




ecodive: Parallel and Memory-Efficient R Package for Ecological Diversity Analysis

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Summary

Characterizing the composition of biological communities is a fundamental task in ecology, but the calculations involved can be computationally prohibitive. *ecodive* is an R package that addresses this challenge by providing a highly optimized implementation of common ecological diversity metrics, including alpha-diversity (within-sample richness and evenness) and beta-diversity (between-sample dissimilarity). These metrics can incorporate species counts, relative abundances, and evolutionary relationships, providing a multi-faceted view of ecological structure. By leveraging a compiled C library with pthreads for parallelization, *ecodive* delivers substantial performance gains in both speed and memory usage, enabling researchers to analyze larger datasets more efficiently.

Statement of Need

The analysis of ecological diversity in large-scale studies is often hampered by the computational demands of calculating metrics across thousands of communities, a common requirement in modern microbiome research. This is particularly true for phylogenetic metrics like Faith's PD (Faith, 1992) and the UniFrac distance family (C. Lozupone & Knight, 2005), which integrate species abundance with evolutionary data from phylogenetic trees. The resulting high demand on processing time and memory can limit the scope and scale of scientific inquiry.

ecodive overcomes these limitations by offering a significantly faster and more memory-efficient solution. This allows researchers to analyze more samples, explore more complex questions, and obtain more robust insights from their data. By providing a high-performance, parallelized engine for these calculations, *ecodive* empowers researchers to push the boundaries of large-scale ecological analysis.

Comparison to Existing Packages

While numerous R packages can calculate diversity metrics, our comparison focuses on those that provide their own implementations: *abdiv* (Bittinger, 2020), *adiv* (Pavoine, 2020), *ampvis2* (Andersen et al., 2018), *ecodist* (Goslee & Urban, 2007), *entropart* (Marcon & Herault, 2015), *GUniFrac* (Chen et al., 2023), *phyloregion* (Daru et al., 2020), *phylloseq* (McMurdie & Holmes, 2013), *picante* (Kembel et al., 2010), and *vegan* (Oksanen et al., 2025). *ecodive* sets itself apart from these packages through its superior performance. Furthermore, *ecodive* has zero external R dependencies. This makes it a lightweight, stable, and secure computational backend, minimizing installation conflicts and simplifying long-term maintenance for developers who build upon it.

Comprehensive benchmarks, conducted using the bench package (Hester & Vaughan, 2025), demonstrate these advantages across a range of metrics (Figures 1-3). The complete benchmark code and results are available in the package vignette (vignette('benchmark')) and online.

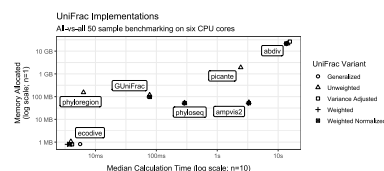


Figure 1: Figure 1: UniFrac benchmarks. ecodiv demonstrates substantial performance gains for UniFrac, being 2 to 3,900x faster and using 50 - 32,000x less memory, which helps overcome computational bottlenecks in large-scale analyses.

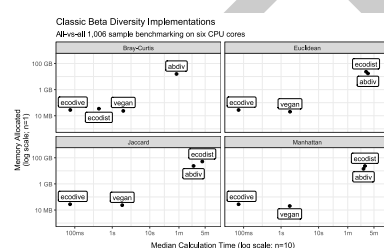


Figure 2: Figure 2: Classic beta diversity benchmarks. ecodiv is 6 to 2,300x faster and uses 1 to 1,800x less memory, enabling more efficient analysis of community dissimilarities.

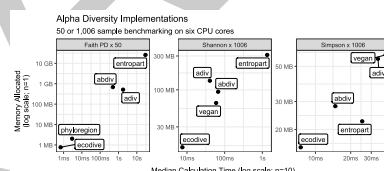


Figure 3: Figure 3: Alpha diversity benchmarks. ecodiv is 2 to 43,000x faster and uses 1 to 33,000x less memory, significantly accelerating the analysis of diversity within single samples.

Implemented Metrics

ecodiv provides a comprehensive suite of alpha and beta diversity metrics. The current implementation includes:

Alpha Diversity

- Classic: Shannon Index (Shannon, 1948), Simpson Index (Gini, 1912; Simpson, 1949), Inverse Simpson Index (Simpson, 1949), and Chao1 (Chao, 1984).
- Phylogenetic: Faith's Phylogenetic Diversity (Faith, 1992).

Beta Diversity

- Classic: Bray-Curtis (Bray & Curtis, 1957; Sorenson, 1948), Canberra (Lance & Williams, 1967), Euclidean (Gower & Legendre, 1986; Legendre & Caceres, 2013), Gower (Gower, 1971; Gower & Legendre, 1986), Jaccard (Jaccard, 1908), Kulczynski (Kulczynski, 1927), and Manhattan (Kaufman & Rousseeuw, 1990).

- Phylogenetic: Unweighted UniFrac (C. Lozupone & Knight, 2005), Weighted UniFrac (C. A. Lozupone et al., 2007), Normalized Weighted UniFrac (C. A. Lozupone et al., 2007), Generalized UniFrac (Chen et al., 2012), and Variance Adjusted Weighted UniFrac (Chang et al., 2011).

For the most up-to-date list and detailed descriptions, please refer to the official ecodive documentation at <https://cmmr.github.io/ecodive/reference/index.html>.

Example Usage

ecodive is designed for ease of use and integrates seamlessly with existing bioinformatics workflows, such as those using phyloseq objects. For example, calculating weighted UniFrac distances is straightforward:

```
library(phyloseq)
data(esophagus)

ecodive::weighted_unifrac(esophagus)
#>           B           C
#> C 0.1050480
#> D 0.1401124 0.1422409
```

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