CESAB
CENTRE FOR THE SYNTHESIS AND ANALYSIS OF BIODIVERSITY

16th June 2022

Assessing the complementary facets of functional diversity with *mFD*: A brief overview

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Preamble

Objectives of this short talk

- Which **data** I need ?
- How to run **preliminary steps** ?
- How to compute **FD indices** ?

⇒ focus on the **multidimensional approach**

⇒ More details in papers and *mFD* tutorials

https://frbcesab.github.io/workshop-free/resources.html

https://cmlmagneville.github.io/mFD/articles/mFD_general_workflow.html

From functional traits to functional diversity

Defining the aim of the study

Ecological question to address

How

environment
(temperature, salinity, nutrients, connectivity)

anthropogenic drivers
(climate change, pollution, habitat loss, exploitation, biotic exchanges)

affect the **biodiversity** of

organisms
(populations within species, species from a clade or an ecological group)

?

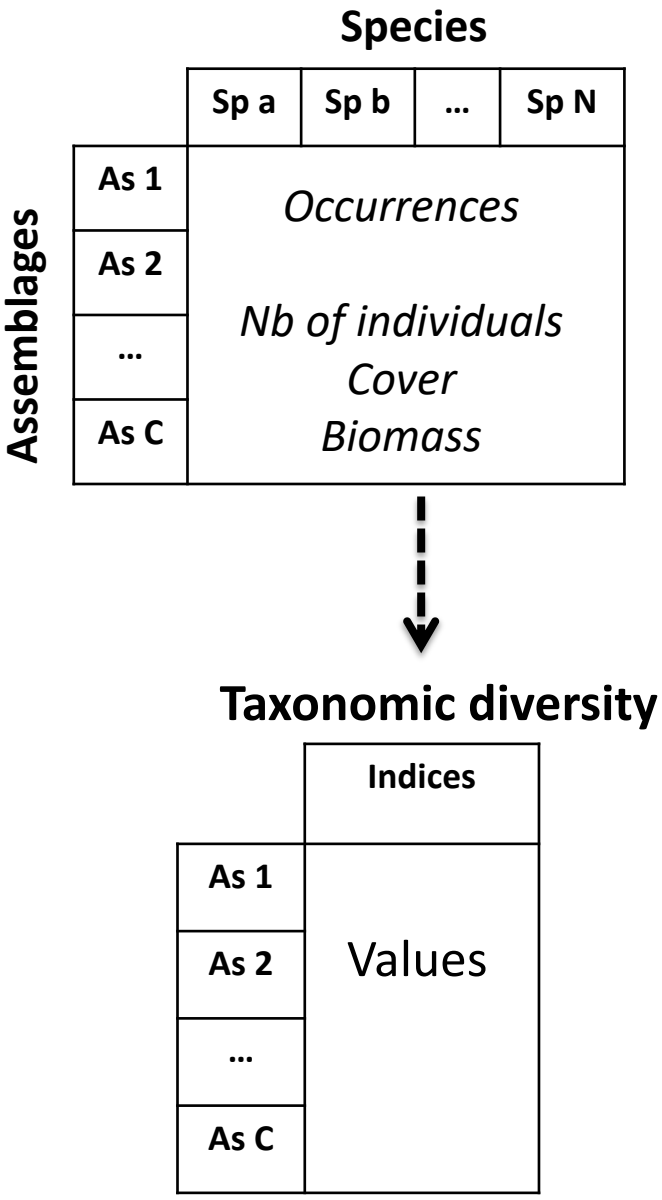
From functional traits to functional diversity

Surveying species assemblages

Sampling design :

- where/when ?
(how many levels * how many replicates)

- Which information about species
Occurrence (presence/absence)
OR
Dominance (abundance, biomass, coverage)



From functional traits to functional diversity

Describing all species with a set of traits

Functional Ecology 1992
6, 621–626

ESSAY REVIEW

A pragmatic approach to functional ecology

P. A. KEDDY

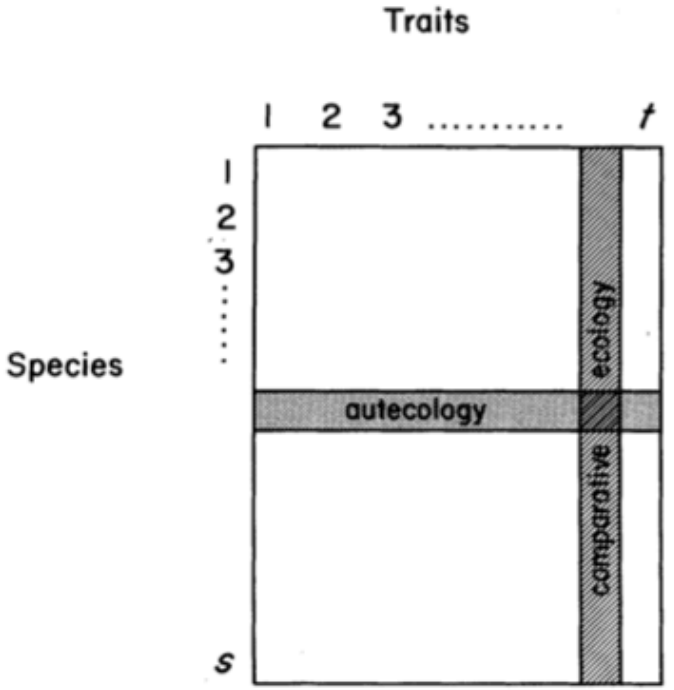


Fig. 1. Trait matrix of *s* species by *t* traits. Few such matrices currently exist, in part because ecologists have emphasized studying species autecology (rows) rather than comparing traits (columns). These matrices are an essential first step to exploring the inter-relations of traits and the distributions of traits along environmental gradients.

From functional traits to functional diversity

Which functional traits to consider ?

Let the concept of trait be functional!

‘‘Functional traits’’ are defined as

morpho-physio-phenological traits which impact fitness indirectly

via their effects on ***growth***, ***reproduction*** *and* ***survival***,

the three components of individual performance.

Violle et al 2007 *Oikos*; doi: 10.1111/j.2007.0030-1299.15559.x

From functional traits to functional diversity

Which functional traits to consider ?

How

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organisms
(populations within species, species from a clade or an ecological group)

?

Trait selection by experts :
question (scale, processes, disturbance)
+ organisms to describe (number, biology)
+ practical constraints (time, money, data available)

From functional traits to functional diversity

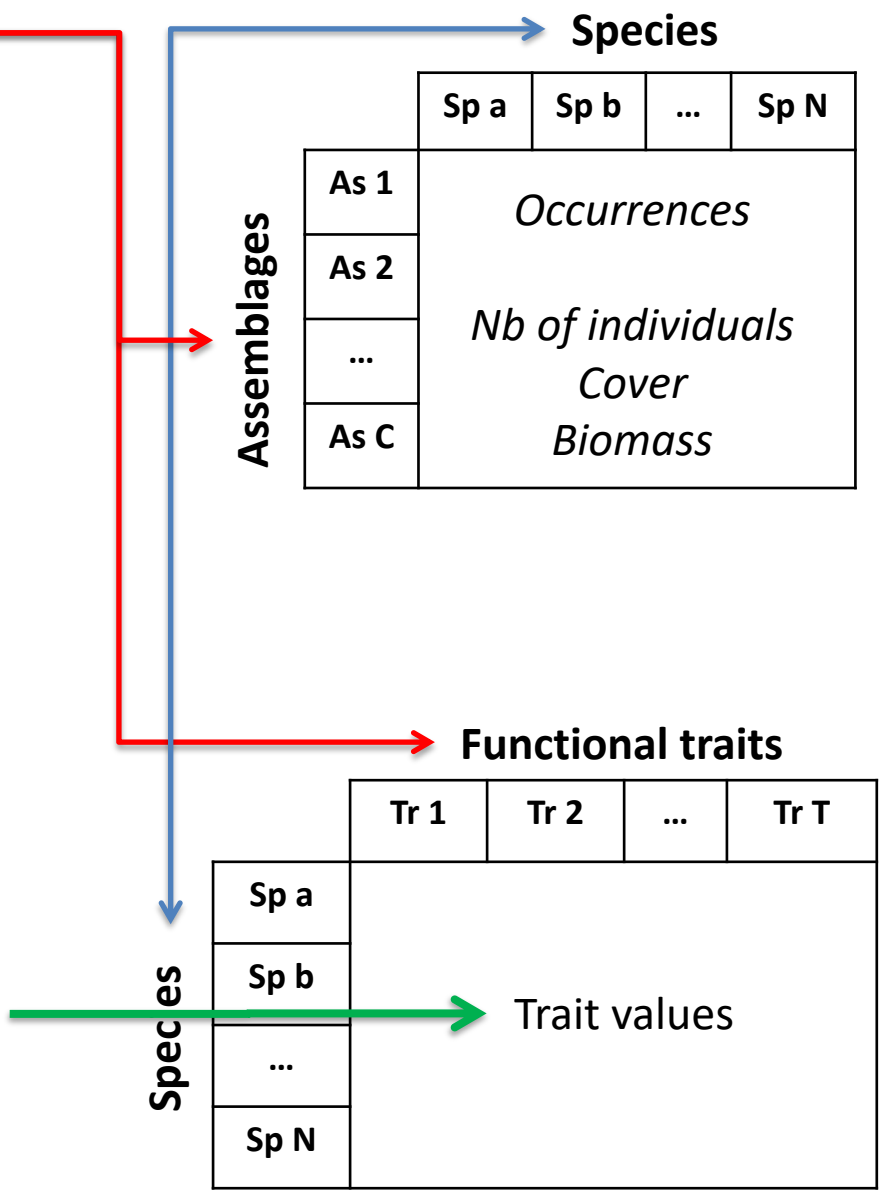
1) Ecological question to address

sampling design and functional traits

2) Sampling species assemblages

=> Species pool

3) Measuring functional traits on all species



From functional traits to functional diversity

How do I measure functional traits ?

- Quantitative traits could be measured with ***continuous*** variables

    => How many replicates per species ?

    => Which precision ?

OR coded as ***ordinal*** variables (from literature)

e.g. small (0-10cm) < medium (10-20cm) < large (>20cm)

From functional traits to functional diversity

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- Strategy (e.g. diet, habitat) could be coded as:
  Fuzzy-coded variables (e.g. proportion of preys in diet)
  Nominal variables (2, 3,…, N categories)

From functional traits to functional diversity

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  Nominal variables (2, 3,…, N categories)

be careful with type of variable when importing traits values to R !

Continuous variable -> *as.numeric*

Ordinal variable -> *as.ordered*

Nominal variable -> *as.factor*

From functional traits to functional diversity

What about missing values ?

Short & simple guidelines:

- Missing values do not prevent computing FD (if not too many)

BUT they could yield patterns hard to discuss

From functional traits to functional diversity

What about missing values ?

Short & simple guidelines:

- Missing values do not prevent computing FD (if not too many)

BUT they could yield patterns hard to discuss

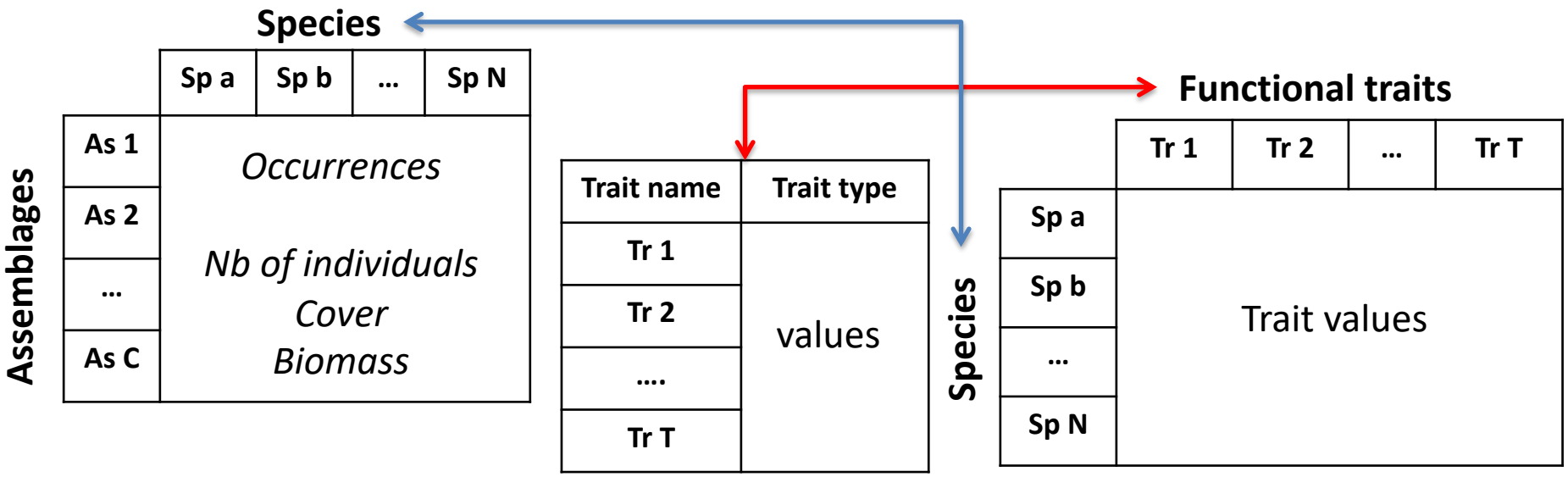
=> Better to have as few as possible using imputation algorithms or expert knowledge

Imputation of missing data in life-history trait datasets: which approach performs the best?

Penone et al 2014 *Methods in Ecology and Evolution* ; doi: 10.1111/2041-210X.12232

From functional traits to functional diversity

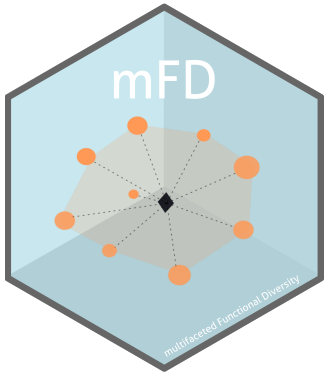
Data to compute FD with *mFD*



Functions

mFD: : sp. tr. summary()

mFD: : asb. sp. summary()

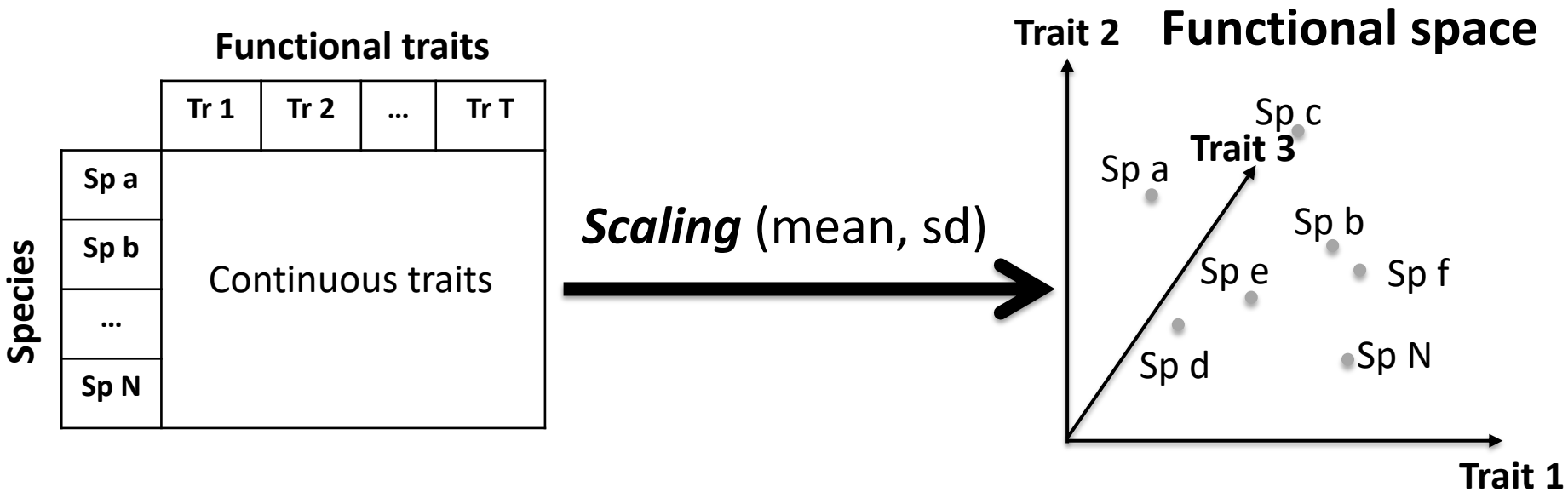


Tutorial

https://cmlmagneville.github.io/mFD/articles/mFD_general_workflow.html

From functional traits to functional diversity

FD with continuous traits



Functional space

=

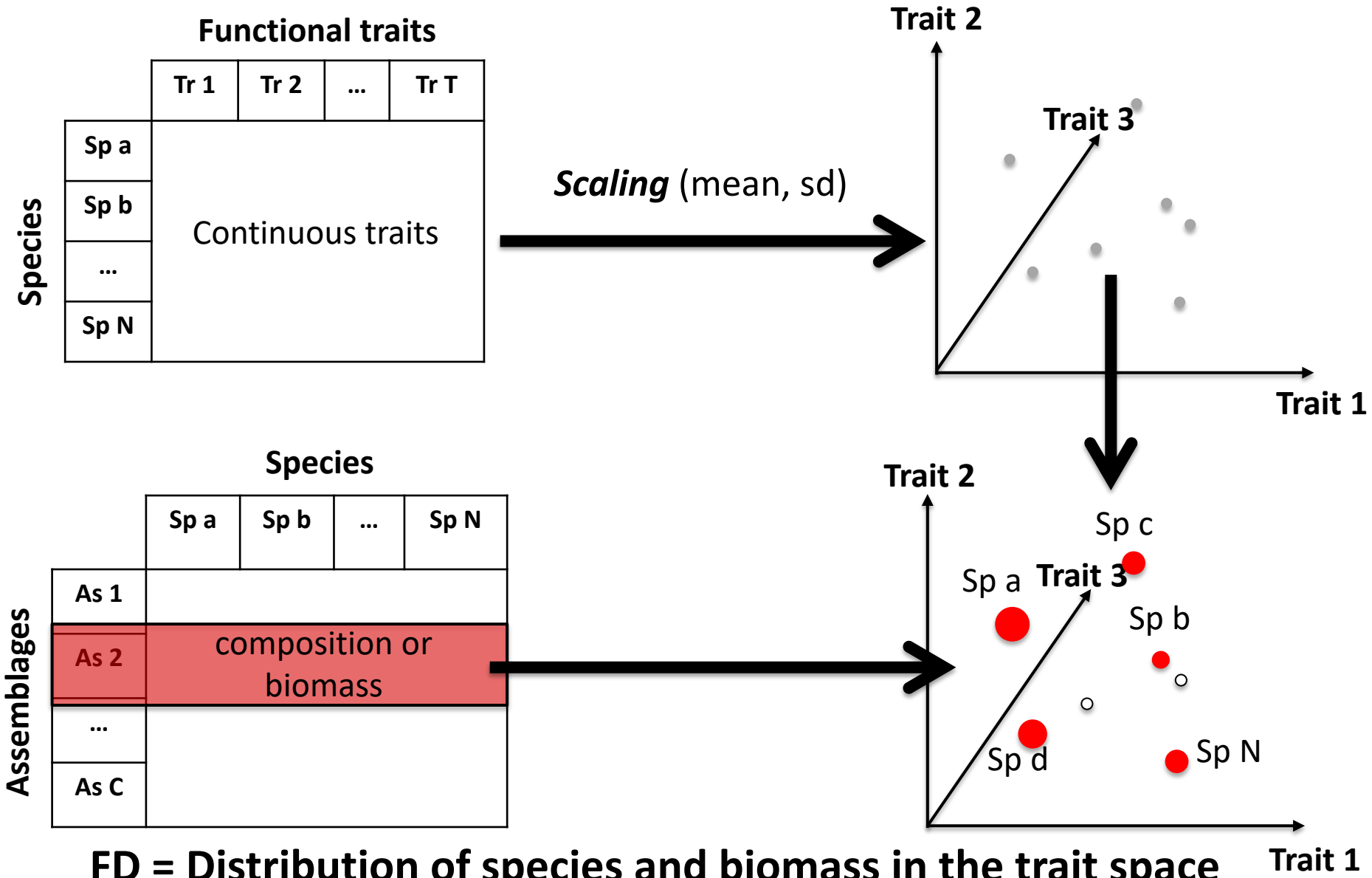
THE Euclidean space

where ALL species present in at least one assemblage

are distributed according to their (transformed) TRAIT values

From functional traits to functional diversity

FD with continuous traits

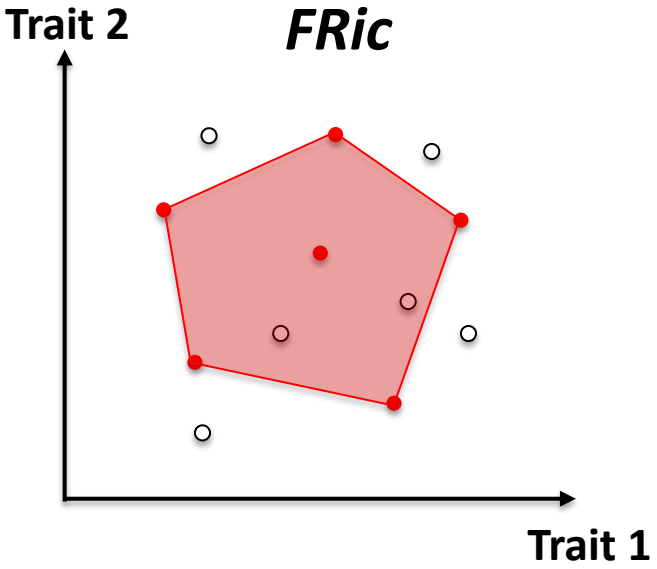


FD = Distribution of species and biomass in the trait space

From functional traits to functional diversity

Complementary indices

All FD indices account for species ***coordinates***
(only from assemblage or also from pool)
Some indices require number of species > threshold
Some indices account for species ***weights***
(relative dominance ; occurrence = same weight)



Mouillot et al 2013, *Trends in Ecology and Evolution* ; doi: 10.1016/j.tree.2012.10.004

https://frbcesab.github.io/workshop-free/biblio/FD_alpha_full.pdf

From functional traits to functional diversity

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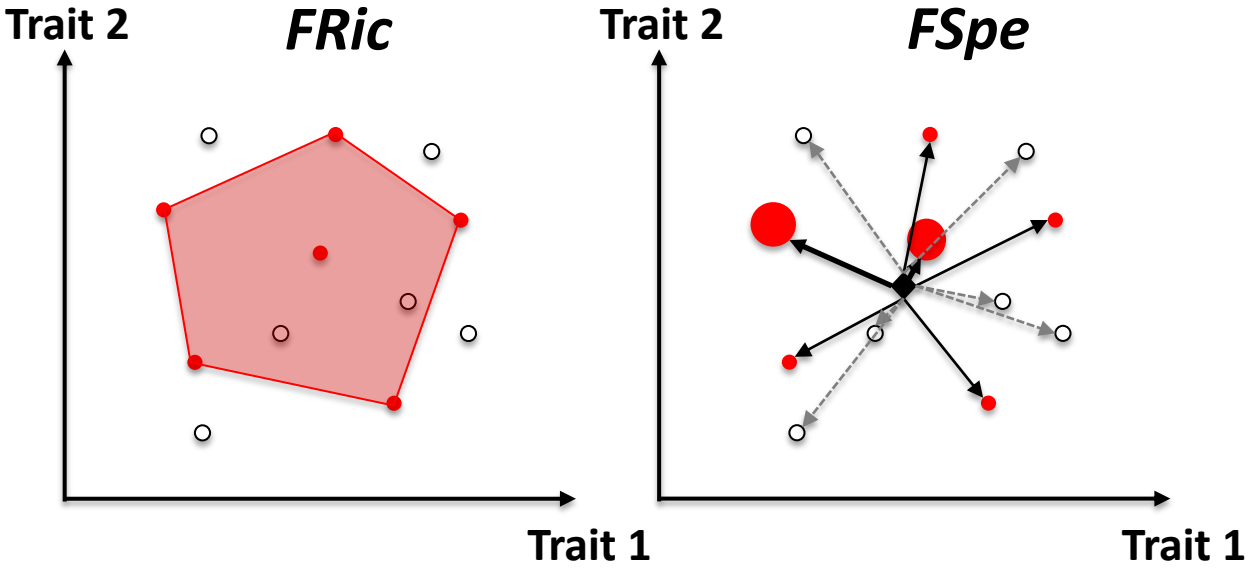

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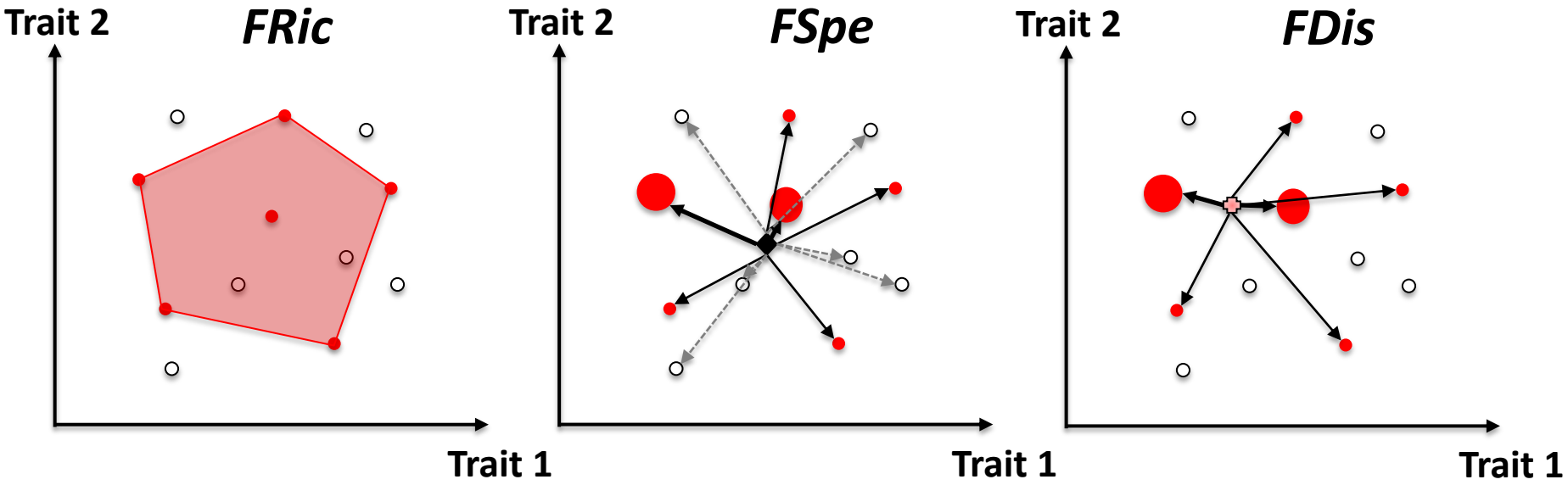

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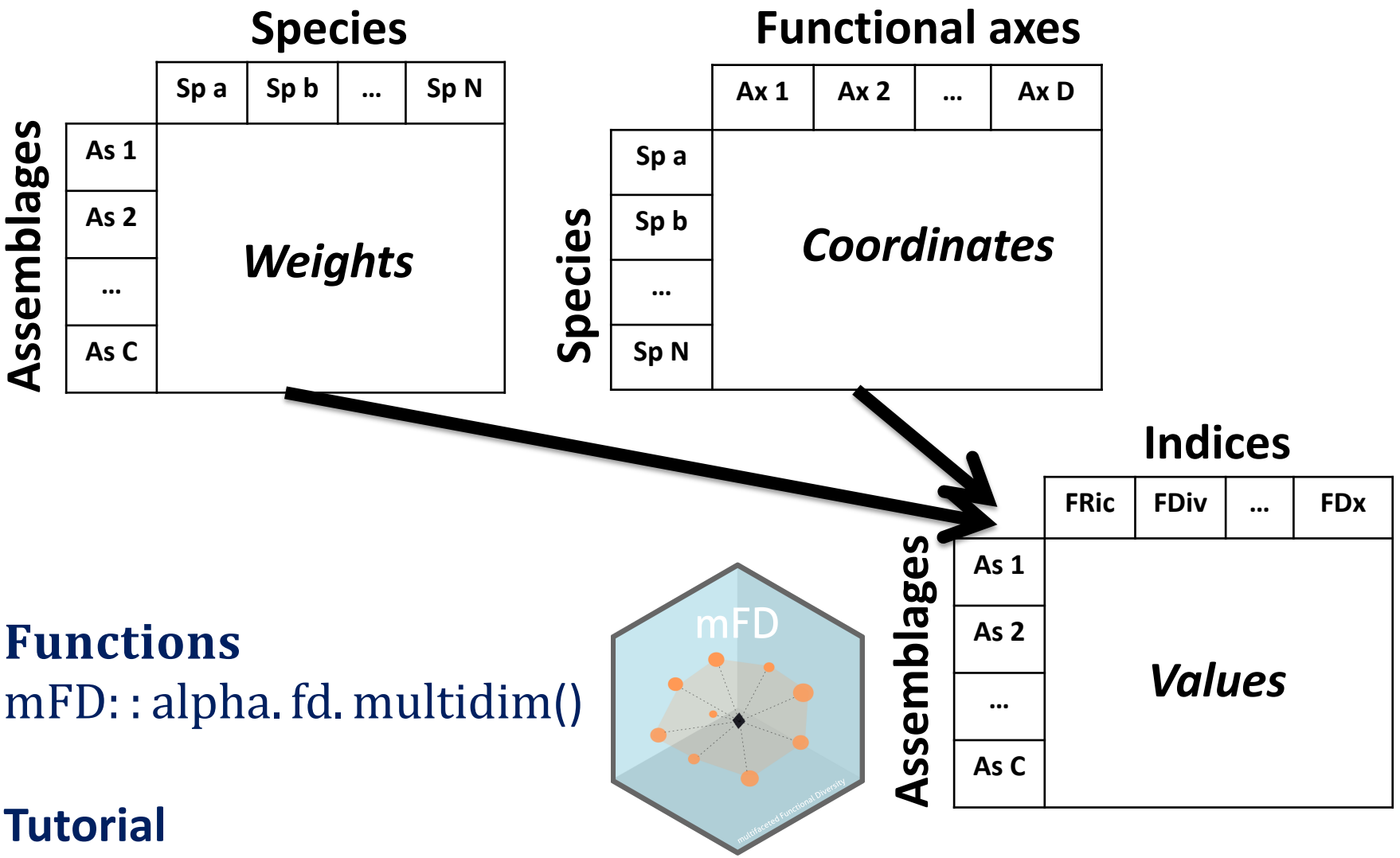
From functional traits to functional diversity

Complementary indices



Functions

mFD: : alpha. fd. multidim()

Tutorial

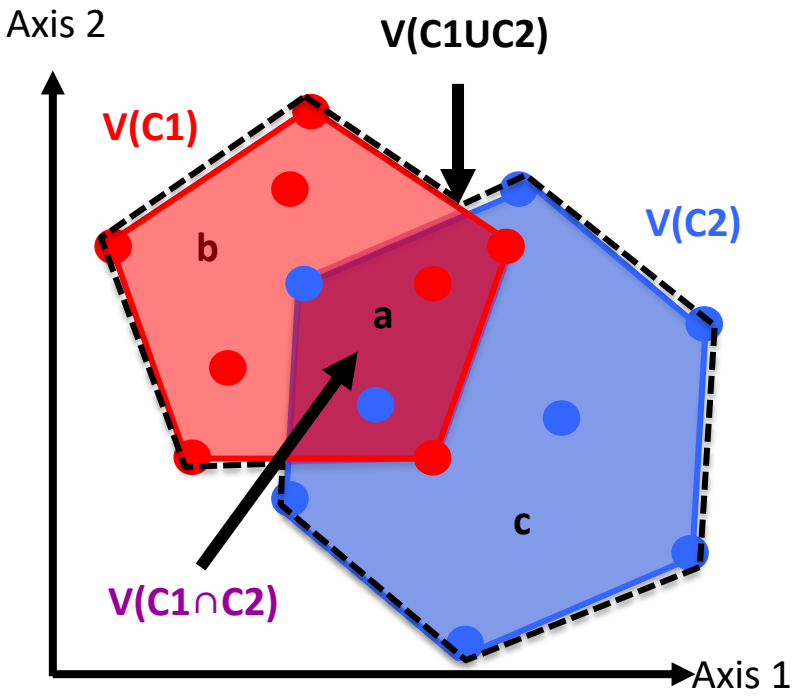
https://cmlmagneville.github.io/mFD/articles/mFD_general_workflow.html

From functional traits to functional diversity

Measuring functional dissimilarity between assemblages

Dissimilarity accounting only for composition

=> Jaccard-like index based on intersection of convex hulls



$$\beta_{functional} = \frac{\text{functional space not shared}}{\text{total functional space filled}}$$

$$\beta_{functional} = \frac{b+c}{a+b+c}$$

Ranges from 0 (perfect overlap) to 1 (no overlap)

Villéger et al. 2013, Global. *Ecol. Biogeogr. ; doi:* 10.1111/geb.12021

From functional traits to functional diversity

Measuring functional dissimilarity between assemblages

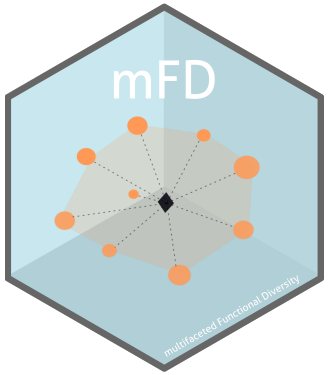
Dissimilarity accounting only for composition

=> Jaccard-like index based on intersection of convex hulls

Functions

mFD: : beta.fd.multidim()

mFD: : beta.multidim.plot()



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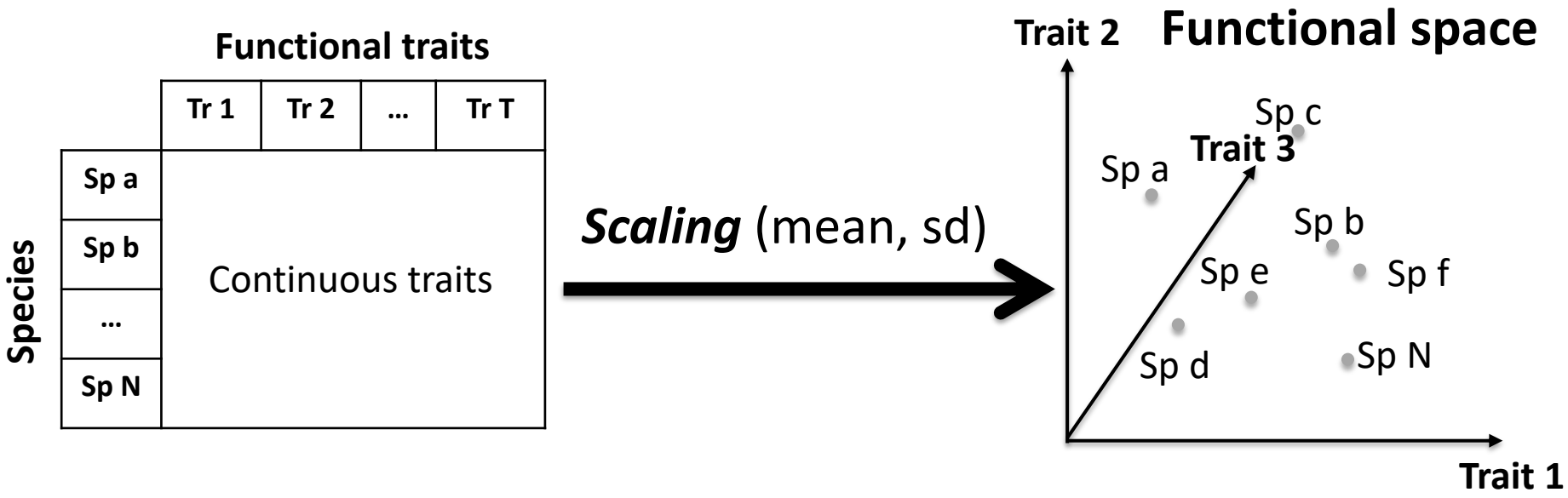
From functional traits to functional diversity

FD with continuous traits



Functional space

=

THE Euclidean space

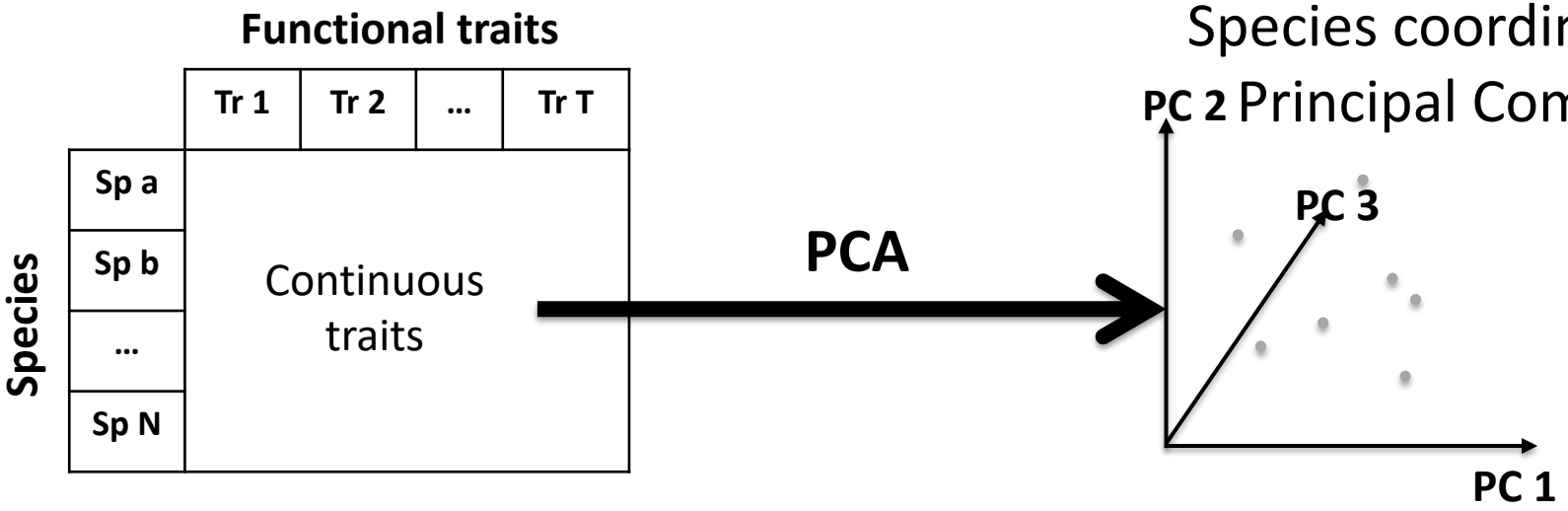
where ALL species present in at least one assemblage

are distributed according to their (transformed) TRAIT values

How to build a space when traits are numerous or not continuous ?

Building a good functional space

Space with continuous traits



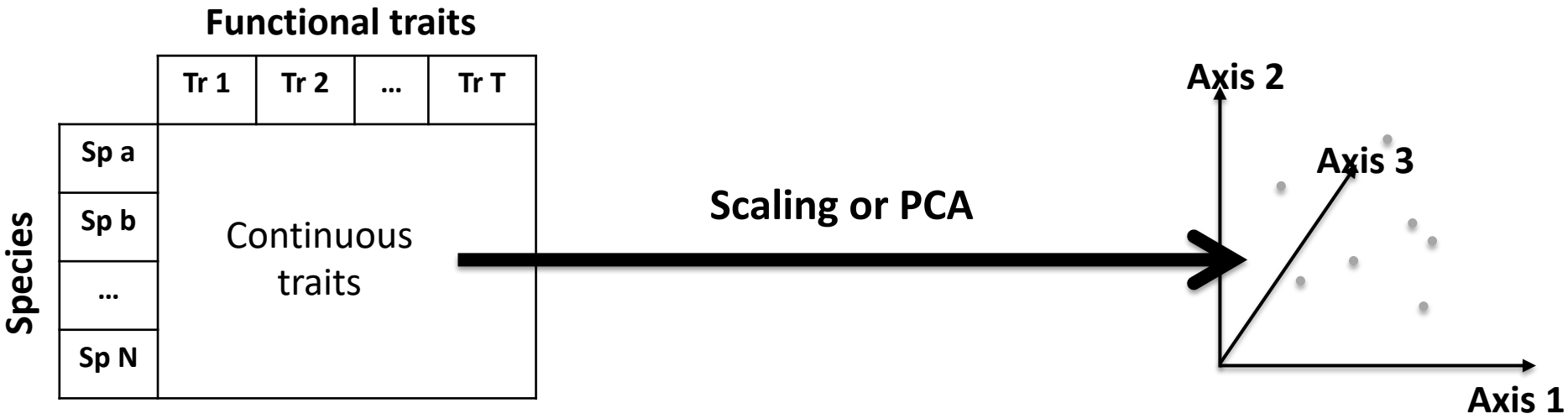
+ % of inertia for each PC
+ correlation between traits and PC

Functional space from Principal Component Analysis

$\Rightarrow$ useful when >5 traits (e.g. morphometrics)
to have a few independent axes

Building a good functional space

Space with continuous traits



Function

mFD::tr.cont.scale

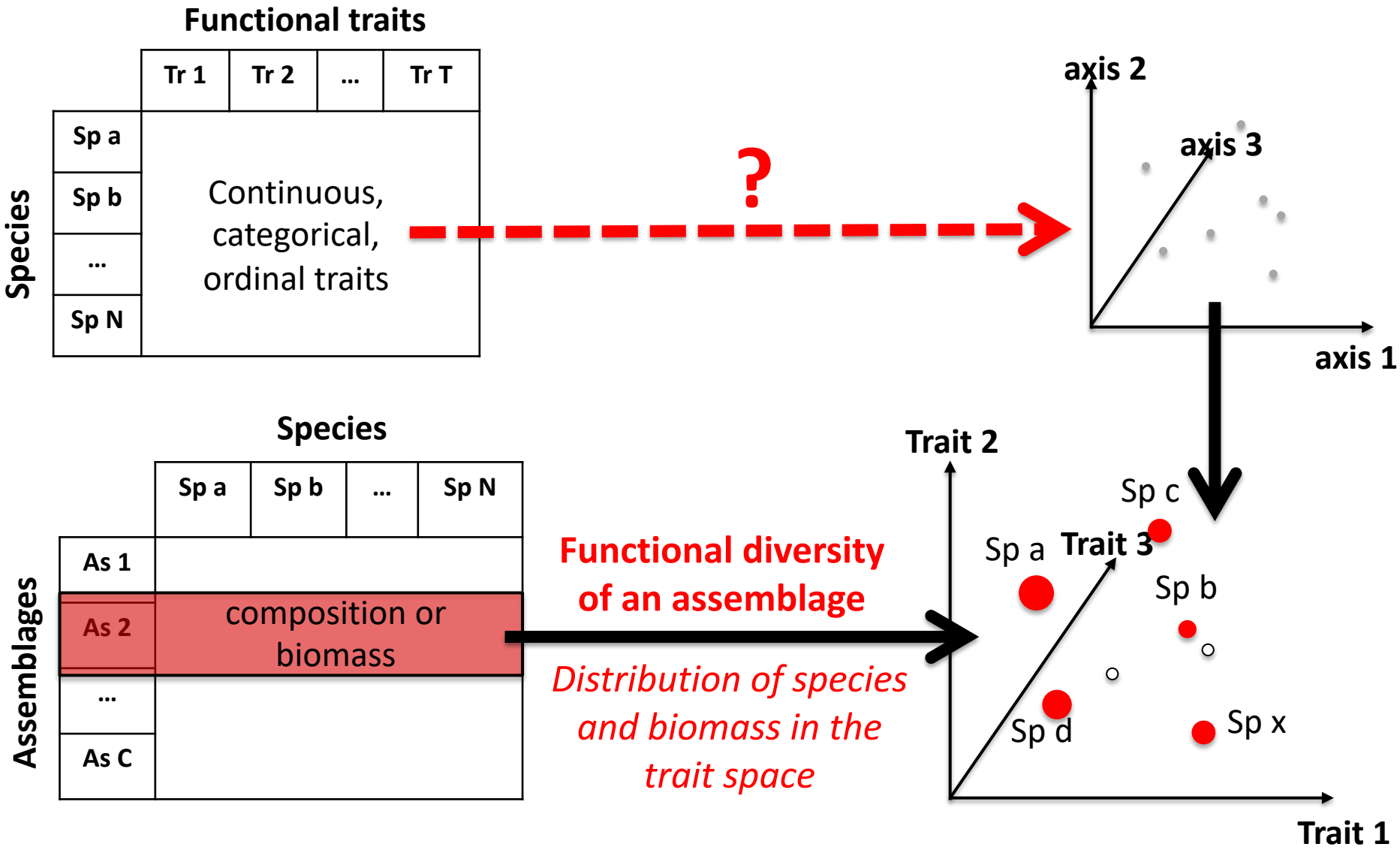
mFD::tr.cont.fspace

Tutorial

https://cmlmagneville.github.io/mFD/articles/Continuous_traits_framework.html

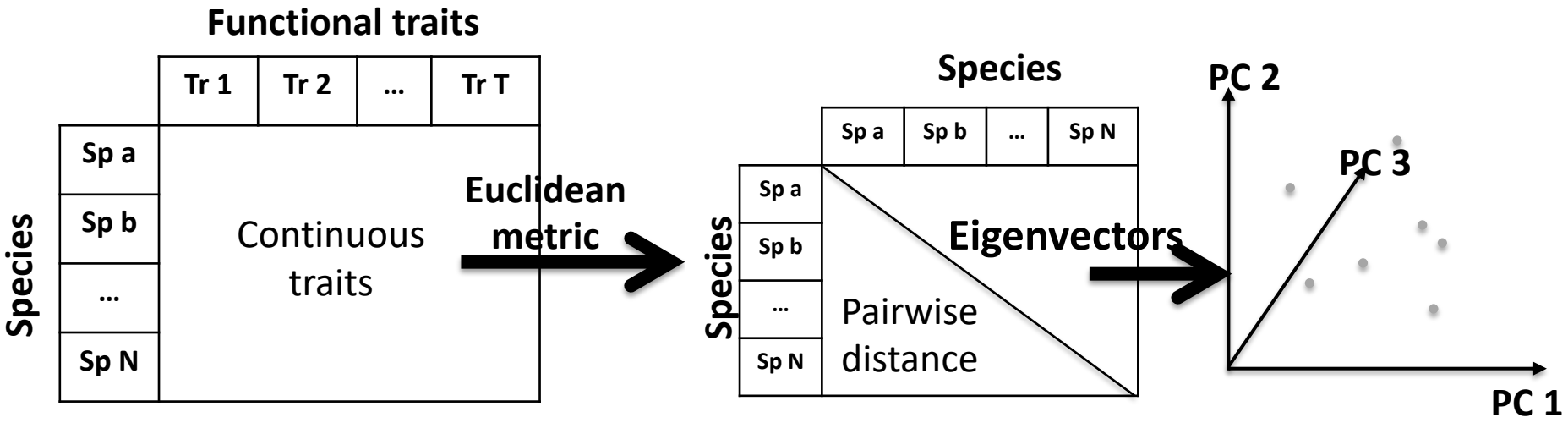
From functional traits to functional diversity

FD with non-continuous traits



Building a good functional space

Space with continuous traits



Principal Component Analysis

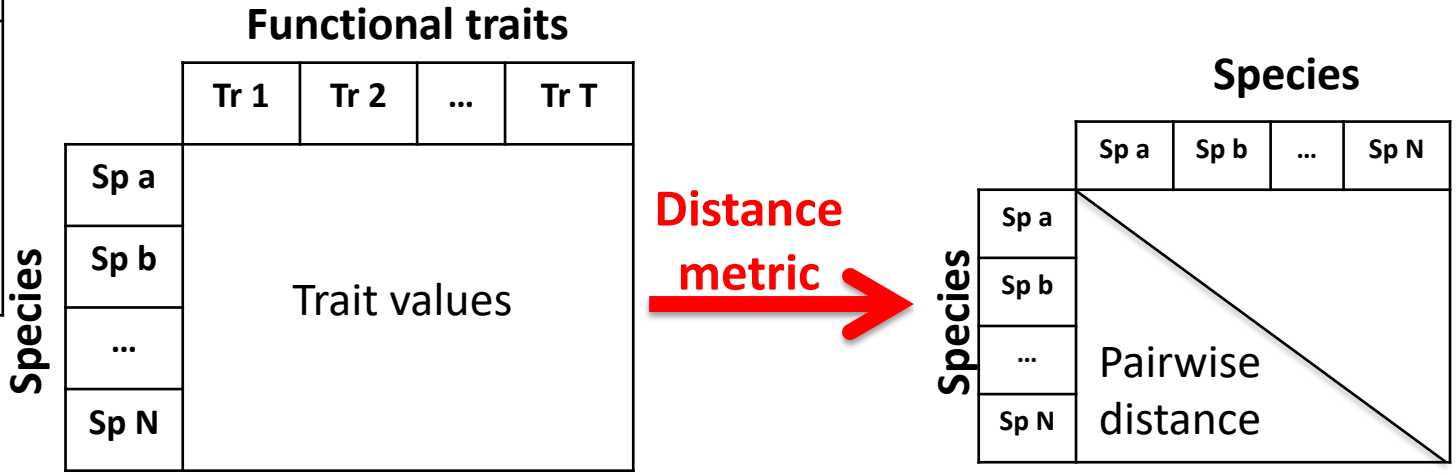
=

Eigenvectors computed on distance matrix

Building a good functional space

Computing functional distances

Trait name	Trait type
Tr 1	
Tr 2	
….	
Tr T	



Generalized Gower distance
is able to deal with all types of traits

Building a good functional space

Computing functional distances

Trait name	Trait type
Tr 1	
Tr 2	
....	
Tr T	

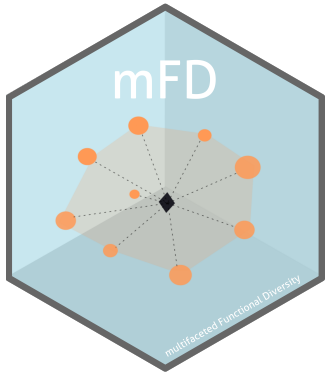
Functional traits

Species	Tr 1	Tr 2	...	Tr T
Sp a	Trait values			
Sp b				
...				
Sp N				

Distance metric

Species

Species	Sp a	Sp b	...	Sp N
Sp a	Pairwise distance			
Sp b				
...				
Sp N				



Function

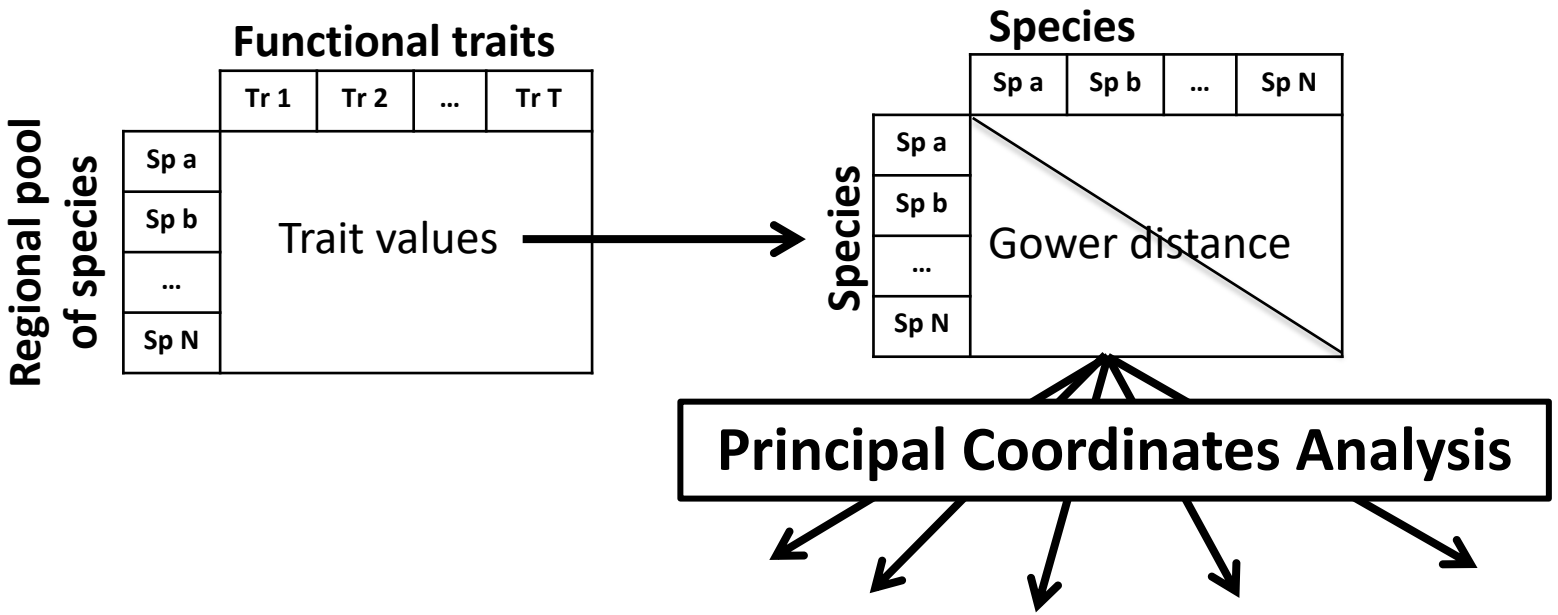
mFD::funct.dist()

Tutorial

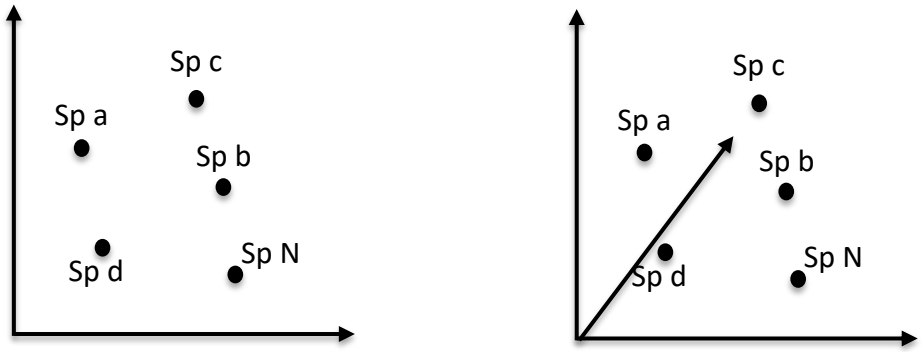
https://cmlmagneville.github.io/mFD/articles/Continuous_traits_framework.html

Building a good functional space

Computing multidimensional spaces

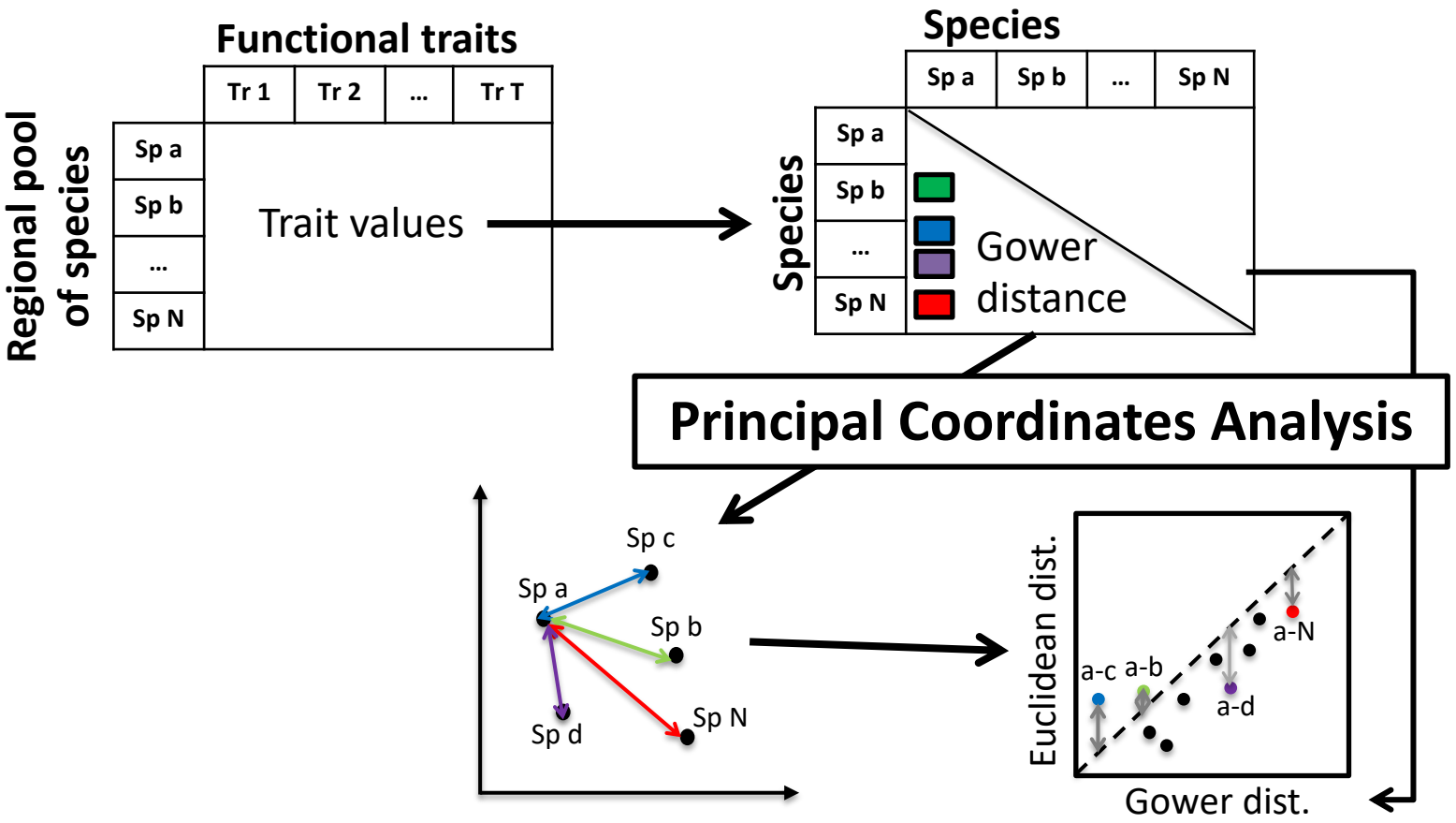


Multidimensional spaces from 2 to N-1 dimensions



Building a good functional space

Computing multidimensional spaces



quality of each space = average of (absolute or squared) **deviations** between trait-based distances and space-based distances

Maire et al. 2015, *Global. Ecol. Biogeogr. ;* doi: 10.1111/geb.12299

Building a good functional space

Computing multidimensional spaces

How many dimensions are needed to accurately assess functional diversity? A pragmatic approach for assessing the quality of functional spaces

Take home messages:

Compute all spaces possible and keep the one with lowest deviations

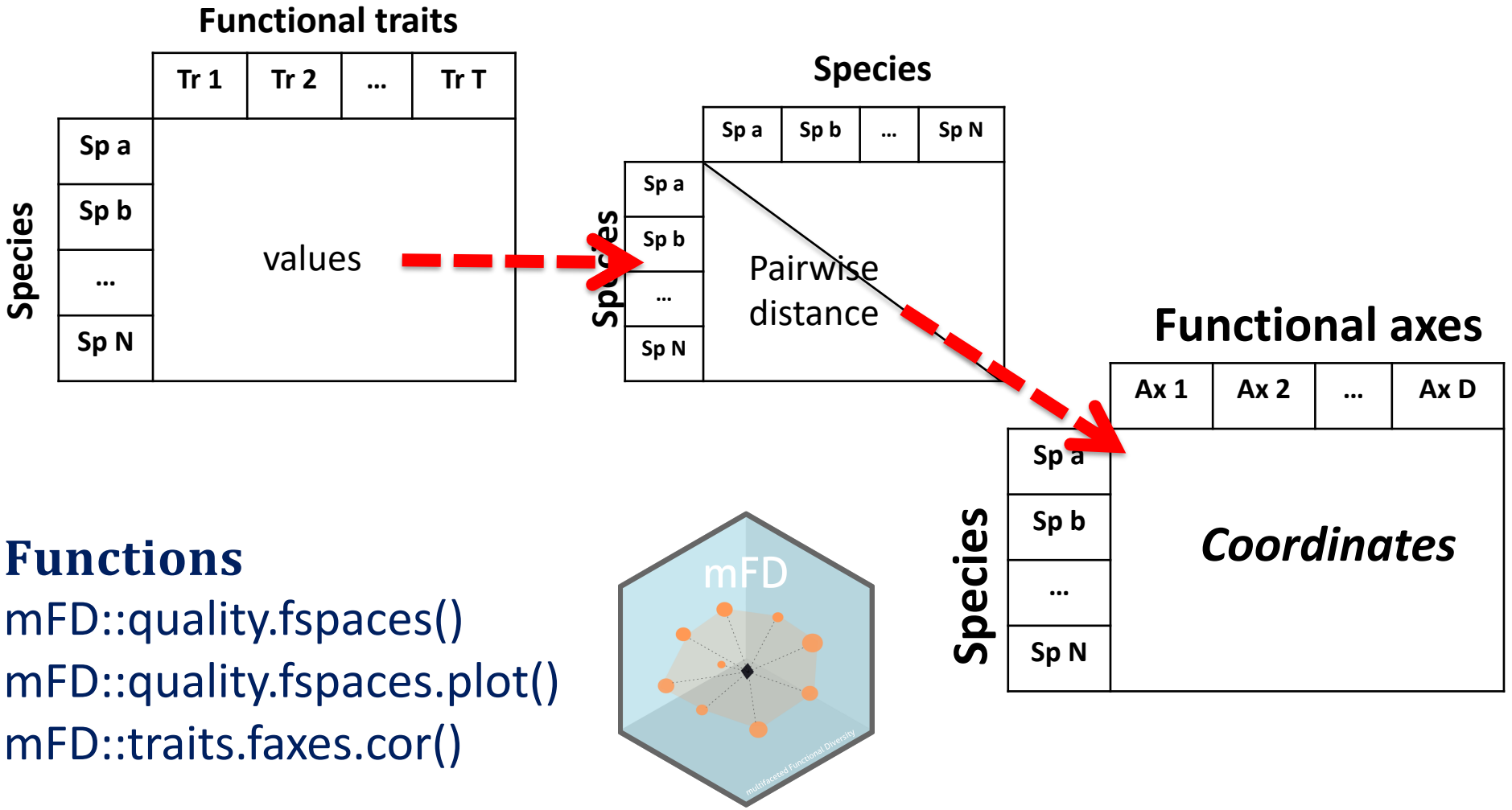
=> 4-D spaces are usually good

=> 2-dim PCoA based spaces and dendrograms are (most) often bad

Maire et al. 2015, *Global. Ecol. Biogeogr. ;* doi: 10.1111/geb.12299
Mouillot et al. 2021, *Ecology Letters;* doi: 10.1111/ele.13778

Building a good functional space

Computing multidimensional space



Functions

mFD::quality.fspaces()

mFD::quality.fspaces.plot()

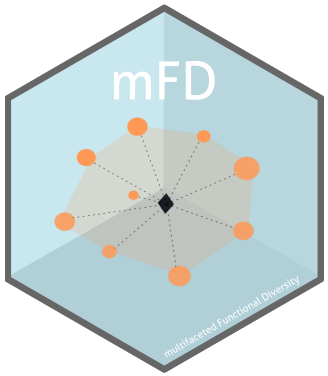
mFD::traits.faxes.cor()

Tutorial

https://cmlmagneville.github.io/mFD/articles/mFD_general_workflow.html

Next step

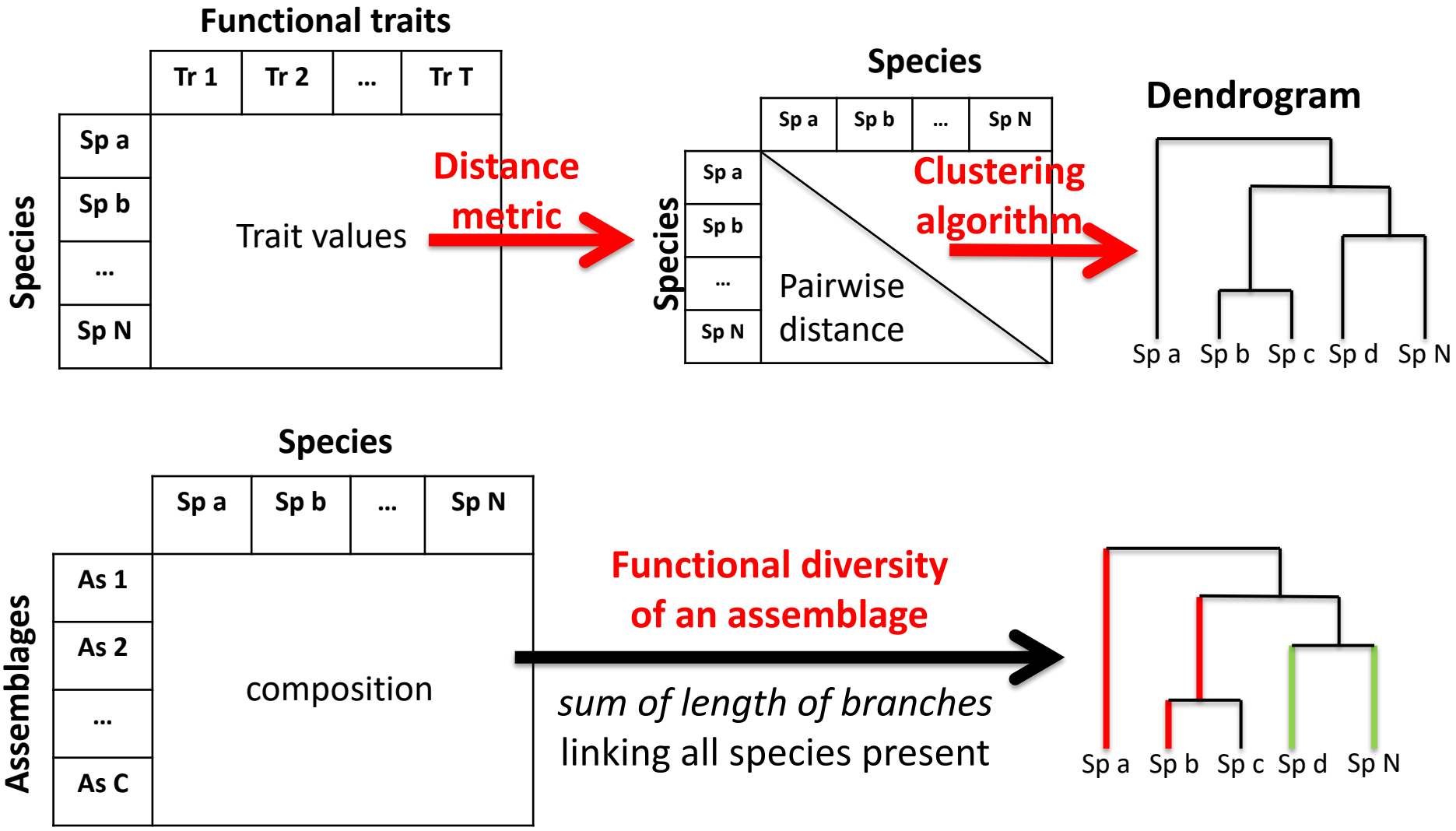
Time to practice !



https://frbcesab.github.io/workshop-free/practice.html

Building a good functional space

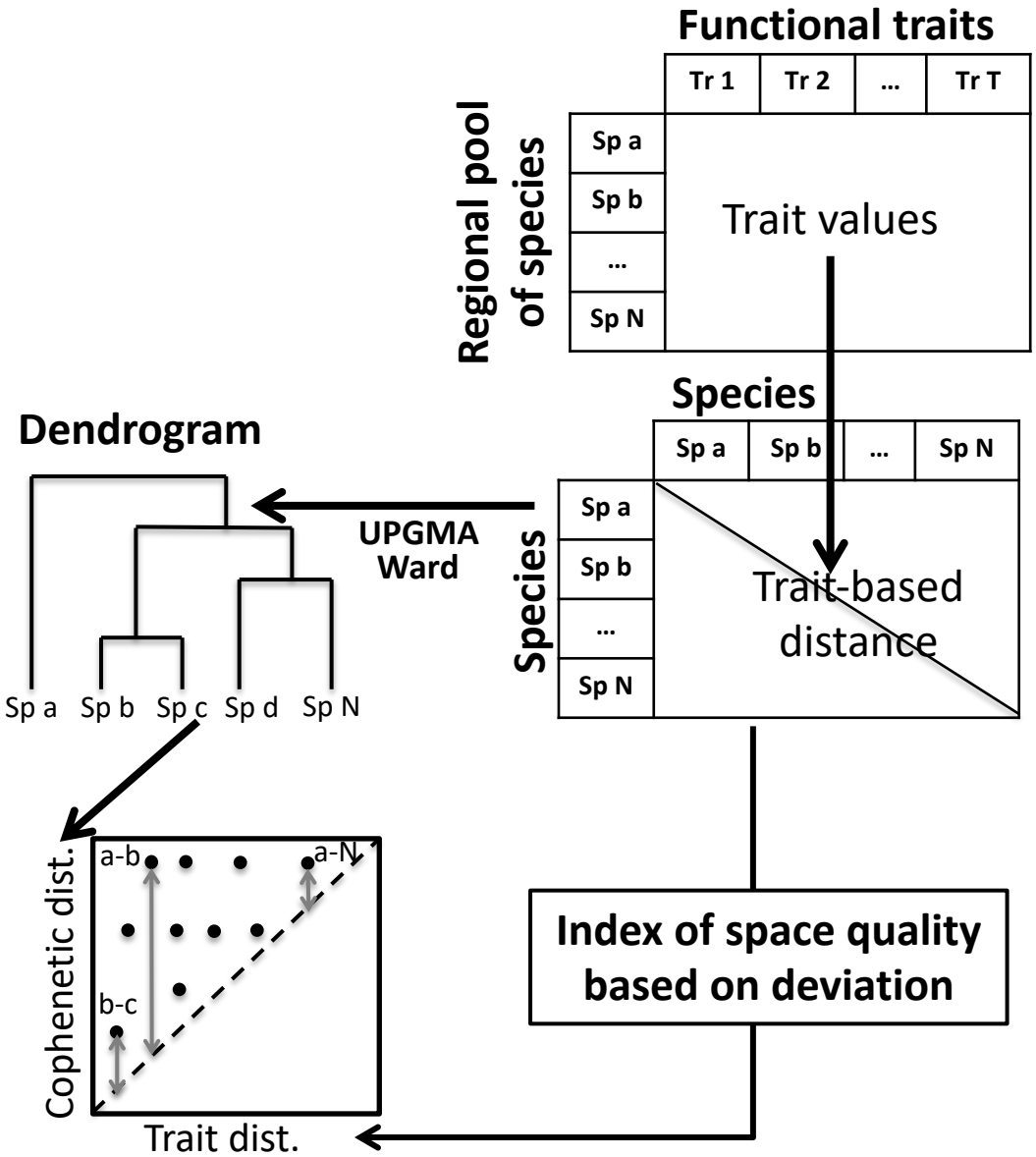
On the risk of using dendrograms



Petchey & Gaston 2002, *Ecol. Lett.*

Building a good functional space

On the risk of using dendrograms



Building a good functional space

On the risk of using dendrograms

Illustration with a fruits study case (5 traits)

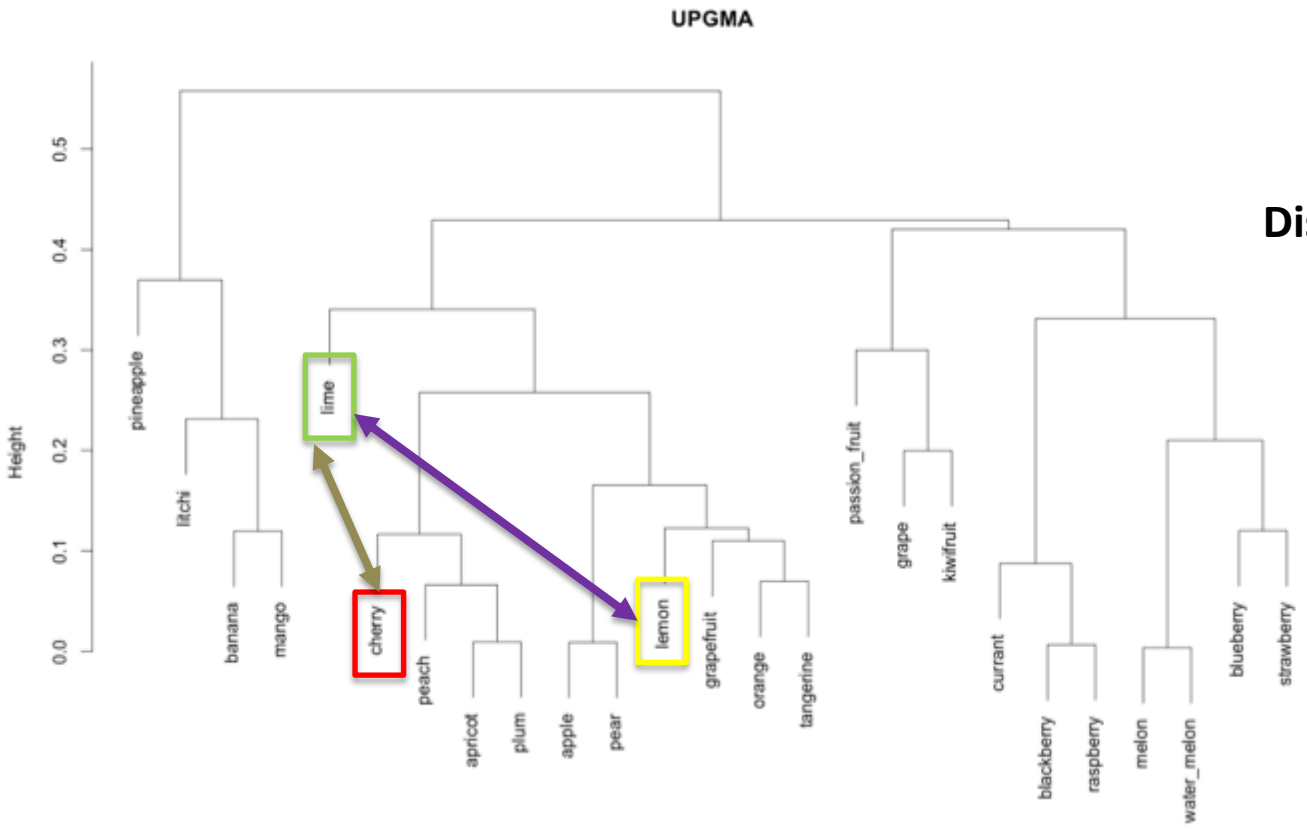
Traits values

	Size	Plant	Origin	Seed	Sugar_content
cherry	small	tree	temperate	pit	0.1282
lime	medium	tree	tropical	pip	0.0169
lemon	large	tree	subtropical	pip	0.0250

Gower distance

	cherry	lime	lemon
cherry	0.000	0.503	0.442
lime	0.503	0.000	0.161
lemon	0.442	0.161	0.000

/3



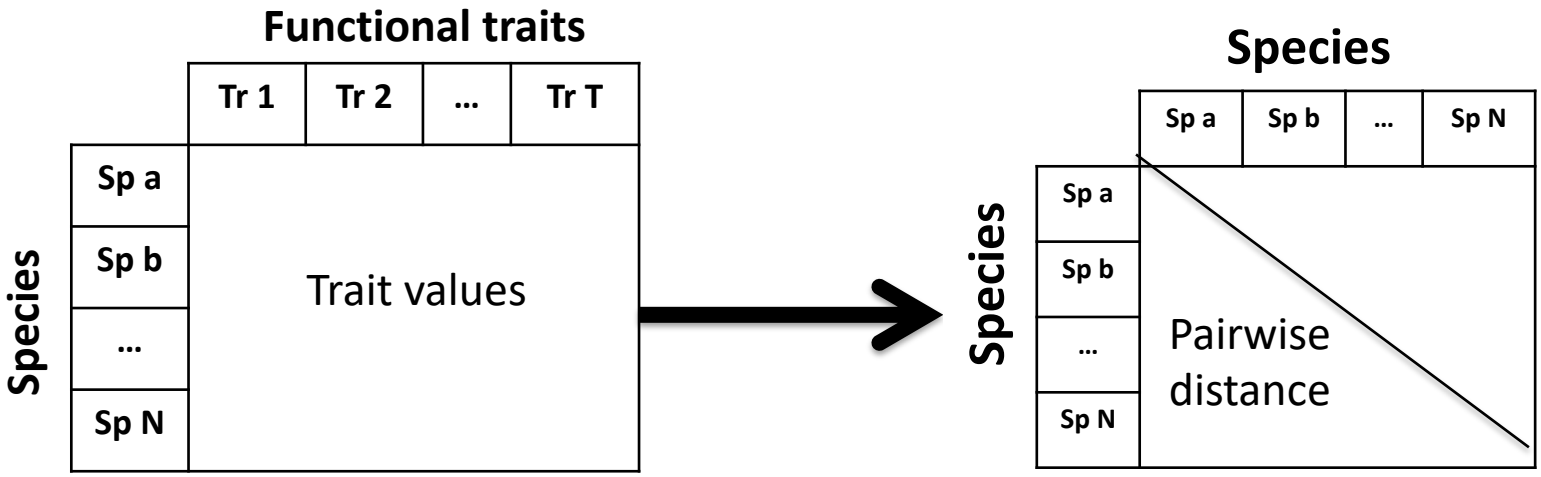
Distance on best dendrogram

	cherry	lime	lemon
cherry	0.000	0.529	0.400
lime	0.529	0.000	0.529
lemon	0.400	0.529	0.000

=

Others approaches to assess functional diversity

Measuring functional diversity with Hill numbers



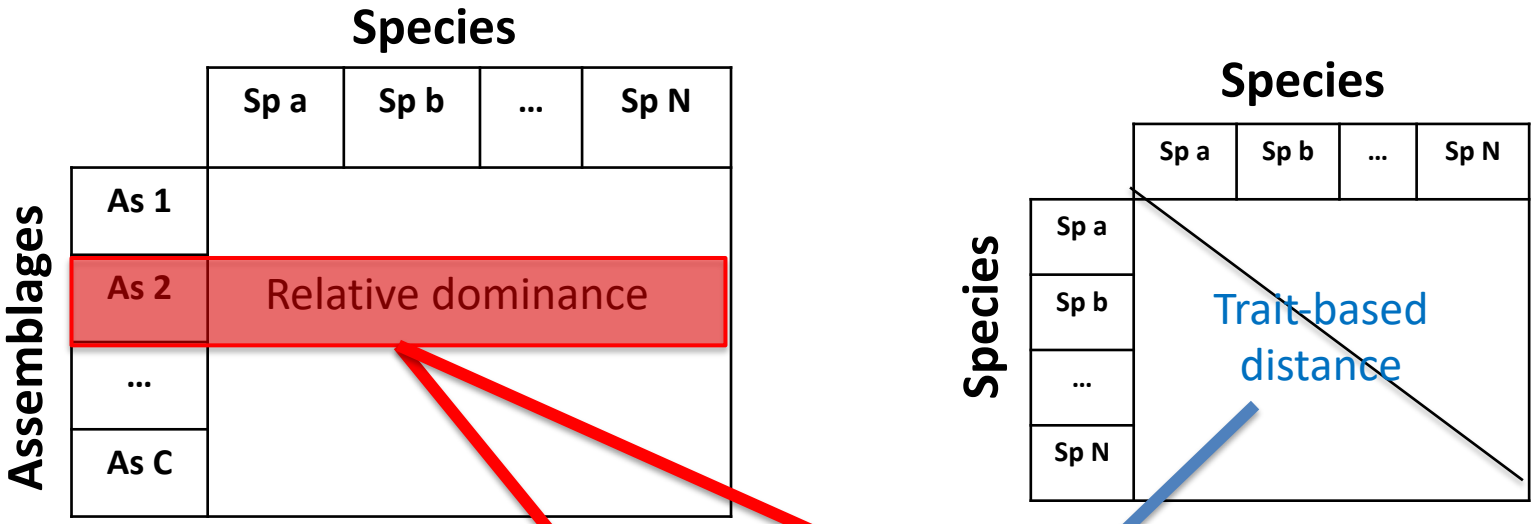
Hill numbers

General framework allowing to compute taxonomic, phylogenetic and functional diversities with the same unit (*number of distinct species*)

Chao et al. 2019, *Ecological Monograph ;* doi: 10.1002/ecm.1343

Others approaches to assess functional diversity

Measuring functional diversity with Hill numbers



$$ {}^{q}FD(\Delta(\tau)) = \left(\sum_{i=1}^{S} p_i \left(\sum_{j=1}^{S} [1 - f(d_{ij}(\tau))] p_j \right)^{q-1} \right)^{1/(1-q)} $$

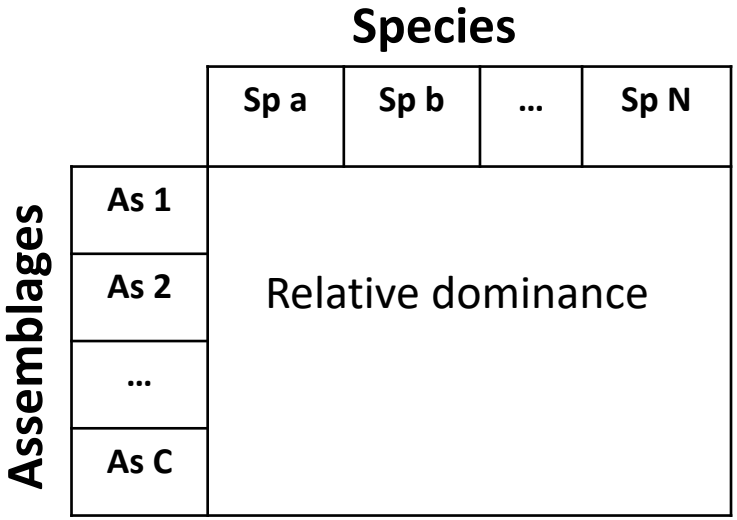
τ: threshold of distinctiveness
=> τ =*mean(d_{ij}) is optimal*

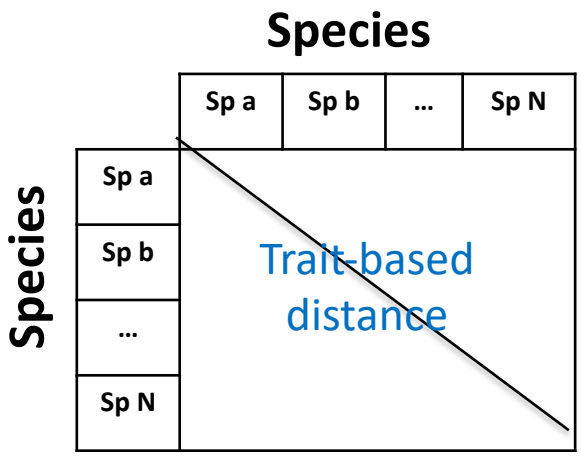
q; relative weight given to dominance vs distance
=> q=0 for richness index
=> q=1 for entropy index

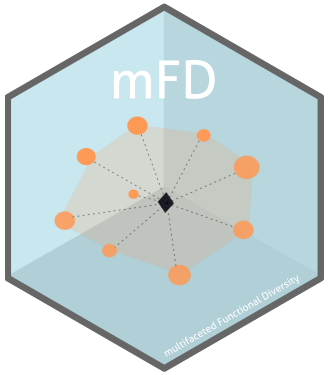
Chao et al. 2019, *Ecological Monograph ;* doi: 10.1002/ecm.1343

Others approaches to assess functional diversity

Measuring functional diversity with Hill numbers







Function

mFD::alpha.fd.hill()

Tutorial

https://cmlmagneville.github.io/mFD/articles/Compute_functional_hill_indices.html

Others approaches to assess functional diversity

Measuring functional dissimilarity between assemblages

Dissimilarity accounting for species dominance

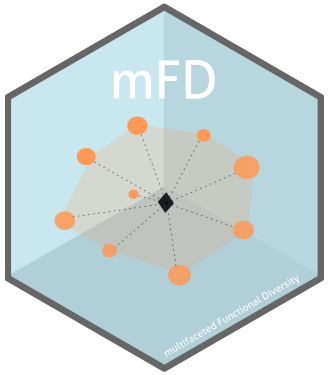
=> index based on Hill numbers (multiplicative decomposition)

$$ {}^{q}FD_{\beta}(\Delta(\tau)) = \frac{{}^{q}FD_{\gamma}(\Delta(\tau))}{{}^{q}FD_{\alpha}(\Delta(\tau))} $$

Tau (τ) is a threshold for functional distance

q (0,1, 2,…) is the weight given to dominance relative to distance

Chao et al. 2019, *Ecological Monograph ;* doi: 10.1002/ecm.1343



Function

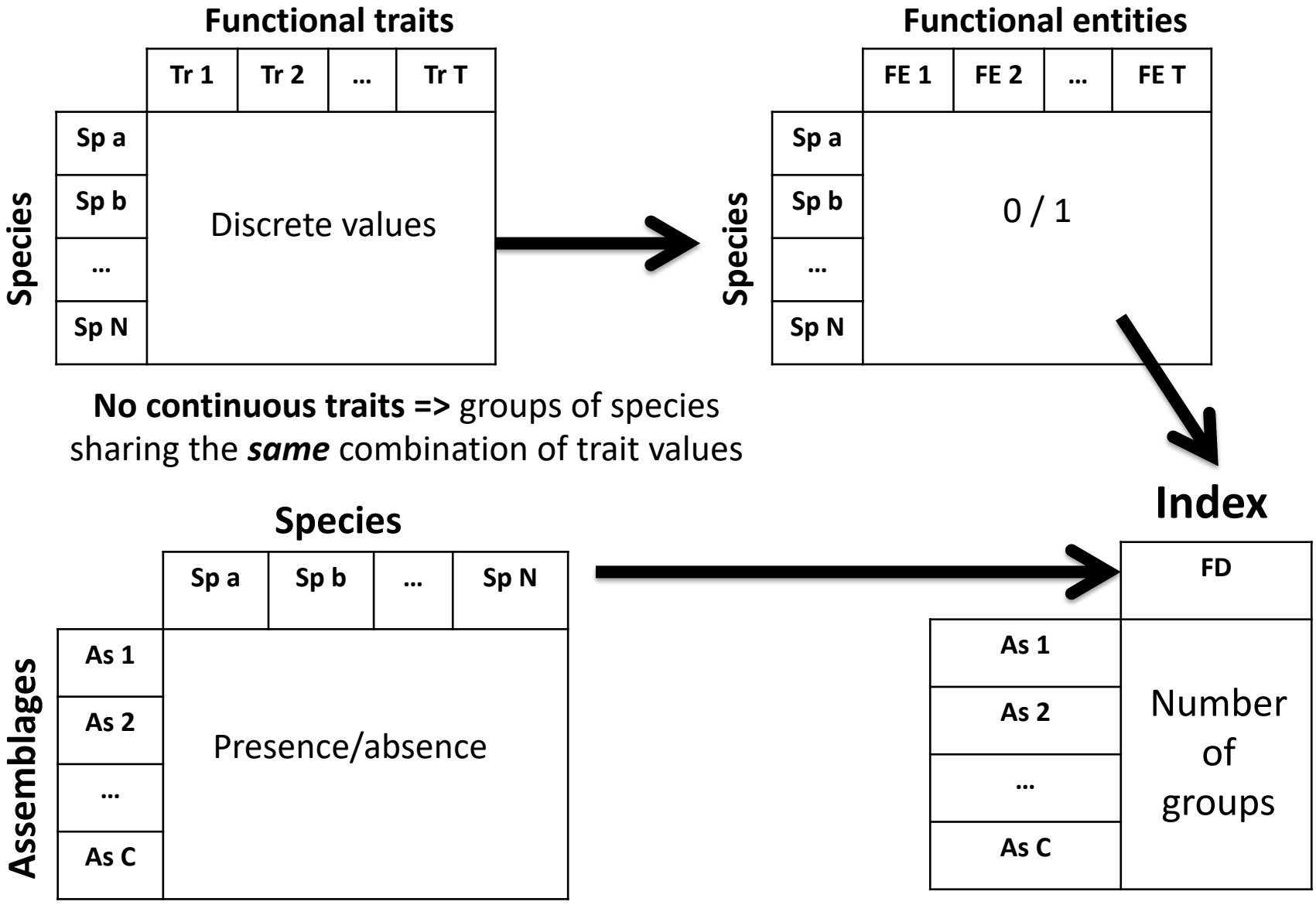
mFD::beta.fd.hill()

Tutorial

https://cmlmagneville.github.io/mFD/articles/Compute_functional_hill_indices.html

Others approaches to assess functional diversity

Measuring functional diversity with functional entities

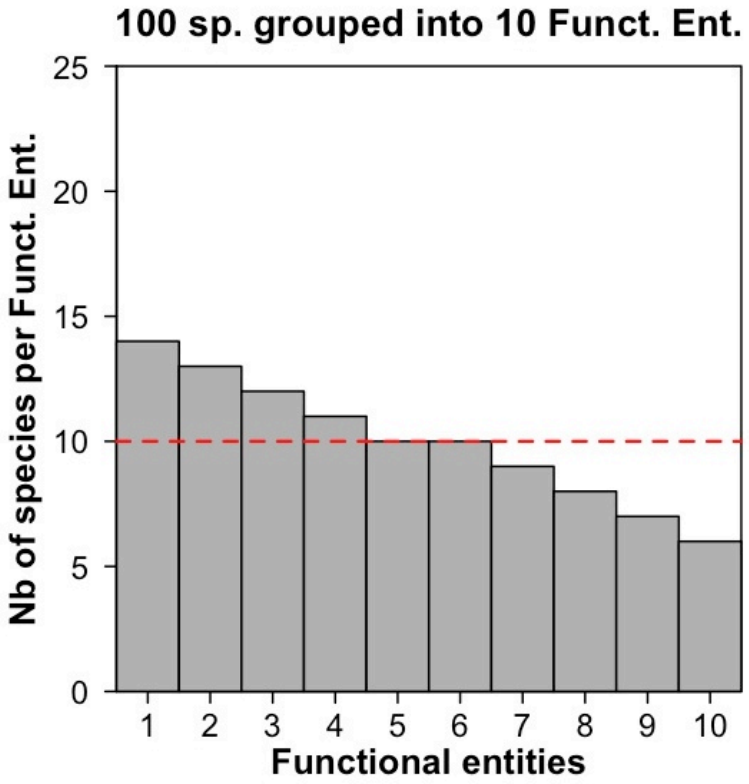


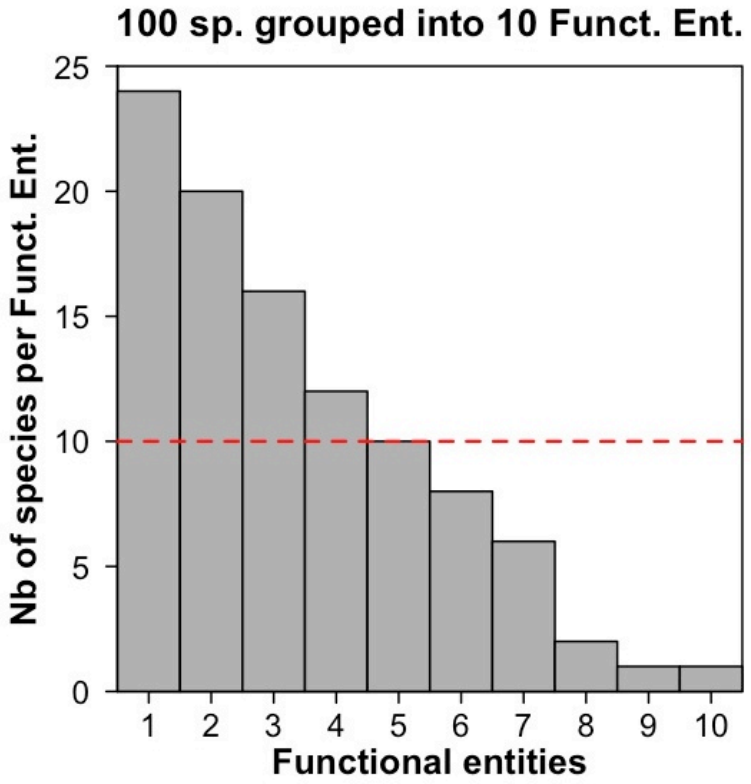
Others approaches to assess functional diversity

Measuring functional diversity with functional entities

Distribution of species among functional entities

Functional redundancy **=** mean number of species per Funct. Ent.





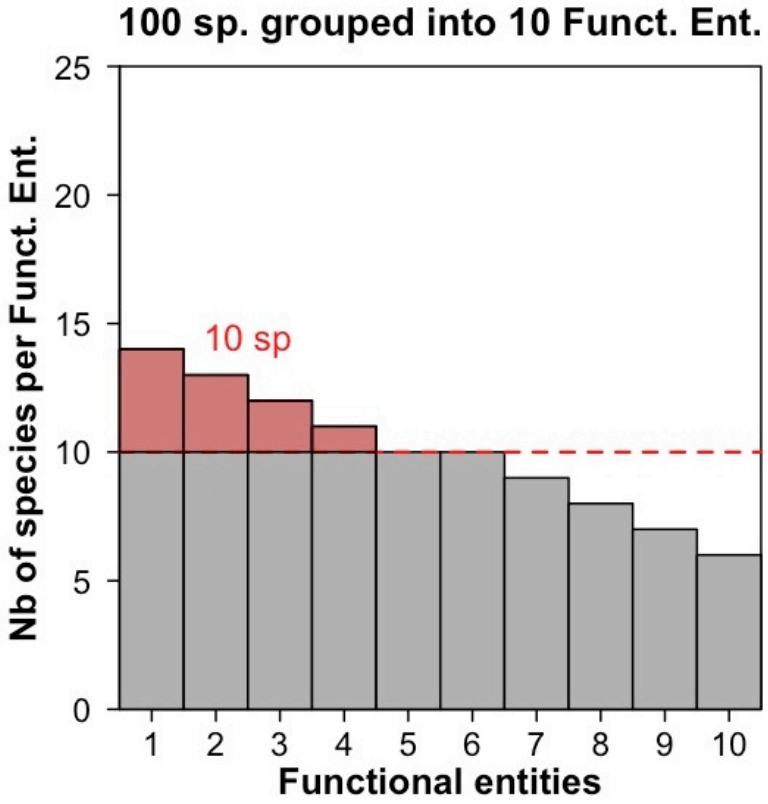
Mouillot et al. 2014, *PNAS* ; doi: 10.1073/pnas.1317625111

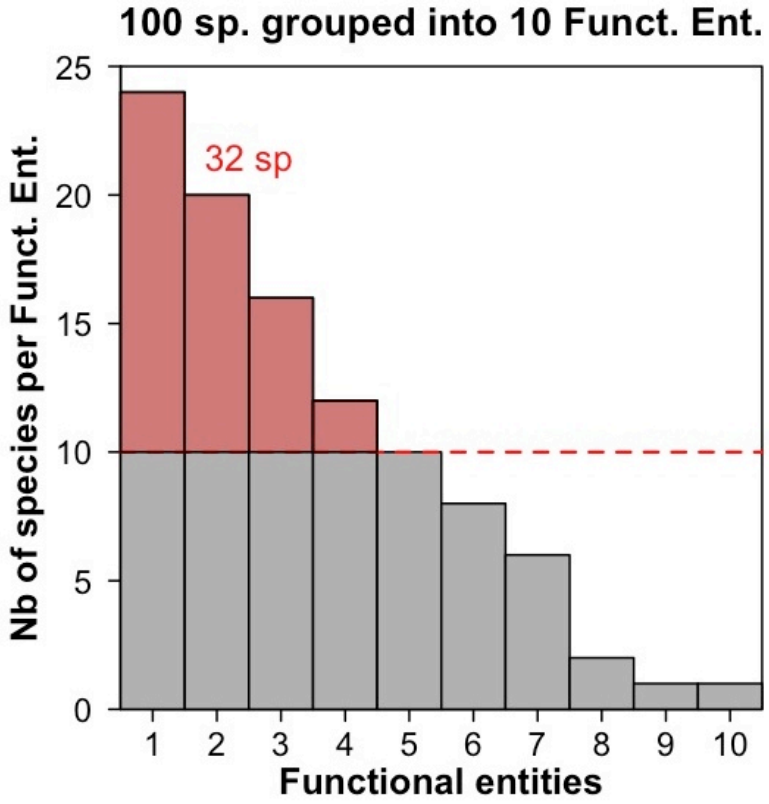
Others approaches to assess functional diversity

Measuring functional diversity with functional entities

Distribution of species among functional entities

Functional over-redundancy = proportion of species in excess in species-rich Funct. Ent.





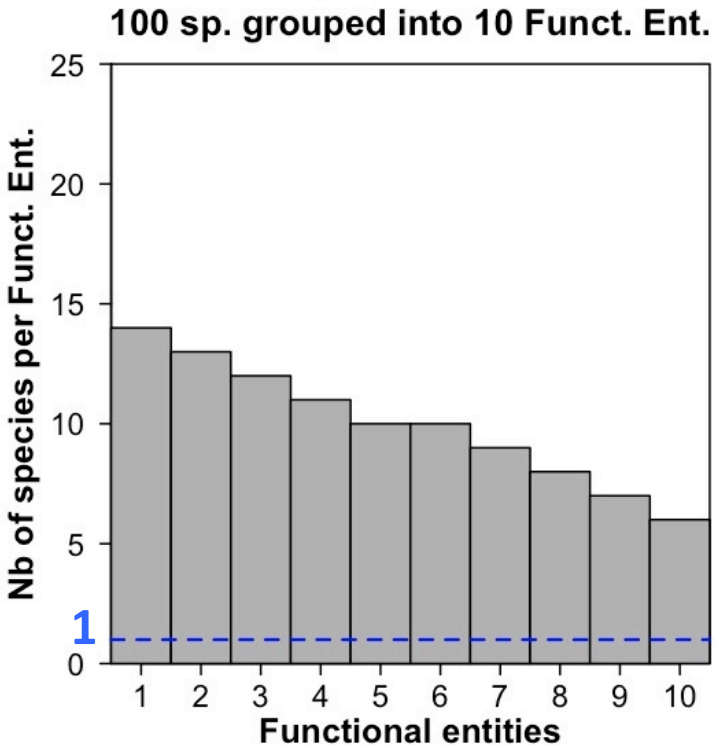
Mouillot et al. 2014, *PNAS* ; doi: 10.1073/pnas.1317625111

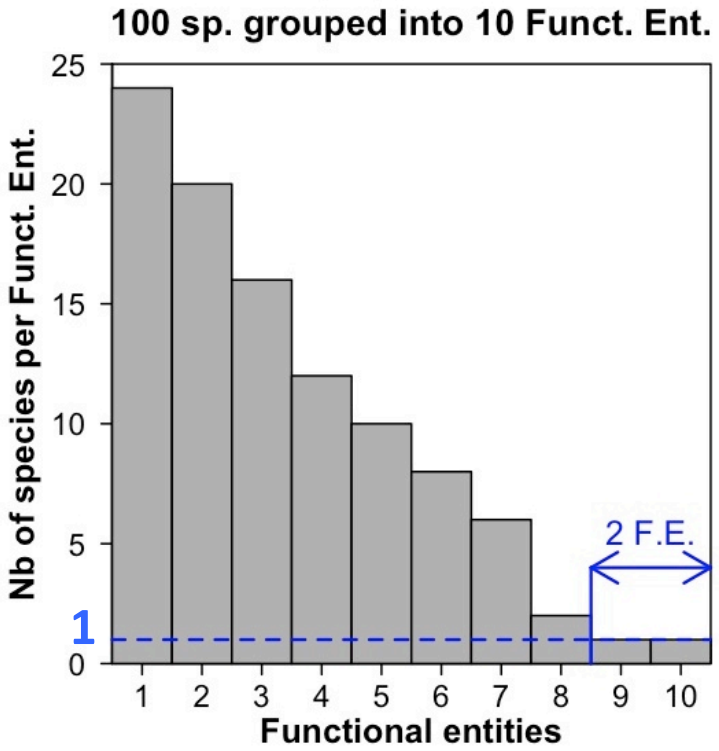
Others approaches to assess functional diversity

Measuring functional diversity with functional entities

Distribution of species among functional entities

Functional vulnerability **=** proportion of Funct. Ent. with a single species





Mouillot et al. 2014, *PNAS* ; doi: 10.1073/pnas.1317625111

Others approaches to assess functional diversity

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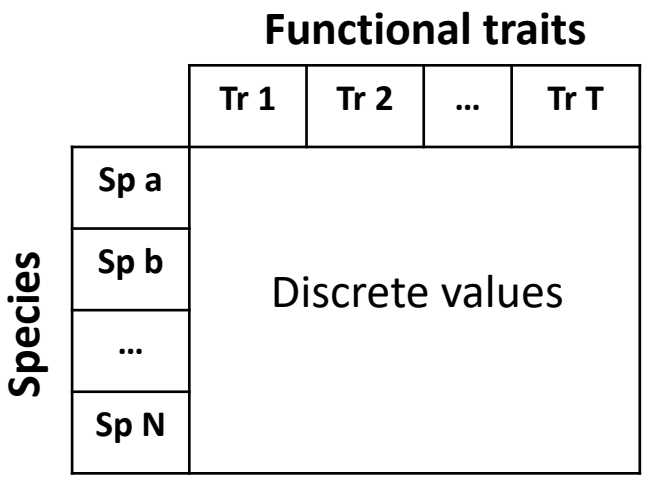
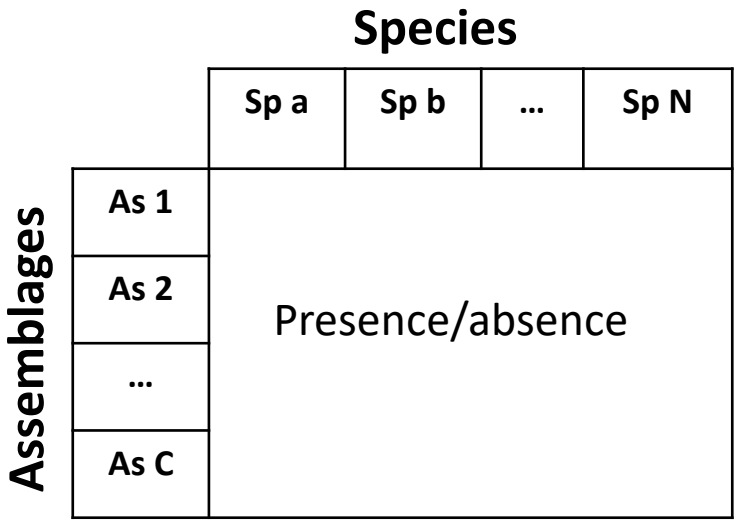
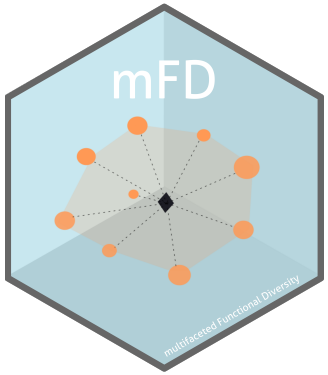




Functions

mFD: : sp. to.fe()
mFD::alpha.fd.fe()
mFD::alpha.fd.fe.plot()



Tutorial

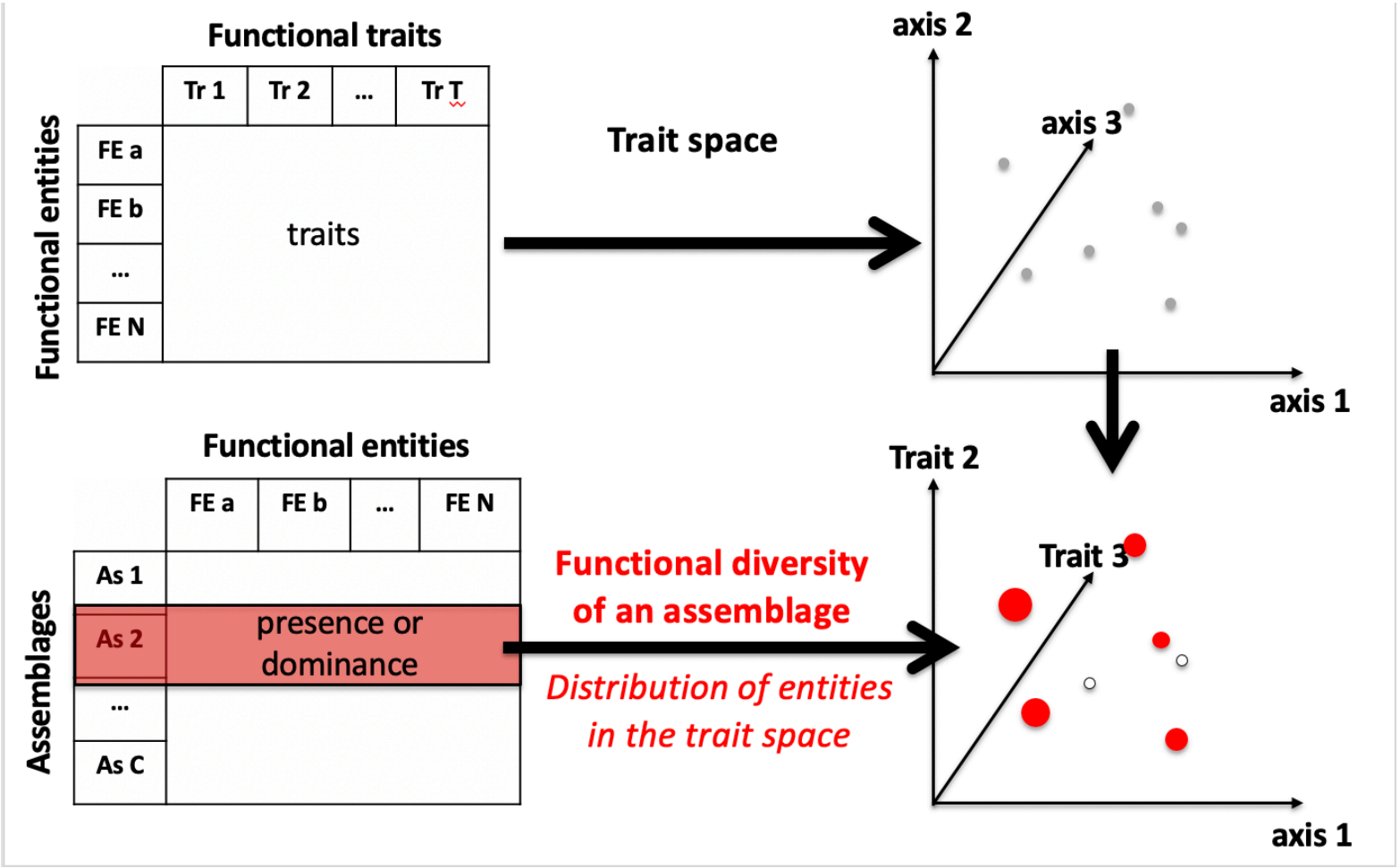
https://cmlmagneville.github.io/mFD/articles/How_to_deal_with_Functional_Entities.html

Others approaches to assess functional diversity

Functional diversity above/beyond species

Trait values and presence (or biomass) measured for:

- groups of species with same trait values => ***functional entities***



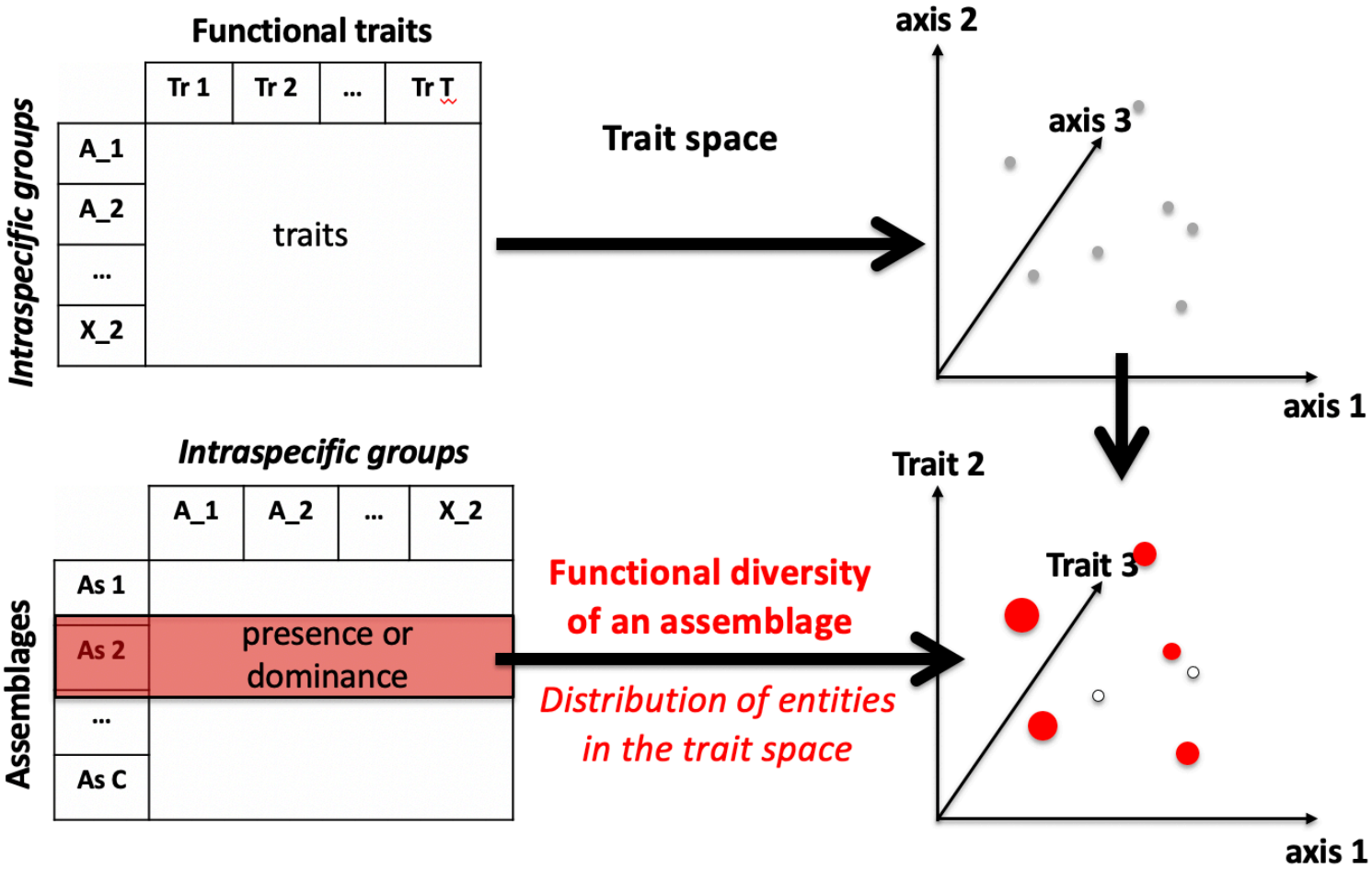
Others approaches to assess functional diversity

Functional diversity above/beyond species

Trait values and presence (or biomass) measured for:

- groups of individuals within each species

=> **accounting for intraspecific variability**



Others approaches to assess functional diversity

Functional diversity above/beyond species

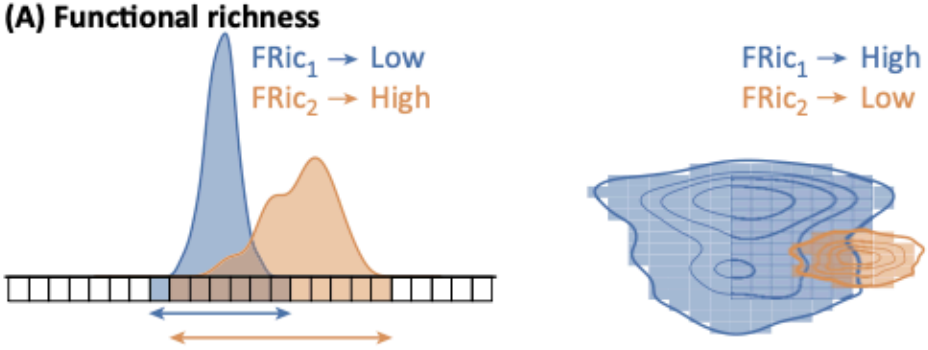
Trait Probability Density within and between species

Traits Without Borders: Integrating Functional Diversity Across Scales

Carmona et al. 2017,

Trends in Ecology and Evolution

doi: 10.1016/j.tree.2016.02.003



package: TPD

https://cran.r-project.org/package=TPD