الجمهورية الجزائرية الديمقراطية الشعبية
République Algérienne Démocratique et Populaire
وزارة التعليم العالي والبحث العلمي
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Ecological Parameters and Indices

Ecological indices or main ecological parameters specific to populations

In order to study populations, it is first necessary to know their numbers within ecosystems.

1. Method for Studying Population Numbers

The assessment differs completely depending on the type of population: populations composed of **sessile organisms** (plants or sessile invertebrates) versus populations composed of **mobile organisms**. In the first case, the main concern is sampling. In the second case, true difficulties arise in counting individuals, especially since animals are mobile and often small.

1.1. Absolute Counting of Individuals

This method involves directly counting individuals at a given time (t). It is feasible for plants when dealing with small areas. Additionally, technological tools allow its application to certain animal populations: radars for birds, mammals, and even amphibians, or infrared photography for homeotherms. Intellectually, this technique is the most satisfactory, but in practice, it can only be applied to a limited number of populations.

1.2. Estimation of Population Numbers

Several methods adapted to the studied populations can be considered. These initially involve a **sampling strategy**, such as the **transect method** for visual counts. Sampling is widely used for small individuals (generally invertebrates): soil fauna, aquatic plankton, river benthos, etc. It consists of taking identical samples according to an appropriate sampling plan. The challenge is then to define the most effective sample volume, which depends closely on the population and its environment. In this case, all individuals in the sample are counted in the laboratory, and results are extrapolated to the total population.

For larger individuals, which are more difficult to capture, this method is not feasible because sampling becomes too random.

Descriptive Parameters of a Population

- **Population Density**
  Knowing the density of a population is a fundamental demoecological parameter. Density is expressed as the number of individuals per unit area. The area is chosen according to the species' abundance.

For example, the density of litter arthropods can be expressed as the number of individuals per m^2. Biomass per unit area can also be calculated. It is important to distinguish **gross density** from **ecological density**:

- **Gross density:** total population / total area of the studied biotope.
- **Ecological density:** total population / area of habitat actually available to the studied population.

Every species has a **maximum and minimum population density** that allows it to sustain itself continuously. The upper limit is linked to the environment's carrying capacity (available energy), while the lower limit is related to the probability of successful reproduction.

For **animal populations**, the observed density depends primarily on their **feeding habits**. The higher a species is on the food chain, the less abundant it tends to be.

Note: Other methods exist to calculate density using **GIS** to compute and illustrate density according to specific objectives.

- **Relative Abundance**
  This is the density of a population relative to the density of a group of species. It allows us to understand the **composition of a community**.

The density of a population, its growth, or decline depends on the number of individuals **added** (births and immigration) and those **removed** (deaths and emigration). The population size of each species primarily depends on the difference between **birth rates** and **death rates**.

Birth rate is the main factor driving population increase. It is important to distinguish between **maximum (physiological) birth rate** and **actual birth rate**. The former reflects the species' **biotic potential**. The **crude birth rate** is expressed as a proportion of the total population, e.g., 50 births per 1,000 individuals per year.

The **net reproduction rate** refers to the total number of females produced by each fertile female; it represents the **multiplication rate per generation**.

Mortality is the second fundamentally important parameter. The **mortality rate** characterizes the number of deaths occurring in a given time interval, divided by the total population at the beginning of that interval.

Ecological (or actual) mortality describes the disappearance of individuals under given environmental conditions. It varies depending on the population and environmental factors. There is also a **theoretical minimum mortality**, representing the disappearance rate of individuals in the absence of limiting factors; this corresponds to **maximum longevity**. Both birth and death rates vary according to the age group considered.

- **Sex Ratio**
  The sex ratio is the proportion of **males to females** in a population.

Population sex ratios are generally balanced, whether the species are **gonochoric** (separate sexes) or **hermaphroditic**. The only natural populations with strongly imbalanced sex ratios are those of **parthenogenetic species**.

In vertebrates, there is a slight excess of males at birth. In adults, the sex ratio changes depending on climate and the **survival of each sex**. Only rodents have populations that are slightly imbalanced in one direction or the other, depending on the species.

Ecological Indices

Ecology uses various **statistical descriptors** to characterize the diversity of communities. Some might refer to this as **biodiversity**, but this term is not entirely appropriate here. When an ecologist studies the communities of an ecosystem, they rather refer to more **specific indices**.

The first of these concern **species richness (S)**, **biomass (B)**, or the **abundance (A)** of a species. The second set relates to the **species diversity** of a habitat or even a particular ecosystem. Species diversity thus considers both the **number of species** and the **distribution of individuals** among these species. Ecologists therefore have access to several **diversity indices**.

These indices are often accompanied by **evenness indices**, which reflect the distribution of species abundances within a community. Thanks to these indices, it becomes possible to **monitor changes in communities over time** and also to **compare different study sites**.

Sampling Quality (Q)

- **a**: represents the number of species with frequency 1, i.e., observed only once in all surveys during the considered period.
- **N**: is the total number of surveys.

The closer the ratio

$$Q=a/N$$

is to zero, the better the quality of the sampling and the more accurately it has been performed.

Ecological Indices of Composition

- **Total and Mean Species Richness**
  - **Total richness (S)** is the total number of species in the community. It is considered a **fundamental parameter** of a species community.
  - **Mean richness (s)** corresponds to the average number of species present in a sample of the biotope.
- **Centile Frequencies (Relative Abundance)**
  This is the percentage of individuals of a species (**ni**) relative to the total number of individuals (Dajoz, 1970).

The **relative abundance** of species in a community or in a sample characterizes the **faunistic diversity** of a given environment (Frontier, 1983). The **centile frequency** is calculated using the formula:

$$F\% = ni \times 100/N$$

Where:

- **ni**: number of individuals of the species considered
- **N**: total number of individuals of all species combined
- **Occurrence Frequency and Constancy**
  The **occurrence frequency** is the percentage of surveys containing the species considered relative to the total number of surveys (Dajoz, 1971).

$$\mathbf{C = P \times 100 / P'}$$

Where:

- **P**: number of surveys containing the studied species
- **P'**: total number of surveys conducted

According to the same source, based on the value of **C**, the following categories are distinguished:

- A species is **ubiquitous** if **C =** 100%
- A species is **constant** if $75\% \leq C \leq 100\%$
- A species is **regular** if $50\% \leq C \leq 74\%$
- A species is **accessory** if $25\% \leq C \leq 50\%$
- A species is **accidental** if $5\% \leq C \leq 25\%$
- A species is **rare** if $C \leq 5\%$

Ecological Structure Indices

Shannon-Weaver Diversity
The most commonly used diversity index is the **Shannon index**, also called the **Shannon-Wiener index**, although these two mathematicians did not work together on it.

Historically, Claude Shannon was a cryptographer who sought to describe the **entropy of characters** in a text (Shannon entropy). His formula accounts for the probability of encountering a specific character among a set of characters. In ecology, the "character" is replaced by a **species**, and the "text" is replaced by the **community studied**.

Blondel et al. (1973) define diversity as the **degree of heterogeneity of a community**. This index is considered the best way to express diversity and is calculated as follows:

$$\mathbf{H' = -\sum qi \log_2 qi}$$

Where:

- H' : diversity index expressed in **bits**
- qi : relative frequency of the category of individuals for species iii
- $\log_2$: logarithm base 2

This index provides insight into the diversity of different environments; specifically, it indicates the diversity of a given species within a community. If H' is high, the community is diverse, and the environment is favorable. Conversely, if H′ is low, the environment is poor in species or unfavorable.

Formulation:

H’ corresponds to the Shannon index, according to the following formulation:

$$H' = -\sum_{i=1}^{S} pi.log_2(pi)$$

pi=proportional abundance or percentage abundance of a species present
(pi=ni/N)

Where:

- ni = number of individuals counted for a given species
- N = total number of individuals counted across all species
- S = total number of species present (species richness)

Maximum Diversity
Blondel (1979) expresses the maximum diversity as:

$$H' \max = \log 2\ S$$

H’max: maximum diversity
S: total species richness

Evenness or Piélou’s Evenness Index
To better interpret the Shannon index, it is often accompanied by **Piélou’s evenness index (J)**, or **equitability index (E)**. Its formula is the ratio between H′ and Hmax. The index corresponds to the ratio of the observed diversity H′ to the maximum diversity H′max (Barbault, 1981).

Blondel (1979) considers equitability as the ratio of observed diversity to maximum diversity. It is calculated as follows:

$$E = H' / H' \max$$

The value of **E** ranges from 0 to 1.

- When **E** approaches 0, this indicates that the abundances of species collected are **not balanced**.
- When **E** approaches 1, this indicates that the abundances of captured species are **well balanced**.

Ecological indices allow the study of community structure, either with reference to a specific **spatio-temporal context** or independently. They provide a quick, single-number evaluation of the biodiversity of communities. However, their **synthetic nature** can also be a limitation, as it conceals a large portion of detailed information.

In other words, these two indices are particularly useful for **monitoring temporal changes in a community** (i.e., the set of species in a given area sharing a similar ecology). The appearance of an invasive species or peaks of opportunistic species typically lead to a **significant simultaneous decline in H' and E**. Conversely, an **ecotone** (ecological transition zone between two ecosystems) or a **stable community** shows high index values. This is why both indices should be considered together to assess the state of an ecosystem.

Finally, the index is not **insensitive to species richness** (the measure of biodiversity in all or part of an ecosystem). Indeed, species richness is reflected by the value of **S**, and the Shannon index tends to increase when **rare species** are present. For example, calculating the Shannon index in a **migratory bird hotspot** known for unusual sightings in autumn may artificially inflate the index due to the presence of rare species. Similarly, the Shannon index is **strongly habitat-dependent**.

Thus, values obtained using the Shannon index are **relative** and are only comparable between stations with similar communities or over a temporal scale. Using this index as an **absolute comparative measure** to assess ecosystem quality across different sites carries a risk of misinterpretation.

Simpson Index

This index, proposed by the statistician **Edward H. Simpson**, measures the probability that **two randomly chosen individuals belong to the same group**. This brilliant mathematician is also famous for **Simpson's paradox**, a well-known statistical example illustrating situations where students can appear more skilled in sports while performing poorly academically.

Formulation

Applied to ecology, the **Simpson index** represents the probability that **two individuals randomly selected from a community belong to the same species**. Several forms of the index exist in the scientific literature, which can complicate the interpretation of values.

In this article, we rely on the probability that two individuals belong to the same species according to Simpson's original formula (1949):

$$\mathbf{P(\omega)=\sum(pi)^2}$$

From this formula, two versions arise depending on whether the sample is **infinite** (sampling with replacement, index λ\lambdaλ) or **finite** (sampling without replacement, index L). For example, for a **phytoplankton community per m³ of seawater**, the λ index is preferred. To monitor a **forest bird population per hectare**, the L index is used.

Where:

$$\lambda = \sum_{i=1}^{S} (p_i)^2$$

$$L = \frac{\sum_{i=1}^{S} n_i.(n_i - 1)}{N.(N - 1)}$$

- pi = proportion of individuals of species iii (pi=ni/N)
- ni = number of individuals of species i
- N = total number of individuals
- S = total number (cardinality) of species present

The closer this index is to 1, the **more homogeneous** the community. Therefore, a **second index**, called the **diversity index**, is often used, calculated as **Simpson's index subtracted from 1**.

This diversity index is generally more **intuitive to interpret** than the original Simpson index. Its formula is:

$$D=1-\lambda \text{ or } D = 1 - L$$

(depending on the sample size).

- If D=0, only **one species** is present in the community.
- If all species have the same probability (pi=1/S), then D=1−(1/S).
- The value D=1 would theoretically occur if an **infinite number of species** were present, each with a probability approaching zero.

Evenness Index

It is accompanied by an **evenness index**:

ED=D/Dmax According to Hurlbert, the case where all species are present with **equal probability** corresponds to the maximum of the diversity index: Dmax=1−(1/S). Another formulation of Simpson's index defines D=1/λ (statistical diversity index).It is thus possible to consider that if ED=D/Dmax, then Dmax=S, giving the equation: ED=D/S.

The choice of formula is therefore **crucial for comparing results**. Simpson's evenness index reflects **species dominance** (ED→0) or **codominance of several species** (ED→1). As previously, it is advisable to examine **multiple indices**.

Simpson's diversity index **gives more weight to abundant species than to rare species**. The presence of rare species in a community **has little impact** on the index value.

Unlike the Shannon index, which is much more sensitive to **rare species**, Simpson's index is less affected by them. This makes it **better suited for comparisons between habitats or specific ecosystems**.

Hill Index
This index provides a measure of **proportional abundance** by comparing the **Shannon and Simpson indices**. The resulting Hill diversity index aims to evaluate the balance between **the influence of abundant species (Simpson)** and **the impact of rare species (Shannon)**. Therefore, the Hill index can be considered a **synthetic diversity index**.

$$Hill = \frac{\lambda^{-1}}{e^{H'}}$$

When the **Hill index** approaches 0, biodiversity is considered **higher**. It is also possible to convert this value to **(1 – Hill)** so that the index **increases with biodiversity**. This index may seem more relevant for **summarizing field results**, but it can also be useful to **compare all three indices simultaneously** to better assess **community structure**.

Exercises:

Exercise 1: Population Density
If 200 bears are counted in a forest of 170 km², what is the **density of this population**?

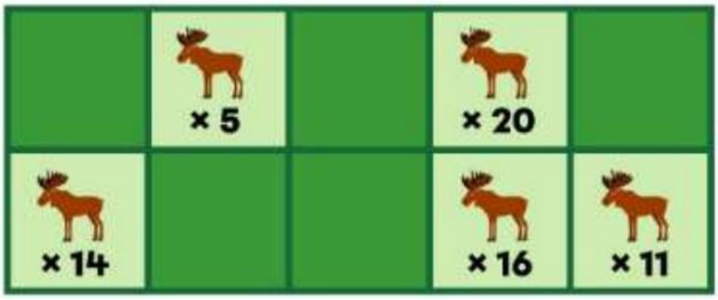
Solution:

$$D = \frac{n}{A} \Rightarrow D = \frac{200 \text{ ours}}{170 \text{ km}^2}$$
$$D = 1{,}18 \text{ ours/km}^2$$

Important!
Population density is often expressed as a **decimal number**, because it represents an average.

For example, even if the density of a hare population is **0.5 hare/km²**, this does **not mean there is literally half a hare in one square kilometer**; it is a **unit rate**. This value can be interpreted as **an average of 1 hare per 2 km²**.

In population density calculation problems, the **number of individuals** is not always given. In such cases, it is necessary to **count the individuals first**.



Sampling by Plot

In this 100 km² area, one can choose to sample only **50 km²**, divided into **five samples** (also called "plots" or "quadrats") of **10 km² each**.

To determine the **population density of moose** in this area, one must count the number of individuals observed in each of the five plots and calculate the **area occupied** by these individuals. The following **three steps** should be followed:

1 – Count the number of moose
To find the number of moose in the area, simply count the individuals observed in each of the five plots. In the image, the numbers of moose are:

14, 5, 20, 16, 11

N=14+5+20+16+11 N = 66 moose

There are **66 moose**.

2 – Find the area occupied
To find the area occupied, multiply the number of plots by the area of each plot. In the example above, there are **5 plots of 10 km² each**:

A=5×10 km²=50 km²

3 – Calculate the population density

$$D = \frac{n}{A} \Rightarrow D = \frac{66 \text{ orignaux}}{50 \text{ km}^2}$$

$$D = 1{,}32 \text{ orignal/km}^2$$

Thus, there are **1.32 moose per km²** (or **132 individuals per 100 km²**).

Exercise Series

Exercise N 1: Population Density

1- What is a population, and what is population size?
2- Provide definitions for the following terms: **Gross density** – **Ecological density**

3- Scientists want to study the number of birds inhabiting **Timerganine (Oum El Bouaghi)**. The area of the studied region is **90 km²**.

Knowing that **600 birds were marked** during the first capture (2014), and the following year (2015), **900 birds were captured**, among which **200 birds had already been marked** the previous year, what is the **population size** of the birds?

4- Name the **sampling methods** used to calculate population size.
5- Using the result from Q.3, calculate the **population density**.

Answers – Exercise 1

1- **Population:** The set of individuals of the same species occupying a given territory.
Population size: The total number of individuals that make up the population.

2- **Gross density:** Total population / total area of the studied biotope.
Ecological density: Total population / area of habitat actually available to the population.

3- The **Capture-Recapture method** is used.

Population size=(Number of marked individuals×Total number of individuals captured [2nd time])/Number of marked individuals recaptured

=600x900/200

=2700 birds

4- **Methods:**

- **Method 1:** Capture-recapture
- **Method 2:** Divide the area into plots / quadrat method

4. Population density:

Population density=Number of individuals/Area or volume occupied

=2700/90=30 birds/km²

Exercise N2: Population Density

In a study on **phytoplankton** in the **Foum el Khengua dam**, a count was conducted for the number of individuals of each inventoried species. The results are shown in the following table:

- **Estimated volume of the Foum el Khengua dam:** approximately **3000 liters**
- **Volume of each sampling station: 2 mL**

espèces/Station	S1	S2	S3	S4	S5
Surirella elegans	20	0	1	15	2
Synedra sp	1	1	0	3	10
synedra ulna	10	11	5	2	8
cocconeis placentula	3	9	4	0	6
navicula directa	8	2	7	6	0
ceratium furca	7	4	0	1	0

1- Give a **title to the table**
2- Calculate the **density for each species** (per mL, per liter, and per m³)
3- Calculate the **overall phytoplankton density** in the dam
4- Please **illustrate the density using graphs**

Answer – Exercise N2

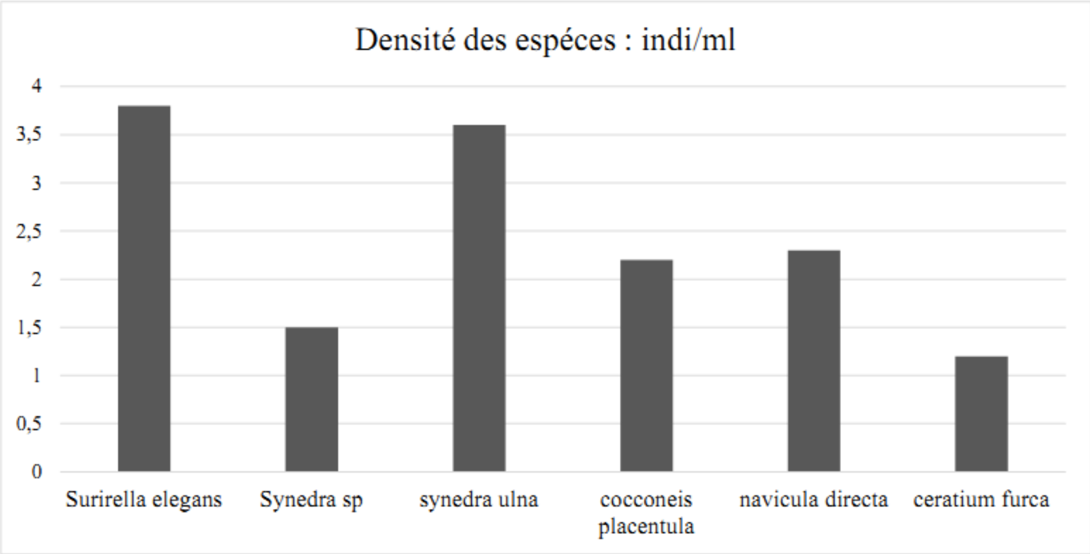
1- The table represents a **matrix of raw results**.
2- **Density of each species**

Station	Densité indi/ml	Densité indi/l	Densité ind/m3
Surirella elegans	3,8	3800	3,8
Synedra sp	1,5	1500	1,5
synedra ulna	3,6	3600	3,6
cocconeis placentula	2,2	2200	2,2
navicula directa	2,3	2300	2,3
ceratium furca	1,2	1200	1,2

3- Calculate the **overall phytoplankton density** in the dam.

nbr totale d'idividus	14,6	14600	14,6
Densité	43800	43800000	43800
unité	Ind/ml	Ind/litre	Ind/ m3

4- **Histograms of species density:**



Exercise No. 03: Relative Abundance
(Demography: describing populations and how they change)

In many cases, ecologists do not study people in cities, but rather study **various species of plants, animals, fungi, and even bacterial populations**.

The **statistical study of any population**, human or otherwise, is called **demography**.

The following table shows **raw results of birth rates and death rates** between **2006 and 2021** for a population of **Barbary deer** in a forest in **eastern Algeria**. The area of the forest is approximately **680 hectares**, and in 2005 the population was about **20 individuals**.

*Photo: Barbary deer (**Cervus elaphus barbarus**)*

Année	Natalité	Mortalité	immigrations	émigrations
2006	12	8	2	0
2007	11	9	5	1
2008	14	5	4	1
2009	13	2	2	1
2010	10	1	3	1
2011	9	5	2	1
2012	8	6	2	1
2013	10	7	3	2
2014	12	8	2	1
2015	14	10	5	1
2016	15	10	4	4
2017	16	11	5	2
2018	17	12	3	1
2019	18	13	8	5
2020	20	14	4	1
2021	22	15	5	1

1- Please calculate the **natural balance** and indicate its evolution

$$\text{Natural balance} = \text{births} - \text{deaths}$$

2- Please calculate the **migration balance** and indicate its evolution

$$\text{Migration balance} = \text{immigrations} - \text{emigrations}$$

3- Please calculate: the **natural growth rate**, the **migration growth rate**, and the **average annual growth rate**

- **Natural growth rate:**

$$TNn = \text{Natural balance}/(Pm \times n)$$

- **Migration growth rate:**

$$TMn = \text{Migration balance}/\ (Pm \times n)$$

- **Average annual growth rate:**

$$TAn = (Pn - P0)/\ (Pm \times n)$$

Where:

- P0 = population at the **start of the period**
- Pn = population at the **end of the period**
- n = number of years in the period
- $Pm = (P0 + Pn)/2$ **average population**
- Population change $= Pn - P0$

4- Please calculate the **density of deer in the forest for each year**

5- In your opinion, **why is demography important**?

Answers – Exercise No. 03

1- **Natural balance and its evolution**

Table: Results of the natural balances of the **Barbary deer population** (2006–2021)

Année	Solde naturel
2006	4
2007	2
2008	9
2009	11
2010	9
2011	4
2012	2
2013	3
2014	4
2015	4
2016	5
2017	5
2018	5
2019	5
2020	6
2021	7

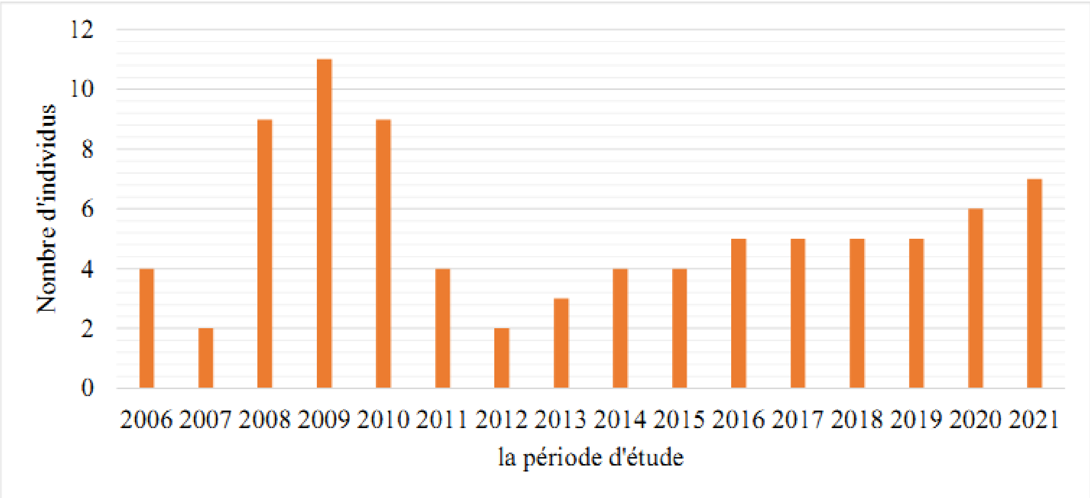


Figure: Evolution of the **natural balances** of Barbary deer in the forest (2006–2021)

2- **Migration balance and its evolution**

Table: Results of the **migration balances** of the Barbary deer population (2006–2021)

Année	Solde migratoire
2006	2
2007	4
2008	3
2009	1
2010	2
2011	1
2012	1
2013	1
2014	1
2015	4
2016	0
2017	3
2018	2
2019	3
2020	3
2021	4

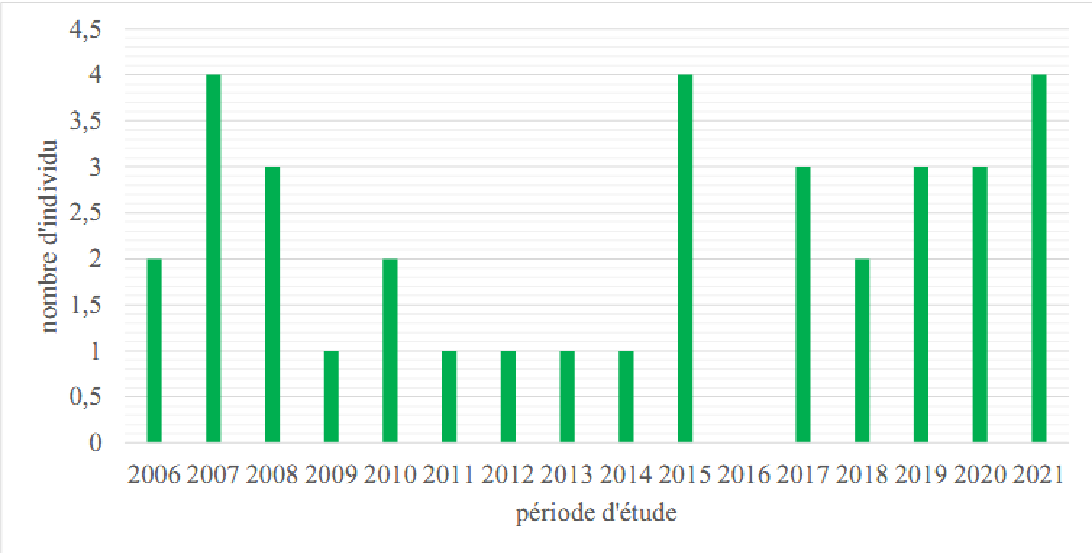


Figure: Evolution of the **migration balances** of Barbary deer in the forest (2006–2021)

3- **Calculation of:** natural growth rate, migration growth rate, and average annual growth rate

To calculate the **natural growth rate**, **migration growth rate**, and **average annual growth rate**, it is first necessary to calculate the **actual number of individuals (population size)** of deer for each year, as well as the **average population**: (Pm = (P0+ Pn) / 2). Remember that in 2005, the population was **20 individuals**.

Table: Results of the **natural growth rates** and **migration growth rates** of Barbary deer (2006–2021)

Année	population	Pm	TAN	TAM
2006	26	29	0,068965517	0,03448276
2007	32	38	0,026315789	0,05263158
2008	44	50	0,09	0,03
2009	56	61,5	0,089430894	0,00813008
2010	67	69,5	0,064748201	0,01438849
2011	72	73,5	0,027210884	0,00680272
2012	75	77	0,012987013	0,00649351
2013	79	81,5	0,018404908	0,00613497
2014	84	88	0,022727273	0,00568182
2015	92	94,5	0,021164021	0,02116402
2016	97	101	0,024752475	0
2017	105	108,5	0,023041475	0,01382488
2018	112	116	0,021551724	0,00862069
2019	120	124,5	0,020080321	0,01204819
2020	129	134,5	0,022304833	0,01115242
2021	140	70	0,05	0,02857143

Table: Results of the **average annual growth rates** of Barbary deer (2006–2021)

Année	Taux d'accroissement annuel moyen
2006	0,103448276
2007	0,078947368
2008	0,12
2009	0,097560976
2010	0,079136691
2011	0,034013605
2012	0,019480519
2013	0,024539877
2014	0,028409091
2015	0,042328042
2016	0,024752475
2017	0,036866359
2018	0,030172414
2019	0,032128514
2020	0,033457249
2021	0,078571429

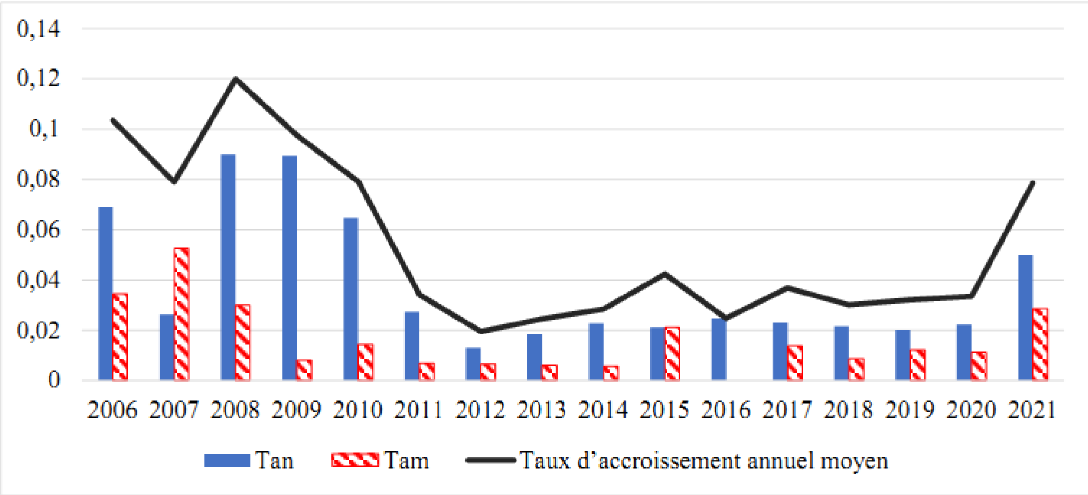


Figure: Variations of the natural growth rate, migration growth rate, and average annual growth rate of Barbary deer in the forest (2006–2021)

4- Density of deer in the forest for each year

The area of the forest is approximately **680 hectares**.

Table: Results of the **density of Barbary deer** (2006–2021)

Année	Densité (ind/hec)
2006	0,038235294
2007	0,047058824
2008	0,064705882
2009	0,082352941
2010	0,098529412
2011	0,105882353
2012	0,110294118
2013	0,116176471
2014	0,123529412
2015	0,135294118
2016	0,142647059
2017	0,154411765
2018	0,164705882
2019	0,176470588
2020	0,189705882
2021	0,205882353

5- Populations can change in **number and structure**, for example in **age and sex distribution**, for various reasons. These changes can affect how a population interacts with its **physical environment** and with **other species**.

By monitoring populations over time, ecologists can observe how these populations have changed and can **predict how they are likely to change in the future**. Monitoring **population size and structure** can also help ecologists **manage populations**, for example by showing whether conservation efforts are helping **endangered species increase in number**.

Exercise N4: Sex Ratio

The **sex ratio** indicates the **ratio of males to females** in a given population, showing the proportion of each sex.

Fish were **captured and dissected** to sample the gonads and determine their sex, allowing us to study the sex ratio. This study allows the estimation of the **proportion of individuals of each sex** in a population. The results are shown in the following table:

	mal	fem
janv-08	5	6
févr-08	2	5
mars-08	4	4
avr-08	6	5
mai-08	3	1
juin-08	2	0
juil-08	3	1
août-08	2	0
sept-08	1	4
oct-08	3	2
nov-08	5	4
déc-08	4	7
janv-09	3	9

1- Please **express the percentages of females and males** relative to the number of individuals captured in each session.

2- Please **calculate the sex ratio**

Sex ratio=M/F where F=number of females, M=number of males and express it as a percentage (%).

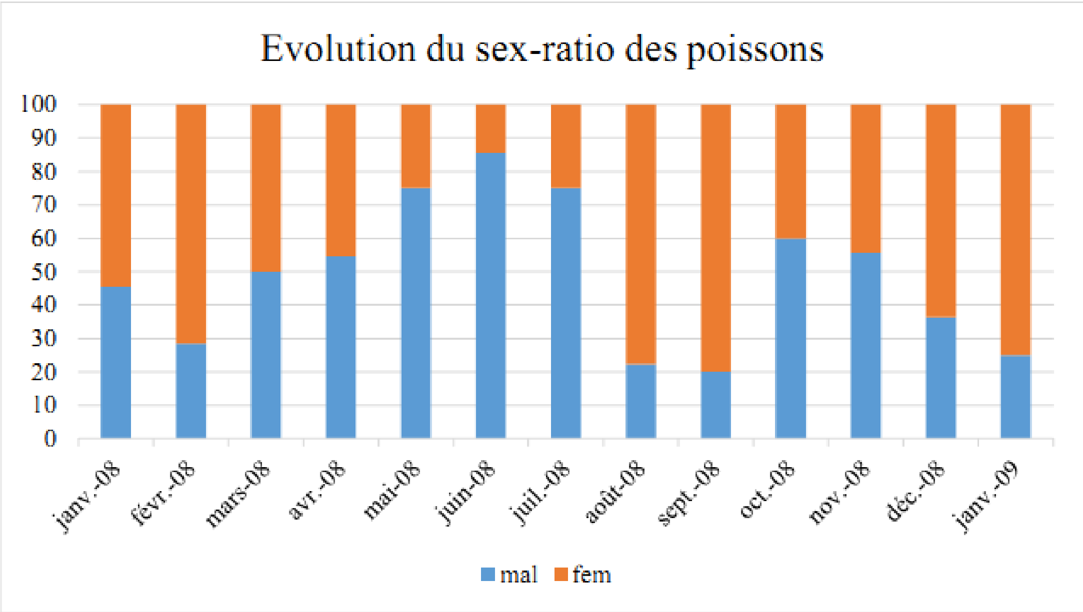
3- In the **answers section**, you will find **graphical representations** of the sex ratio (SR) results; please **interpret them**.

Answer – Exercise N4: Sex Ratio

1- **Percentages of females and males** relative to the number of individuals captured in each session.

Table: Percentages of males and females.

mois	(%) mal	(%) fem
janv-08	45,45	54,55
févr-08	28,57	71,43
mars-08	50	50
avr-08	54,55	45,45
mai-08	75	25
juin-08	85,72	14,28
juil-08	75	25
août-08	22,23	77,77
sept-08	20	80
oct-08	60	40
nov-08	55,55	44,45
déc-08	36,36	63,64
janv-09	25	75



The **sex ratio** of fish captures over the entire period 2008–2009 is slightly **imbalanced**, with **56 females and 47 males** across all captures, corresponding to **54.36% males** and **45.64% females**.

2- **Calculation of the sex ratio for each session:**

Table: Sex ratio (SR) for each session.

mois	SR	SR (%)
janv-08	0,83	7,57
févr-08	0,4	3,63
mars-08	1	9,09
avr-08	1,2	10,90
mai-08	3	27,27
juin-08	6	54,54
juil-08	3	27,27
août-08	0,28	2,59
sept-08	0,25	2,27
oct-08	1,5	13,63
nov-08	1,25	11,36
déc-08	0,57	5,19
janv-09	0,33	3,03

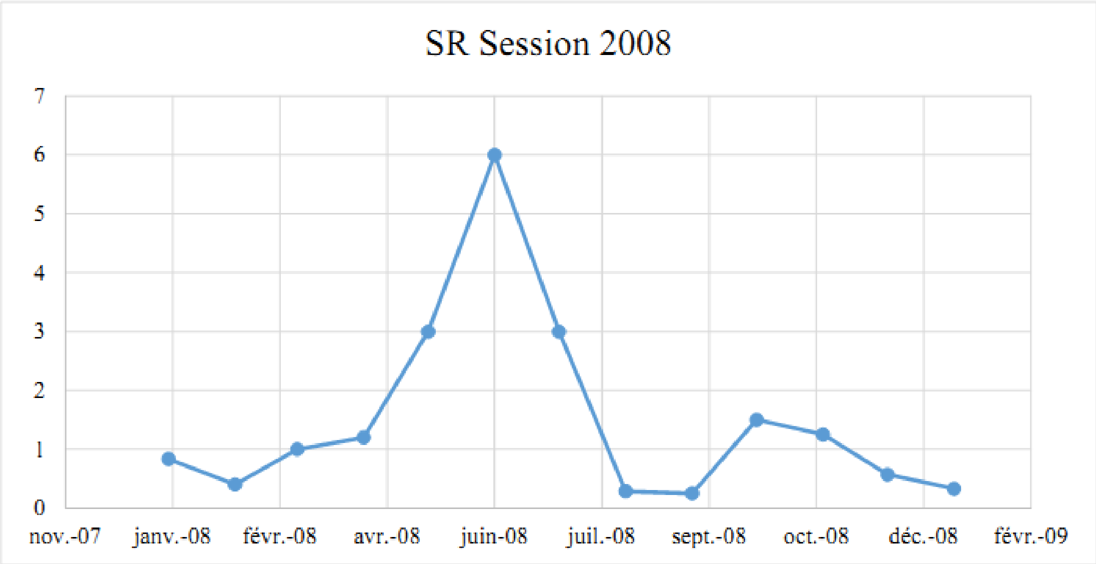


Figure: Graphical representation of SR for the 2008–2009 session

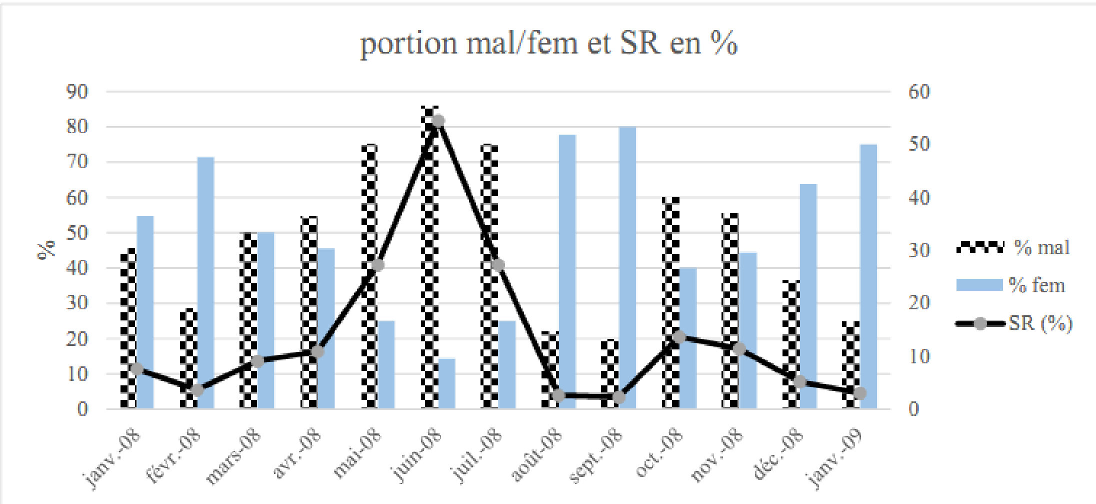


Figure: Graphical representation of SR and the percentages of males and females for the 2008–2009 session

3- The **highest percentages of males** were observed in **June 2008**, coinciding with the **beginning of the dry season** and the **start of the mating period**.

The **lowest percentages of males** were observed in **August 2008** and **September 2008**, during the **sexual rest period**. The variations in male percentages should be explained **not by sampling fluctuations**, but by **seasonal variations in male availability**. For example, these variations may be related to **bio-ethological-ecological factors** such as reproduction (sexual rest and mate searching), feeding, adaptation to unfavorable conditions, or predator avoidance.

Exercise N5: Ecological Indices

Bees are involved in the **ecosystem service of pollination**, which is important both for the **sexual reproduction of most flowering plants** and for **many agricultural productions**. In a study, the following results were obtained:

Table: Raw results of the bee inventory.

Nom commun	**L'abeille noire**	**L'abeille italienne**	**L'abeille caucasienne**	**L'abeille carnolienne**	**L'abeille Buckfast**
espèce	*Apis Mellifera Mellifera*	*Apis Mellifera Ligustica*	*Apis mellifera caucasica*	*Apis mellifera carnica*	*Apis mellifera Buckfast*
Site1	9	0	2	11	2
Site2	5	0	9	8	0
Site3	2	1	2	5	3
Site4	10	0	8	0	5
Site5	3	0	0	0	0
Site6	12	0	0	0	1
Site7	5	0	5	0	0
Site8	20	0	8	0	4
Site9	11	0	0	0	0
Site10	8	0	0	0	0

- Please **assess the sampling quality (Q)**
- As in all studies, it is essential to calculate the following **ecological indices**:

A- Ecological composition indices
These include total richness, average richness, relative abundance, and occurrence frequency:

1- Total and average richness
2- Centennial frequencies (relative abundance)
3- Occurrence frequency and constancy

B- Ecological structure indices
The structure indices to be used for analyzing the results are:

1- Shannon-Weaver diversity
2- Equitability or Piélou's equitability index
3- Simpson's index

Answer – Exercise N5: Ecological Indices

- **Sampling quality (Q):**

$$Q=a/N=1/50=0.02$$

Where:

- a = number of species with frequency 1, i.e., observed only once during all surveys
- N = total number of surveys

The closer **Q** is to zero, the better the quality and precision of the sampling.

A- Ecological composition indices

1- **Total and average richness:**

- **Total richness (S):** S=5
- **Average richness:**
  Average richness corresponds to the **mean number of species present in a sample of the biotope**. It has the advantage of giving **low weight to rare species** and reflects only the number of species that can be considered **representative of a given environment**.

Formula:

$$S=\Sigma s/N$$

Table: Result of the average richness

Sites	s	s= Σ s / N	Richesse moyenne
Site1	4	0,4	0,4
Site2	3	0,3	0,3
Site3	5	0,5	0,5
Site4	3	0,3	0,3
Site5	1	0,1	0,1
Site6	2	0,2	0,2
Site7	2	0,2	0,2
Site8	3	0,3	0,3
Site9	1	0,1	0,1
Site10	1	0,1	0,1

2- **Centennial frequencies (relative abundance) F%**:

F%=ni×100/N

- N=159

Table: Results of the centennial frequencies.

espèce	ni	F%
L'abeille noire	85	53,45912
L'abeille italienne	1	0,628931
L'abeille caucasienne	34	21,38365
L'abeille carnolienne	24	15,09434
L'abeille Buckfast	15	9,433962

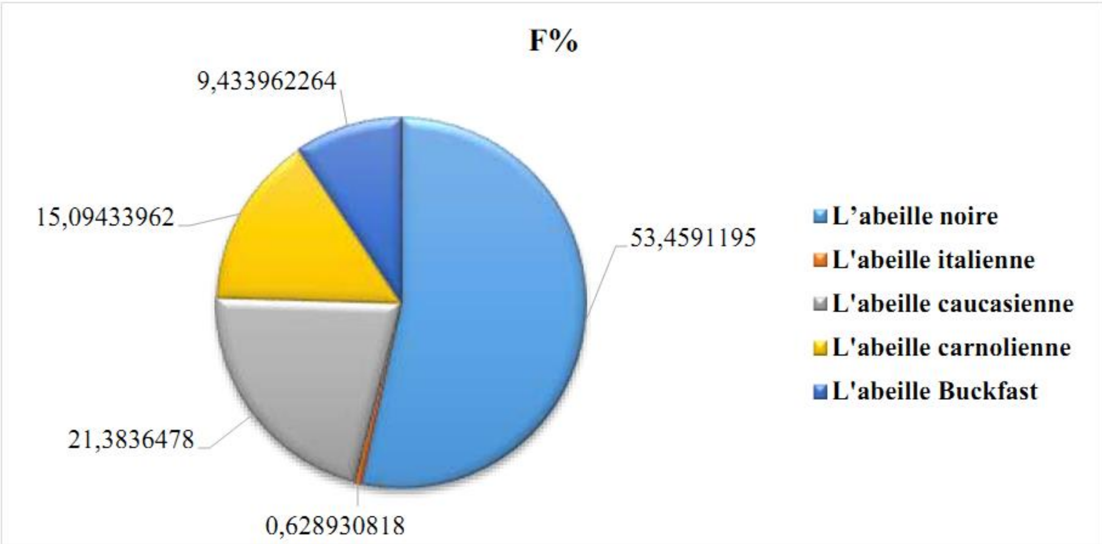


Figure: Graphical representation of the centennial frequencies (relative abundance)

3- **Occurrence frequency and constancy:**

$$C = P \times 100 / P'$$

Where:

- P = number of surveys containing the species studied
- P′ = total number of surveys conducted

Table: Occurrence frequency matrix

Nom commun	L'abeille noire	L'abeille italienne	L'abeille caucasienne	L'abeille carnolienne	L'abeille Buckfast
espéce	*Apis Mellifera Mellifera*	*Apis Mellifera Ligustica*	*Apis mellifera caucasica*	*Apis mellifera carnica*	*Apis mellifera Buckfast*
Site1	1	0	1	1	1
Site2	1	0	1	1	0
Site3	1	1	1	1	1
Site4	1	0	1	0	1
Site5	1	0	0	0	0
Site6	1	0	0	0	1
Site7	1	0	1	0	0
Site8	1	0	1	0	1
Site9	1	0	0	0	0
Site10	1	0	0	0	0

Table: Results of the occurrence frequency.

ESPECE	C (%)
L'ABEILLE NOIRE	100
L'ABEILLE ITALIENNE	10
L'ABEILLE CAUCASIENNE	60
L'ABEILLE CARNOLIENNE	30
L'ABEILLE BUCKFAST	50

Table: Classes of occurrence frequency.

omniprésent	C = 100 %	espèce		
constante	75 % ≤ C ≤ 100 %	1	L'abeille noire	
régulière	50 % ≤ C ≤ 74 %	1	L'abeille caucasienne	
accessoire	25 % ≤ C ≤ 50 %	2	L'abeille carnolienne	L'abeille Buckfast
accidentelle	5 % ≤ C ≤ 25 %	1	L'abeille italienne	
rare	C ≤ 5 %	0		

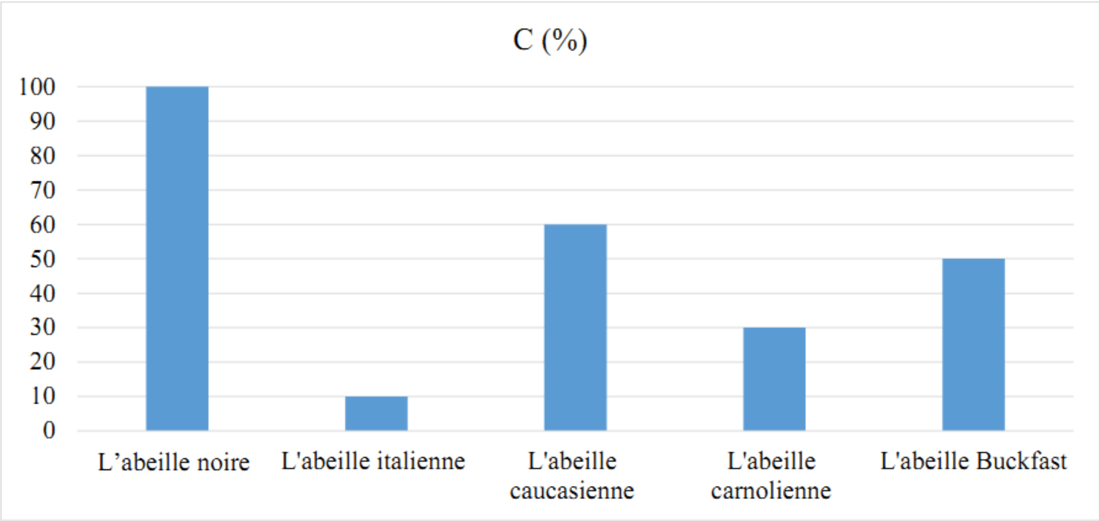


Figure – Graphical representation of occurrence frequency (constancy).

B- Ecological structure indices

1- **Shannon-Weaver diversity index**

$$H' = -\sum_{i=1}^{S} pi.\log_2(pi)$$

- *pi* = proportional abundance or percentage abundance of a species present (*pi* = *ni* / *N*).
- *ni* = number of individuals counted for a given species.
- *N* = total number of individuals counted, all species combined.
- *S* = total number or cardinality of the list of present species.

Table: Calculation of the diversity index (Shannon-Weaver).

Nom commun	L'abeille noire	L'abeille italienne	L'abeille caucasienne	L'abeille carnolienne	L'abeille Buckfast
espéce	*Apis Mellifera Mellifera*	*Apis Mellifera Ligustica*	*Apis mellifera caucasica*	*Apis mellifera carnica*	*Apis mellifera Buckfast*
Site1	9	0	2	11	2
Site2	5	0	9	8	0
Site3	2	1	2	5	3
Site4	10	0	8	0	5
Site5	3	0	0	0	0
Site6	12	0	0	0	1
Site7	5	0	5	0	0
Site8	20	0	8	0	4
Site9	11	0	0	0	0
Site10	8	0	0	0	0
ni	**85**	**1**	**34**	**24**	**15**
pi	**0,534591195**	**0,006289308**	**0,213836478**	**0,150943396**	**0,094339623**
Log2 (pi)	**-0,271978199**	**-2,201397124**	**-0,669918207**	**- 0,821185883**	**-1,025305865**
H	**-0,14539715**	**-0,013845265**	**-0,14325295**	**- 0,123952586**	**-0,096726968**

The Shannon–Weaver diversity index

H′=0.52

1 – Evenness or Pielou's Evenness Index

$$E = \frac{H'}{H'\ max}$$

The value of evenness E ranges from 0 to 1.
When E tends toward 0, it means that the abundances of the collected species are not balanced with each other.

S=	**5**
H'max=	**Log2 S**

H'max	**0,698970004**

Equitabilité	H'/ H'max
E	0,748494093

0<E<1	en équilibre entre eux

2 – Simpson's Index

$$\lambda = \sum_{i=1}^{S} (p_i)^2 \qquad L = \frac{\sum_{i=1}^{S} n_i.(n_i - 1)}{N.(N-1)}$$

pi=proportion of individuals of species i(pi=ni/N)
ni=number of individuals of species i
N=total number of individuals S=total number of species present
The closer this index is to 1, the more homogeneous the community is.

A second index, often used, is the **diversity index**, which corresponds to **1 minus Simpson's index**.

This diversity index is easier to interpret. Its formula is:

D=1−λ or D=1−L(depending on sample size), if D = 0, then only one species is present in the community. If all species have the same probability of occurrence (pi=1/S), then: D=1−(1/S); Finally, D=1 would appear in the case where an infinite number of species are present, but each with an almost negligible probability.

Table: Calculation of the diversity index (Simpson).

Nom commun	L'abeille noire	L'abeille italienne	L'abeille caucasienne	L'abeille carnolienne	L'abeille Buckfast
espéce	*Apis Mellifera Mellifera*	*Apis Mellifera Ligustica*	*Apis mellifera caucasica*	*Apis mellifera carnica*	*Apis mellifera Buckfast*
Site1	9	0	2	11	2
Site2	5	0	9	8	0
Site3	2	1	2	5	3
Site4	10	0	8	0	5
Site5	3	0	0	0	0
Site6	12	0	0	0	1
Site7	5	0	5	0	0
Site8	20	0	8	0	4
Site9	11	0	0	0	0
Site10	8	0	0	0	0
ni	**85**	**1**	**34**	**24**	**15**
pi	**0,534591195**	**0,006289308**	**0,213836478**	**0,150943396**	**0,094339623**
(pi)2	**0,2857877**	**0,0000396**	**0,0457260**	**0,0227839**	**0,0089000**

N=159	Simpson
λ	**D**
0,363237214	**0,636762786**

Evenness Index

It is accompanied by an evenness index **ED = D/Dmax**. According to Hurlbert, the case where all species are present with the same probability corresponds to the maximum diversity index, that is **Dmax = 1 − (1/S)**. Another formulation of Simpson's index states that **D = 1/λ** (statistical diversity index). Thus, it becomes possible to consider that if **ED = D/Dmax**, then **Dmax = S**, giving the equation **ED = D/S**. The choice of the formula is therefore crucial for comparing results with one another. Simpson's evenness index makes it possible to express either the dominance of a single species (ED tends toward 0) or the codominance of several species (ED tends toward 1). As before, it is advisable to examine several indices.

ED = D/Dmax

ED = D/Dmax	**ED=**	**0,795953483**
S =5		
Dmax=1-(1/S)=	**0,8**	