

## Measuring morphological richness in morphospace: another look at disparity

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Detecting patterns of change in biodiversity has been at the center of paleontological studies during the past quarter-century. Recently, there has been much interest in relationship between taxonomic diversity and morphological disparity. Studies on diversity change need an appropriate measure of diversity as well as removal of sampling overprints. The taxonomic diversity is assessed through compilations of the number of taxa, i.e., taxonomic richness. Meanwhile, the morphological disparity is commonly based on measurements of morphological distance between objects, e.g., sum of variance, mean pairwise distance, range of variation etc. Richness and distance (or dissimilarity) are different properties of diversity and cannot be compared on an equal plane. Comparison between taxonomic diversity and disparity needs to develop measures of morphological richness such as number of pairwise character-state combinations and participation ratio. Counting the number of pairwise characters requires the division of the morphospace up into discrete bins. However, measures of morphological richness hitherto been available highly depends on how to bin the morphospace as well as on sample size.

Here, I would propose a method to assess morphological richness and morphological evenness that are robust with respect both to option for analysis and sampling effort. At the first step, the probability density of data in a morphospace is estimated using multi-dimensional kernel density estimation instead of depicting a histogram. In the next step, randomized subsampling of data is designed to remove sampling intensity biases using the probability densities at the positions where the sampled data occupy in the morphospace. Subsampling is carried out until the data that have been sampled have a summed total of the probability densities which equals a fixed proportion. This approach is closely related to the shareholder quorum sampling rather than classical rarefaction. A morphological richness is assessed by an extent of the Bayesian highest posterior density region of the probability density of the subsample in the morphospace. Conventional participation ratio based on discrete criteria is extended to a case of continuous variables so as to define a new measure of morphological evenness.

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