A global dataset of leaf $\Delta^{13}C$ values

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Abstract

We gathered 3985 bulk leaf δ^{13}C and Δ^{13}C values from 594 sites on seven continents, from published and unpublished sources. All records have a location and a photosynthetic system—C_3, C_4, or CAM. Δ^{13}C gives a uniquely time–integrative view into plant water use, hence this data set is useful for understanding and modeling plant water use at the global scale.

Background & Summary

Plant water relations reflects a complex balance between the demand for water by the atmosphere and the supply of water to the leaf. Both demand and supply vary widely across the globe, and leaf carbon isotopes provide a unique view into a plant's response to this variation [1, 2]. As such, to understand plant water relations in different climatic contexts, the ratio of the stable carbon isotopes, ^{13}C and ^{12}C, is one of the most powerful investigative tools available [1, 2].

We built a large global database of bulk leaf δ^{13}C and Δ^{13}C from natural and semi-natural terrestrial habitats across the world. We gathered data from published and unpublished sources that include sites across all seven continents (Figures 1, 2, and 3).

The database of leaf carbon isotopes contains 3985 species-site combinations, including 3645 species-site combinations for C_3 photosynthesis. Each record contains a geographic location, the photosynthetic system of the species—C_3, C_4, or CAM—and either bulk leaf δ^{13}C—the stable isotope ratio relative to a standard material—or an estimate of Δ^{13}C—the difference between the leaf stable isotope ratio and the atmospheric stable isotope ratio at that place and time. Because Δ^{13}C is the more interesting biological quantity, in the cases where δ^{13}C was reported, we estimate Δ^{13}C from the reported of δ^{13}C value.

This new and comprehensive global dataset has the potential to support more work on connecting the carbon and water cycles on a global scale.

Methods

We gathered bulk leaf carbon isotopic data from published and unpublished records from vascular plants in natural and semi-natural habitats across the world (see Figure 1). In all cases, bulk leaf data records were measured by an isotopic ratio mass spectrometer. While we make no claims to have exhaustively surveyed the extensive plant carbon isotope literature, the data collected does span all seven continents and a wide range of climatic conditions where vascular plants are found (Figure 1).

The fundamental "data unit" presented here is a species-site observation. The data unit includes 3985 observations from 594 sites on seven continents. Of those, 3645 observations were C_3 plants. To rectify various taxonomies used through the years and find misspellings we used the synonymy tools from The Plant List (v1.1) and an "approximate grepping" method which was able to correct basic spelling mistakes, such as double letters and species epithet gender errors. In a few cases the species identity was uncertain, the observations were left in the database because the plant was identified at a higher taxonomic level. We also left species in the database that we could not match to The Plant List (v1.1) because of current taxonomic uncertainty. For observations in which the photosynthetic system of the species was not reported in the original paper, the observation was completed by a literature search using the species names.

After name rectification, the database comprises in total 2783 species. Of these 2482 are thought to be C_3 species. There are 140 records from 127 C_4 species, and 194 records from 179 species known to use CAM in at least some circumstances. When multiple measurements were available, we used the upper, most-exposed leaves measured as the value for each species at each site. Some observations are labeled as "shade" and "sun" leaves following their designation in the original papers, although in practice is often hard to distinguish between those two categories. In cases where there were multiple replicates for a species at a given site, we report the mean of those measurements as the species–site value.

Estimating Δ

In order to make data comparisons possible across large geographical and temporal scales, we estimated Δ^{13}C—"big delta", the difference between the bulk leaf tissue δ^{13}C and the atmospheric δ^{13}C at the time and place of collection. Some papers reported Δ^{13}C and in this case we left the original values unchanged. More commonly, the papers listed only δ^{13}C, the difference in isotope ratios between the leaf and a standard material, Pee Dee Belemnite. In this case, we estimated the isotopic signature of well-mixed atmospheric air at that site, adjusting for both time and latitude relative to a 1992 reference [4]:

$$\delta^{13}C_{air,1992} = a * (sin(L * \frac{\pi}{180}))^2 + b * sin(L * \frac{\pi}{180}) - c \tag{1}$$

where L is latitude and a and b are empirically fit parameters with the values $a = 0.0819$, $b = 0.0983$, and $c = 7.7521$ [4]. This value is then adjusted for progressive depletion of ^{13}C in the atmosphere through time by:

$$\delta^{13}C_{air} = \delta^{13}C_{air,1992} + g(x - 1992) \tag{2}$$

where x is the year that the leaf was sampled and $g = -0.0227$.

Δ^{13}C is then defined as:

$$\Delta^{13}C = \frac{(\delta^{13}C_{air} - \delta^{13}C_{leaf})}{1 + \frac{\delta^{13}C_{leaf}}{1000}} \tag{3}$$

Note that this calculation of Δ^{13}C will not exclude any "source air effect" in which the isotopic signature of the CO_2 outside the stomata at the time of photosynthesis is different from that of the well-mixed atmosphere at that site [5, 6]. Because the available data are bulk leaf isotope (including lamina and midrib), there is also an effect of the relative sizes of the within–leaf carbon pools [2].

We plot the full distribution of $\Delta^{13}C$ within the database, including C_3, C_4 and facultative and obligate Crassulacean acid metabolism (CAM) species (Figure 2).

Data Records

The sites and the species are described by 9 columns. The data include species binomial, latitude, longitude, photosynthetic system, author of the original study for published work, and year of publication. The original values from the studies are in two separate columns for $\Delta^{13}C$ and $\delta^{13}C$. There is a third column with either the original $\Delta^{13}C$ value or the value estimated from $\delta^{13}C$ by the procedure described above. The units of these three columns are, following the standard convention, parts per thousand (*per mille*, ‰).

The data and meta-data are available from Zenodo (DOI: 10.5281/zenodo.569501).

Technical Validation

We examined the database for outliers for each photosynthetic system (see Figure 2 and 3). Data points greater than 3 SD from the mean for each photosynthetic type were rechecked against the original publication values. For C_3 plants, the lowest $\Delta^{13}C$ values are from the Atacama Desert in Chile, and the largest $\Delta^{13}C$ values in the dataset are from the Brazilian Amazon.

Latitude and longitude were validated by plotting the values on the maps (see Figure 1) and geo-referenced aerial photography. We then checked if the location matched the verbal description in the paper. In a few cases, observations from clearly incorrect coordinates were removed from the database. Note, however, that the precision of the reported coordinates varies greatly among the studies.

Usage Notes

Traits have been a key method for understanding the ecology of plants across the globe. This dataset presents another useful plant trait that provides a time-integrative view into plant water use. These data will also be useful as an empirical check on global models of terrestrial plant water use.

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LS, IW, and WC wrote the grant that led to the meeting where the dataset was assembled.

JT and VM helped assemble and error check the dataset.

WC, LS, IW, MB, LC, TD, DE, GF, HG, CK, AK, PR, and DW designed the dataset assembly methods.

WC, IW, LS, MB, LC, TD, DE, GF, HG, CK, AK, PR, DW, RB, JC, AR, SS, FV, CK, ES, NB, and LS contributed published and unpublished data.

WC wrote the dataset descriptor.

Competing financial interests

The authors declare no competing financial interests.

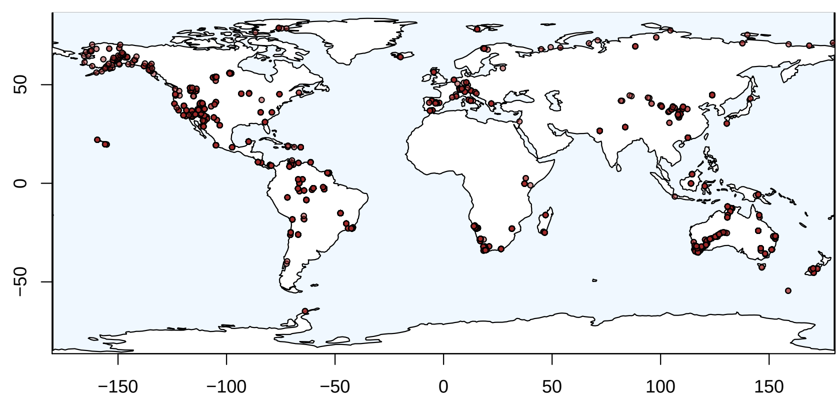

Figure 1: Collection locations for the data in this study. Each point is plotted semi-transparent such that darker red areas represent dense sampling, while less saturated red indicates less dense sampling.

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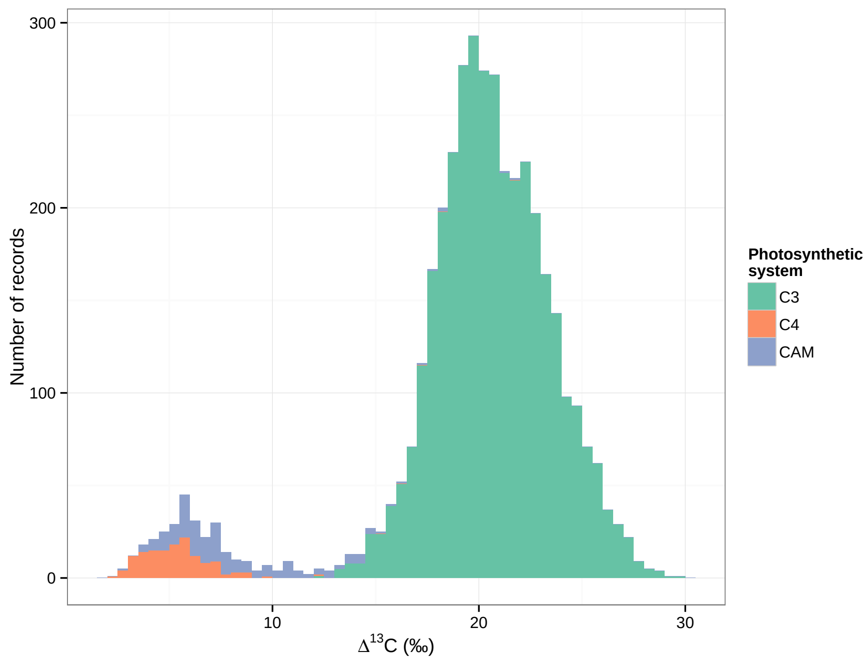

Figure 2: Distributions of Δ^{13}C across photosynthetic systems.

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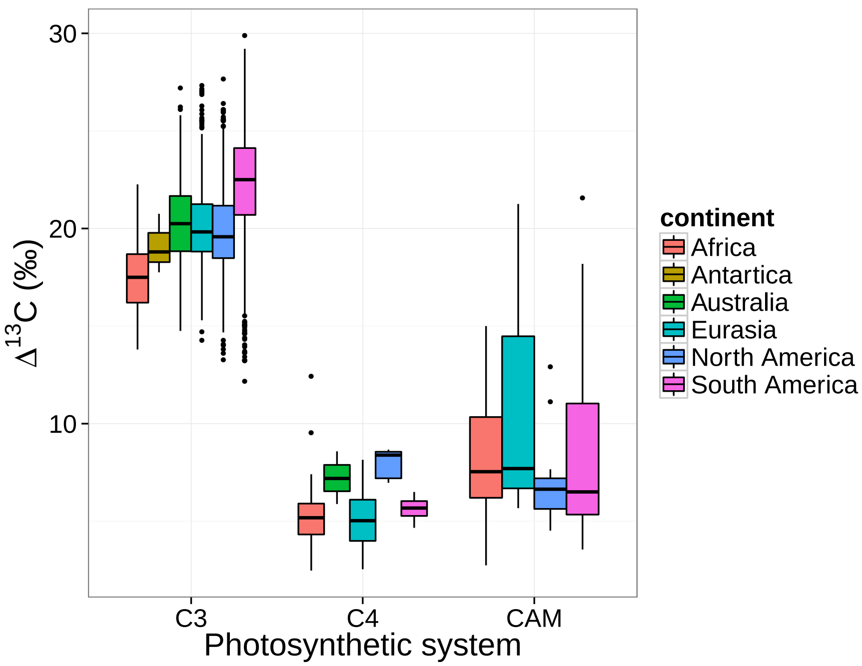

Figure 3: Distributions of Δ^{13}C across continents and across photosynthetic system. Please note that some of the patterns within specific continents may be explained by the non-random geographic samples within for example Africa (see Figure 1).

Data Citations

Cornwell WK, Wright I, Turner J, Maire V, Barbour M, Cernusak L, Dawson T, Ellsworth D, Farquhar G, Griffiths H, Keitel C, Knohl A, Reich P, Williams D, Bhaskar R, Cornelissen JHC, Richards A, Schmidt S, Valladares F, Körner C, Schulze E, Buchmann N, Santiago L. Data from: A global dataset of leaf Δ^{13}C values. Zenodo. DOI: 10.5281/zenodo.569501