



How to quantify biological diversity: taxonomical, functional and evolutionary aspects

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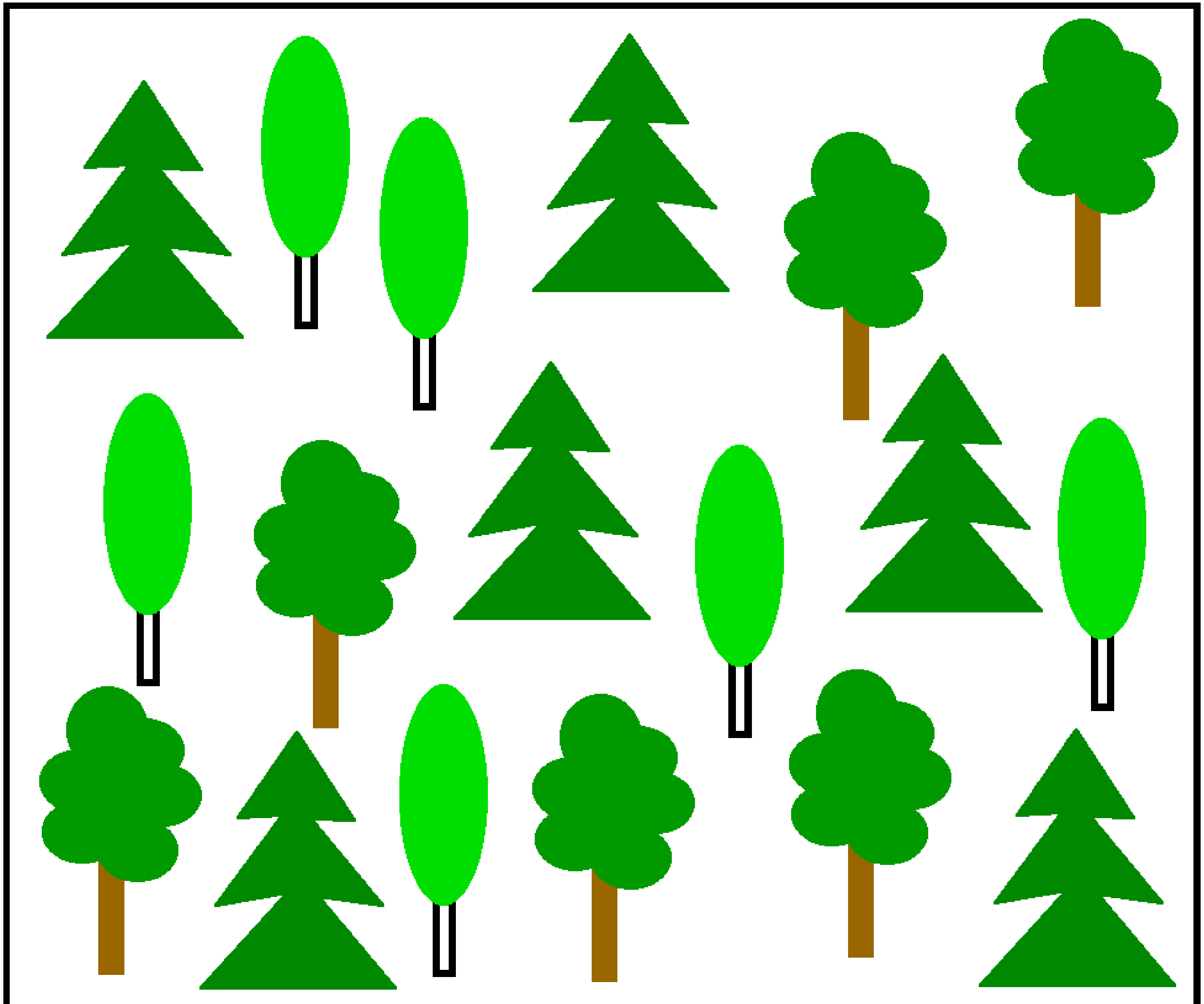
Why quantify biological diversity?

- understanding the structure and function of biological communities
- assessing ecosystem services
- assessing conservation value
- establishing conservation priorities

Getting started

- the diversity of what?
  - fish, nesting birds, big trees, annual herbs, nematodes, bacteria
  - vegetation types, life forms, ecological functions
- resolution of the classification
  - species, genera, families
  - number of recognized vegetation types
- abundance measure
  - individuals, cover, biomass
- sampling setup
  - spatial and temporal resolution

How to calculate diversity

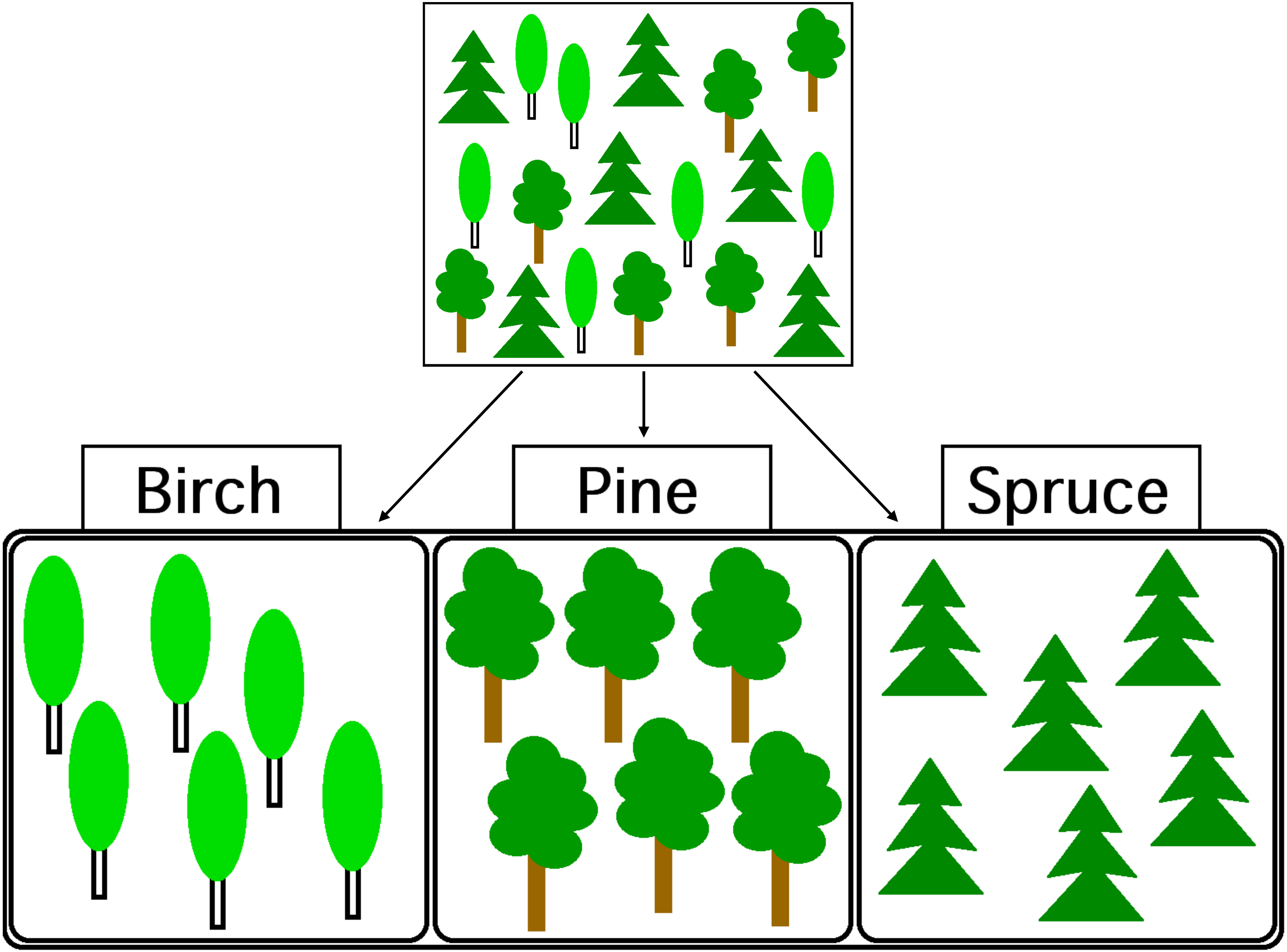


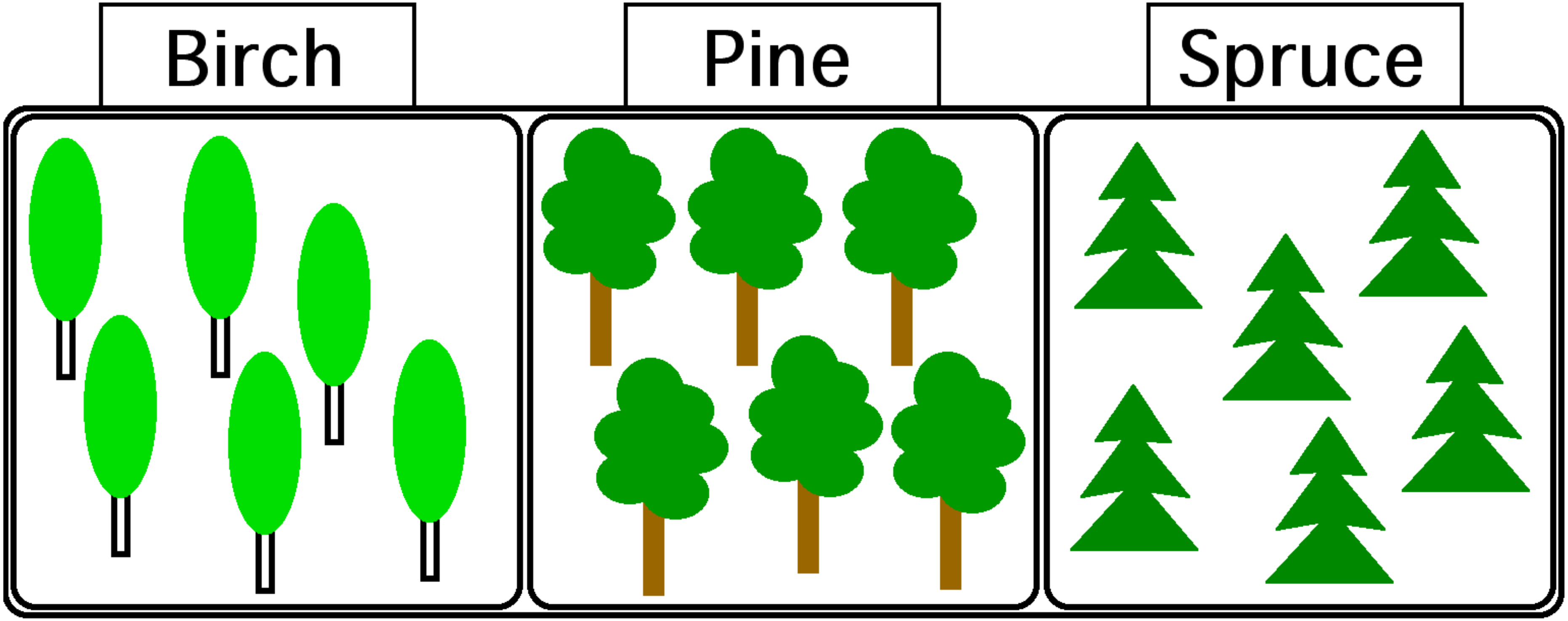
Many popular diversity indices

- species richness = number of species
- Shannon index = uncertainty in the species identity of a randomly picked individual
- Gini-Simpson index = probability that two individuals picked at random are different species

Many popular diversity indices

- species richness = number of species
  - range: [1, ∞[
- Shannon index = uncertainty in the species identity of a randomly picked individual
  - range: [0, ∞[
- Gini-Simpson index = probability that two individuals picked at random are different species
  - range: [0, 1[
- each index quantifies a different phenomenon
- calling all of these ‘diversity’ causes confusion
  - what is true diversity?


Birch
Pine
Spruce

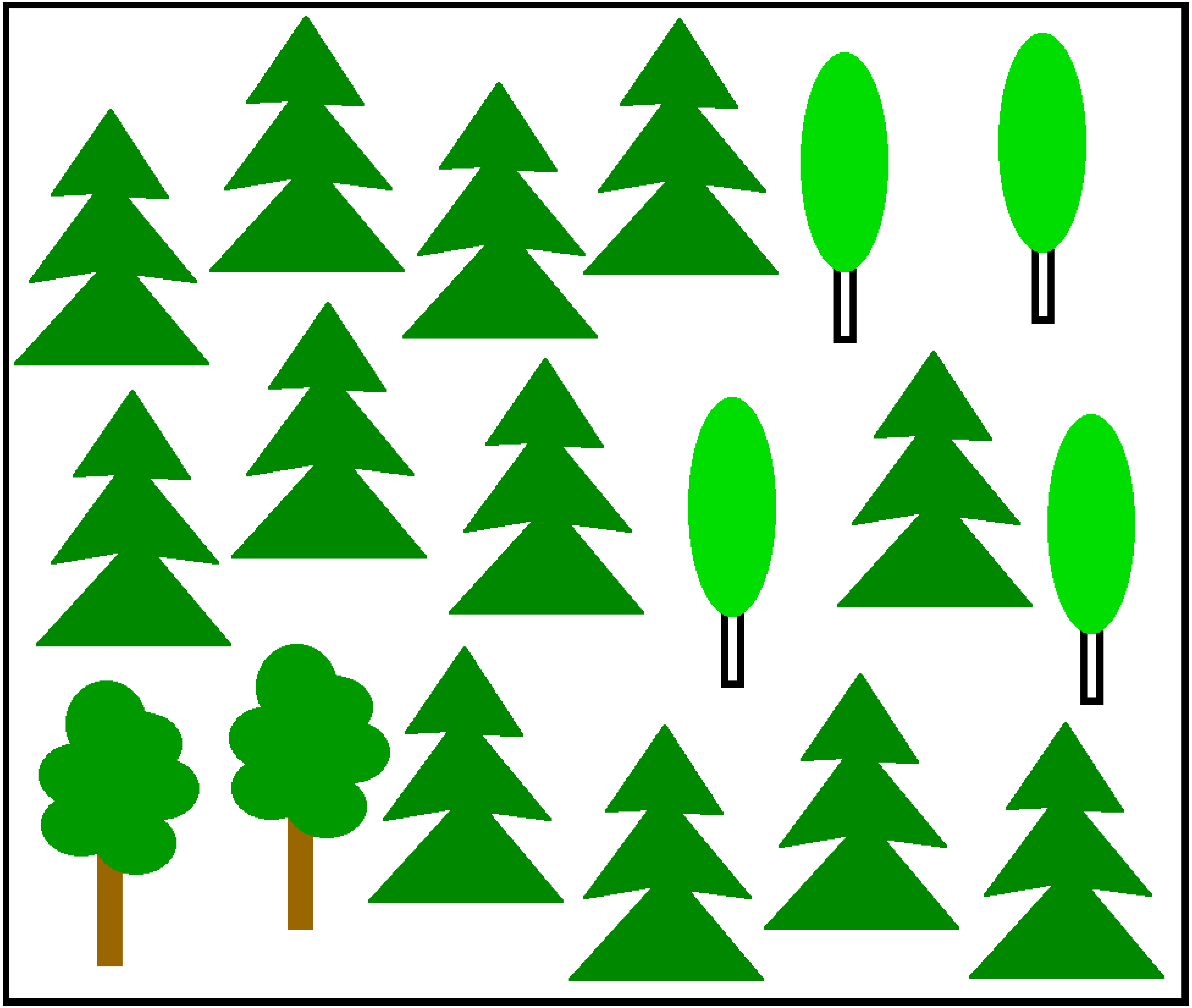


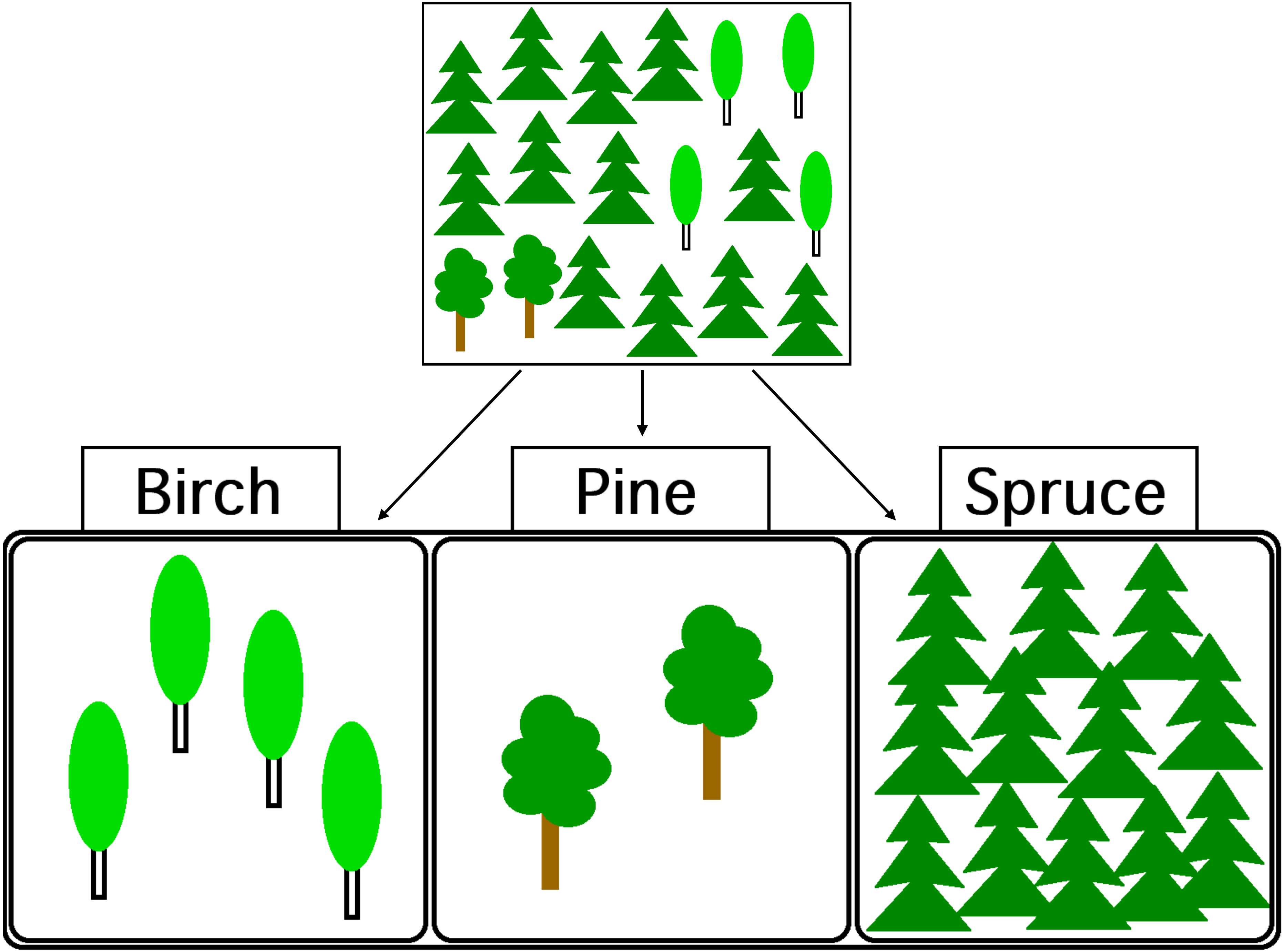
Species richness S = 3 species

If all species equally abundant, each has

- proportional abundance $p_i = 1/3$
- absolute abundance

$$m_i = p_i m = 1/3 * 18 \text{ ind.} = 6 \text{ ind.}$$

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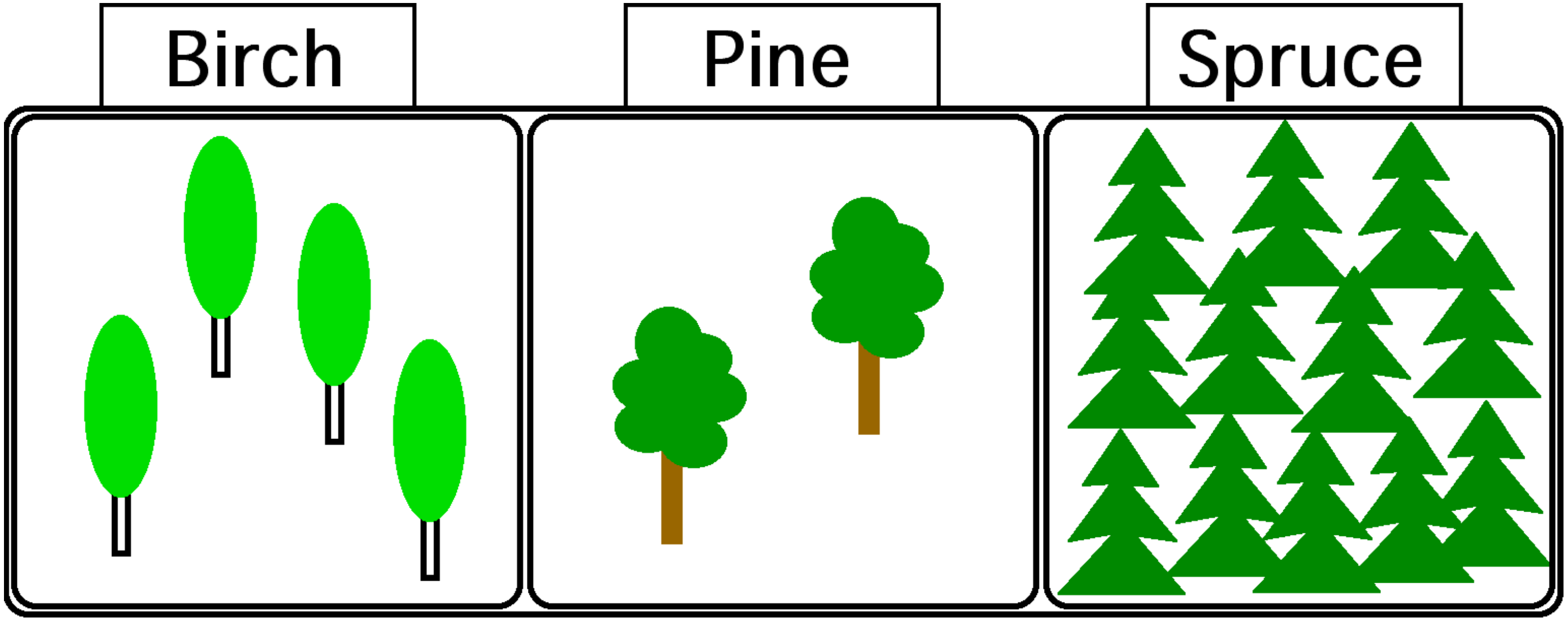


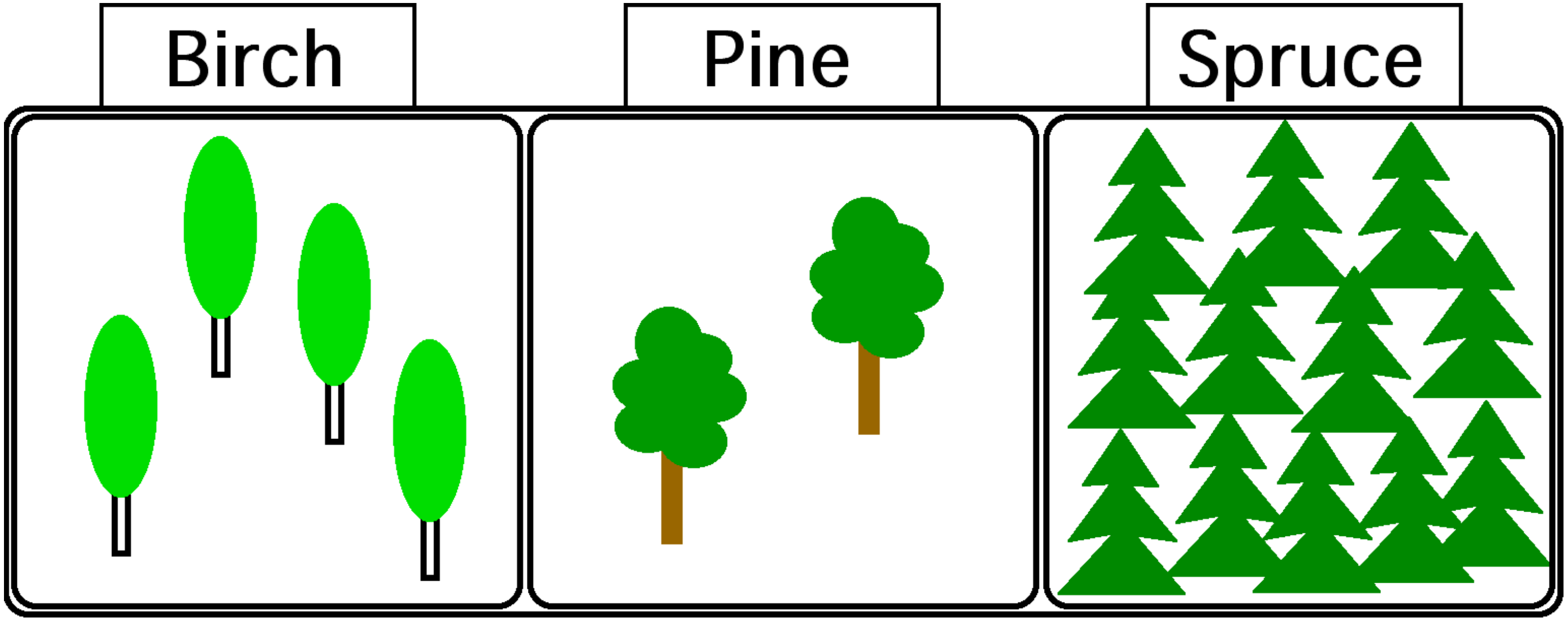
Species richness S = 3 species

Evenness smaller due to species dominance

-> diversity smaller

Species diversity D

= the effective number of species

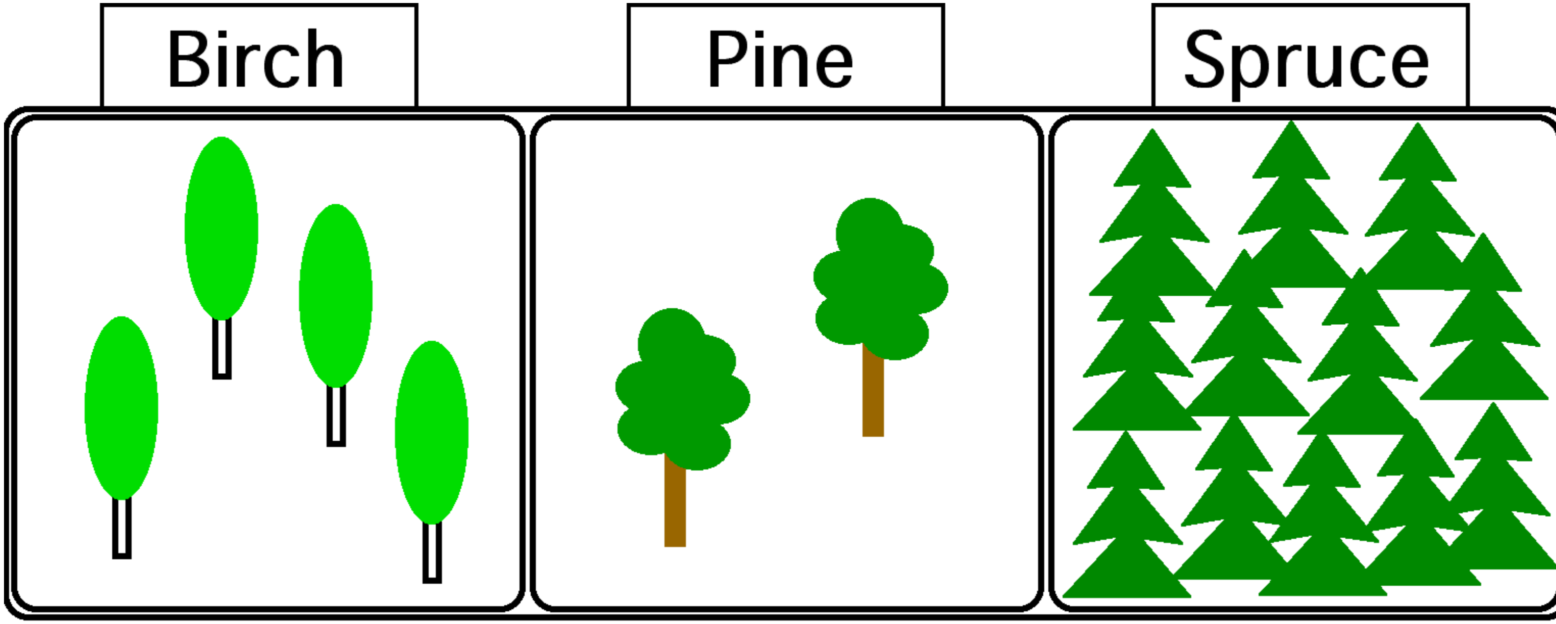


m_1 = 4 ind. m_2 = 2 ind. m_3 = 12 ind.

p_1 = 4/18 = 1/4.5 p_2 = 2/18 = 1/9 p_3 = 12/18 = 1/1.5

Species diversity if the mean abundance is like that of

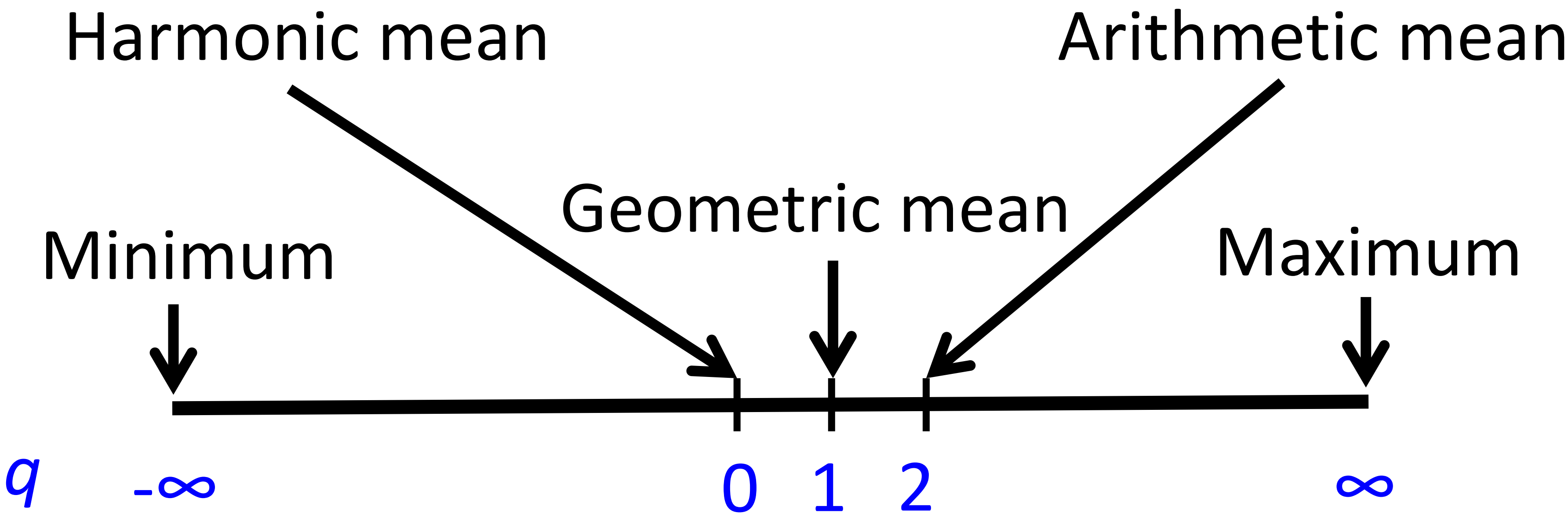
birch: 4.5 sp_E pine: 9 sp_E spruce: 1.5 sp_E



$p_1 = 4/18 = 0.22$ $p_2 = 2/18 = 0.11$ $p_3 = 12/18 = 0.67$

Mean species abundance:

$$\overline{p}_i = \sqrt[q-1]{\sum_{i=1}^{S} p_i p_i^{q-1}}$$



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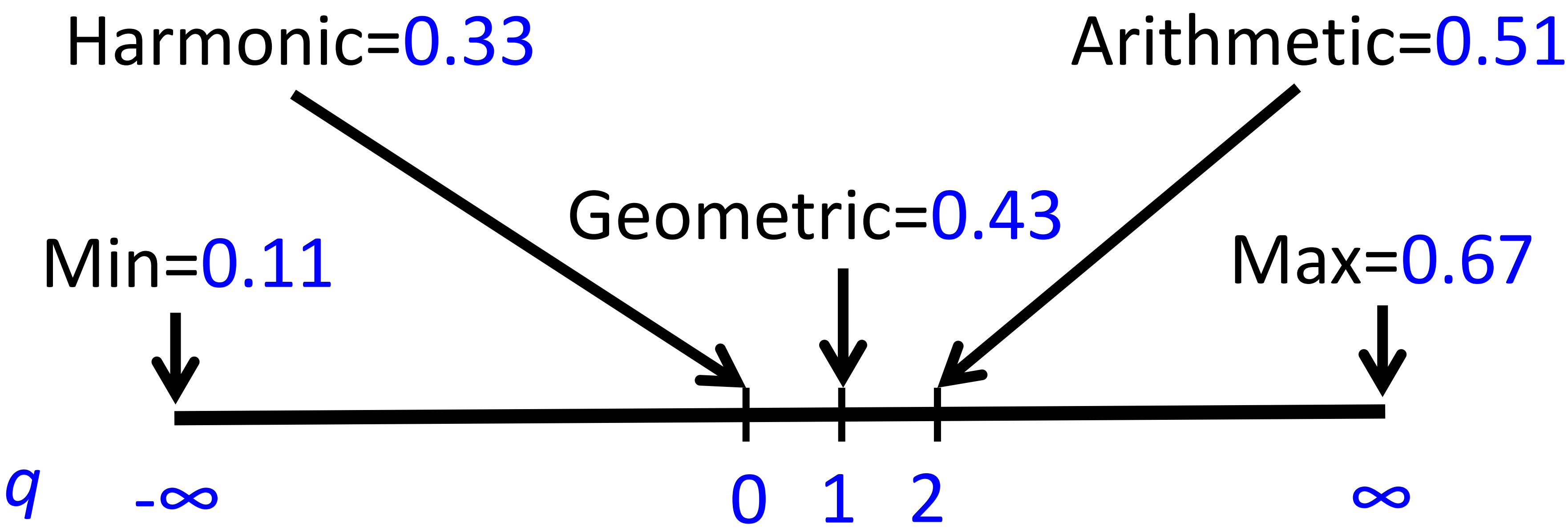

Mean species abundance:

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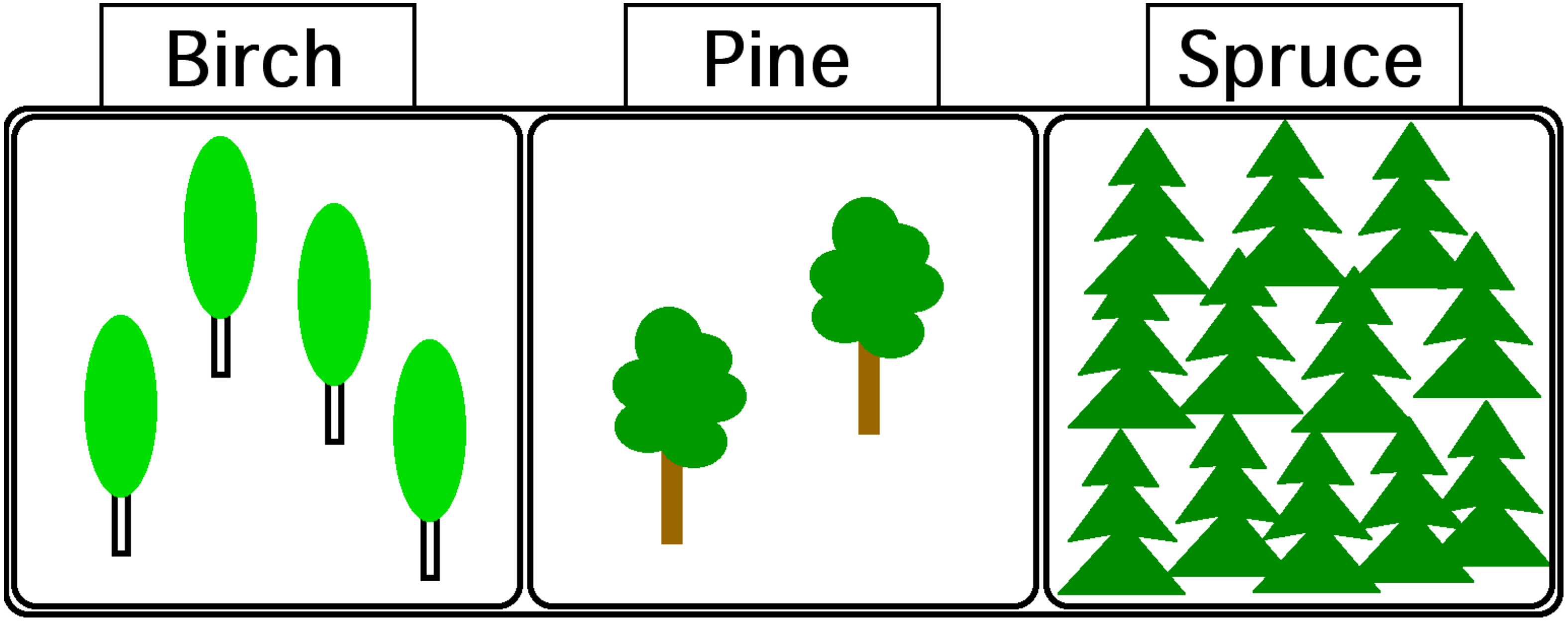
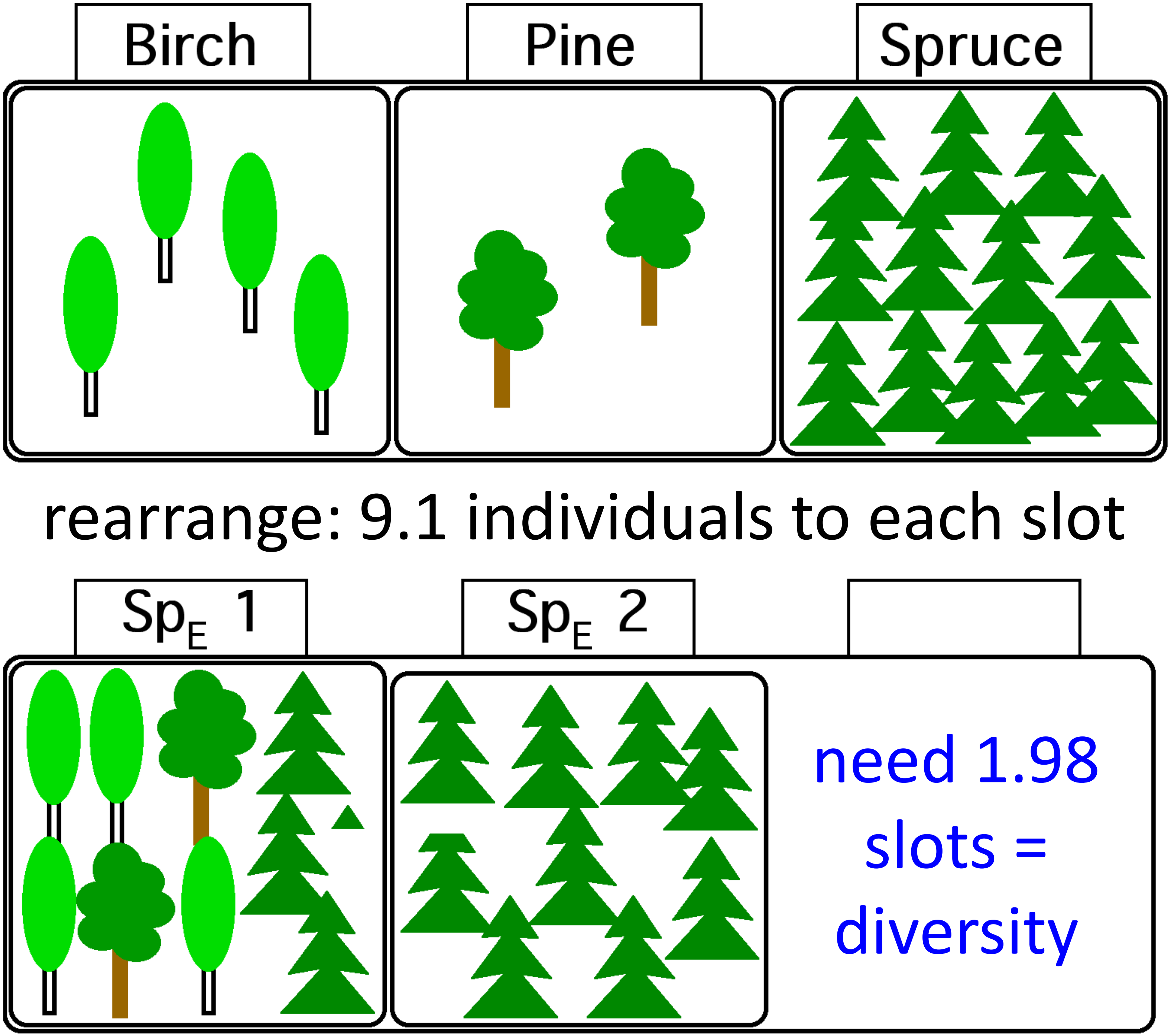


arithmetic mean:

$$\overline{p}_i = p_1 p_1 + p_2 p_2 + p_3 p_3$$ = 0.51 = 1/ 1.98

Diversity = 1/0.51 = 1.98 effective species

$$\overline{m}_i = p_1 m_1 + p_2 m_2 + p_3 m_3$$ = 9.1 ind.



Birch
Pine
Spruce
rearrange: 9.1 individuals to each slot
Sp_E 1
Sp_E 2
need 1.98 slots = diversity

True diversity = ^qD

= 1/(mean p_i)

= the number of equally-abundant species needed to get the observed mean species proportional abundance

= effective number of species

Popular diversity indices

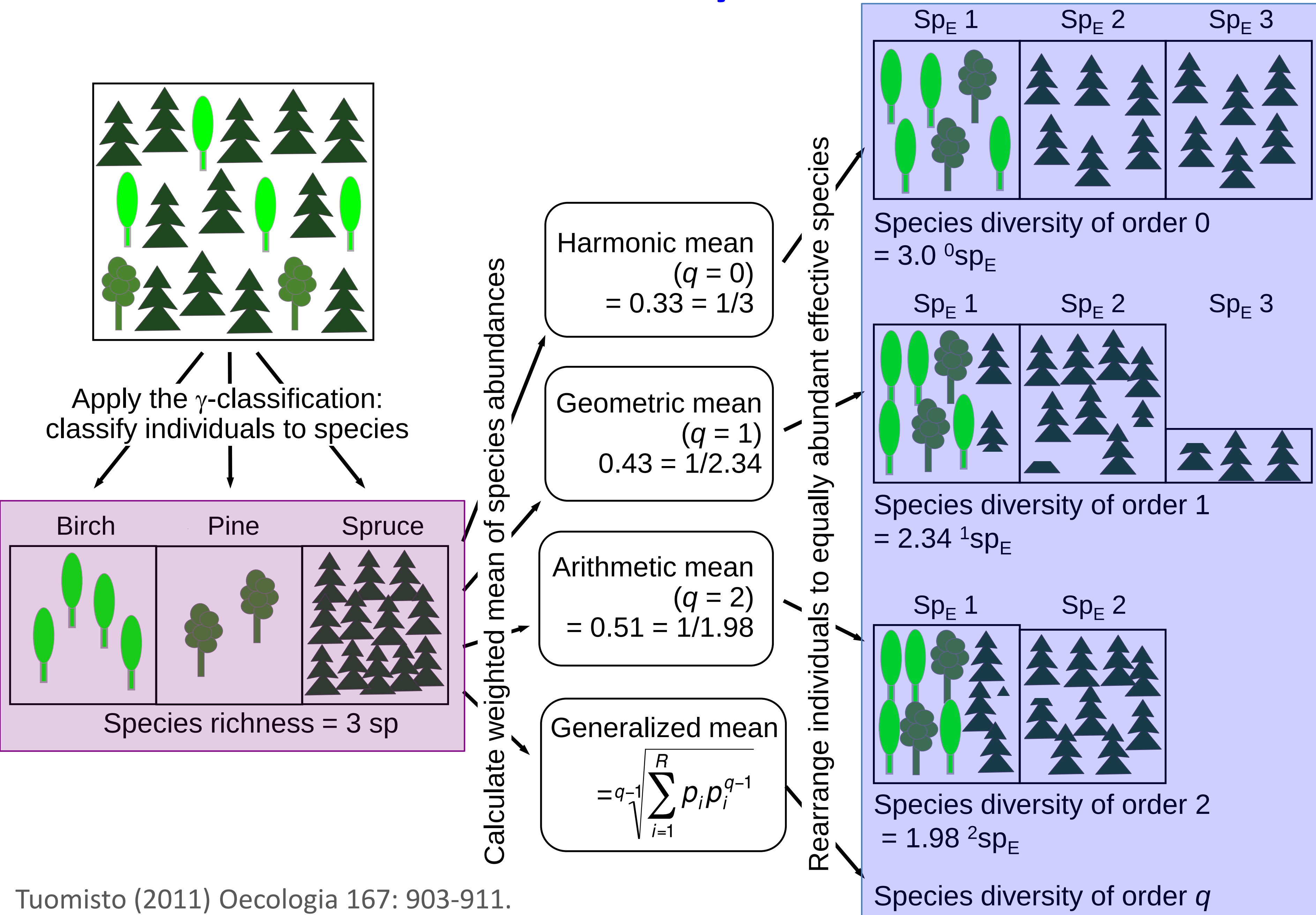
Species richness = ^0D

Shannon index = $\log(^1D)$

Gini-Simpson index = $1 - 1/\,^2D$

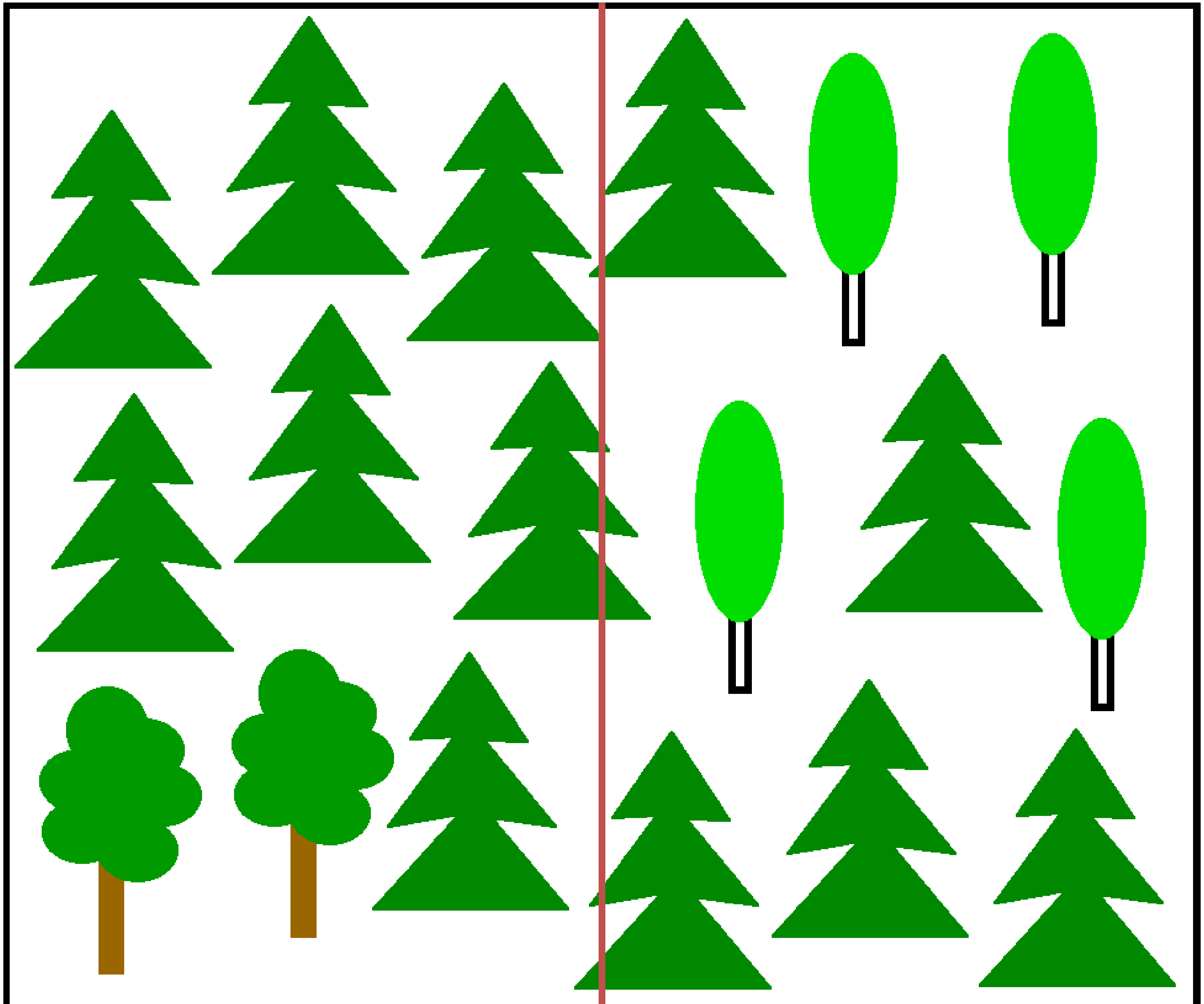
Inverse Simpson index = ^2D

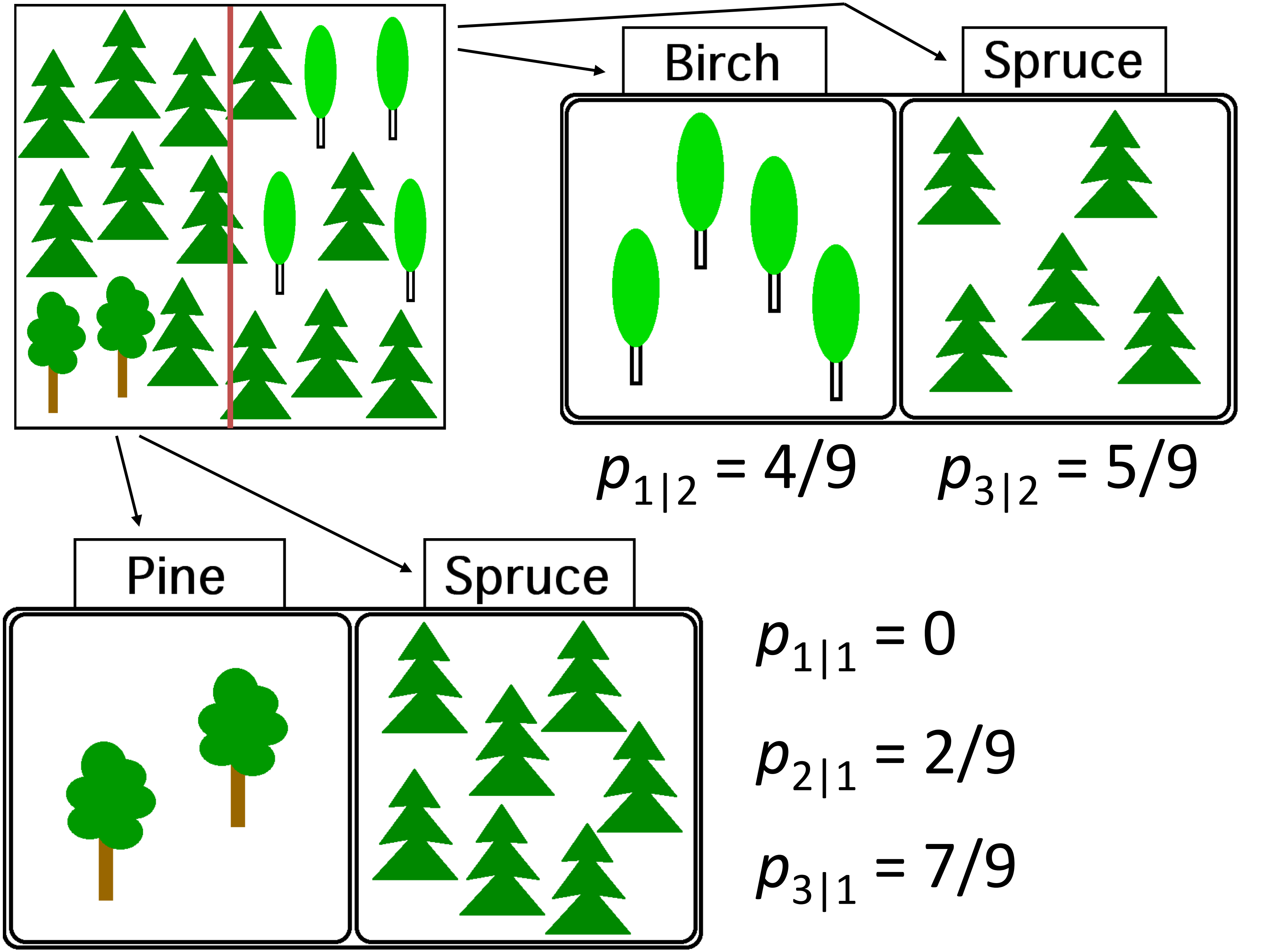
Richness vs. diversity

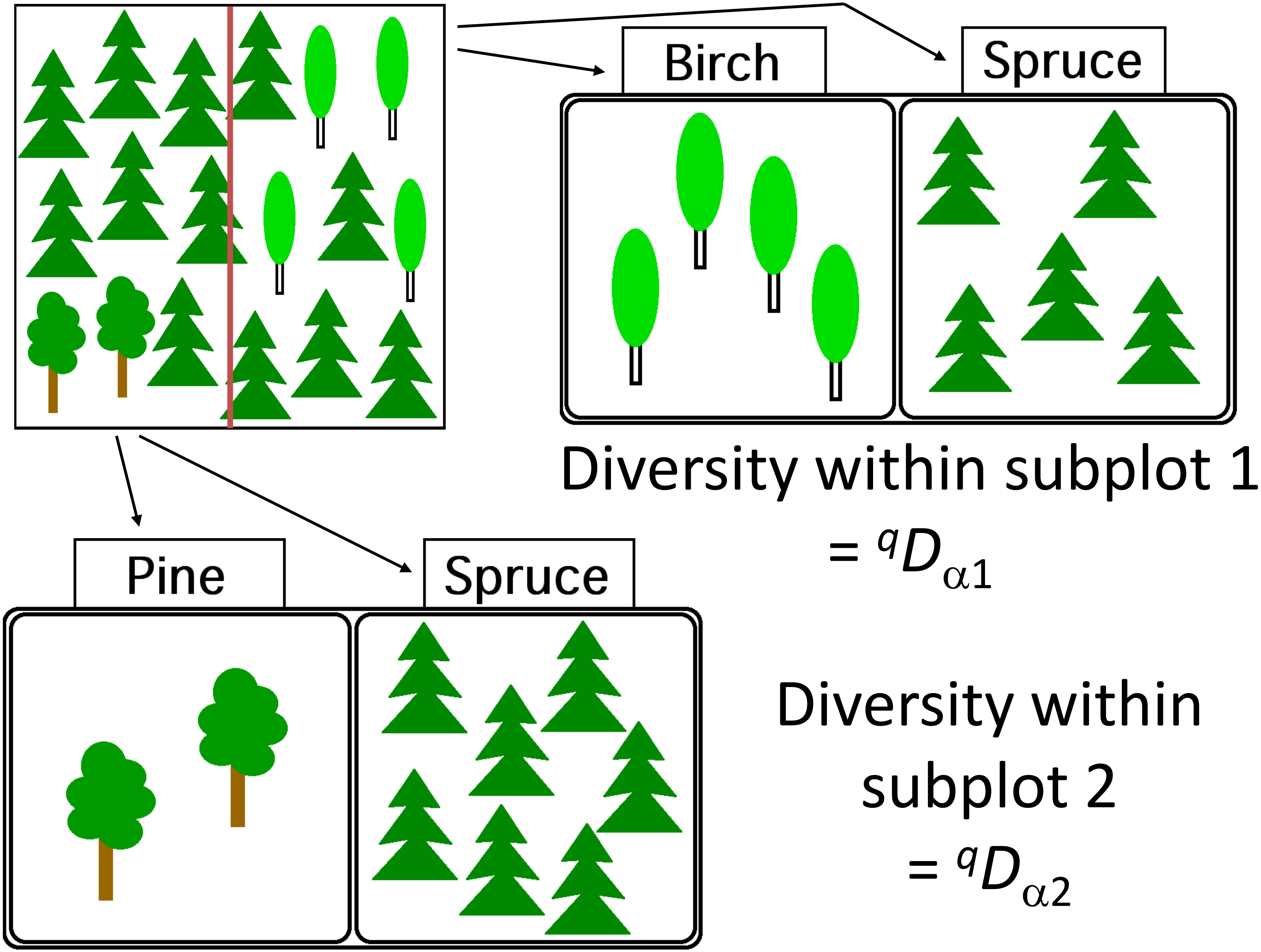


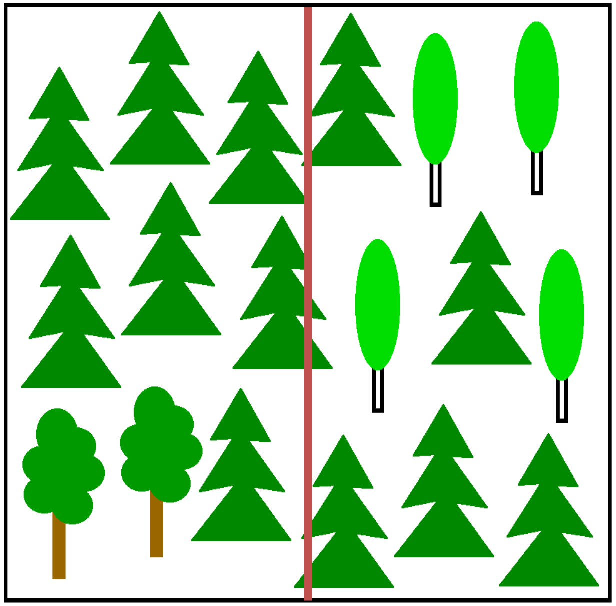
Tuomisto (2011) Oecologia 167: 903-911.

Alpha, beta and gamma diversity




Birch
Spruce
p1|2 = 4/9
p3|2 = 5/9
Pine
Spruce
p1|1 = 0
p2|1 = 2/9
p3|1 = 7/9


Birch
Spruce
Diversity within subplot 1
= $^{q}D_{\alpha1}$
Pine
Spruce
Diversity within subplot 2
= $^{q}D_{\alpha2}$



Alpha diversity

= mean of the within-subplot diversities

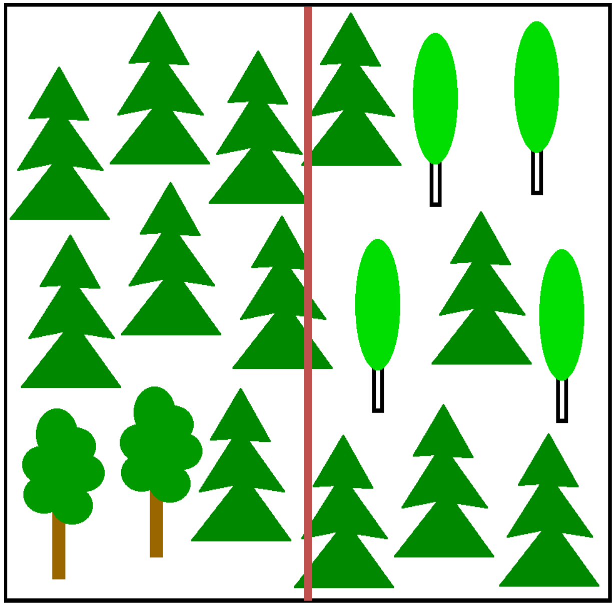
$$ {}^{q}D_{\alpha} = \sqrt[1-q]{\sum_{j=1}^{N} w_j \left({}^{q}D_{\alpha j}\right)^{1-q}} $$

= 2.00 effective species at $q = 0$

= 1.83 effective species at $q = 1$

= 1.73 effective species at $q = 2$

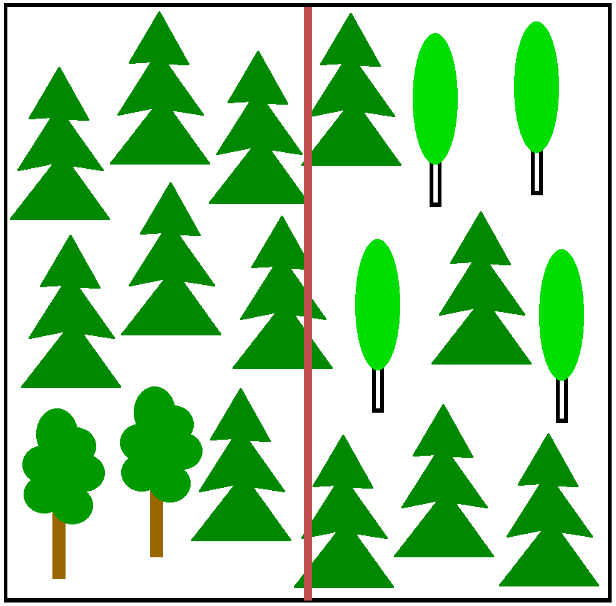
= 1.29 effective species at $q \to \infty$

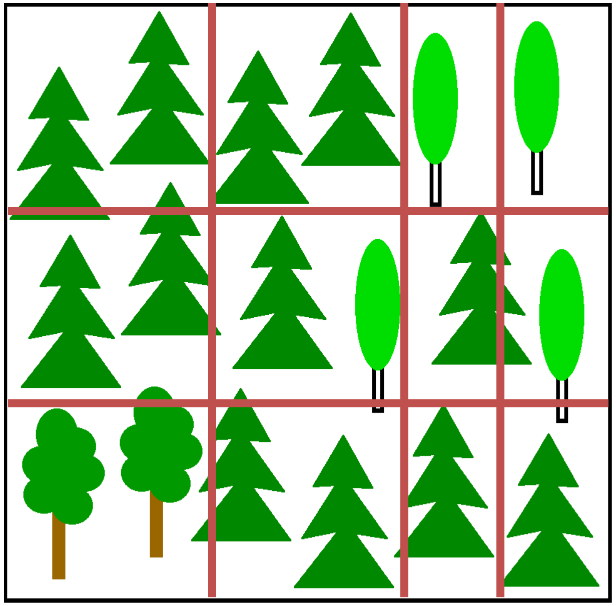


Two species diversity values for the dataset:

Gamma diversity ${}^{q}D_{\gamma}$
= inverse of overall mean p_i
= nr. of effective species in entire plot

Alpha diversity ${}^{q}D_{\alpha}$
= inverse of mean within-suplot p_i
= nr. of effective species per average subplot





Beta diversity $^{q}D_{\beta}$

$= {}^{q}D_{\gamma} / {}^{q}D_{\alpha}$

= effective number of compositionally non-overlapping subplots

The amounts of alpha, beta and gamma diversity are properties of a dataset:

- depend on arbitrary **dataset limits**
- depend on arbitrary **subunit limits**
- depend on arbitrary **taxon limits**

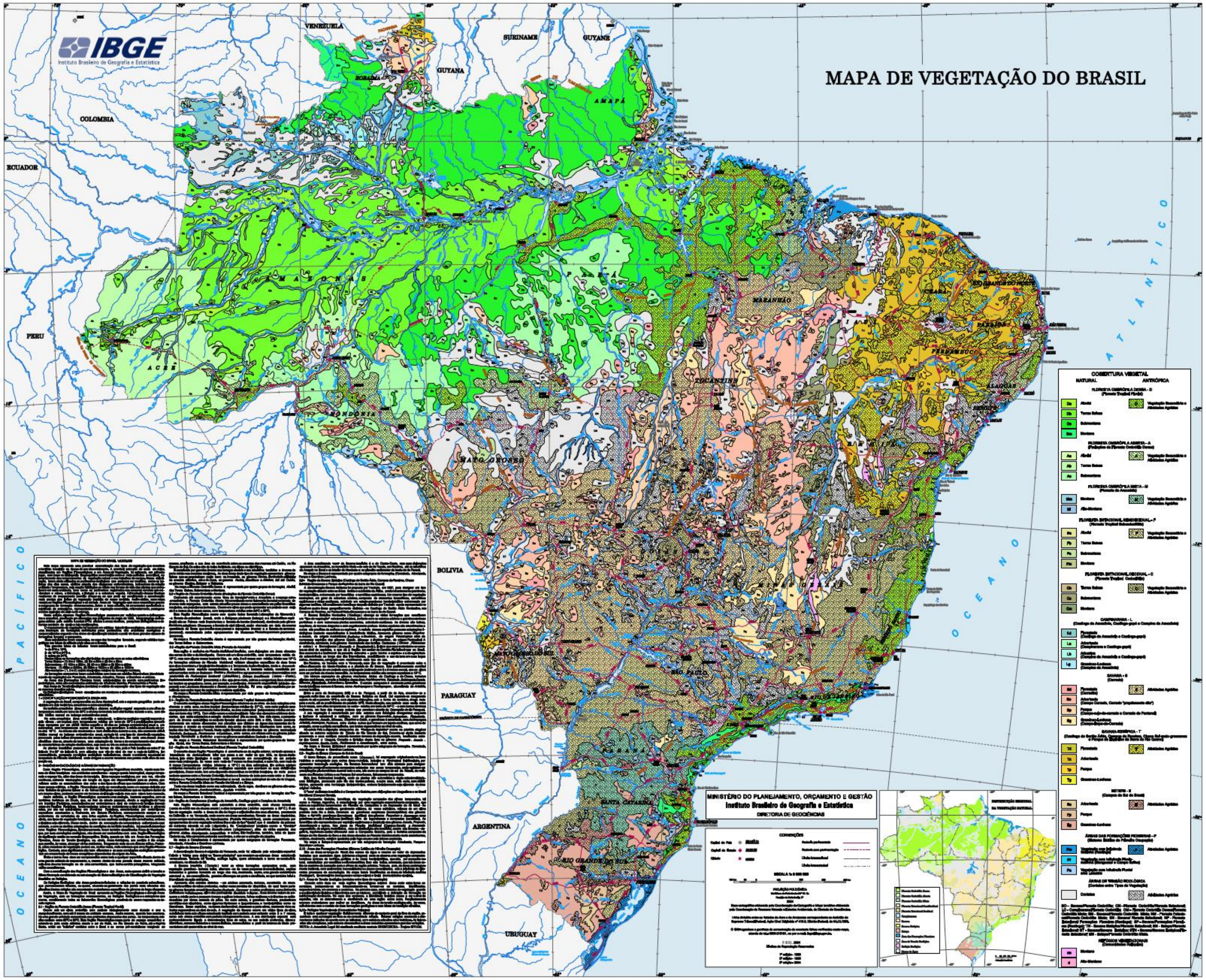
=> observed diversity depends on sampling strategy

=> diversity is *not* an inherent property of a community

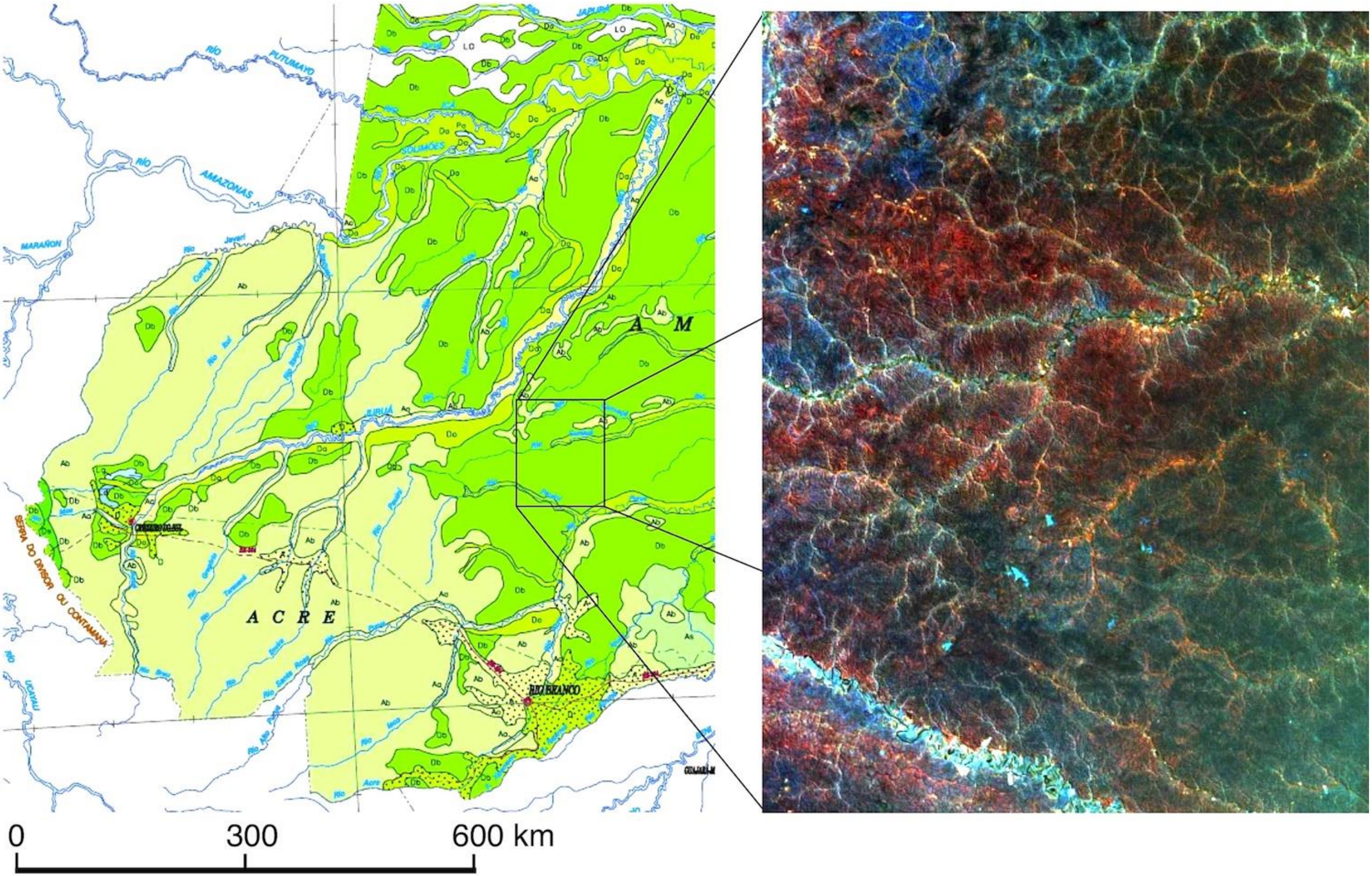
Vegetation diversity

Oliveira-Ferreira *et al. Malaria Journal* (2010) 9:115

Vegetation diversity

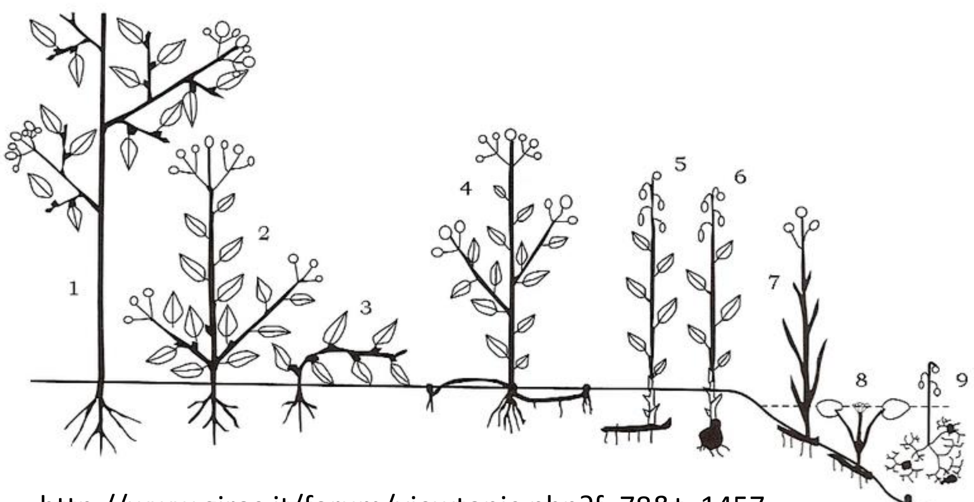


Vegetation map vs. satellite image



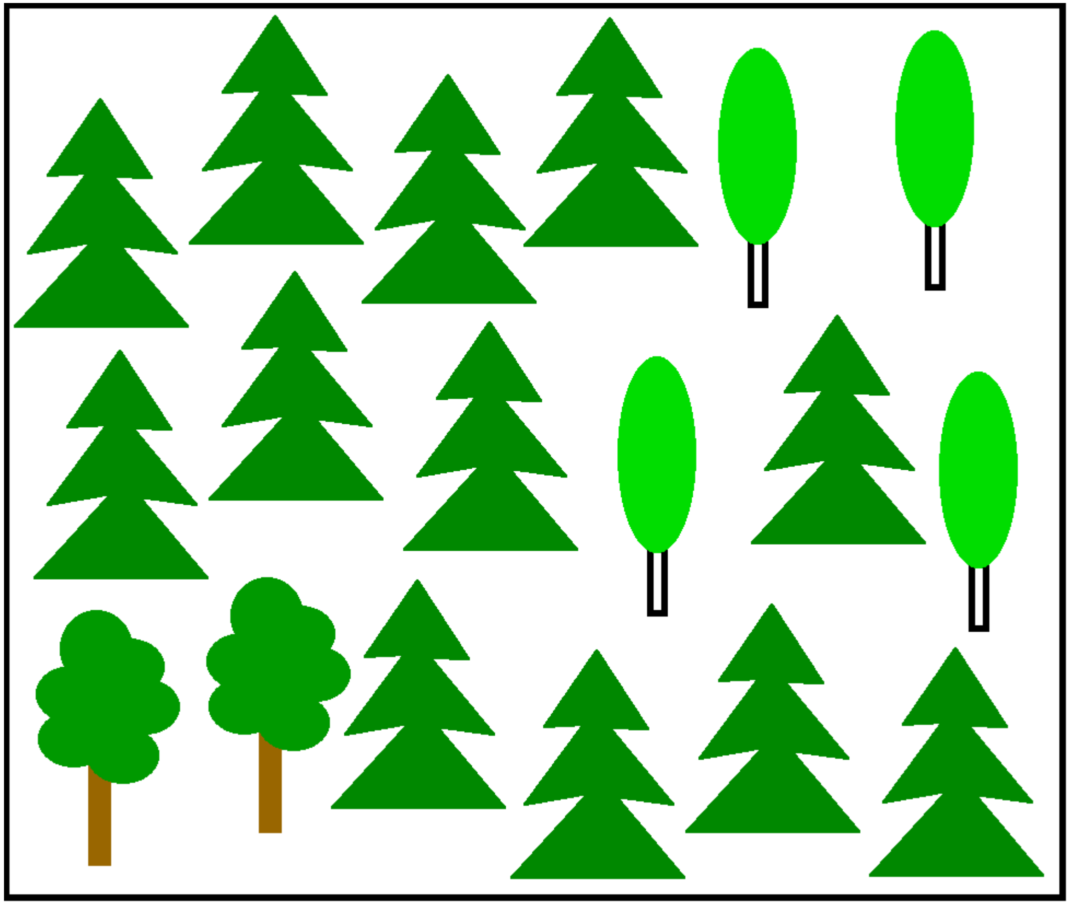
Vegetation diversity

- number of vegetation types (richness)
- their proportional abundances (and evenness)
- structural differences
  - canopy height, canopy cover
- functional differences
  - life form distribution, seasonality

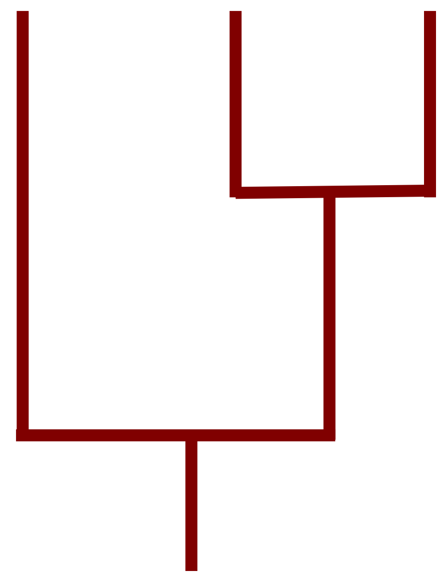


http://www.giros.it/forum/viewtopic.php?f=78&t=1457

Taxon diversity: evolutionary aspects



3 species
3 genera
2 families



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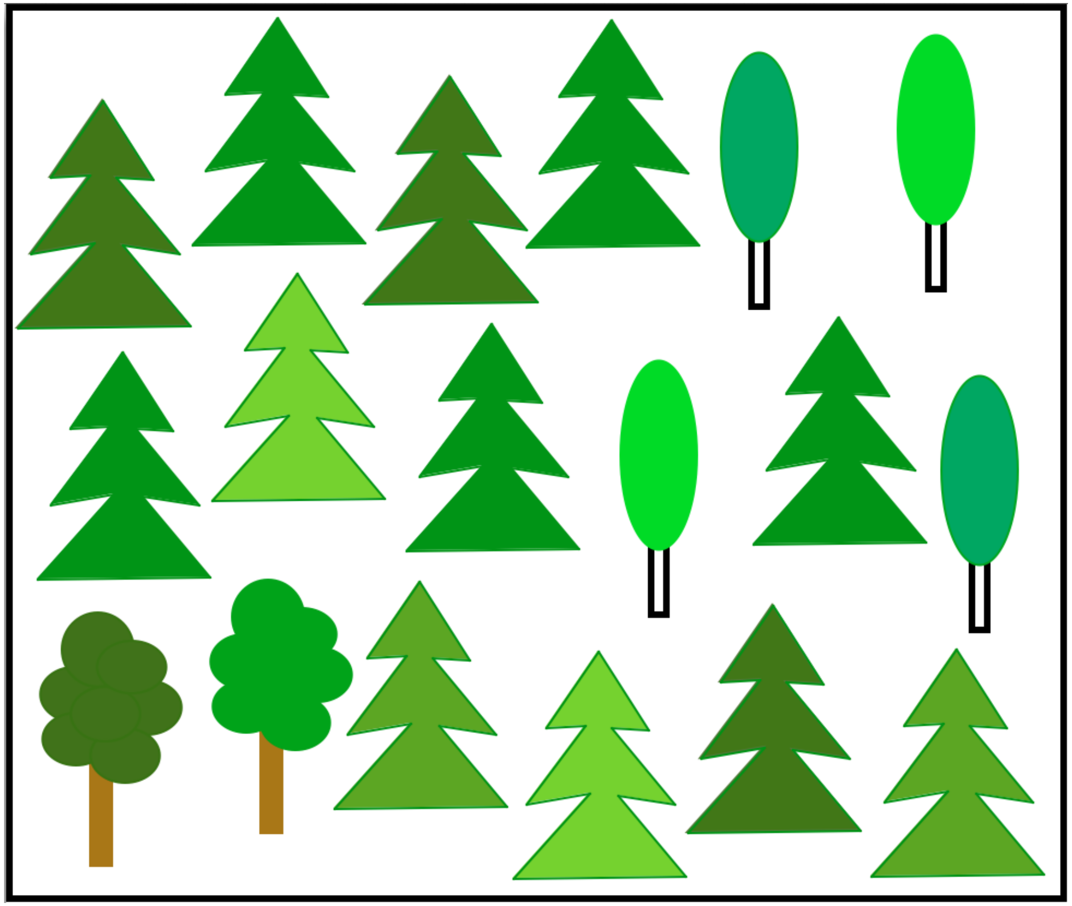
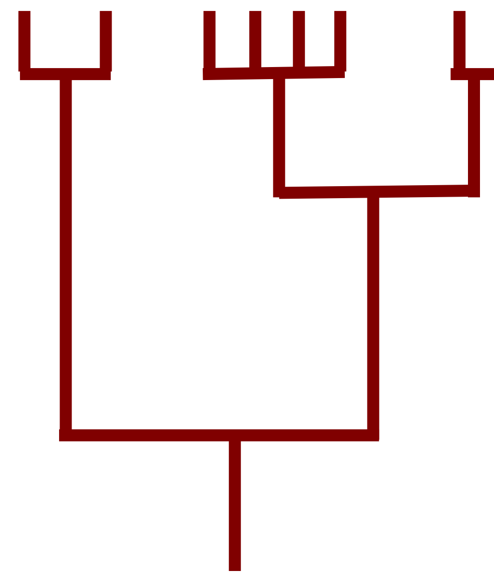
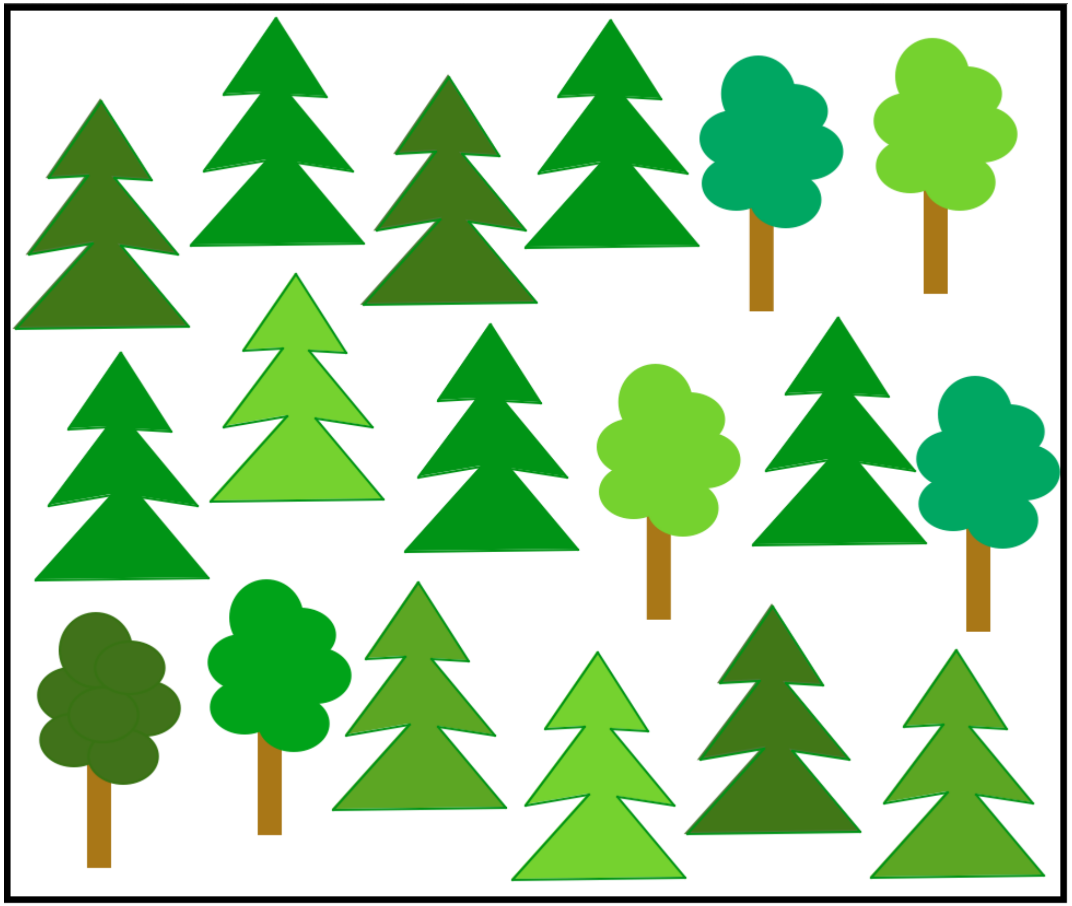


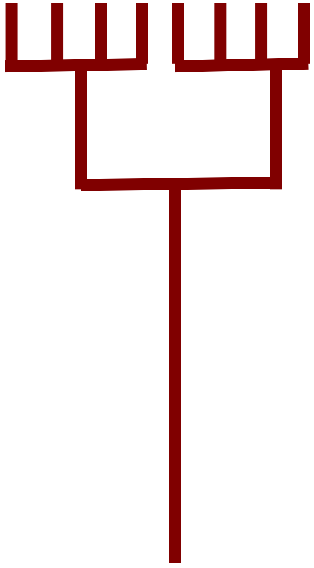
8 species
3 genera
2 families



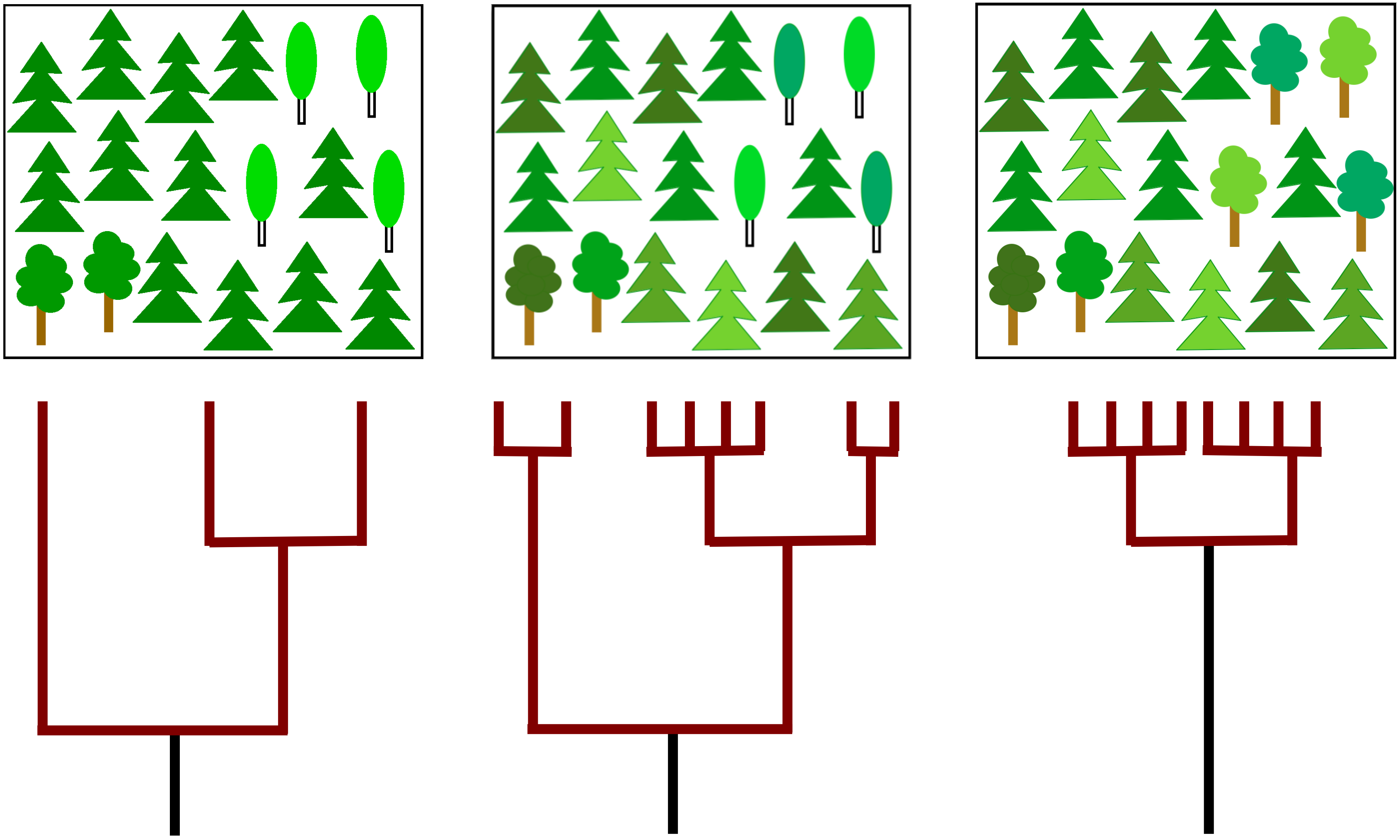
Taxon diversity: evolutionary aspects



8 species
2 genera
1 family

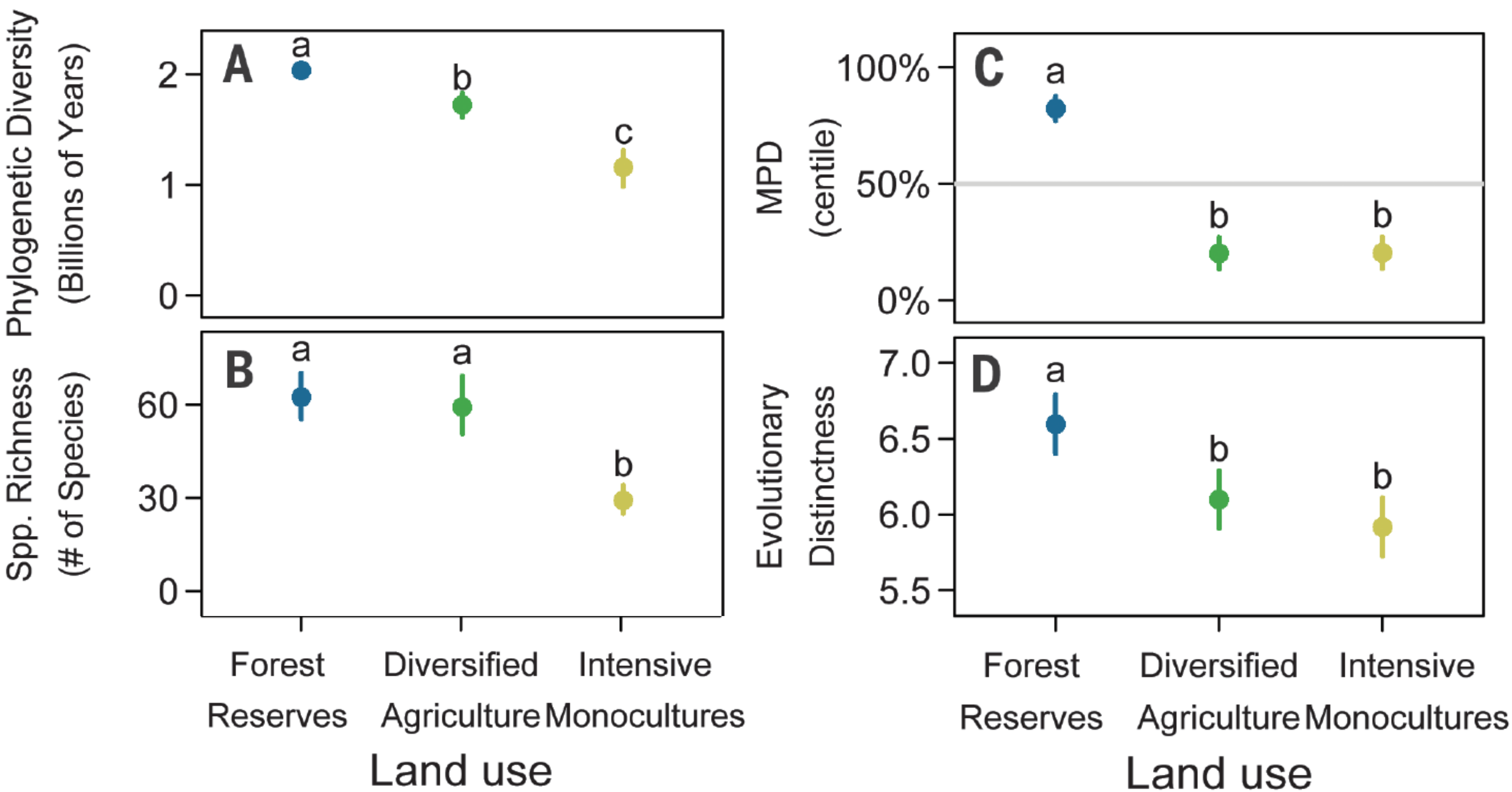


Phylogenetic diversity



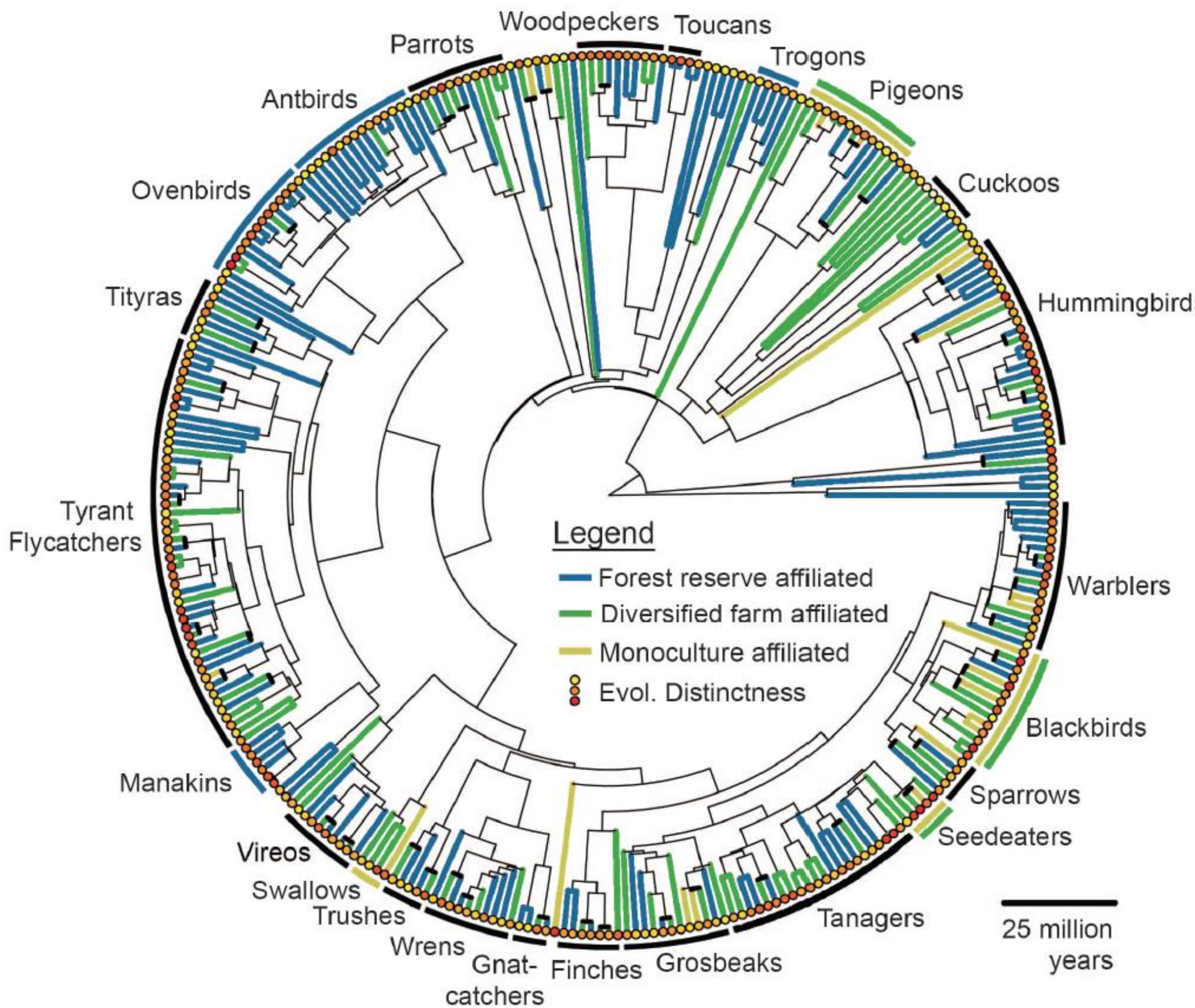
PD = total length of the phylogeny branches that connect all species of the sample

Loss of avian phylogenetic diversity in neotropical agricultural systems



Frishkoff et al. (2014) Science 345: 1343-1346.

Loss of avian phylogenetic diversity in neotropical agricultural systems



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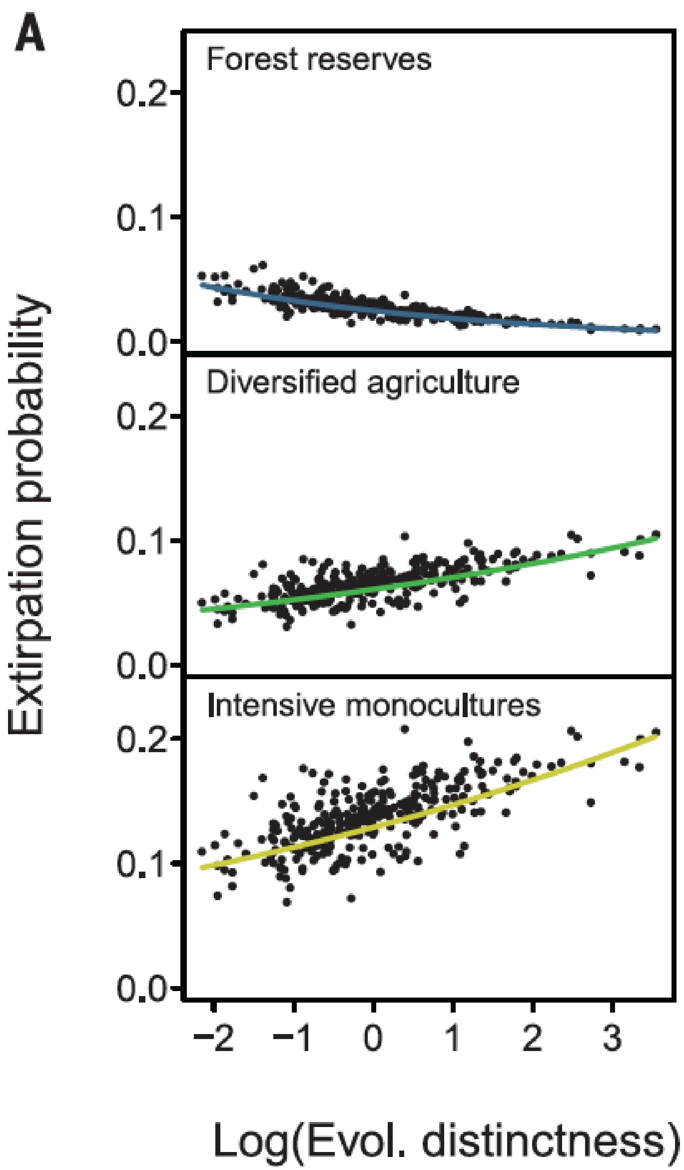
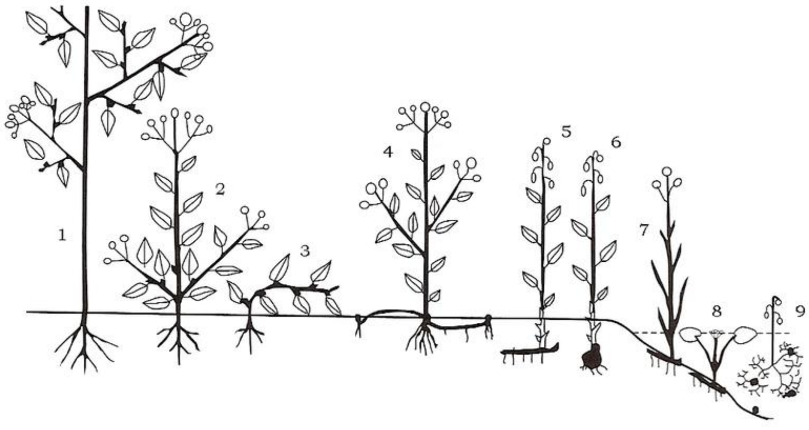


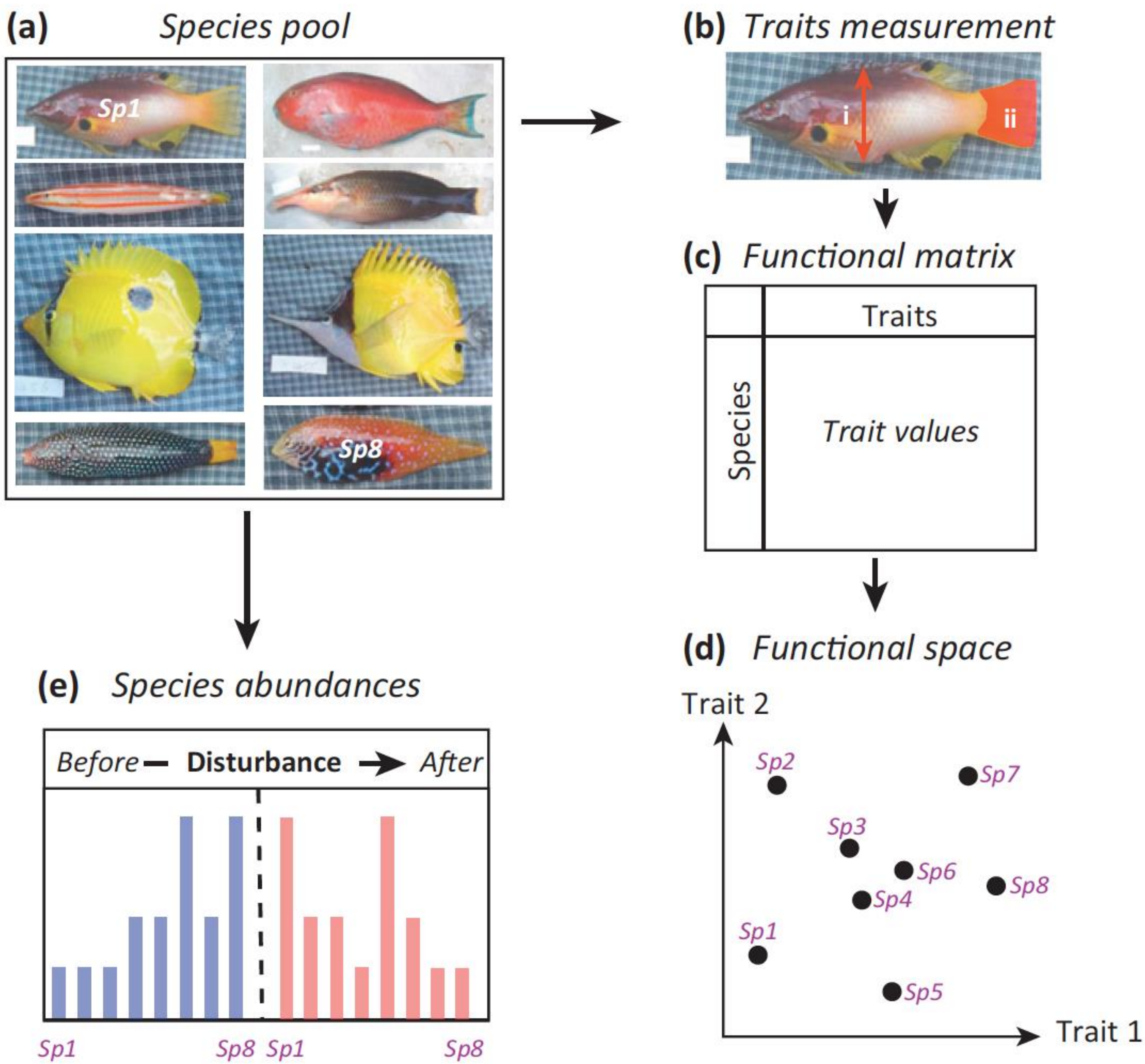
Frishkoff et al. (2014) Science 345: 1343-1346.

Diversity: functional aspects

- strictly analogous to species diversity:
  - number of functional types (richness)
  - their proportional abundances (and evenness)
- based on quantitative measures rather than a classification:
  - amount of trait space occupied
  - amount of difference in function
  - degree of uniqueness in function

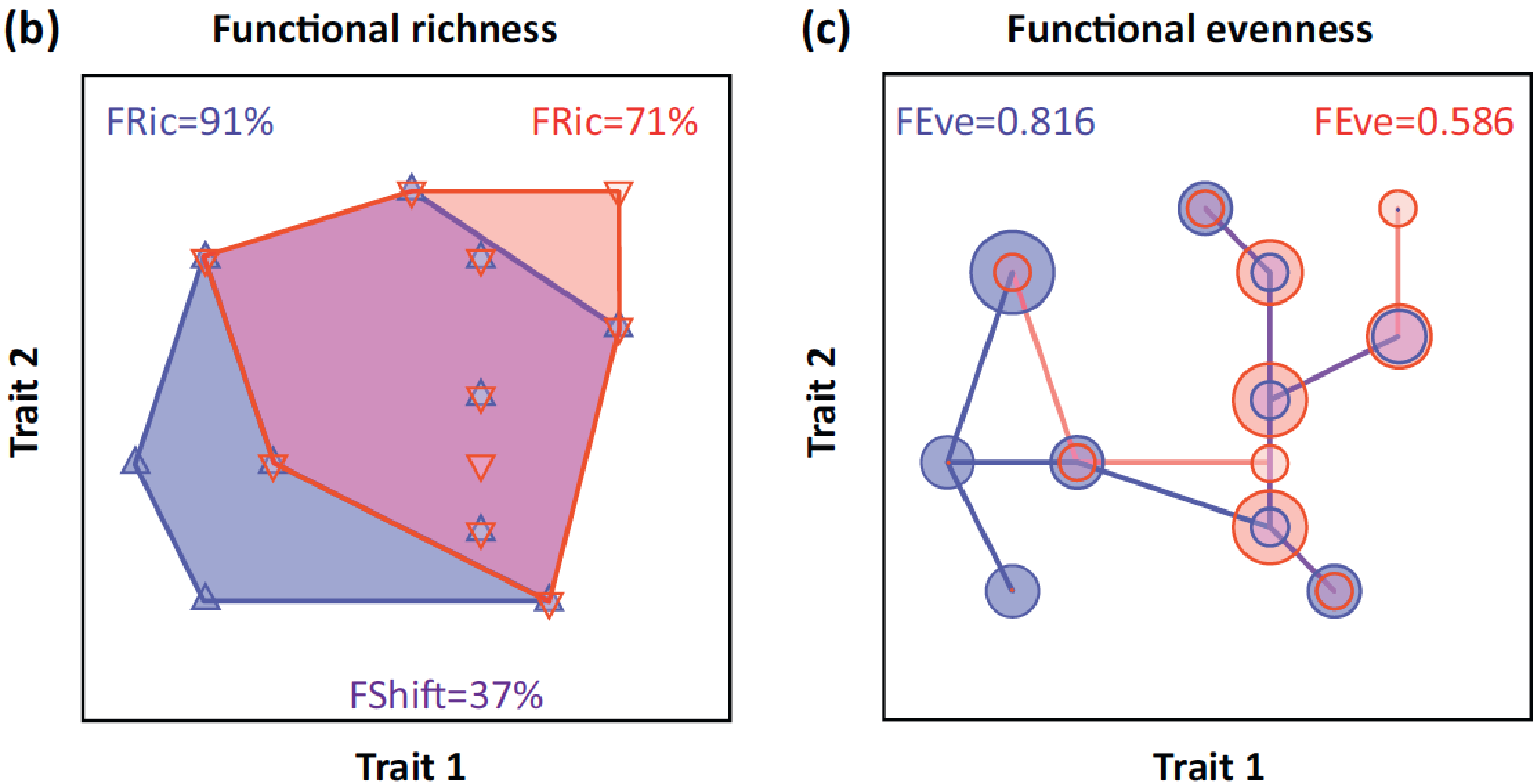


Diversity: functional aspects



Mouillot et al. (2013) TREE 28: 167-177.

Diversity: functional aspects



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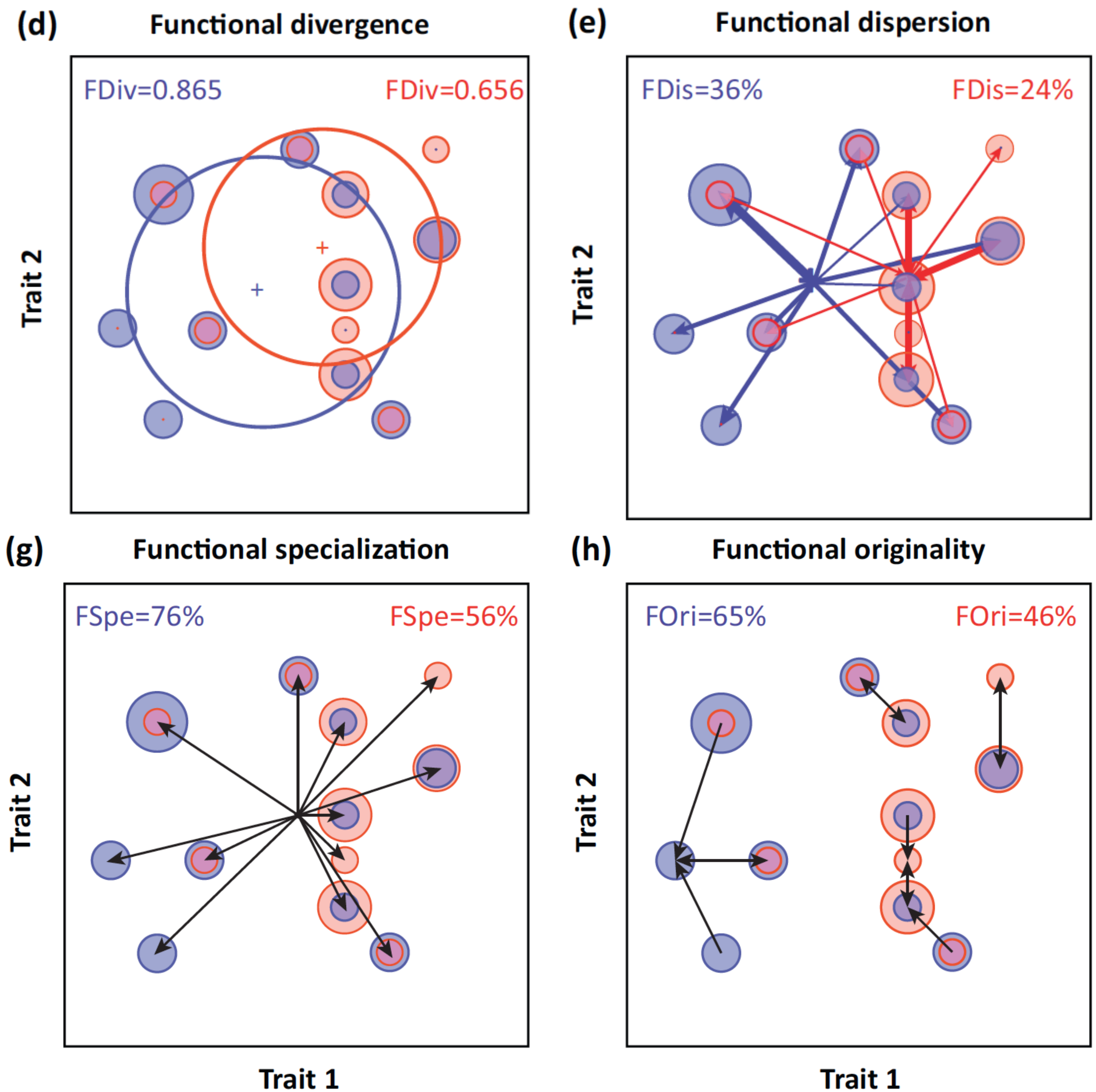
Diversity: functional aspects



Mouillot et al. (2013) TREE 28: 167-177.

1. 'Diversity' has a diversity of meanings
2. Conservation often aims at preserving areas of high diversity

➢ important not to compare apples and oranges when establishing priorities





Thank you!