***Ecology.* 2017. Data Paper.**

**Title**

LCE: Leaf carbon exchange dataset for tropical, temperate, and boreal species of North and Central America

**Authors and data compilers**

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**Abstract and keywords**

Leaf canopy carbon exchange processes, such as photosynthesis and respiration, are substantial components of the global carbon cycle. Climate models base their simulations of photosynthesis and respiration on an empirical understanding of the underlying biochemical processes, and the responses of those processes to environmental drivers. As such, data spanning large spatial scales are needed to evaluate and parameterize these models. Here, we present data on four important biochemical parameters defining leaf carbon exchange processes from 626 individuals of 98 species at 12 North and Central American sites spanning ~53° of latitude. The four parameters are the maximum rate of Rubisco carboxylation (*Vcmax*), the maximum rate of electron transport for the regeneration of Ribulose-1,5,-bisphosphate (*Jmax*), the maximum rate of phosphoenolpyruvate carboxylase carboxylation (*Vpmax*), and leaf dark respiration (*Rd*). The raw net photosynthesis by intercellular CO2 (*A/Ci*) data used to calculate *Vcmax*, *Jmax*, and *Vpmax* rates are also presented. Data were gathered on the same leaf of each individual (one leaf per individual), allowing for the examination of each parameter relative to others. Additionally, the dataset contains a number of covariates for the plants measured. Covariate data include (a) leaf-level traits (leaf mass, leaf area, leaf nitrogen and carbon content, predawn leaf water potential), (b) plant-level traits (plant height for herbaceous individuals and diameter at breast height for trees), (c) soil moisture at the time of measurement, (d) air temperature from nearby weather stations for the day of measurement and each of the 90 days prior to measurement, and (e) climate data (growing season mean temperature, precipitation, photosynthetically active radiation, vapor pressure deficit, and aridity index). We hope that the data will be useful for obtaining greater understanding of the abiotic and biotic determinants of these important biochemical parameters and for evaluating and improving large-scale models of leaf carbon exchange.

Keywords: Photosynthesis, respiration, leaf carbon exchange, soil moisture, climate, temperature, precipitation, leaf traits, Vcmax, Jmax, DBH, LMA

**Metadata**

**Class I. Dataset descriptors**

**A. Dataset identity**

LCE: Leaf carbon exchange dataset for tropical, temperate, and boreal species of North and Central America

**B. Dataset identification code**

**C. Dataset description**

**1. Originators:** This study was initiated by N. G. Smith and J. S. Dukes, Purdue University.

**2. Abstract:** Leaf canopy carbon exchange processes, such as photosynthesis and respiration, are substantial components of the global carbon cycle. Climate models base their simulations of photosynthesis and respiration on an empirical understanding of the underlying biochemical processes, and the responses of those processes to environmental drivers. As such, data spanning large spatial scales are needed to evaluate and parameterize these models. Here, we present data on four important biochemical parameters defining leaf carbon exchange processes from 626 individuals of 98 species at 12 North and Central American sites spanning ~53° of latitude. The four parameters are the maximum rate of Rubisco carboxylation (*Vcmax*), the maximum rate of electron transport for the regeneration of Ribulose-1,5,-bisphosphate (*Jmax*), the maximum rate of phosphoenolpyruvate carboxylase carboxylation (*Vpmax*), and leaf dark respiration (*Rd*). The raw net photosynthesis by intercellular CO2 (*A/Ci*) data used to calculate *Vcmax*, *Jmax*, and *Vpmax* rates are also presented. Data were gathered on the same leaf of each individual (one leaf per individual), allowing for the examination of each parameter relative to others. Additionally, the dataset contains a number of covariates for the plants measured. Covariate data include (a) leaf-level traits (leaf mass, leaf area, leaf nitrogen and carbon content, predawn leaf water potential), (b) plant-level traits (plant height for herbaceous individuals and diameter at breast height for trees), (c) soil moisture at the time of measurement, (d) air temperature from nearby weather stations for the day of measurement and each of the 90 days prior to measurement, and (e) climate data (growing season mean temperature, precipitation, photosynthetically active radiation, vapor pressure deficit, and aridity index). We hope that the data will be useful for obtaining greater understanding of the abiotic and biotic determinants of these important biochemical parameters and for evaluating and improving large-scale models of leaf carbon exchange.

**D. Keywords**

Photosynthesis, respiration, leaf carbon exchange, soil moisture, climate, temperature, precipitation, leaf traits, Vcmax, Jmax, DBH, LMA

**Class II. Research origin descriptors**

**A. Overall project description**

**1. Identity:** Terrestrial vegetation in the Earth System

**2. Originators:** N. G. Smith and J. S. Dukes, Purdue University

**3. Periods of study:** August 2010 – December 2016

**4. Objectives:** The project encompassed the majority of the dissertation for N. G. Smith under advisor J. S. Dukes. The primary objective of the project was to quantify the drivers of variation in leaf carbon exchange across space and time, to help understand the potential feedbacks from these processes to climate. Field and laboratory data were collected in natural and manipulative settings. Data were collected in a manner that would easily facilitate integration with Earth System Models. Quantitative analyses were performed to guide future data collection.

**5. Abstract:** Plant carbon uptake through photosynthetic assimilation and release through respiration are two of the largest fluxes of carbon between the atmosphere and the Earth’s surface. As such, the Earth System Models (ESMs) used to project future changes in climate are highly sensitive to the parameterization of these processes, and most models do not include representations of long-term responses of carbon exchange to environmental drivers. The objective of this project was increase the reliability of simulations of these processes by examining their drivers over large spatial and temporal scales, relevant for future global simulations. For photosynthesis, we focused on two of the primary rate limiting parameters, the maximum rate of Rubsico carboxylation (*Vcmax*), which defines CO2 limitation in biochemical models of photosynthesis, and the maximum rate of electron transport for regeneration of Ribulose-1,5-bisphosphate (*Jmax*), which defines light limitation in biochemical models of photosynthesis. For C4 species we also examined a third rate limiting parameter, the maximum rate of phosphoenolpyruvate carboxylase carboxylation (*Vpmax*). For respiration, we focused on leaf respiration in dark (*Rd*) the dominant respiratory flux for most species. The project examined acclimation responses of these parameters to temperature and water availability in each of the major plant types simulated by ESMs under a range of manipulative settings, from natural conditions to highly controlled growth chambers. The data collections were motivated by modeling work examining the sensitivity of these processes to long-term dynamics, such as acclimation. Resulting data were used to test and refine the parameterizations used in ESMs.

**Sources of funding:** National Aeronautics and Space Administration (NNX13AN65H), National Science Foundation (1311358)

**B. Specific subproject description**

**1. Site description**

**La Selva Biological Station (“LaSelva”)**

* **Site type:** Tropical rain forest
* **Geography:** Latitude = 10.42°, Longitude = -84.02°
* **Site history:** Unmanaged
* **Climate:** Mean annual temperature = 25.52°C, Mean annual precipitation: 4036 mm

**Horizontes Experimental Forest (“Horizontes”)**

* **Site type:** Tropical dry forest
* **Geography:** Latitude = 10.9°, Longitude = -85.6°
* **Site history:** Unmanaged
* **Climate:** Mean annual temperature = 24.98°C, Mean annual precipitation: 1809 mm

**Donald E. Davis Arboretum (“Auburn”)**

* **Site type:** Managed arboretum
* **Geography:** Latitude = 32.6°, Longitude = -85.5°
* **Site history: A**rboretum managed by Auburn University
* **Climate:** Mean annual temperature = 17.07°C, Mean annual precipitation: 1418 mm

**Southeast Purdue Agricultural Center (“SEPAC”)**

* **Site type:** Managed agriculture and restored tallgrass prairie
* **Geography:** Latitude = 39.03°, Longitude = -85.52°
* **Site history:** Agricultural center managed by Purdue University
* **Climate:** Mean annual temperature = 11.8°C, Mean annual precipitation: 1091 mm

**Blandy Experimental Farm (“Blandy”)**

* **Site type:** Managed arboretum
* **Geography:** Latitude = 39.06°, Longitude = -78.06°
* **Site history:** Arboretum managed by the University of Virginia
* **Climate:** Mean annual temperature = 11.67°C, Mean annual precipitation: 966 mm

**Morgan Monroe State Forest (“MMSF”)**

* **Site type:** Temperate deciduous forest
* **Geography:** Latitude = 39.32°, Longitude = -86.41°
* **Site history:** Unmanaged
* **Climate:** Mean annual temperature = 11.39°C, Mean annual precipitation: 1088 mm

**Fermi National Accelerator Laboratory (“Fermi”)**

* **Site type:** Managed agriculture and native tallgrass prairie
* **Geography:** Latitude = 41.86°, Longitude = -88.22°
* **Site history:** Agricultural center managed by Fermi National Accelerator Laboratory
* **Climate:** Mean annual temperature = 9.26°C, Mean annual precipitation: 931 mm

**Kellogg Biological Station (“KBS”)**

* **Site type:** Managed agriculture, restored tallgrass prairie, and temperate deciduous forest
* **Geography:** Latitude = 42.41°, Longitude = -85.4°
* **Site history:** Agriculture managed by Michigan State University
* **Climate:** Mean annual temperature = 8.74°C, Mean annual precipitation: 912 mm

**University of Guelph Arboretum (“Guelph”)**

* **Site type:** Managed arboretum
* **Geography:** Latitude = 43.5°, Longitude = -80.21°
* **Site history:** Arboretum managed by the University of Guelph
* **Climate:** Mean annual temperature = 6.42°C, Mean annual precipitation: 909 mm

**University of Michigan Biological Station (“UMBS”)**

* **Site type:** Temperate mixed forest
* **Geography:** Latitude = 45.56°, Longitude = -84.71°
* **Site history:** Unmanaged
* **Climate:** Mean annual temperature = 5.95°C, Mean annual precipitation: 794 mm

**Groundhog River (“GR”)**

* **Site type:** Boreal mixed forest
* **Geography:** Latitude = 48.22°, Longitude = -82.16°
* **Site history:** Unmanaged
* **Climate:** Mean annual temperature = 1.19°C, Mean annual precipitation: 765 mm

**Bonanza Creek (“BNZ”)**

* **Site type:** Boreal mixed forest
* **Geography:** Latitude = 63.92°, Longitude = -145.38°
* **Site history:** Unmanaged
* **Climate:** Mean annual temperature = -3.54°C, Mean annual precipitation: 338 mm

**2. Sampling design**

**a. Design characteristics:** At each site, individuals were sampled over the course of 1-2 weeks during the middle of the growing season (May-August). Individuals of dominant species were chosen for sampling and, where possible, multiple individuals of the same species were measured within and across sites to maximize intraspecific diversity. In all cases, outer canopy leaves were sampled. For trees taller than ~2 m, we measured leaves on detached branches, because in-situ measurements of upper canopy leaves were not feasible. Branches were acquired by severing a branch using an arborist slingshot. The slingshot was equipped with a beanbag attached to climbing rope, which was used to sever the branch. Severed branches were then immediately recut under water prior to leaf gas exchange measurements. Photosynthetic measurements were made within 30 minutes of branch cutting and monitored for stomatal closure induced by the cutting. Respiration measurements were made after 30 minutes of dark acclimation following the photosynthetic measurements.

**b. Permanent plots:** Permanent plots were not established

**c. Data collection periods**

Donald E. Davis Arboretum: May 19-22, 2014

Blandy Experimental Farm: May 26-29, 2014

Morgan Monroe State Forest: June 9-12, 2014

Fermi National Accelerator Laboratory: June 17-19, 2014

Southeast Purdue Agricultural Center: June 23-25, 2014

Kellogg Biological Station: June 30-July 3, 2014

University of Michigan Biological Station: July 7-11, 2014

Groundhog River: July 14-17, 2014

University of Guelph Arboretum: July 21-23, 2014

Bonanza Creek: July 31-August 7, 2014

La Selva Biological Station: May 18-28, 2015

Horizontes Experimental Forest: June 4-11, 2015

**3. Research methods**

**a. Field/laboratory**

**Leaf gas exchange measurements:** For each plant, net photosynthesis (*A*) was measured across a range of intracellular CO2 concentrations (*Ci*) in order to produce *A/Ci* curves. Curves were generated using, in order, air CO2 (*Ca*) values of 400, 300, 200, 100, 50, 400, 400, 600, 800, 1000, 1200, 1500, and 2000 µmol mol-1 for C3 species and 400, 300, 200, 100, 50, 0, 400, 400, 600, 800 µmol mol-1 for C4 species. An internal LED light source kept light at 1800 µmol m-2 s-1 for all curves. Where possible, we attempted to maintain leaf temperatures near 25°C and relative humidity inside the chamber between 40-80%, though this varied due to different ambient conditions at each site. The flow rate was maintained at 300 µmol s-1 and the humidity was adjusted by adjusting the flow of air through dessicant. Immediately following *A/Ci* curve measurements, light inside the chamber was set to 0 µmol m-2 s-1. After stabilization of leaf fluxes (~30 minutes), measurements of dark respiration were taken. For trees, all gas exchange data were taken within one hour of severing of the leaves from the tree. All data are presented at the leaf temperature at which the individual was measured (i.e., not standardized to 25°C).

**A/Ci curve fitting:** For C3 species, *A*/*Ci* curves were fit using the Farquhar, von Caemmerer, and Berry (Farquhar et al. 1980) model via the ‘plantecophys’ package (Duursma 2015) in R version 3.2.1 without consideration of triose phosphate utilization limitation. In each case, observed *Rd* values were used in the curve-fitting process and not estimated by the program (i.e., dark respiration was assumed equal to light respiration). We did not consider light inhibition of dark respiration. Values of the maximum rate of Rubisco carboxylation (*Vcmax*) and maximum rate of electron transport rate (*Jmax*)were obtained from the curve fitting process. For C4 species, *A/Ci* curves were fit using the equations of von Caemmerer (Von Caemmerer 2000) using non-linear least squared (nls) parameter estimation in R version 3.2.1. The enzyme- and light-limited portions of the curve were fit separately following visual estimation of the *Ci* transition value (i.e., the *Ci* value at which photosynthesis transitions from a CO2- to light-limited state). The maximum rate of phosphoenolpyruvate carboxylase (PEPc) carboxylation (*Vpmax*) and *Vcmax* were estimated from the enzyme-limited portion of the curve and *Jmax* was estimated from thelight-limited portion of the curve. All raw *A/Ci* data are included in the dataset to, for example, facilitate the implementation of different curve fitting methods. A R script with an example for curvefitting C3 and C4 species is included as part of the dataset.

**Leaf trait analyses:** After gas exchange measurements, leaf area of each leaf was measured with a portable leaf area meter (LI-COR Bioscience, Lincoln, NE) or with image analysis software ImageJ (Schneider et al. 2012). Following leaf area analysis, all leaves were dried to a constant mass at ~65°C, weighed, and ground using a mortar and pestle. Ground material was analyzed for carbon and nitrogen concentrations through combustion analysis. Leaf nitrogen concentration on an area basis (*Na*) was calculated using the ratio of leaf area to dry mass of each leaf and used for later analyses.

**Individual size:**Diameter at breast height (~1.5 meters; DBH) was measured for each non-juvenile tree as an estimate of plant size. Juvenile DBH was recorded as 0 meters. The height of each non-tree species was recorded as an estimate of individual size. Only one indicator of individual size, DBH (trees) or height (non-trees), was used for each individual.

**Pre-dawn water potential:** Pre-dawn leaf water potential of non-juvenile trees was measured the night following leaf gas exchange measurements at the Donald E. Davis Arboretum, Blandy Experimental Farm, University of Guelph Arboretum, and University of Michigan Biological Station.

**Soil moisture:** We measured moisture in the top 10 centimeters of soil (as volumetric water content; VWC) below the canopy of each measured plant during each measurement. Field capacity and the level at which soils become saturated was estimated at each site using the site soil characteristics and estimates of field capacity from Saxton and Rawls (Saxton and Rawls 2006).

**Recent temperature:** We acquired daily mean temperature values for each measurement day, and the 90 days prior to each measurement day, from airport-based weather stations near each site. The International Air and Transport Association (IATA) airport abbreviation for each site was: La Selva Biological Station = SJO, Horizontes Experimental Forest = LIR, Donald E. Davis Arboretum = MGM, Southeast Purdue Agricultural Center = SDF, Blandy Experimental Farm = WGO, Morgan Monroe State Forest = BMG, Fermi National Accelerator Laboratory = DPA, Kellogg Biological Station = BTL, University of Guelph Arboretum = YKF, University of Michigan Biological Station = PLN, Groundhog River = YTS, Bonanza Creek = BIG.

**Climate:** Latitude and longitude were used to extract growing season mean temperature, precipitation, leaf-to-air vapor pressure deficit, and incoming photosynthetically active radiation for each site from monthly, 1901-2015, 0.5° resolution data provided by the Climatic Research Unit (CRU TS3.24.01) (Harris et al. 2014). Growing season was defined as months with temperatures greater than 0°C. The ratio of MAP to mean annual potential evapotranspiration, or aridity index (AI), for each site from 1950-2000 was acquired from the Consultative Group for International Agricultural Research (CGIAR) Consortium for Spatial Information (Trabucco and Zomer 2009).

**b. Instrumentation**

**Gas exchange:** LI-COR LI-6400 portable photosynthesis machine (LI-COR Bioscience, Nebraska, USA)

**Water potential:** Model 600 Pressure Chamber Instrument (PMS Instrument Company, Oregon, USA)

**Leaf area:** LI-COR LI-3100 portable leaf area meter (LI-COR Bioscience, Nebraska, USA)

**Elemental analysis:** Costech 4010 (Costech Analytical Technologies, California, USA)

**Soil Moisture:** ML3 Theta Probe connected to a HH2 moisture meter (Delta-T Devices, Cambridge, UK)

**c. Taxonomy and systematics**

**d. Permit history**

**La Selva Biological Station:** Sampling and export permits granted by the Costa Rican Ministry of Environment

**Horizontes Experimental Forest**: Sampling and export permits granted by the Area de Conservacion Guanacaste

**e. Legal/organizational requirements**

**4. Project personnel:** Nicholas G. Smith (principal investigator), Jeffrey S. Dukes (principal investigator), Kyle Puls (student), Kylie Jungles (student)

**Class III. Dataset status and accessibility**

**A. Status**

**1. Latest update:** May 22, 2017

**2. Last archive date:** May 22, 2017

**3. Metadata status:** Metadata are complete to last update

**4. Data versification:** Data was checked for quality, including units, before, during, and after compilation of the dataset by N. G. Smith.

**B. Accessibility**

**1. Storage location and medium:** The dataset will be posted as Supporting Information to this Data Paper published in *Ecology.* In addition, the dataset will be permanently stored at github.com/SmithEcophysLab/LCE. The Zenodo snapshot DOI for this release is 10.5281/zenodo.826930. Problems with the dataset can be reported at github.com/SmithEcophysLab/LCE/issues or to Nick Smith at nick.gregory.smith@gmail.com.

**2. Contact person:** Nick Smith, nick.gregory.smith@gmail.com

**3. Copyright restrictions:** The dataset is released under the Creative Commons Zero dedication. We please ask that you cite this article when using this dataset.

**4. Proprietary restrictions:** There are no proprietary restrictions for using this dataset.

**5. Costs:** There are no costs associated with using this dataset.

**Class IV. Data structural descriptors**

**A. Dataset file**

**1. Identity**

**LCE\_data.csv**

Dataset containing all data. Each row in the dataset indicates a unique individual and each column a unique variable. Variable descriptions and units can be found in file LCE\_dictionary.csv. The column ‘aci\_id’ in this file corresponds to the identifier ‘id’ in the files within the LCE\_ACi\_curves file, thus facilitating a link between the raw *A/Ci* and fitted curve data.

**LCE\_dictionary.csv**

Description and units for each variable in LCE\_data.csv.

**LCE\_ACi\_curves**

Folder containing individual A/Ci curve data used to generate the biochemical parameters. The column ‘id’ in these files corresponds to the identifier ‘aci\_id’ in LCE\_data.csv, thus facilitating a link between the raw *A/Ci* and fitted curve data.

**LCE\_ACi\_dictionary**

Description and units for each variable in LCE\_ACi\_curves files.

**Curvefitting\_example.R**

R script with examples for fitting C3 and C4 *A/Ci* curves as was implemented in the analysis.

**2. Size**

LCE\_data.csv (858 KB)

LCE\_dictionary (10 KB)

LCE\_ACi\_dictionary (0.7 KB)

LCE\_ACi\_curves (600 files; 2.5 MB total)

Curvefitting\_example.R (7.7 KB)

**3. Format and storage mode:** All files are stored as plain text comma separated values files (.csv). All files are stored on GitHub at github.com/SmithEcophysLab/LCE. The Zenodo snapshot DOI for this release is 10.5281/zenodo.826930.

**Acknowledgments**

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