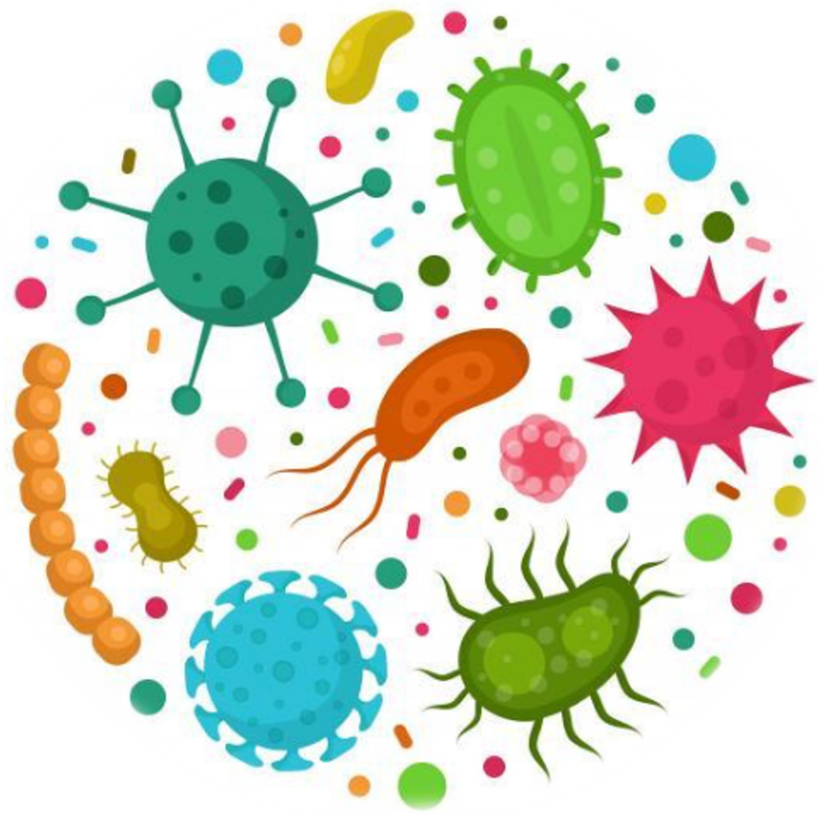
# $\alpha$-diversity

**j3**

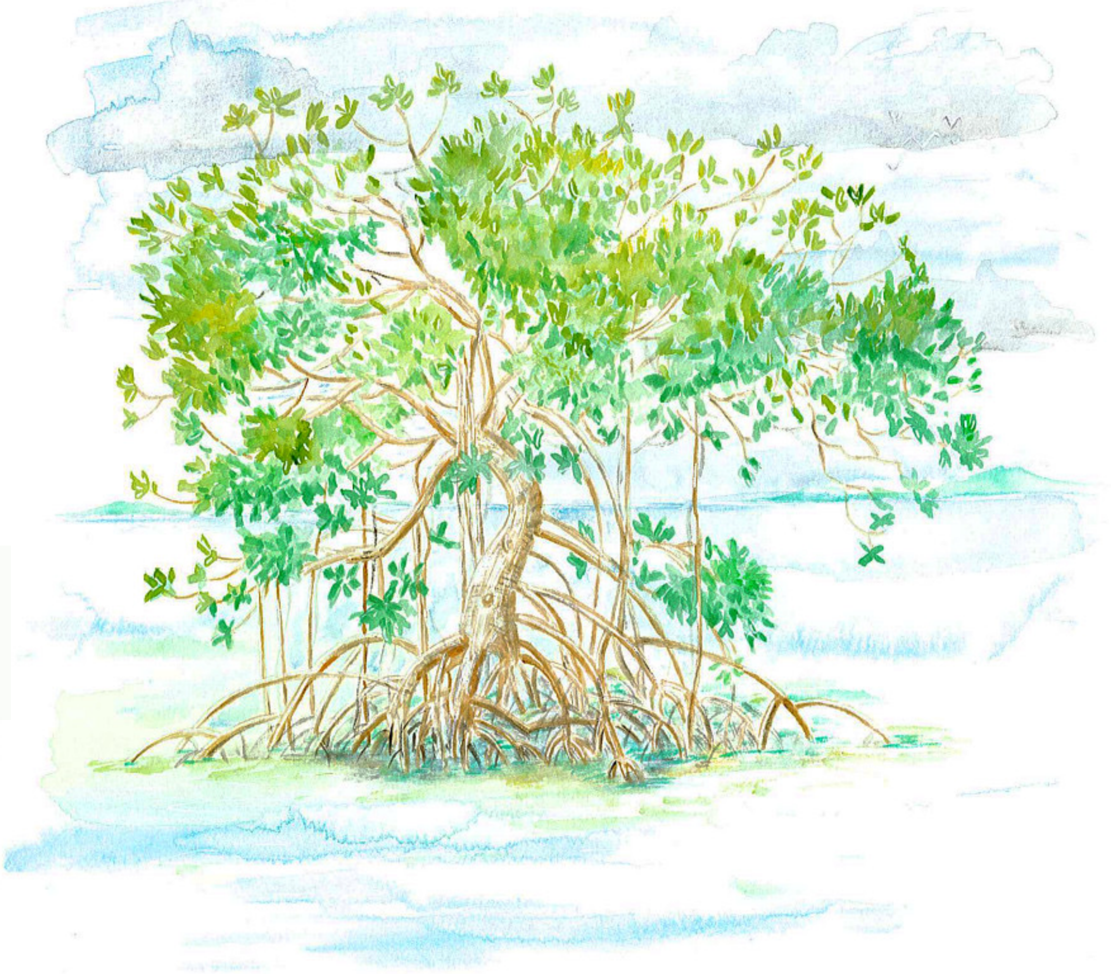
– 01.04.26 –



Plateforme OMICS - MIO

**Bio-informatique & Sciences de l'Environnement : Exploration de la Diversité Taxonomique des Ecosystèmes par Metabarcoding**

# What is Biodiversity?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The **variety** and **variability** among living organisms on site, ecosystem and their **interractions** between them

**Diversity** can be use to describe **variation** in several forms:

- **Genetic**
- **Taxonomic**
- **Functional** group (e.g. nitrogen-fixing)

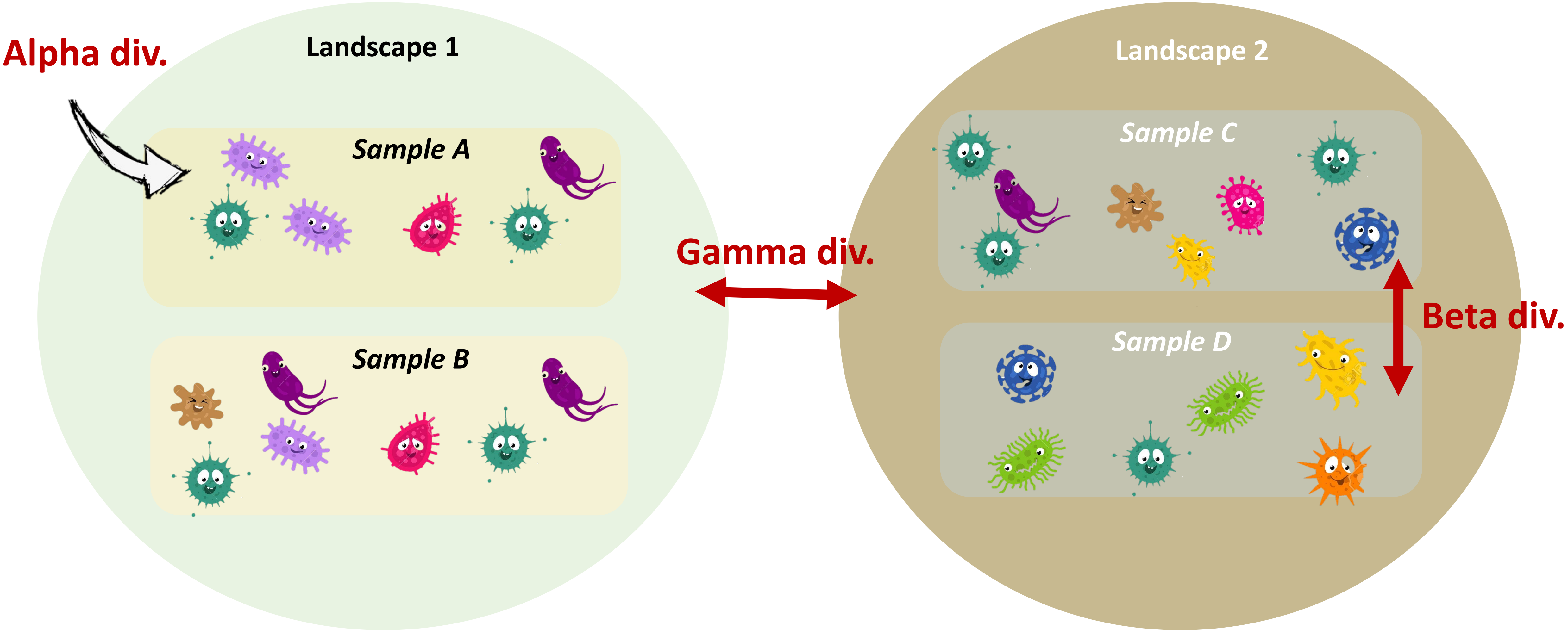
# Why measuring  Biodiversity?

**Biodiversity** $\xrightarrow{\text{proxy}}$ **Ecosystem health**

In general, diverse communities are believed to have increased stability, increased productivity, and resistance to invasion and other disturbances

# Alpha vs Beta vs Gamma Diversity (Whittaker, 1972)

Alpha, beta and gamma diversity are three types of biodiversity measures described over a special scale



# α-Biodiversity ?

$\alpha$-diversity is local diversity, measured within a closed system

→ **The diversity within an habitat of fixed size**

$\alpha$-biodiversity has **two components**

- **Richness**
- **Evenness**

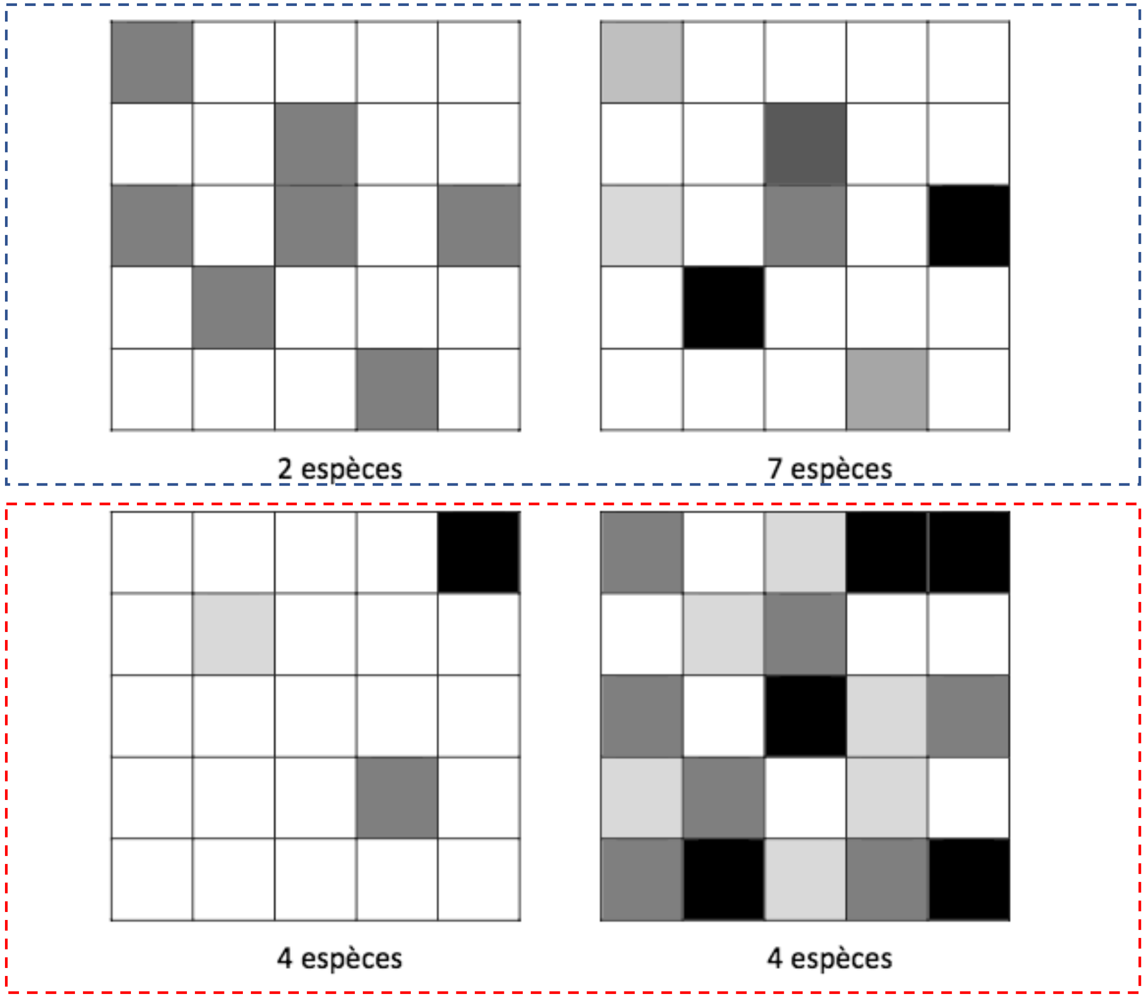
**And another one…**

- **Disparity (A. Stirling)**

→ **Follow the evolution of populations over time, but also to compare them between the stations studied**

# Components of Diversity

**Species richness**



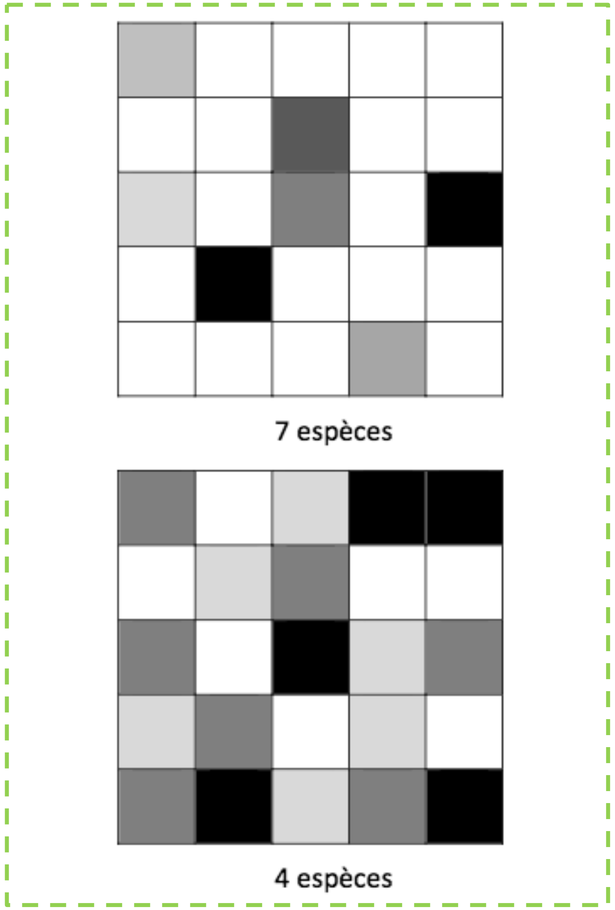
2 espèces

7 espèces

4 espèces

4 espèces

**Species evenness**



?

Two components are necessary for describing diversity

- **Richness**
- **Evenness**

# Definition

**Specific Richness (S)** = The measurement of the **number of species** present in a location/studied system

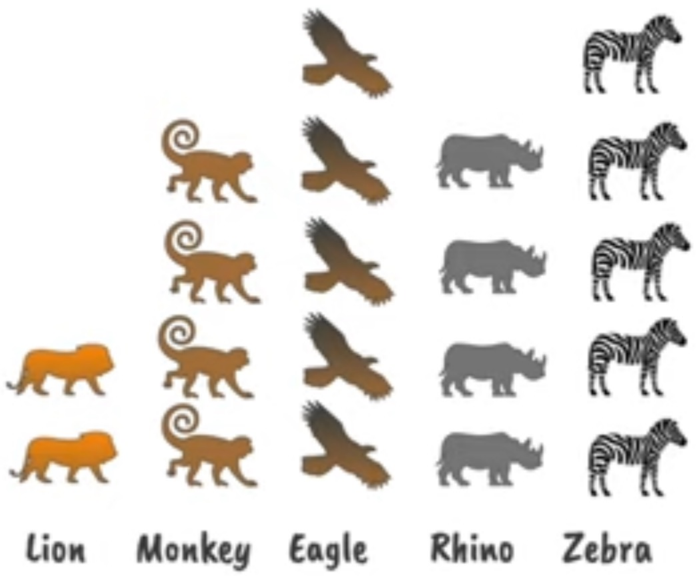
- The more species present, the richer sample is
- Gives equal weight to species which have many/few individuals

**Evenness** (equitability) = **Relative population of each species**

- Species represented by many individuals or by few ones do not give the same contribution

Evenness index is independent of Richness!!

## Higher biodiversity

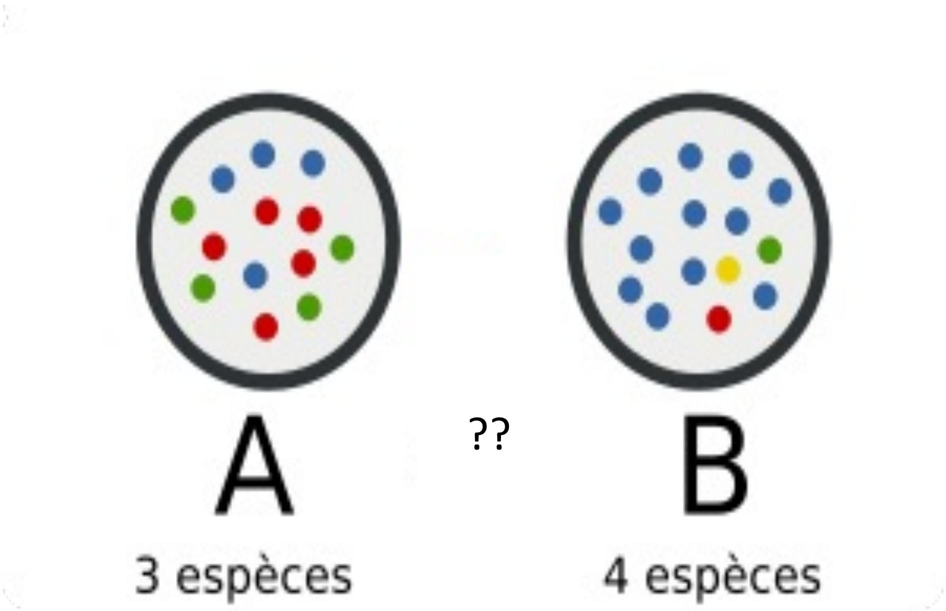


Wide range of species = High richness
Relatively **equal** proportion = high evenness

## Lower biodiversity

Few species = low richness
**Unequal** proportion = low evenness

# Which one is more diversified ?



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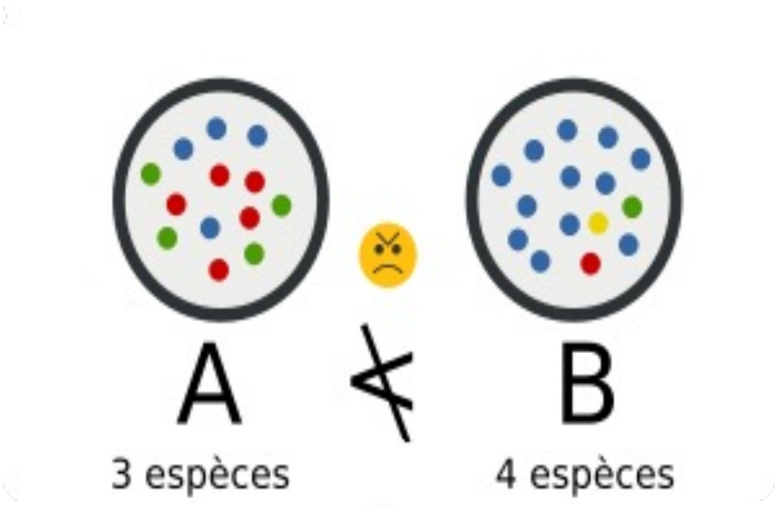
# Difficult to judge by only looking the numbers !!

Use $\alpha$**-diversity indices to quantify the biodiversity** of an habitat/sample



# Neutral Diversity Indices (=Taxonomic)

Why neutral?

- Species are considered as equidistant (= do not consider species relatedness)

**Common indices are Shannon, Simpson and specific richness**

- **Subjected to estimation bias because of species not sampling**

- Suppose that the delineation of « species » is clear!

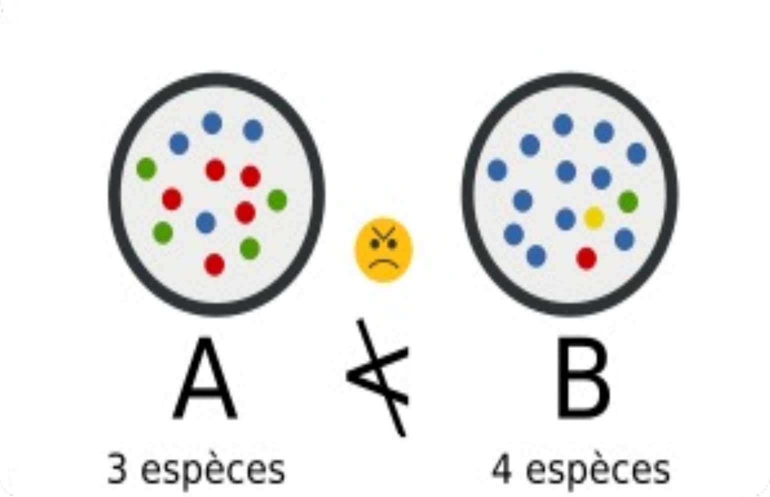
→ It's not!

- Species concept definition (phylogenetic, biological, ecological niche)
- Methodological issues

# Shannon-Weaver Index: Combine Richness & Evenness

$$H(X) = H_2(X) = -\sum_{i=1}^{n} P_i \log_2 P_i .$$

Pi : relative abundance of the species i

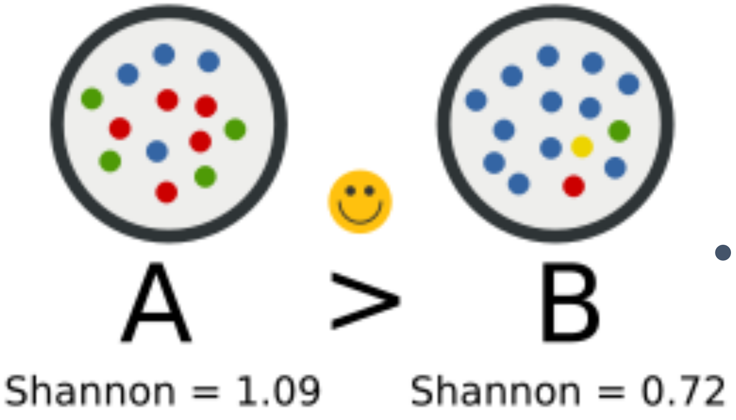


- A: consists of 3 species, of which 4 green, 5 red & 4 blue

The Shannon index will be :

$$-\left(\frac{4}{13}log\left(\frac{4}{13}\right) + \frac{5}{13}log\left(\frac{5}{13}\right) + \frac{4}{13}log\left(\frac{4}{13}\right)\right) = 1.09$$

# Finally, after estimating Shannon for B sample …



- B consist of 4 species, of which 1 green, 1 red, 1 yellow & 11 blue

**Shannon value: Influenced by richness**

**H is generally between 1.5 - 4**

H gets higher when :
- There are **more species**
- There is **greater evenness**

**There's no upper limit to the index**

The maximum : All species have the same number of individuals (perfect evenness)

**H max = log(S)**

100 species : log(100) = 4.6
1000 species : log(1000) = 6.9

# Equitability Pielou Index… with Shannon Scores

**Shannon is dependent on species richness!**

$\rightarrow$ **Pielou index is independent of species richness**

$$\text{Pielou index} = \frac{\textit{Shannon Index}\ (H)}{\log(S)}$$

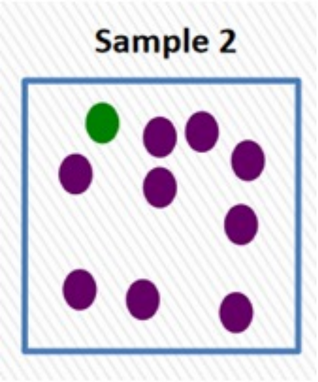
S is Species Richness

**Pielou index is a way to measure how the species are evenly distributed in a community**

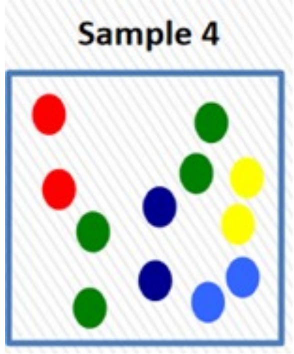
Range 0 to 1 (max equitability, habitat diversity increase)

# Simpson's Index of Diversity

**Idea : Indicates the taxa dominance and gives the probability of two individuals that belong to the same taxa being randomly chosen**



A value of 0.8 ...
2 sequences randomly selected
have 80% chance to belong to the same ASV!



**Simpson index = D**

$$D = \sum_{i=1}^{S} p_i^2$$

P = proportion of the species

**Gini-Simpson = 1 - D**

$$E = 1 - \sum_{i=1}^{S} p_i^2$$

- Influenced by highly abundant Taxa
- Greater weight on evenness
- Range 0 to 1 (high)

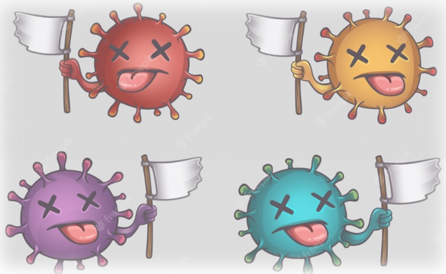
**The closer the value to 1, the more diverse the habitat is**

**0**
**No diversity**

**1**
**Infinite Diversity**

**Low sp. Diversity :**

- **Few successful species** in the habitat
- **Env stressful**, few niches, few organisms well adapted to env
- Any **change** in env may have **serious effect on ecosystem**



**High sp. Diversity :**

- **Great number** of successful species, more **stable ecosystem**
- Env is less likely to be hostile
- Complex food
- Env change is **less likely to dammage** the whole ecosystem

# Diversity Estimators

- Chao1 & ACE are non-parametric estimators of taxa richness

- Sampling at infinity

- Good sampling gives you a total number of ASV/OTU observed not far from the Chao1 / ACE value (predicted for the sampled environment)

Chao1= $S_{obs}$ + Adjustment (linked to the rare)

Chao1 adjustment

$$\frac{F_1(F_1-1)}{2(F_2-1)},$$

Singletons = F1

Doubletons = F2

Idea : Rare taxa bring most information about the number of missing taxa

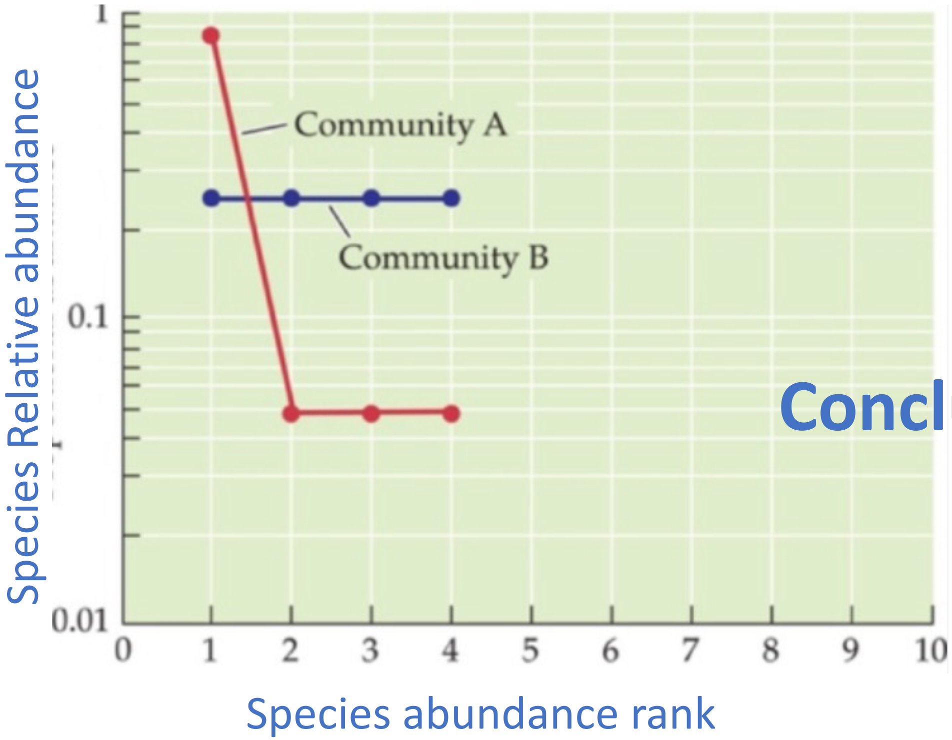
ACHTUNG

→ Issue : DADA2 remove singletons !!!

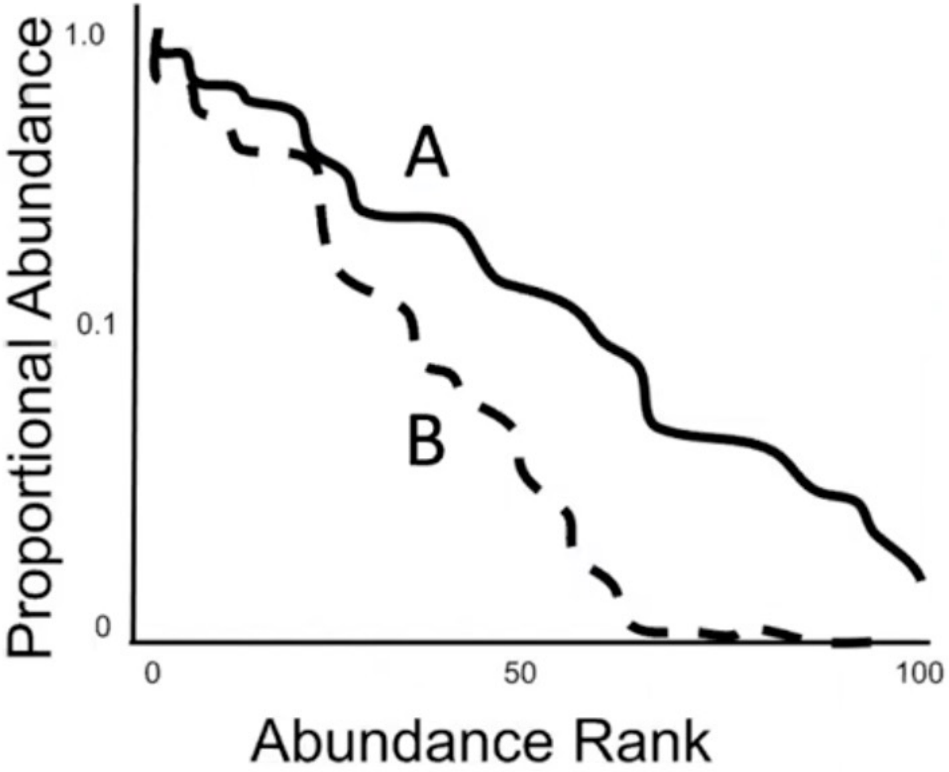
# Rank Abundance Curves

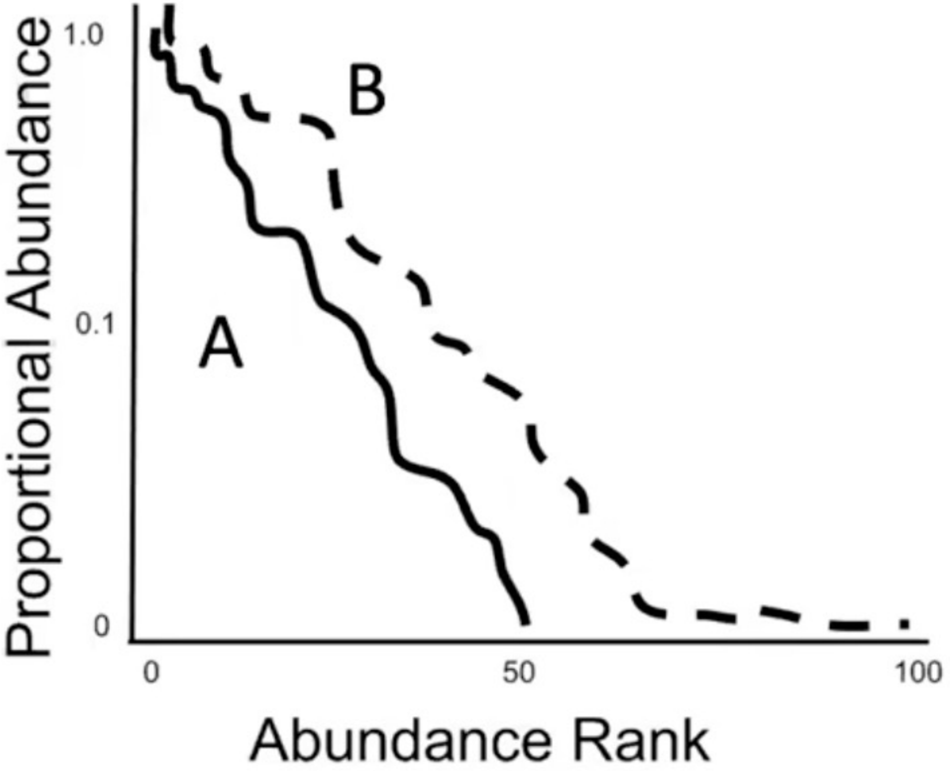
## Plot relative abundance of species against their rank in abundance

### Dominance and diversity… graphically



Conclusions?





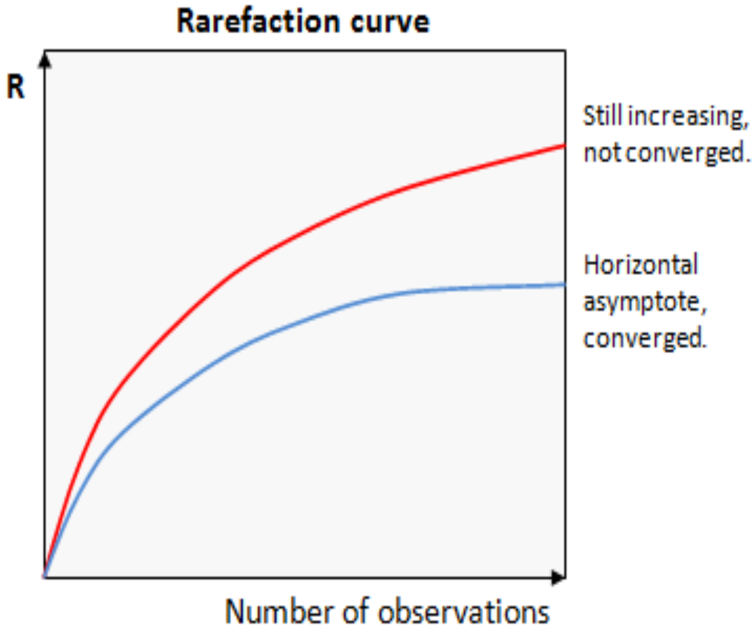
- **Which one has the greatest evenness?**

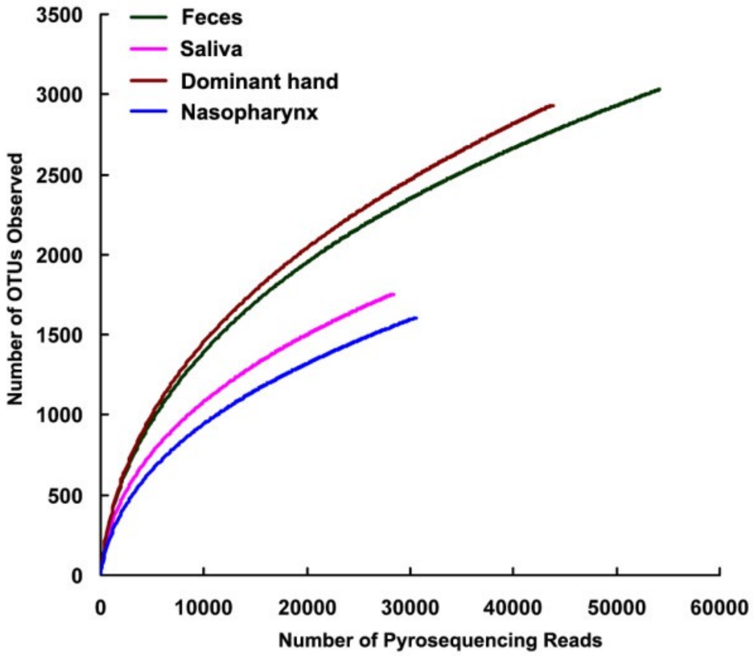
**Which one has :**

- **Greatest evenness?**
- **Greatest richness?**

# Rarefaction Curves

« Is the sequencing effort performed (sequencing depth) for a sample (s) sufficient for the number of species observed ? »





→Reach the asymptote ???

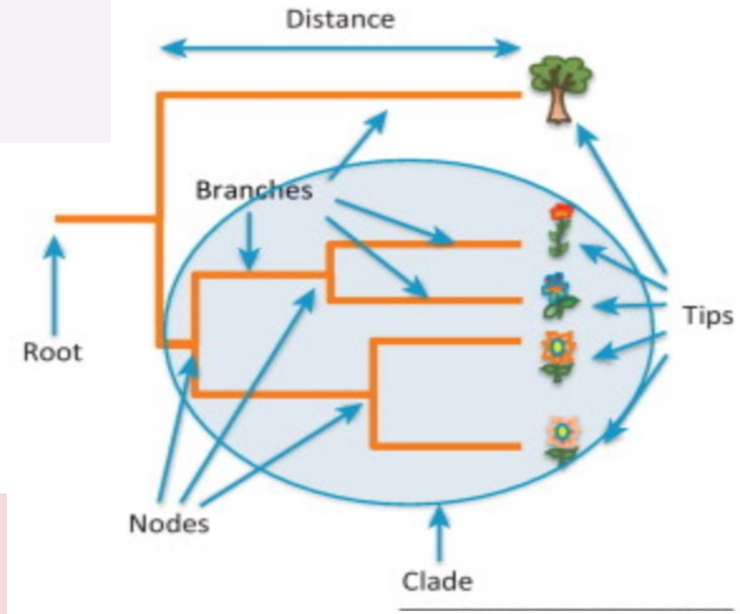
Asymptote means that sequencing more (depth), will not increase your number of OTU/ASVs observed

# Phylogenetic Indices

**Phylogenetic Diversity (PD) measure of the evolutionary history within a set of species :**

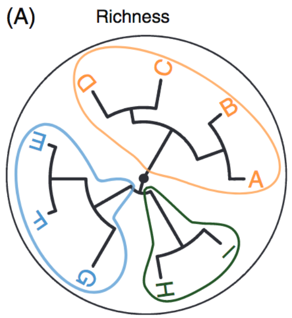
**- Relatedness, speciation, events …**

**→ describes a fundamental aspect of biodiversity**



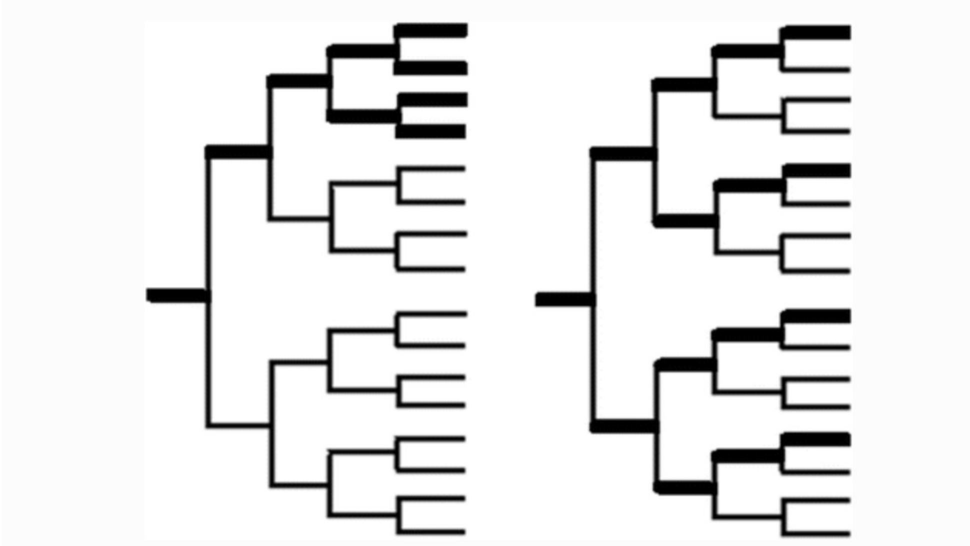
**A better predictor of ecosystem function than species richness & evenness**

# Richness = How much ?



- **PD** $_{\text{faith}}$ (Faith’s Phylogenetic Diversity)

→ As the minimal total length of all the branches required to span a given set of taxa to the root (Related to SR)

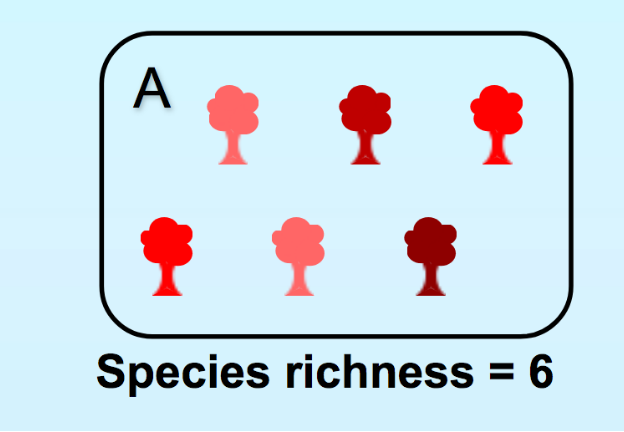


**Low PD**

**Assemblage of taxa with more recent evolutionary history**

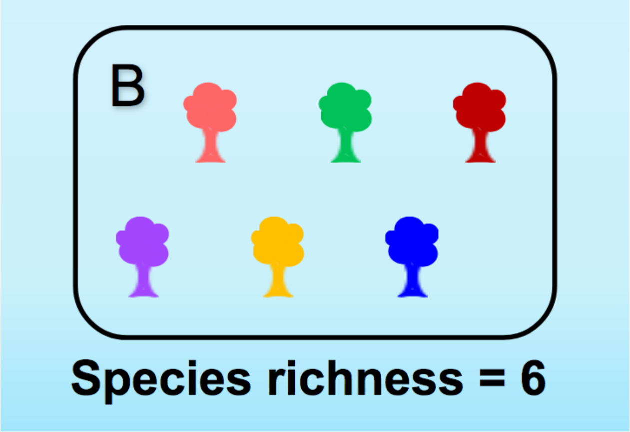
**High PD**

**Communities with more evolutionary divergent taxa and older history**

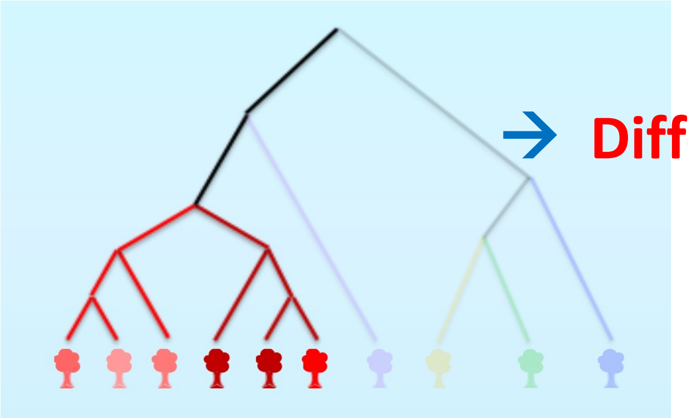


**Species richness = 6**

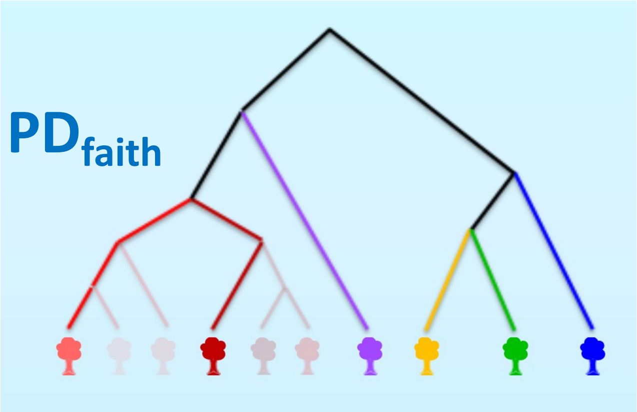
**Same SR**



**Species richness = 6**



→ **Different PD$_{faith}$**



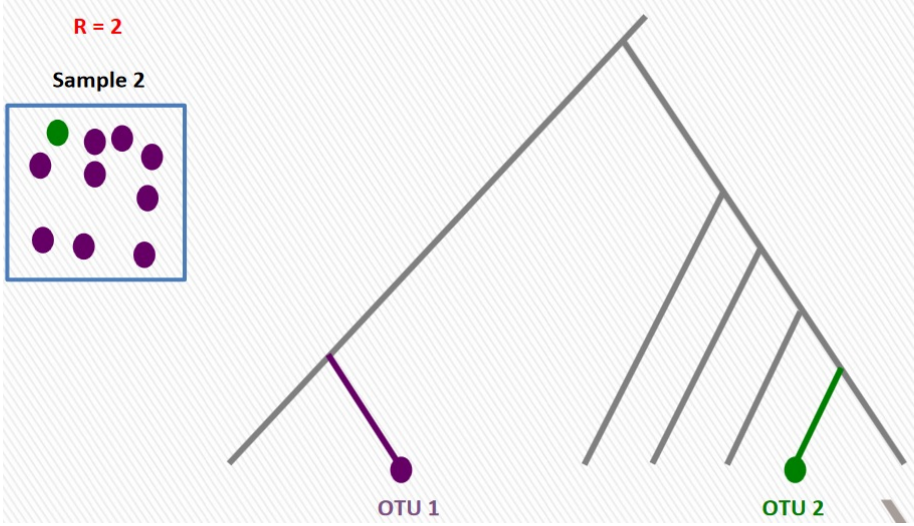
EnvA : Sum up branch lengths

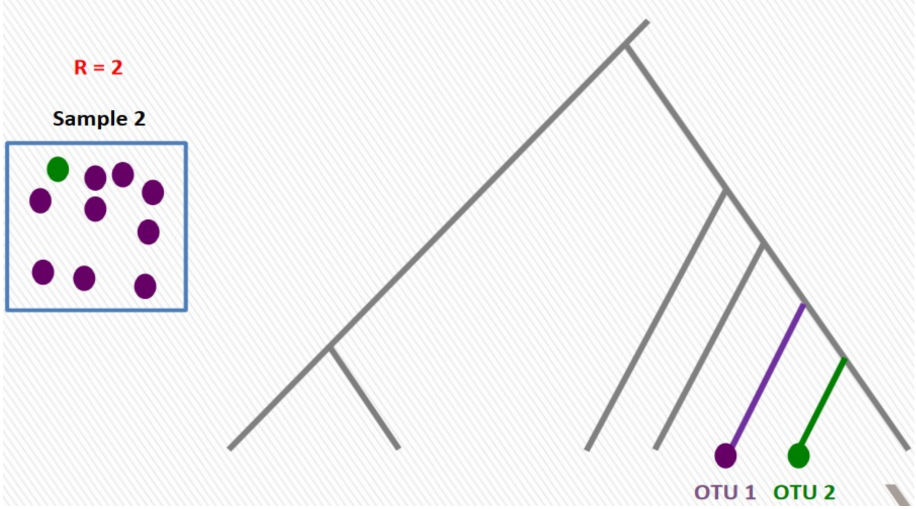
EnvB : Sum up branch lengths

**Higher PD**

**If not using phylogenetic indices : lost of this information !**

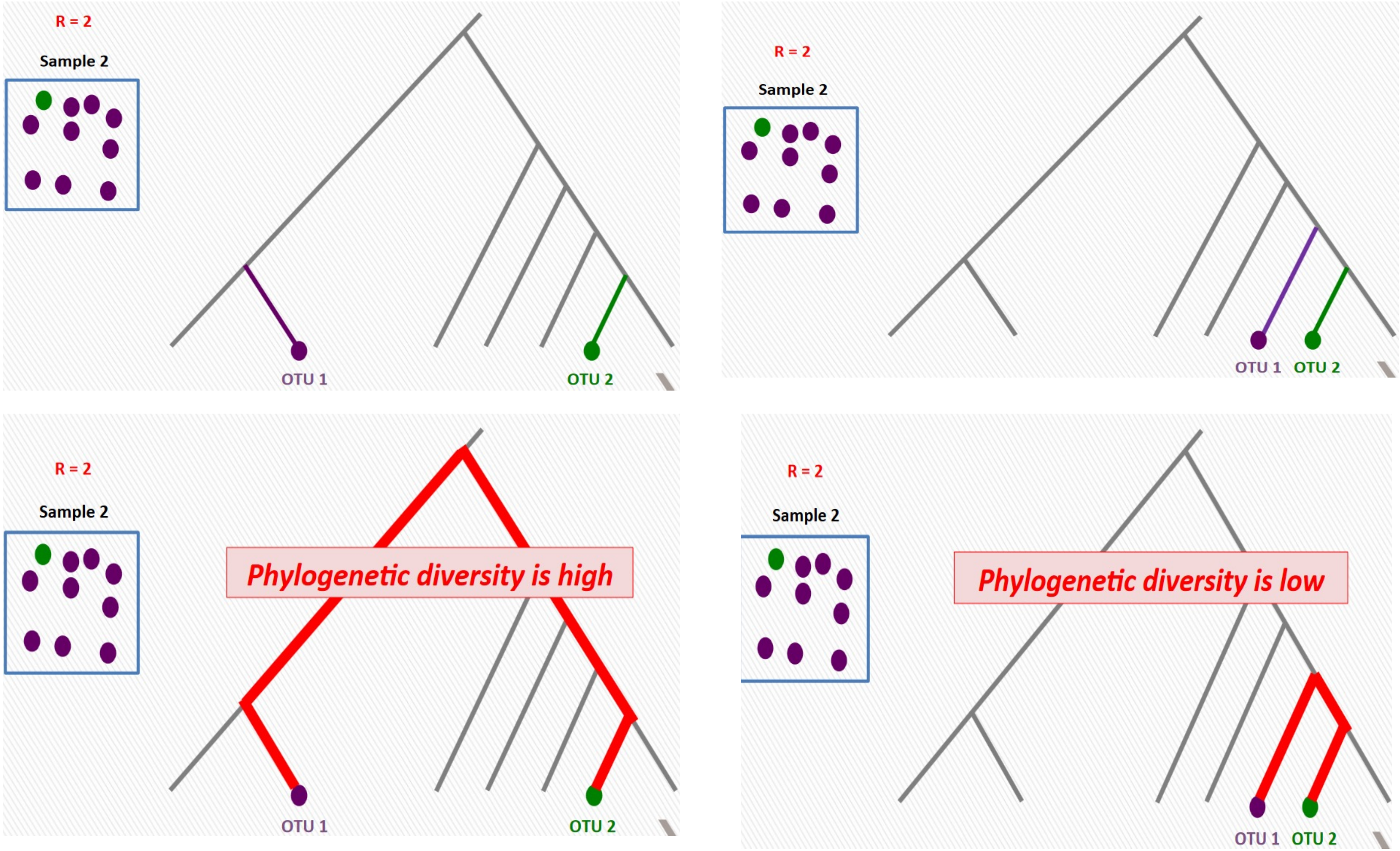
# Same SR & same evenness = Same Shannon/simpson





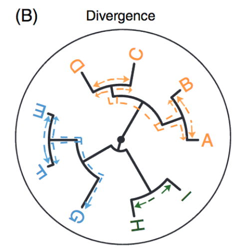
Same phylogenetic diversity ???

# Same SR & same evenness = Same Shannon/simpson



**BUT different PD$_{faith}$!!!!**

# Divergence : Quantify the phylogenetic difference…



**Why PD is a proxy of functional diversity, niche/community dissimilarity :**

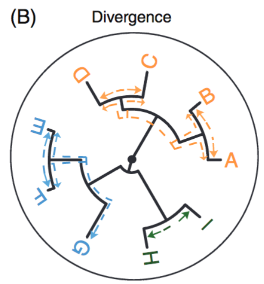
- **Closely related species tend to have similar functions/traits** **(similar habitat requirement)**
- **Distant related species tend to have greater complementary functions**

**Meaning for the community assemblage :**

Dominance of **closely related** species → **Clustering pattern**
Dominance of **distant related** species → **Overdispersion pattern**

Given species richness,
does the **phylogenetic diversity** in **AN** assemblage
is greater or less than that expected?

# Divergence : How different?



**Two commonly used metrics were used to quantify:**
**the Net Relatedness Index (NRI) and Nearest Taxon Index (NTI)**

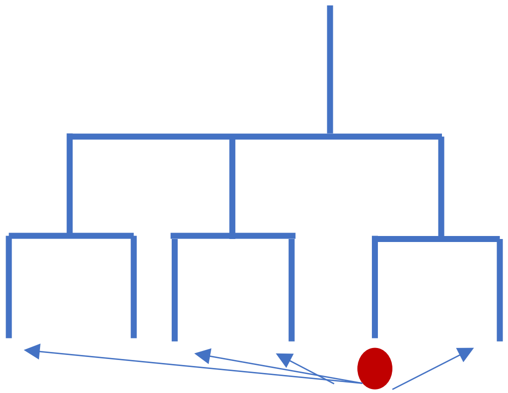
Highlight phylogenetic structure of assemblages **at different evolutionary depths**

# NRI : Net Relatedness Index

- Based on the **Mean Phylogenetic Distances (MPD)** in each community.

→ **Average** phylogenetic **distance** of species (**to every other species)**

→ « Basal measure » : Clade representation. **Strongly influenced by the 'basal' structure** of the phylogenetic tree



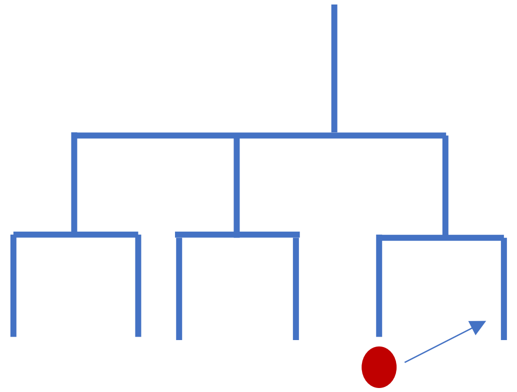
« Global »

# NTI : Nearest Taxonomy Index

- Based on **MNTD** the Mean Nearest phylogenetic Neighbor Distance

→ **Average** phylogenetic **distance** to the **nearest neigbour**

→ **Reflect Phylogenetic structure of the tree tips**



« Local »

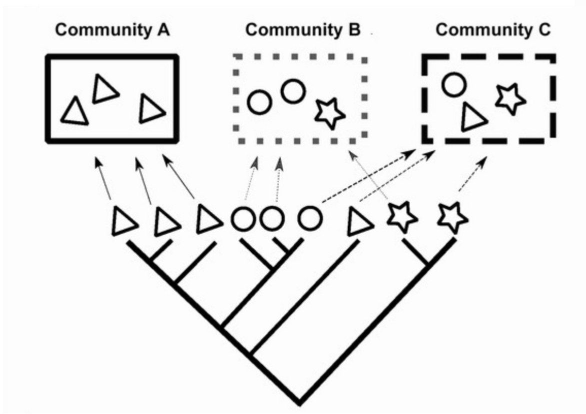
So get NRI /NTI values .. And so what ????

# The « Null model » : Phylogeny randomization…

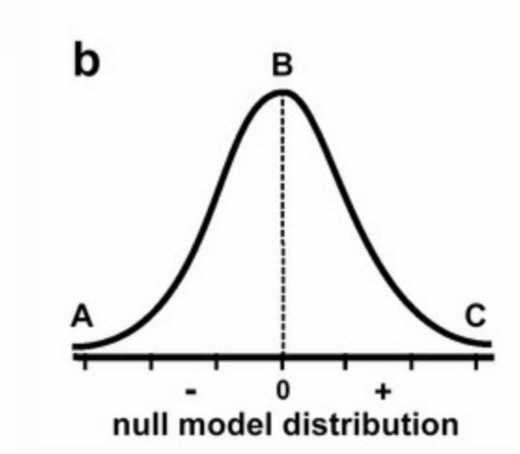
Need a **reference** for comparison → Absence/overdispersion/Clustering!

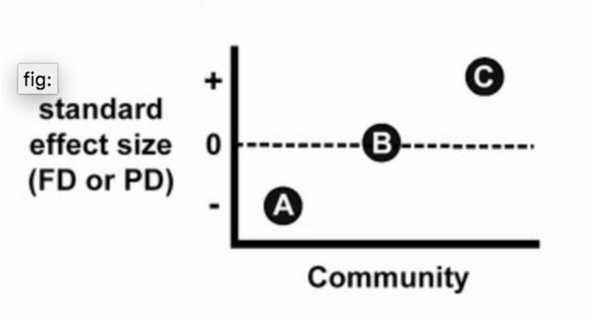
→ A distribution « Null Model » based on random taxa positions within tree

→Is the measure for a specific community is more or less expected by chance ?



**Randomization**





**SES for your values**

**NTI and NRI are Z scores!!**

# Interpretation

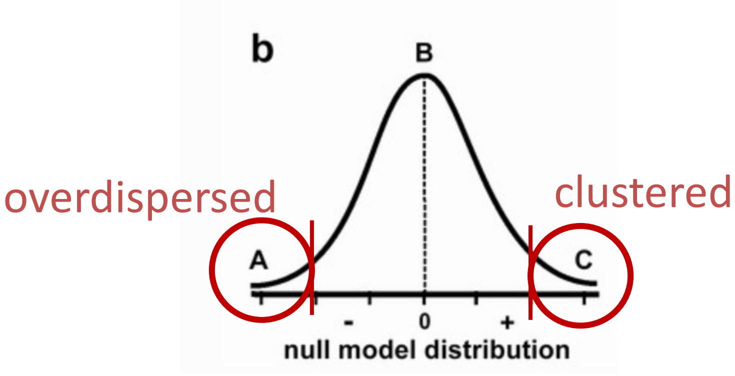
- A negative NRI/NTI value indicates an overdispersed phylogeny where taxa are less related to each other than expected by chance

→ Significance < -1.96

- Positive NRI/NTI values indicate a clustered phylogeny

where taxa are more related to each other than expected by chance

→ Significance > 1.96



# Community Assembly : Spatial and Temporal processes

- Niche-driven = Deterministic
- Selection

- Biotic interactions (taxa interactions)

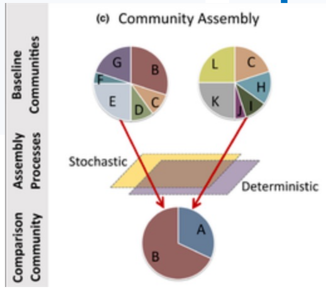
- Environmental filtering
 (=Abiotic conditions, physico-chemical)

- Neutral = Stochastic process
- Unpredictable

- Random profileration, dispersal

- Random birth-death events

Ecological drift (loss diversity, small pop)

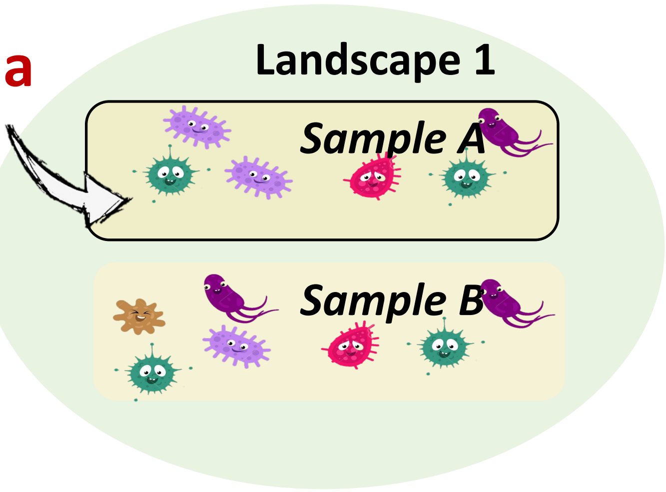


→ See $\beta$ NTI/NRI

# Sum up …

**Be aware of the biases/limitations associated with the indices you use when interpreting your results !!**

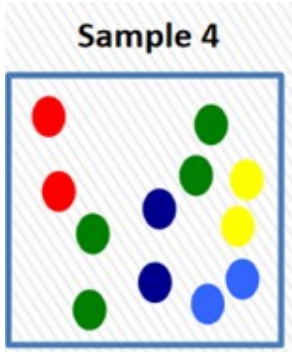
**Alpha div.**



**Diversity within an habitat of fixed size**

Use $\alpha$-diversity indices to quantify the biodiversity of an habitat/sample

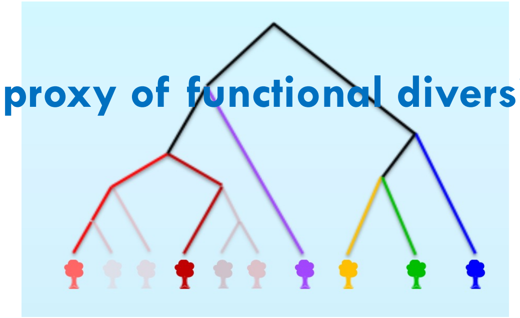
Neutral diversity indices (taxonomic)



Richness & equitability

*Shannon, Simpson , pielou …*

Phylogenetic indices



**proxy of functional diversity**

*NTI/NRI*