (N_2)** that's why represent as ($\mathbf{a_{12}}$). Similarly for the equation of population of N_2, a_{21}depicts the competitive effect on population N_2 by the population N_1represented as (a_{21}). If a_{12}<1 it means species 1 has more effect on its own rather than the effect of species 2 on species 1 i.e. more intense intra-specific competition.

In short the effected population comes first to the population affecting it.

Outcomes Interpretation

1. If a_{12}=0, this means species 1 follow logistic model of population dynamics.
2. If a_{21}=0, this means species 2 follow logistic model of population dynamics.
3. If a_{12}=1, species 1 and 2 strongly compete with equal magnitude for common resources means intraspecific competition equals interspecific competition.
4. If a_{12}= "-" negative, species 2 facilitates resource availability to species 1.

5. a_{12}/ a_{21} both negative indicate symbiotic relationships.
6. If one is zero (0) among two, either a_{12} or a_{21} and the other is negative it indicates commensalism.
7. If one is positive among two, either a_{12} or a_{21} and the other has no affect it means parasitism.
8. If both have negative values it indicates competition.

Lotka Volterra Predation equations

The Predator prey equations given by Lotka-Volterra describe the interaction between prey and predation as a dynamic biological system.

The population follows a non-linear, first order differential equation and represented in pair of equation as

$$dx/dt = ax - \beta xy$$
$$dy/dt = \delta xy - \gamma y$$

where "x" and "y" is the number of prey and predator population and "dx/dt" or "dy/dt" are the growth rate of prey and predator population in time "t". The symbols α, β, γ and δ denotes the real and positive parameters related to the interaction between prey and predator species.

Assumptions

Lotka-Volterra predation equation is based on the assumptions:

1. Predator can eat limitless.
2. Supply of food resource (i.e. prey) depends on the prey population size.
3. The rate of change of population directly depends on its size.
4. Environment is constant, inconsequential genetic adaptations for both species.
5. All time unlimited food supply for prey.

The equation is continuous and deterministic indicated continuous overlapping of prey and predator population.

Prey

The rate of growth for prey population is given by equation:

$$dx/dt = ax - \beta xy$$

The change in prey population follows exponential growth model represent as "ax" in the equation unless subjected to predation. The rate of predation is directly dependent on the rate of prey-predator interaction represented as "βxy". "x" and "y" are the population size of prey and predator, if x/y is zero it clearly indicates that there is no predation.

Predator

The rate of growth for predator population is given by equation:

$$dy/dt = \delta xy - \gamma y$$

The change in predator population equals to food supply mediated growth minus death of predators.

The growth of predator population is represented as "δxy". "δ" is different from "β" as the rate of predator population growth is very much different from the rate of predation on prey. "γy" is the decay rate of predator either due to emigration or mortality. In the prey absence the predator follow an exponential decay.

The solution to equation is periodic and yields a simple harmonic motion where prey population is traced by predation population by 90° in cycle.

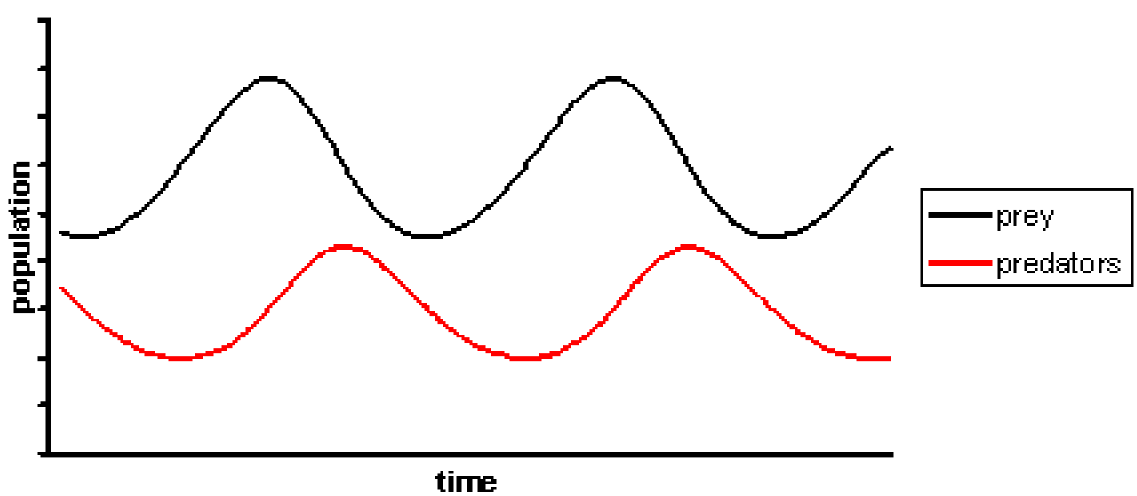


Figure 27: Harmonic motion of prey-predator system

Functional and numerical responses

In 1959, Holling suggested that as the prey density increases it leads to increase in Predation rates due to two effects:

(a) **Functional Response** where the consumption rate of predator increases in presence of high prey population density.

(b) **Numerical Response** in which increase in prey density leads to increase in predator population density.

a. **Functional Response**

There are three types of functional response curves which relate density of prey population to prey consumption by single predator per unit time.

Type I Response curve

It's a rare form of response in nature, for example in Filter feeders.

It's an initial exponential relationship between prey and predator and its consumption by predator till reaches saturation point where predator cannot eat maximum from that rate.

Type II Response curve

It's a common type of response in nature, for example rodents and weasels. At low population density the rate of consumption increases at decelerating rate (increases at slow rate).the rate of consumption is dependent on two factors, (a) the searching or locating a prey and (b) handling time of prey (capture, kill and eat). At low population density the searching for prey is important and predator kill prey at constant effort fashion while at high density of prey searching for prey becomes easy but handling time is limiting factor and thus the rate of consumption increases slowly. Subsequently, searching Is not required and rate of consumption levels off at maximum rate.

Type III Response curve

Type III response is also common in nature depicting logistic increase in the rate of consumption on increase in prey density.

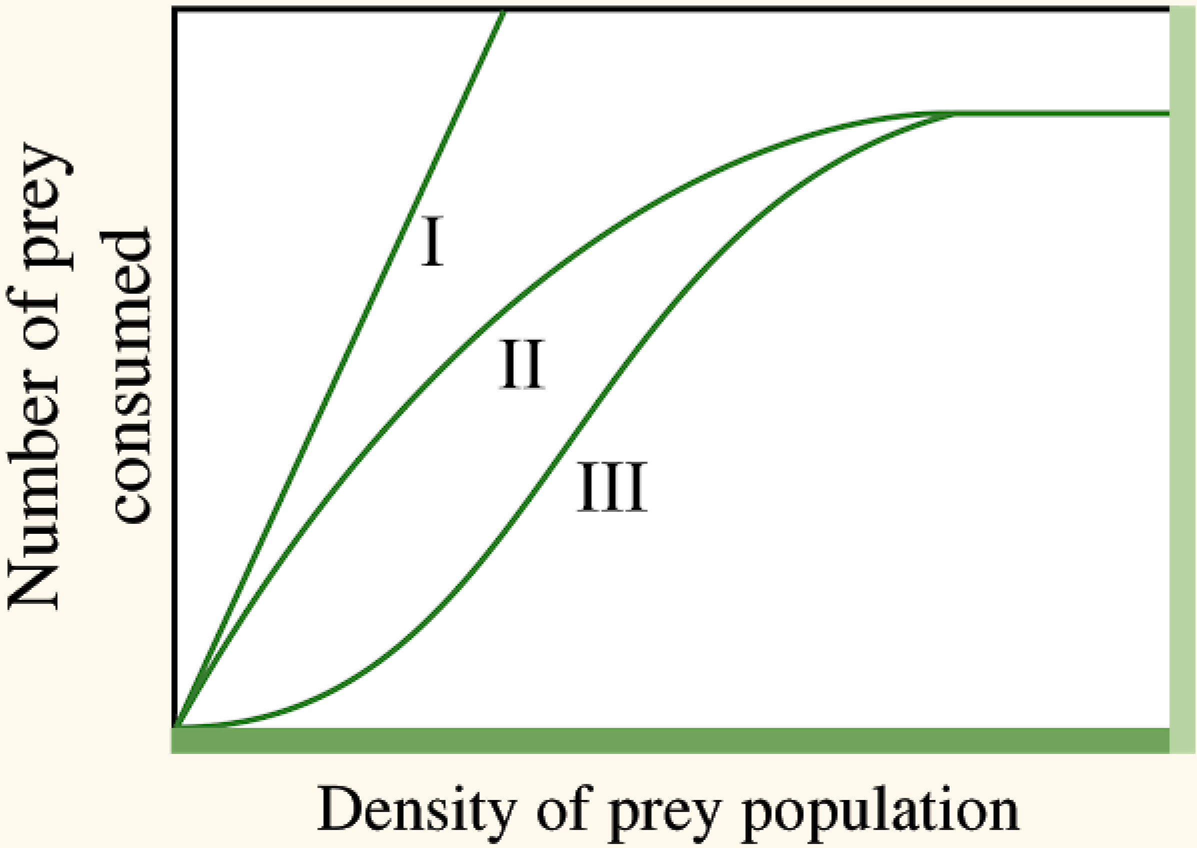


Figure 28: Three types of Functional response curves

Numerical response curves

Numerical response means increase in predator density on increase in prey population density due to direct responses i.e. (a) on increase in prey density the fecundity rate of predator increases and (b) Aggregation response

a. As the prey population size increases, the consumption rate of predator increases leads to high fecundity rate and low mortality rate.
b. Aggregation response: Predators aggregation in prey hot spots is called aggregation response. This type of response increase prey-predator system stability.