Studying the effect of species dominance on diversity patterns using Hill numbers-based indices

Loïc Chalmandrier
Meta-community diversity is the result of ecological processes that can be identified by studying the structure of communities.
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Use of proxies of species ecological niche: functional traits, phylogeny...
Methodological steps

Species' pool

Observed community
Methodological steps

Null model. H0

Species' pool

Drand_1

Drand_2

Drand_i

...
Methodological steps

Species' pool

Null model. H0

- $\text{Drand}_1$
- $\text{Drand}_2$
- $\text{Drand}_i$

...
To test a functional/phylo diversity pattern, you need:

A diversity index

- for a given facet, $\alpha$, $\beta$, $\gamma$, $\sigma$...
- Richesse, Shannon, Rao, MPD, MNTD...
- **Function of species relative abundances.**
To test a functional/phylo diversity pattern, you need:

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**A species ecological similarity matrix**
- Different traits, phylogeny.
- **Link function between data and species ecological similarity metric.**
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A species ecological similarity matrix

- Different traits, phylogeny.
- **Link function between data and species ecological similarity metric.**

A null model

- **Null hypothesis.**
- A species pool.
Choosing Rao’s QE

\[ QE = \sum_i \sum_j d_{ij} p_i p_j \]
Choosing Rao’s QE

\[ QE = \sum_i \sum_j d_{ij} p_i p_j \]

- Species contribution to diversity proportional to relative abundance.

\[ Choler \ et \ al. \ 2001 \]
Diversity index assumptions

Choosing Rao’s QE

\[ QE = \sum_i \sum_j d_{ij} p_i p_j \]

- Species contribution to diversity proportional to relative abundance.
- Linear relationship between ecological niche dissimilarity and trait/phy. species distances.

Godoy et al. 2014
Diversity index assumptions

Choosing Rao’s QE

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BRIEF COMMUNICATION

ASSESSING PHYLOGENETIC SIGNAL WITH MEASUREMENT ERROR: A COMPARISON OF MANTEL TESTS, BLOMBERG ET AL.’S K, AND PHYLOGENETIC DISTOGRAMS

Olivier J. Hardy\(^1,2\) and Sandrine Pavoine\(^3,4\)
Diversity index assumptions

- Dominance effect: how species abundance are taken into account
- Similarity effect: how species similarities (functional, phylogenetic) are taken into account
The dominance effect: Hill numbers

- Derives from information theory
- Parametric diversity metric that unified Richness, Shannon, Simpson...

\[
D(q) = \left( \sum_i p_i^q \right)^{1/(1-q)} \quad \text{if } q \neq 1
\]
\[
D(1) = \exp\left( - \sum_i p_i \ln(p_i) \right) \quad \text{if } q = 1
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D(0) = \left( \sum_i p_i^0 \right) = N \quad \text{Richesse}
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D(1) &= \exp\left(-\sum_i p_i \times \ln(p_i)p_i\right) \quad \text{Exp. of Shannon entropy}
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D(2) = \left( \sum_i p_i^2 \right)^{1/(1-2)} = \frac{1}{\sum_i p_i^2} & \text{Inverse of Simpson}
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\[
D(\infty) = \frac{1}{\max(p_i)} \quad \text{Indice de Berger-Parker}
\]
Properties

- Increase when the number of species increases and when species abundances are more even
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- Concave metric of diversity
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- Quantify species “effective number” (Value between 1 and N).

Example

- One community with 8 equally abundant species and another with 16 equally abundant species.
- With Shannon entropy : 2.07 vs. 2.77; Gini-Simpson : 0.875 vs. 0.9375
- With D(1) : 8 vs. 16; D(2) : 8 vs. 16
Testing across diversity indices
How doing it?

Properties

- Increase when the number of species increases and when species abundances are more even
- Concave metric of diversity
- Quantify species “effective number” (Value between 1 and N).
- Return “true” estimates of β-diversity *(Jost 2007, Tuomisto 2011)*

**beta-diversity**

- γ/α
- Quantifies the “effective number” of site in a meta-community set between 1 and the number of site
- “independent” from the α-diversity
Behavior with uneven abundance

Example of a two species community

- Species richness
Behavior with uneven abundance

Example of a two species community

- Species richness
- Exp. of Shannon
Behavior with uneven abundance

Example of a two species community

- Species richness
- Exp. of Shannon
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Behavior with uneven abundance

Example of a two species community

- Species richness
- Exp. of Shannon
- Inverse of Simpson
- Berger-Parker
Parametrization of the dominance effect

- When 'q' is low, all species are taken into account
- When 'q' is high, only dominant species are taken into account

Example: Change of community ranking with $q$

Leinster & Cobbold 2012
How to adapt Hill numbers to phylogenetic and functional distances?

Leinster’s generalization of Hill numbers (includes Rao...)

\[
D(q, \delta) = \frac{\left( \sum_i p_i (\sum_j Z_{ij} p_j)^{q-1} \right)^{1/(1-q)}}{\text{if } q \neq 1}
\]

\[
D(q, \delta) = \exp\left( -\sum_i p_i \log(\sum_j Z_{ij} p_j) \right) \quad \text{if } q = 1
\]

\(p_i\): rel. abun. of species \(i\)

\(Z_{ij}\): similarity between species \(i\) and \(j\).

Chao’s generalization of Hill numbers (includes Faith, Allen, Rao, (MPD)...)

\[
D(q, \delta) = \left( \sum_b \frac{L_b(\delta)}{T} \times p_b^q \right)^{1/(1-q)} \quad \text{if } q \neq 1
\]

\[
D(q, \delta) = \exp\left( -\sum_b \frac{L_b(\delta)}{T} \times \ln(p_b)p_b \right) \quad \text{if } q = 1
\]

\(p_b\): rel. abun. of branch \(b\) descendants

\(L_b\): branch \(b\) length.

\(T\): Tree length.
The similarity effect

- Idea: Varying the link between ecological similarity and phylo. distance
- Link to niche evolution theory through Pagel’s tree transformations

More weight on close-to-root divergences

δ < 1

More weight on close-to-tips divergences

δ > 1

δ = 1
Varying plant meta-community phylogenetic $\beta$-diversity

120 communities across the gradients of the Guisane valley (Alps)
Genus-level phylogeny as species ecological similarity.

Chalmandrier et al. 2015 Ecology
Results: varying diversity pattern according to $q$ and $\delta$.

Conclusions

- Abiotic filtering on plant functional traits.
- Abiotic filtering on lineage composition.
- Widespread dominant and recent lineages.

Chalmandrier et al. 2015 Ecology
Results: varying diversity pattern according to $q$ and $\delta$.

Conclusions with Faith’s index

- Abiotic filtering on plant functional traits.
- Abiotic filtering on lineage composition.
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Chalmandrier et al. 2015 Ecology
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Conclusions with Allen’s index

- Abiotic filtering on plant functional traits.
- Abiotic filtering on lineage composition.
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Chalmandrier et al. 2015 Ecology
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Conclusions with Rao’s index

- Abiotic filtering on plant functional traits.
- Abiotic filtering on lineage composition.
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*Chalmandrier et al. 2015 Ecology*
Results: varying diversity pattern according to q and $\delta$.

Conclusions with a transformed tree

- Abiotic filtering on plant functional traits.
- Abiotic filtering on lineage composition.
- Widespread dominant and recent lineages.

*Chalmandrier et al. 2015 Ecology*