

## Chapter 2: Population dynamics

This chapter focuses on variations in population abundance. At the most basic level, it involves describing a population at a given moment using several variables: abundance, structure, and demographic processes. Based on this knowledge, it is possible to establish projections that describe the expected changes in population size and the structural changes of the populations studied.

### 2.1 Biological materials

Biological materials are those found in living organisms. They are the constituents of cells, intercellular spaces, tissues, and organs of living beings. Primarily, holoproteins, heteroproteins, lipids, nucleic acids, and others are integrated in nature into a certain number of increasingly complex levels of organization to form: the cell ... the population ... the community.

**a) The cell:** In biology, the cell is the basic functional unit that composes all living organisms. With the invention of the first microscope in 1664 by the Dutch scientist Antoni van Leeuwenhoek, it became possible to observe the first cells. Their size is so small that they cannot be distinguished with the naked eye.

**b) The individual (organism):** An individual is a functional biological system which, in the simplest case, is reduced to a single cell (unicellular). More often, however, it is composed of several cells that are organized into tissues and organs. Moreover, at a given moment, an individual possesses a defined biomass, which can be expressed as live (fresh) weight or dry matter (DM) weight. This biomass is the result of metabolism.

Metabolism is the set of synthetic reactions that generate materials (anabolism) and degradative reactions that generate energy (catabolism), which take place within living matter using chemical constituents supplied to the organism through nutrition and under the action of specific catalyts.

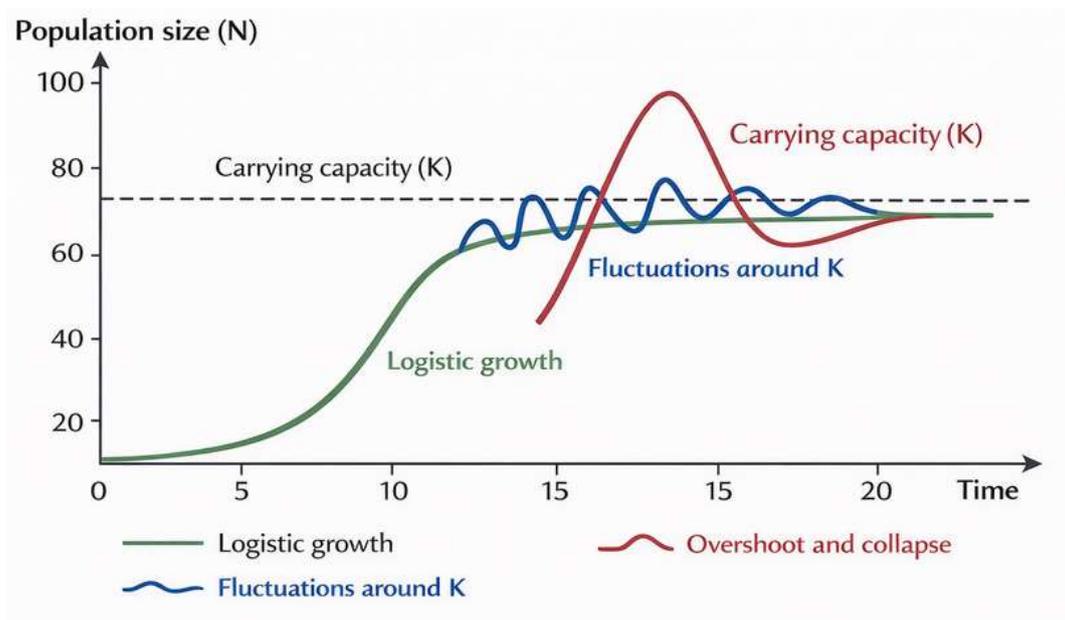
It includes consumption (C), through diffuse absorption or ingestion, and the assimilation (A) of a portion of the consumed products.

## 2.2 Population ecology

The aim of population ecology is to measure and explain variations in the size and composition of populations. No population can increase indefinitely. Population explosions may occur, followed by a possible decline; this is why one of the main criteria of a population is its size or density.

Individuals within a population can communicate with one another. A population is considered a system with its own characteristics, known as state variables, the main ones being: population size (or density), type of distribution, age structure, genetic structure, and social organization.

State variables are affected by demographic processes, which give the population a certain dynamic behavior.



**Figure 2.1** illustrates several population growth models, showing how the population approaches its biotic capacity  $K$  (Geeklhem, 2016).

## 2.3 Main population parameters

Populations, considered as fundamental biological units, are characterized by a set of state variables such as size (or density), spatial structure (modes of distribution of individuals within the environment), demographic structure (age and sex), genetic structure (allele frequencies), and social organization.

However, natural populations are never isolated entities: they are embedded in an environment with which they are in close interaction and on which they depend. Thus, for the population ecologist, the true functional unit is the population-environment system. The environment in question is defined relative to the population considered, and not in absolute terms. It includes:

- the climatic and physico-chemical framework in which the population evolves, insofar as it influences population dynamics;
- other populations which, for the species studied, may represent sources of food, enemies (predators and parasites, herbivores in the case of plants), competitors that may compete for food resources or space, or species that cooperate to ensure or improve certain functions (mutualism, symbiosis).

It may seem paradoxical to model the temporal evolution of population size-which is an integer number of individuals-using the solution of a differential equation, which is necessarily a continuous (and even differentiable) function.

An animal population changes through births and deaths, which increase or decrease its size by one unit at a time. However, for a large population, and depending on the time scale considered, population variations may effectively appear continuous.

**Example:**

For the human population on Earth, which numbers in the billions, the numbers of births and deaths occurring each second are in the thousands. Moreover, it is impossible to know all birth times to the nearest second. The only meaningful interpretation of the statement “the world population increased by 30 individuals per second on December 8, 2026” is: “the world population increased by a certain number of individuals on that day, corresponding to an average of about 30 per second.”

Consequently, over an interval of 2 seconds the increase would be 60 individuals, over 3 seconds 90 individuals, and so on. Let us denote the world population at a given instant, and choose the second as the unit of time. As stated above, the population increase over a time interval of several seconds can thus be approximated accordingly.

### 2.3.1 Density and relative abundance

Knowledge of population density is a fundamental demoeological parameter. Density (D) is expressed as the number of individuals relative to a given area or volume, per unit of habitat, at a specific time.

Densities vary greatly:

$$D = \frac{\text{number of individuals}}{\text{area or volume}}$$

**For example:** the density of ungulates in an African savanna is expressed as the number of individuals per km<sup>2</sup>; that of trees in a temperate forest as the number of individuals per hectare; that of litter-dwelling arthropods as the number of individuals per m<sup>2</sup>; and in a steppe as the number of sheep per hectare.

Another way to express density is through biomass, which refers to the mass of living or dry matter present at a given time in a given environment. Biomass represents the mass of living individuals at a specific place and time and reflects differences in the nutritional requirements of each species.

According to Philippe (2008), the biomass of a given species is expressed as follows:

$$B = P \times N$$

Where:

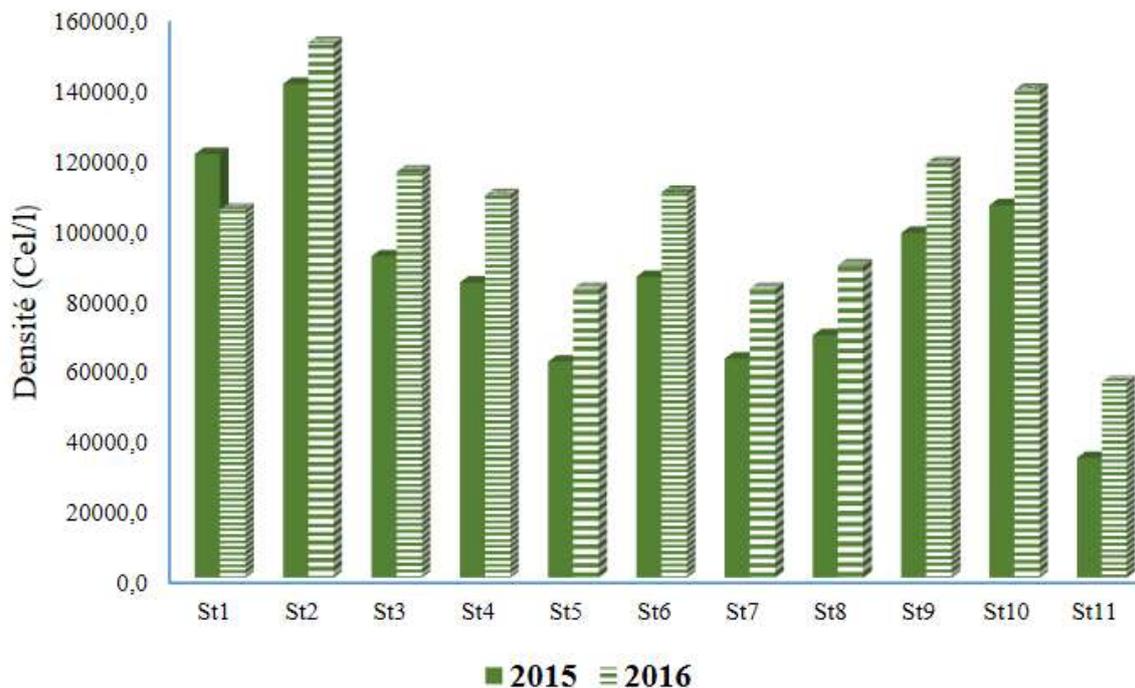
- B : biomass (kg)
- P : average weight of the species considered (kg)
- N : number of individuals of the species considered

It is also useful to estimate biomass per unit area (B/S in kg/km<sup>2</sup>) for a given species, calculated as:

$$P \times D = B/S$$

To determine the density or biomass per unit area of all species present, it is sufficient to sum the density or biomass per unit area of each species.

In conclusion, for animal populations, the observed density (expressed as biomass) depends essentially on their position within the trophic network. The higher a species' position in the food chain, the lower its biomass density tends to be.



**Figure 2.2.** Annual mean density dynamics of phytoplankton at the different sampling stations of the Beni Haroun Dam in 2015 and 2016 (Kherief Nacereddine, 2019).

Determination of population density is important because the impact of a population largely depends on its density. Indeed, there are numerous methods for estimating population density, which can be grouped as follows.

### 2.3.1.1 Direct population counts

Several methods can be used to estimate population size, including censuses and sampling techniques. According to Monfort (1975), a census consists of the direct counting of all individuals in a population. Although this method provides highly reliable results, it is time-consuming and costly, which explains why it is relatively rarely used in practice.

A **complete census** of a population can only be carried out if two main conditions are met:

**a) Negligible demographic changes during the census period**

Mortality and natality rates (recruitment and disappearance) must be negligible during the counting period. Consequently, the census must be conducted over a very short time span. This often requires either a large workforce, which is expensive, or the use of aircraft such as airplanes or helicopters.

**b) Equal probability of detection for all individuals**

All individuals in the population should have the same probability of being detected and counted. In reality, this condition is almost never fully satisfied.

For example, an elephant is much easier to detect than a duiker (*Cephalophus* spp.). Similarly, individuals of the same species may be more or less visible depending on whether they inhabit open or closed environments. Ultimately, the probability of detecting a species or an individual depends largely on the counting technique employed.

**c) Aerial photography and aerial surveys**

Aerial surveys conducted from airplanes are commonly used in open habitats such as steppes, grass savannas, tundra, and deserts. In practice, these environments are the only ones in which aerial techniques yield results close to reality. Aerial methods have the advantage of being rapid and relatively cost-effective, and total aerial counts are particularly suitable for large mammals in open landscapes.

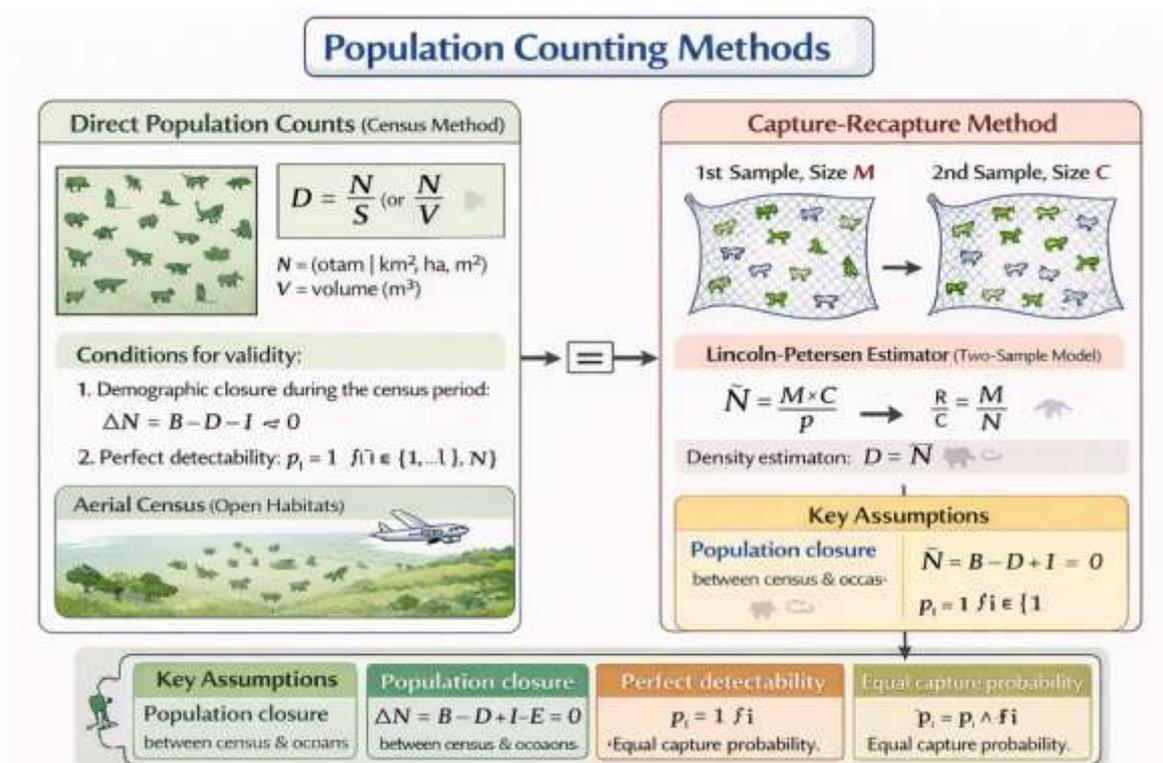
### **2.3.1.2 Capture-recapture method**

The capture–recapture method was initially developed in zoology to estimate the size of animal populations, particularly birds and fish.

**Principle of the method:**

- a random sample of individuals from the target species is captured;
- the captured individuals are marked and released back in to the population;
- a second sample is then captured, and the number of marked individuals is recorded;
- the total population size is estimated using a proportionality rule (rule of three).

This method makes it possible to estimate population size from different data sources and to assess the completeness of epidemiological surveillance systems, as well as incidence and prevalence rates. The capture–recapture method has been widely developed and refined and is now used in ecology, epidemiology, and conservation biology.



**Figure 2.3.** Population estimation methods schematic overview of two main population estimation approaches: direct census and capture-recapture. The figure illustrates population density calculations, key assumptions, and the lincoln-petersen estimator for capture-recapture.

### 2.3.1.3 Determination of population density by sampling

The choice of a sampling method depends on the specific objectives of the study. Each method has its own technical characteristics for implementation and for analyzing the results.

Sampling methods can generally be grouped in to three categories:

- Non-probabilistic sampling methods,
- Probabilistic sampling methods,
- Probabilistic spatial sampling methods.

### a) Non-probabilistic sampling methods

In non-probabilistic sampling, the selection of sampling units is not based on randomization. The researcher chooses units based on convenience, accessibility, or perceived importance.

#### Examples:

- **Convenience sampling:** selecting areas that are easily accessible.
- **Judgmental sampling:** choosing sites based on prior knowledge of species distribution.
- **Quota sampling:** Ensuring a pre-determined number of individuals or units from specific strata.

**Advantages:** simple and quick.

**Limitations:** Subject to bias, results may not be statistically representative of the population.

### b) Probabilistic sampling methods

In probabilistic sampling, every individual or sampling unit has a known and non-zero probability of being selected. This allows statistically unbiased estimates of population density.

#### Examples:

- **Simple Random Sampling (SRS):** Each unit in the population has an equal probability of being selected. The estimated density  $D$  is calculated as:

$$D = \frac{\sum_{i=1}^n y_i}{n \times S}$$

where:

- $y_i$  = number of individuals in the  $i$ -th sampled unit,
- $n$  = number of sampled units,
- $S$  = area of a single sampling unit.
- **Systematic sampling:** Units are selected at regular intervals (e.g., every 10 m along a transect).
- **Stratified random sampling:** The habitat is divided into strata (homogeneous sub-areas), and random samples are taken within each stratum to improve accuracy.

**Advantages:** unbiased, statistically robust.

**Limitations:** may require prior knowledge of the population or habitat structure.

### c) Probabilistic spatial sampling methods

These methods incorporate spatial structure and are designed for populations with uneven or clustered distributions. They combine randomization with spatial coverage to obtain accurate density estimates.

#### Examples :

- **Transect sampling:** counting individuals along lines (transects) placed randomly or systematically across the habitat.
- **Quadrat sampling with spatial layout:** randomly placed quadrats or grids that account for the spatial distribution of organisms.
- **Geostatistical sampling:** uses spatial autocorrelation and variograms to optimize sampling locations.

#### Advantages:

- Provides reliable estimates for heterogeneous habitats,
- Captures spatial patterns and variability of the population.

So,

Non-probabilistic methods are simple but potentially biased.

Probabilistic methods provide statistically sound estimates.

Spatial probabilistic methods are necessary when populations are patchily distributed.

### Random sampling

Simple random sampling is a method that consists of selecting, at random and independently,  $n$  sampling units from a population of  $N$  elements. The sampled units are distributed randomly, so that each individual or point within the studied area has an equal probability of being selected.

In practice, this method involves selecting  $n$  individuals from a sampling frame or list by random drawing, in a single step, without replacement. Random sampling ensures objectivity and minimizes selection bias, making it a reference method for estimating population parameters such as density, abundance, and biomass.

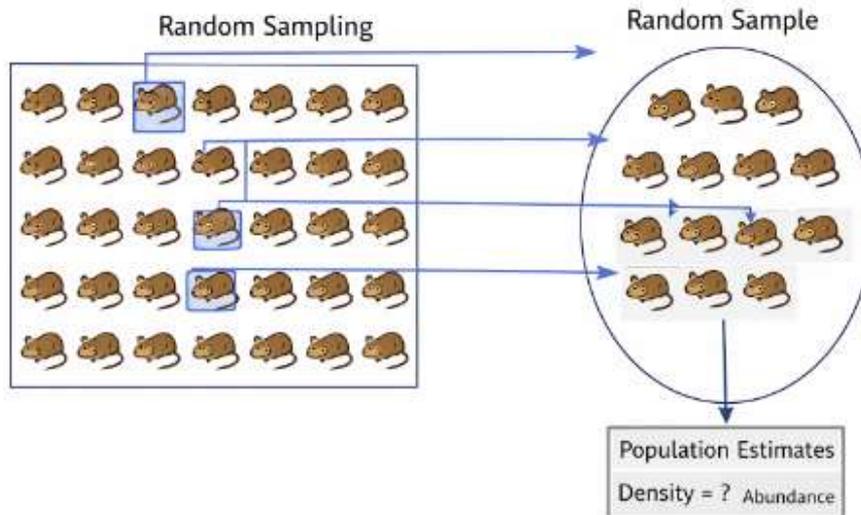


Figure 2.4. Random sampling in animal populations

### 2.3.2 Birth rate and mortality

The density, growth, or decline of a population depends on the number of individuals added (births or natality) and the number of individuals lost (deaths or mortality, as well as emigration). In other words, the population size of each species is primarily determined by the difference between birth and death rates, as well as the balance between immigration and emigration.

- **Natality (Birth Rate):** the main factor driving population increase.
- **Mortality (Death Rate):** the second fundamental demographic parameter.

Like natality, mortality varies according to age class and can be expressed as a mortality rate or as the probability of death.

### 2.3.3 Sex ratio

The **sex ratio** is the ratio of males to females in a population and represents an important demographic parameter.

- Most animal species are gonochoric, meaning they have separate sexes, although hermaphroditism or parthenogenesis is common in some invertebrate groups.
- In certain rodent populations, significant sex ratio imbalances may occur.

For example:

- In **muskrats (*Ondatra zibethicus*)**, although the sex ratio at birth is 1:1, it rises to 1.4 (140 males per 100 females) among individuals older than three weeks.
- Conversely, an excess of females occurs in populations of two North American squirrel species (*Sciurus niger* and *Sciurus carolinensis*), where females are 5–55% more numerous than males.

### 2.3.4 Age pyramids

Age pyramids provide a clear and informative representation of the age structure of a population. They are constructed by stacking rectangles of constant width, with lengths proportional to the number of individuals in each age class.

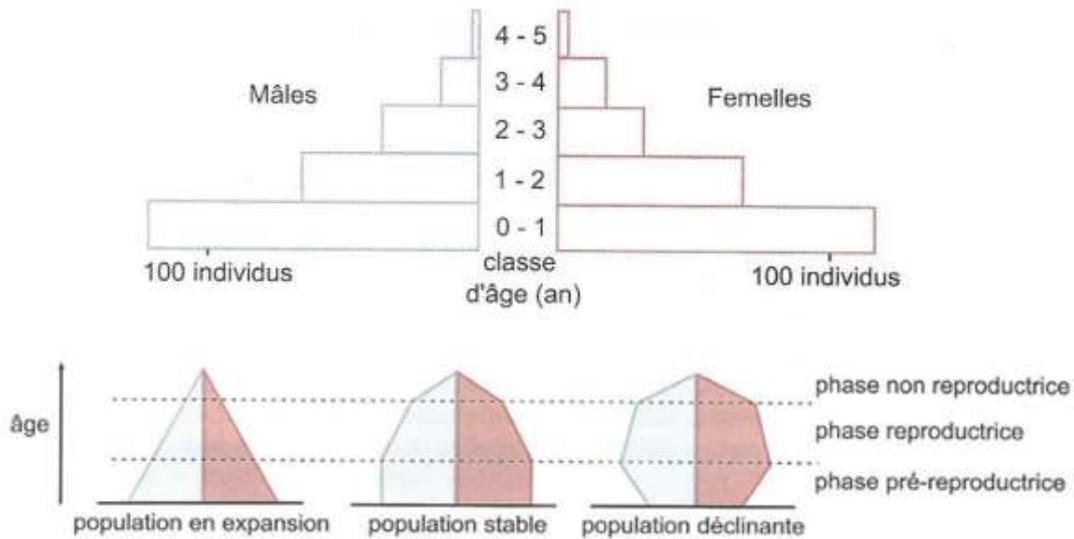
- Males and females are displayed in two separate groups on either side of a central axis, reflecting the fact that mortality often affects the sexes differently across age classes.

A simplified representation of an age pyramid can categorize the population into three main groups: Young individuals, Adults and Elderly individuals

This graphical representation allows ecologists to quickly assess population growth trends, reproductive potential, and demographic balance.

**Table 1.** Some demographic characteristics of a tit population, according to Peycru et al. (2014).

| Age (years)  | Total number | Males      | Females    | Eggs laid  | Number of eggs per female |
|--------------|--------------|------------|------------|------------|---------------------------|
| 0–1          | 241          | 124        | 117        | 0          | 0                         |
| 1–2          | 128          | 63         | 65         | 455        | 7                         |
| 2–3          | 67           | 36         | 31         | 279        | 9                         |
| 3–4          | 30           | 13         | 17         | 102        | 6                         |
| 4–5          | 5            | 2          | 3          | 9          | 3                         |
| <b>Total</b> | <b>471</b>   | <b>238</b> | <b>233</b> | <b>845</b> | <b>–</b>                  |



**Figure 2.5.** Schematic representation of the main types of age pyramids (age pyramid of the studied great tit population with the numbers from the first year of observation at the top and the typology at the bottom), according to Peycru et al. (2014).

### How to determine the age of an individual

The age of an individual can be determined using one of two main approaches:

- **Marking the individual at birth**, the age is known exactly from the date of marking.
- **Using morphological or anatomical characteristics** that are related to seasonal metabolic changes or growth patterns.

### Examples of age-related characteristics include:

- **Annual growth rings in woody plants**, each ring corresponds to one year of growth.
- **Annual growth rings or lines in animals**, observed in various structures such as:
  - Mollusk shells
  - Fish scales or **otoliths** (calcified structures in the inner ear used for balance)
  - Horns or antlers of ungulates
  - Dental wear or eruption patterns
  - Lens weight (increases with age)

These features allow ecologists to estimate the age of individuals, which is essential for constructing age pyramids, studying population dynamics, and understanding life-history traits.

## 2.4 Laws of population growth

### 2.4.1 Intrinsic rate of increase

When an environment temporarily provides natural resources in abundant quantities, the populations inhabiting it can increase without being constrained by limiting factors. In the absence of limiting factors, the rate of increase in population size per unit time remains constant.

Let  $N_0$  be the population size at time  $t_0$ , and  $N$  the population size at time  $t$ . The per capita rate of increase  $R$  is expressed as:

$$R = \frac{N - N_0}{N(t - t_0)} = \frac{\Delta N}{N \Delta t} \quad (1)$$

When  $\Delta t \rightarrow 0$ ,  $R \rightarrow r$  and equation (1) becomes:  $r = \frac{dN}{N dt}$  (2)

The parameter  $r$  is called the intrinsic rate of natural increase. It is a constant characteristic of the species considered and expresses its biotic potential, that is, the maximum reproductive capacity it can exhibit in the absence of limiting factors.

Equation (2) makes it possible to determine the rate of population increase, which is proportional to population size:

$$V = \frac{dN}{N dt} = rN \quad (3)$$

Thus, we can write:  $dN = rN dt$  (4)

Integrating equation (4) yields the solution:  $N = N_0 e^{r(t-t_0)}$  (5)

Which can be written, by taking  $t_0 = 0$ , as:  $N = N_0 e^{rt}$  (6)

It therefore appears that when a population is placed in the absence of limiting factors, its growth follows an **exponential law**. Moreover, referring to equation (3), the rate of population increase itself rises exponentially.

### 2.4.2 Population growth under limiting factors

The density of a population, as well as its growth or decline, depends on the number of individuals added to the population (births and immigration) and those that are lost (deaths and emigration).

The **birth rate** and **death rate** correspond to the number of individuals added to or removed from a population per unit of time. These rates can be expressed either as percentages or as follows:

- **Birth rate (BR)** = (number of births / total population) × 100
- **Death rate (DR)** = (number of deaths / total population) × 100
- **Population growth rate** = BR – DR

Population growth mainly results from the balance between two opposing processes: **natality** and **mortality**, to which **immigration** and **emigration** may be added.

In the presence of limiting factors (such as limited resources, competition, predation, or environmental constraints), these demographic parameters regulate population size and prevent unlimited growth.

#### 2.4.2.1 Simple population growth model

Population size varies according to the balance between recruitment processes (births + immigration) and loss processes (mortality + emigration).

$$N_t = N_{t-1} + (n + i - m - e) \quad (1)$$

Where  $N_t$  and  $N_t - N_{t-1}$  represent the population sizes at the end and at the beginning of the considered time interval (for example, one year), and **n**, **i**, **m**, **a**, **e** are respectively the numbers of births, immigrants, deaths, and emigrants recorded during this interval.

To characterize population growth over successive intervals of equal duration, it is convenient to define the per capita growth rate **r**:

$$r = \frac{N_t - N_{t-1}}{N_{t-1}} \quad (2)$$

The population size at time  $t$  is given by the following relationship:

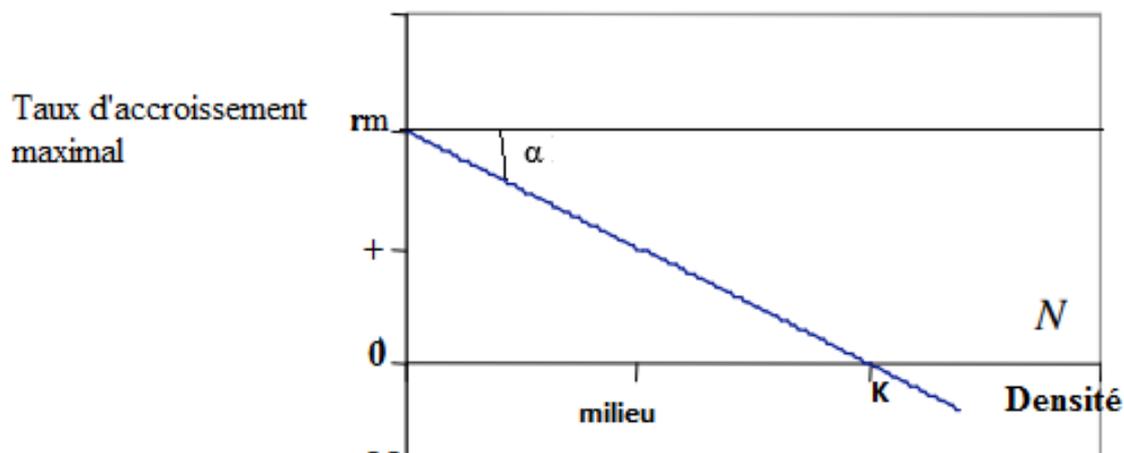
$$N_t = N_{t-1} + r N_{t-1} \quad (3)$$

The per capita rate of increase ( $r$ ) depends both on the intrinsic properties of the individuals composing the population and on the conditions provided by the environment. Under optimal conditions, in the absence of spatial and trophic limitations, this rate reaches a maximum value ( $r_m$ ), which reflects the full growth potential of individuals. This situation may occur in nature during the colonization phase of a habitat. As population density increases, resources may become insufficient for each individual, and  $r$  decreases as a function of population density. The simplest assumption is that of a linear relationship between  $r$  and  $N$ .

$$r = r_m - \alpha N \quad (4)$$

Where  $\alpha$  is the coefficient of competitive interaction.

Here,  $r_m$  is the maximum rate of increase, and  $\alpha$  represents the depressive effect exerted by each individual on the other members of the population (competitive interaction coefficient).



**Figure 2.6.** Variation of the per capita growth rate ( $r$ ) as a function of population density ( $N$ ), assuming a linear relationship (modified after Ramade, 2009).

The mean rate of increase  $r$  becomes zero when the population size reaches the equilibrium density or the carrying capacity of the environment ( $K$ ).

By definition, population growth is here regulated by its own density.

Equation (3) can therefore be written as:

$$N = N_{t-1} + (r_m - \alpha N_{t-1}) N_{t-1} \quad (5)$$

**The exponential model:** It represents the ability of a species to reproduce and increase in number in the absence of any constraints.

$$R_{max}N = \frac{dN}{dt}$$

For a very short time interval:

$$\frac{dN}{dt} = b \text{ (birth rate)} * N - m \text{ (death rate)} * N = (b-m) * N$$

Where :

- **R max : maximum rate of increase**

**R max** is also called the **intrinsic rate of increase** or **biotic potential**.

### The logistic model

The growth of a species eventually stops because of environmental resistance, due to the presence of limiting factors (e.g. space, food, competition).

$$\frac{dN}{dt} = NR_{max} \frac{K-N}{K} \quad N = R_{max} \frac{(K-N)}{N}$$

### Exponential demographic growth models

- They describe the growth of a population living in an ideal environment.
- If nothing limits population growth, the population increases faster and faster. The more individuals there are, the more offspring they produce; the more offspring are produced, the faster the population grows.
- This model produces a J-shaped curve (exponential curve): growth is initially slow because the population size is small, but it rapidly accelerates afterward.

### **2.4.2.2 Complexity and stability of communities**

Community stability involves two main components:

**A) Elasticity (resilience):** the ability of a community to return rapidly to its original state after a disturbance.

**B) Resistance:** the ability of a community to avoid displacement or change when subjected to a disturbance.

The size of a population is never truly stable; in biology, perfect equilibrium does not exist. Instead, populations exhibit fluctuating equilibria, in which two processes play a determining role:

**A) Recruitment processes** birth and immigration, which increase population size.

**B) Disappearance (limiting) processes:** death and emigration, which decrease population size.

All these processes are ultimately controlled by the biological potential of the environment.

### **2.4.2.3 Regulatory factors**

**Natural selection and polymorphism:** Individuals with high fitness are characterized by a large number of successful offspring and a longer life expectancy. Natural selection is based on the fact that natural populations exhibit **genetic polymorphism**, meaning a high level of genetic diversity. As a result, some genes are expressed more frequently or more effectively than others, leading to the establishment of natural selection.

**Example:** In nature, stronger and healthier animals tend to produce more offspring than weak or diseased individuals do.

When environmental factors change-such as during climatic or geological disturbances-genetic adaptations to new conditions may occur. There are three main selective responses of a population to environmental variation:

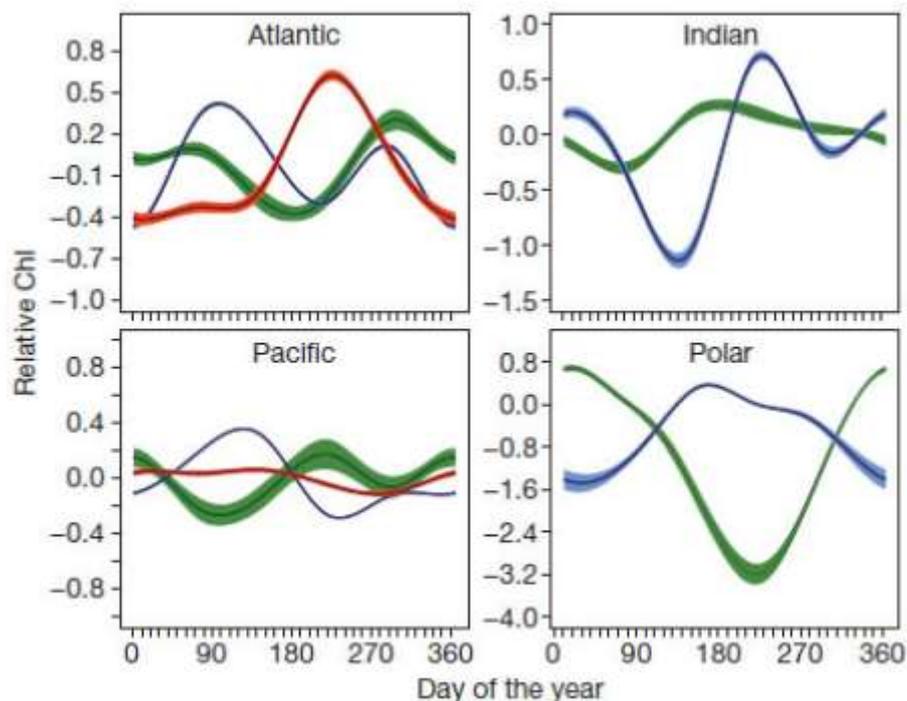
- **Stabilizing selection:** the environment does not favor the expression of new genotypes; intermediate phenotypes are selected, and variability is reduced.
- **Directional selection:** the environment favors a shift in a trait in one direction or the other, leading to a change in the population mean.
- **Disruptive (diversifying) selection:** the environment allows the coexistence of several distinct phenotypes; extreme phenotypes are favored over intermediate ones.

## 2.5 Temporal fluctuations of natural populations

Population dynamics aims primarily to describe and explain variations in species abundance over time and across space. It therefore seeks, on the one hand, to identify the factors responsible for changes in population size and, on the other hand, to determine the mechanisms that regulate populations.

As early as 1756, the naturalist Buffon emphasized that all plant and animal populations, including the human species, are subject to natural fluctuations. These variations are linked to the action of environmental factors that exert a negative influence on population size, such as diseases, overcrowding, food limitation, and predation.

Buffon concluded that populations fluctuate between a lower and an upper limit as a consequence of variations in birth and death rates. Thus, the population growth rate is positive when natality ( $N$ ) exceeds mortality ( $M$ ), negative when mortality is higher than natality, and zero when both rates are equal ( $N = M$ ), indicating a state of demographic equilibrium.



**Figure 2.7.** Relative variation of chlorophyll concentration over the course of the year. The blue curves represent measurements taken in the Northern regions, the green curves indicate equatorial variations, and the red curves correspond to those in the Southern regions (Source: Boyce et al., 2010).

### **2.5.1 Stable population**

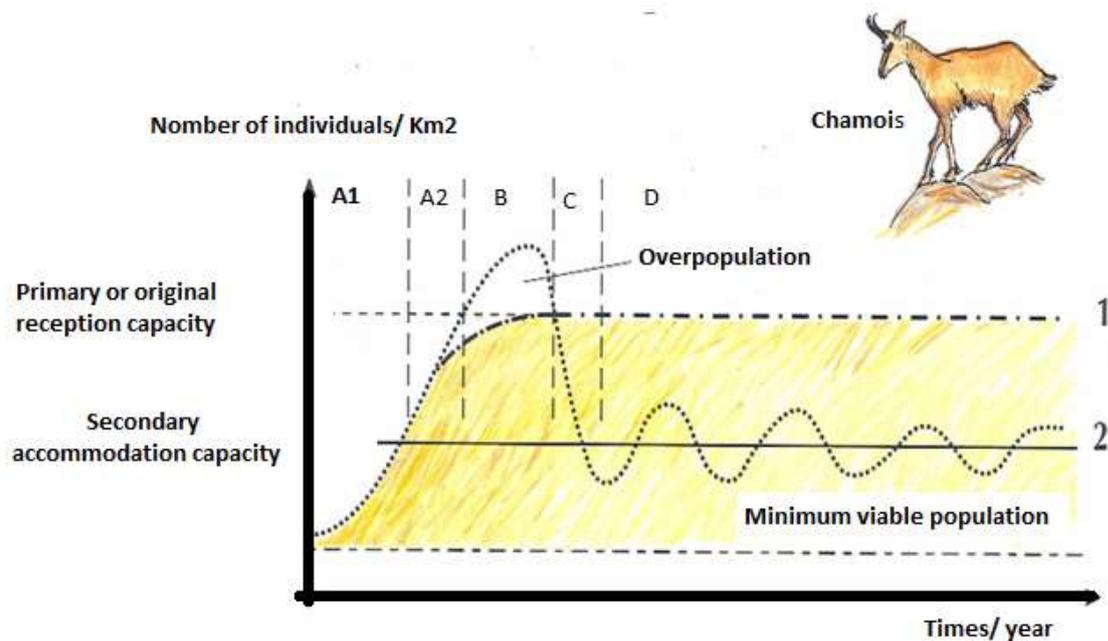
A stable population refers to a natural population that exhibits low-amplitude fluctuations around a mean population size. Such populations are generally characteristic of large-sized species living in environments where biotic factors, such as intense competition, play a dominant regulatory role. These biotic constraints exert a strong controlling influence on population dynamics.

A typical example is that of dominant tree populations in primary forests, where population density per hectare shows only slight variation, even over periods exceeding several decades.

### **2.5.2 Cyclic population**

Most animal species, as well as many herbaceous plant species (particularly annual plants), or species growing in environmentally constrained habitats (such as Sahelian ecosystems), exhibit cyclic fluctuations in population size. These fluctuations may be of large, and sometimes very pronounced, amplitude.

Depending on their temporal scale, population fluctuations can be classified as daily, seasonal, annual, or multi-annual. Such cyclic dynamics are often driven by environmental variability, resource availability, climatic factors, and interactions with predators, competitors, or pathogens.



**Figure 2.8.** Cyclic growth curve of a wild ungulate population under natural conditions and in the absence of predators (after Riney, 1957). *Population dynamics in relation to carrying capacity.* Variation in population density (number of individuals per km<sup>2</sup>) over time, illustrating successive phases of population growth and regulation. Following an initial phase of slow growth (A1) and rapid growth (A2), the population exceeds the primary (original) carrying capacity of the environment (phase B), leading to environmental degradation and overpopulation. This is followed by a sharp increase in mortality that restores ecological balance (phase C). Subsequently, the population persists with oscillations around a reduced, secondary carrying capacity, while remaining above the minimum viable population threshold (phase D). The example illustrated corresponds to a chamois population.

### A) Daily fluctuations

Characterizes living organisms with a short lifespan and a life cycle that does not exceed one day. Examples include unicellular algae, bacteria, protozoa, etc.

### B) Seasonal fluctuations

These can result from the existence of several generations per year in the species in question (at least two), migratory movements, or significant mortality at the end of the breeding season. In migratory bird populations, two annual peaks are observed-spring and autumn-linked to the outward and return migrations.

**C) Annual fluctuations**

Also linked to the cycle of seasons, these fluctuations are observed in the majority of animal populations and in annual plants. Here again, migrations can play an important role in species with a lifespan exceeding one year. In birds and sedentary mammals, the maximum population size is reached at the end of the warmer months and the minimum at the end of winter.

**D) Multi-year fluctuations**

Some species of forest insects, such as defoliating caterpillars, leaf miners, or leaf rollers, also exhibit such multi-year fluctuations. Certain species, like the larch leaf roller, can show a high degree of regularity in their population cycles. In Switzerland, this species has a 10-year lag period between successive population explosions.

**E) Aperiodic but cyclical fluctuations**

These are characterized by exceptional increases or decreases in population size, such as the case of desert locusts and the sudden decline of South African rhinoceroses, which are economically sought after for their horns. The emergence of an epidemic disease can also cause significant fluctuations.

**2.6 Spatial distribution of populations**

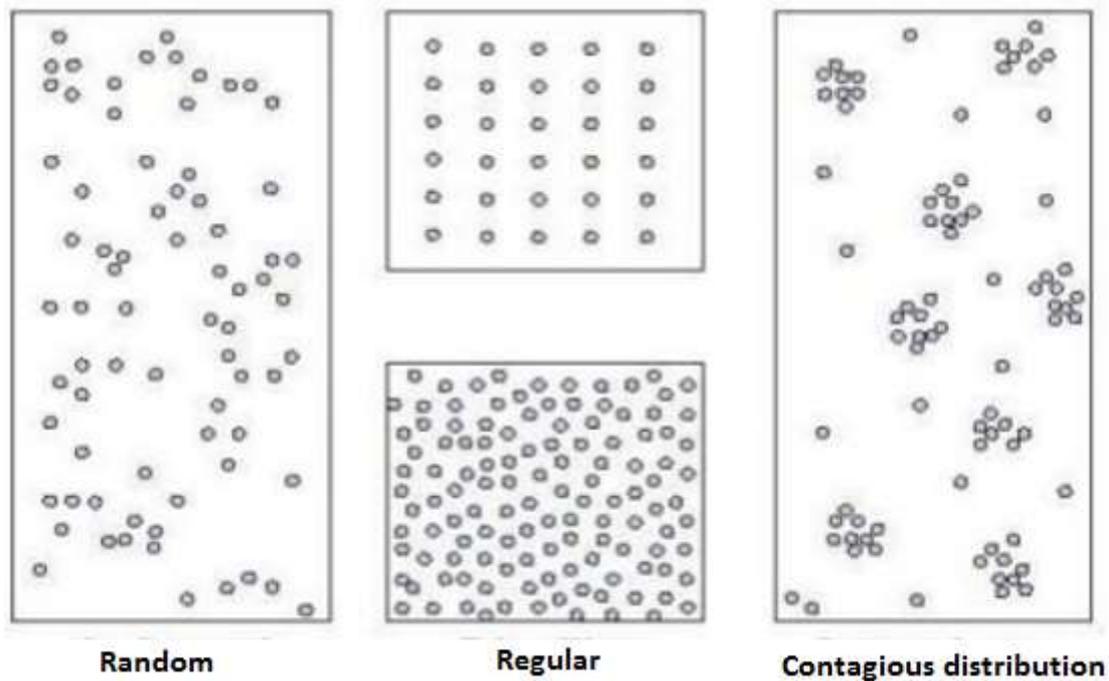
The term "distribution" commonly refers to how individuals are physically spread across the landscape. This is a shorthand term because different types of distribution can be modeled using statistical laws whose distributions can be calculated.

However, the word "distribution" obviously has a very different meaning depending on whether we are talking about concrete individuals or an abstract law. Generally, plant species consist of randomly distributed individuals, while animal populations very often exhibit a clustered distribution.

However, this latter type of distribution is also quite common among large, tree-like plants, as the distribution of plants and middle-aged individuals is determined by that of older, seed-bearing trees. Individuals descended from the same seed-bearing tree tend to cluster together in its vicinity.

In higher animals, this aggregation of individuals can result from social attraction (gregarious behavior), the outcome of reproductive processes, the daily or seasonal influence of climatic fluctuations, or the population's response to local differences in the nature of the biotope.

In plants and primitive aquatic invertebrates, the degree of aggregation is inversely proportional to the mobility of reproductive forms (spores, seeds, propagules, statoblasts, etc.).



**Figure 2.9.** The different modes of spatial distribution of individuals (Fellah, 2019).

## 2.7 Population regulation: The role of ecological factors

### 2.7.1 The concept of density dependence

It is therefore necessary to explain how the mechanisms come into play that slow the decline in population size when environmental conditions become unfavorable, or their increase when the environment is favorable. Population density depends on intrinsic and extrinsic factors. Intrinsic factors, on which the biological potential (and therefore fecundity, fertility, and longevity) of the species in question primarily depends, generally tend to favor population growth. Conversely, extrinsic factors specific to each species' environment exert negative or positive effects on the populations concerned, depending on their intensity.

Ultimately, the densities reached and the stability of population sizes depend on the interaction between these intrinsic and extrinsic influences; populations are by no means inert entities passively undergoing the influence of extrinsic factors.

In highly differentiated and diverse ecosystems, where fluctuations in physicochemical factors are small, population control is ensured by biotic factors. Through the action of selection, this results in a self-regulating system, as overpopulation is not in the interest of any species.

### **2.7.2 Density-independent and density-dependent factors**

In population ecology, it is particularly interesting to analyze the action of ecological factors through the concept of density dependence. Ecological factors are divided into two categories: density-independent factors and density-dependent factors.

- Density-independent factors are those whose action on living organisms is completely independent of the population density of any species for which they constitute limiting factors (almost all abiotic factors);
- Density-dependent factors are biotic factors whose action is directly linked to the population densities of the affected populations. The amount of food available to each individual, and the risks of an epidemic spreading, obviously depend on the population densities of the populations concerned.

#### **2.7.2.1 Influence of density-independent factors**

Climatic factors are the best studied among density-independent factors. The effect of low temperatures on animal populations is often catastrophic. The cold wave of February 1956, which reached Western Europe and the western Mediterranean basin, affected most olive trees, and Aleppo pines located in exposed habitats were destroyed by the cold.

Edaphic factors can also play a role in adjusting the population sizes of not only plants but also animals. For example, it has been shown that soil sodium content influences the population densities of voles and other ground-dwelling rodents.

The acidification of water by acid rain can have negative effects on aquatic populations, even leading to their disappearance, etc.

### **2.7.2.2 Influence of density-dependent factors**

Density-dependent factors play a fundamental role in determining population fluctuations. These are primarily biotic factors, whose influence is decisive on population dynamics; they include competition, predation, parasitism, and disease.

#### **A) Competition**

In nature, competition plays an important role in the evolution and organization of populations, regulating the distribution and abundance of species. There can be variation in ecological niches and niche overlaps.

Competition also has other consequences:

- It can modify the phenotypic characteristics of the individual (morphological, physiological, and ethological traits): reduction in size, seed size, or weight.
- It can exert a selective effect that transforms the ecological performance of one or both of the populations present, and consequently, changes in their genetic structure.

Competition can also be a factor in the evolution of vegetation or animal diversity. Furthermore, the outcome of interspecific competition can be modified by an external organism such as a predator (Dajoz, R. 2006).

- **Influence of competition on geographic distribution:**

When a new, more robust, and more prolific species is introduced into the same environment, it tends to eliminate native species. Example: In Australia: Kangaroos have declined or disappeared due to competition from rabbits and sheep.

- **Influence of competition on food resources:**

Different species exploiting the same food resource compete until one species is eliminated. Example: Domestic poultry.

○ **Influence of competition on the morphology and productivity of animals or plants:**

A dominant species gradually eliminates a subordinate species. Example: A plant species spreads its leaves more widely to gain more light; the other species remains shaded to carry out photosynthesis.

**A) Predation**

Predation is a relationship in which one species (the predator) consumes another (the prey). It becomes energetically advantageous for predators to attack dense prey. This type of relationship includes carnivores (predation on other animals) and herbivores (predation on plants).

The predator is a free-living organism that seeks live food, animal or plant; the predator hunts and kills its prey to eat it.

**Example:** A snake is a predator of a frog. The predator species attacks the prey species to feed on it.

**B) Parasitism (Diseases)**

Proximity facilitates the transmission of diseases and parasites. Unlike the predator, the parasite does not kill its host, as its survival depends on it. However, it can weaken the host or cause diseases that could be fatal. A parasitic species is generally smaller, inhibits the growth or reproduction of its host species, and depends directly on it for nutrition. The parasite may or may not cause the death of its host. The parasite does not lead a free life; it is attached to its host, either:

- outside or on the surface of the body: Ectoparasite
- inside a living organism: Endoparasite

The parasite has a specificity to its host.

**Ex1:** Lice are parasites of humans and monkeys.

**Ex2:** Parasitic plants: Mistletoe burrows its haustoria into the vascular system of the host plant.

**Ex3:** The human species harbors several types of endoparasitic worms: roundworms, pinworms, whipworms, etc.

## **2.8. Role of biotic factors**

Compared to abiotic factors, biotic factors exhibit interactive characteristics. Predation or parasitism pressure, the importance of mutualistic relationships between communities of species or individuals, and the level of competition within populations or communities are factors likely to shape biocenoses and influence their equilibrium or evolution.

For example, competition between species with similar needs is a major determinant of community structure. It limits the size of interacting populations and leads to a diversification of niches and phenotypes. In doing so, it prevents the competitive exclusion of weaker competitors.