Tundra Trait Team: A database of plant traits spanning the tundra biome

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DATA PAPER

Tundra Trait Team: A database of plant traits spanning the tundra biome

Anne D. Bjorkman1,2,3 | Isla H. Myers-Smith1 | Sarah C. Elmendorf4,5,6 |
Signe Normand2,7,8 | Haydn J. D. Thomas1 | Juha M. Alatalo9 | Heather Alexander10 | Alba Anadon-Rosell11,12,13 | Sandra Angers-Blondin1 | Yang Bai14 | Gaurav Baruah15 | Mariska te Beest16,17 | Logan Berner18 |

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Katharine Suding4 | Ken D. Tape79 | Marcello Tomaselli27 | Andrew Trant80 | Urs A. Treier2,7,8 | Jean-Pierre Tremblay81 | Maxime Tremblay63 | Susanna Venn82 | Anna-Maria Virkkala49 | Tage Vowles19 | Stef Weijers83 | Martin Wilmking13 | Sonja Wipf56 | Tara Zamin44

1School of GeoSciences, University of Edinburgh, Edinburgh, UK
2Ecoinformatics and Biodiversity, Department of Bioscience, Aarhus University, Aarhus, Denmark
3Senckenberg Gesellschaft für Naturforschung, Biodiversity and Climate Research Centre (BiK-F), Frankfurt, Germany
4Department of Ecology and Evolutionary Biology, University of Colorado, Boulder, Colorado
5National Ecological Observatory Network, Boulder, Colorado
6Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado
7Arctic Research Center, Department of Bioscience, Aarhus University, Aarhus, Denmark
8Center for Biodiversity Dynamics in a Changing World (BIOCHANGE), Department of Bioscience, Aarhus University, Aarhus, Denmark
9Department of Biological and Environmental Sciences, Qatar University, Doha, Qatar
10Department of Forestry, Forest and Wildlife Research Center, Mississippi State University, Mississippi
11Department of Evolutionary Biology, Ecology and Environmental Sciences, University of Barcelona, Barcelona, Spain
12Biodiversity Research Institute, University of Barcelona, Barcelona, Spain
13Institute of Botany and Landscape Ecology, Greifswald University, Greifswald, Germany
14Center for Integrative Conservation, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Xishuangbanna, China
15Department of Evolutionary Biology and Environmental Studies, University of Zurich, Zurich, Switzerland
16Department of Ecology and Environmental Science, Umeå University, Umeå, Sweden
17Environmental Sciences, Copernicus Institute of Sustainable Development, Utrecht University, Utrecht, The Netherlands
18School of Informatics, Computing, and Cyber Systems, Northern Arizona University, Flagstaff, Arizona
19Department of Earth Sciences, University of Gothenburg, Gothenburg, Sweden
20Gothenburg Global Biodiversity Centre, Göteborg, Sweden
21Department of Physical Geography and Ecosystem Science, Lund University, Lund, Sweden
22Martin Luther University Halle-Wittenberg, Institute of Biology / Geobotany and Botanical Garden, Halle (Saale), Germany
23German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Leipzig, Germany
24Adam Mickiewicz University, Institute of Geocology and Geoinformation, Poznan, Poland
25University of Alaska Anchorage, Department of Biological Sciences, Anchorage, Alaska
26Technische Universität München, Freising, Germany
27Department of Chemistry, Life Sciences and Environmental Sustainability, University of Parma, Parma, Italy
28The Alaska Department of Fish and Game, Anchorage, Alaska
29Department of Biology, Memorial University, St. John’s, Newfoundland and Labrador, Canada
30Department of Arctic and Marine Biology, Faculty of Biosciences, Fisheries and Economics, UiT- The Arctic University of Norway, Tromsø, Norway
31Systems Ecology, Department of Ecological Science, Vrije Universiteit, Amsterdam, The Netherlands
32Department of Botany, University of Otago, Dunedin, New Zealand
33Department of Botany and Biodiversity Research, University of Vienna, Vienna, Austria
34Center for Permafrost (CENPERM), Department of Geosciences and Natural Resource Management, University of Copenhagen, Copenhagen, Denmark
35Department of Physiological Diversity, Helmholtz Centre for Environmental Research - UFZ, Leipzig, Germany
36Department of Ecology and Genetics, University of Oulu, Oulu, Finland
37Arctic Centre, University of Lapland, Rovaniemi, Finland
38Swiss Federal Research Institute WSL, Birmensdorf, Switzerland
39Department of Geography, University of British Columbia, Vancouver, British Columbia, Canada
40Faculty of Science and Technology, Federation University, Ballarat, Victoria, Australia
41Global Ecology Unit, CREAFT CIES-CIAB, Bellaterra, Catalonia, Spain
42CREAF, Bellaterra, Cerdanyola del Vallès, Catalonia, Spain
43Department of Ecology, Environment and Evolution, La Trobe University, Bundoora, Australia
44Department of Plant and Soil Sciences, University of Pretoria, Pretoria, South Africa
45Department of Biology, Queen’s University, Kingston, Ontario, Canada
The database contains 91,970 measurements of key traits related to plant form and function at multiple sites across the tundra biome. This dataset can be used to address theoretical questions about plant strategy and trade-offs, trait–environment relationships and environmental filtering, and trait variation across spatial scales, to validate satellite data, and to inform Earth system model parameters.

**Main types of variable contained:** The database contains 91,970 measurements of 18 plant traits. The most frequently measured traits (> 1,000 observations each) include plant height, leaf area, specific leaf area, leaf fresh and dry mass, leaf dry matter...
1 | INTRODUCTION

Plant traits reflect species’ ecological strategies and life histories, and underlie differences in the way plants acquire and use resources. Traits related to plant size and the leaf economics spectrum, for example, represent fundamental trade-offs between the capture and conservation of resources (Díaz et al., 2016; Wright et al., 2004). Because plant traits reflect the direct interaction between a plant and its habitat, variation in plant traits is often closely linked to environmental (including climatic) variation (Moles et al., 2006, 2009; Sandel et al., 2010). As such, plant traits can be used to predict species’ responses to environmental and climate change (Fridley, Lynn, Grime, & Askew, 2016; Soudzilovskaia et al., 2013). Furthermore, many plant functional traits are directly related to key community and ecosystem processes (Díaz et al., 2009; Lavorel & Garnier, 2002; Reichstein, Bahn, Mahecha, Kattge, & Baldocchi, 2014), and are thus considered essential biodiversity variables necessary for assessing biodiversity and ecosystem change globally (Pereira et al., 2013).

Global trait databases (Kattge et al., 2011) have dramatically increased the accessibility of plant trait data over the past decade, but these databases are heavily geographically biased towards temperate regions (e.g. 98% of observations in the TRY trait database were measured south of 60°N). In contrast, the tundra is the most rapidly warming biome on the planet (IPCC, 2013), but until now has been underrepresented in global trait databases, which limits our ability to predict the functional consequences of climate change. This poor geographical coverage of tundra species is especially pronounced in the most remote (e.g. high Arctic, upper alpine) regions. Because intraspecific trait variation is thought to be particularly important in ecosystems such as the tundra where diversity is low and species’ ranges are large (Siefer et al., 2015), multi-site trait observations on many individuals are needed to capture the full extent of tundra plant trait variation.

Here, we present the Tundra Trait Team (TTT) database, which contains more than 90,000 unique observations of 18 plant traits on 978 tundra species (Figures 1 and 2, Table 1). The TTT database is unique in its depth and spread. Trait data were collected at 207 unique tundra locations ranging from 47°S (the sub-Antarctic Marion Island) to 79.1°N (Sverdrup Pass, Ellesmere Island, Canada), and include multiple observations on individuals at the same location as well as of the same species at different locations. In addition, 99.8% of the observations in the database are georeferenced, thus allowing trait observations to be linked with environmental data such as gridded climate datasets (e.g. WorldClim, www.worldclim.org, CHELSA, chelsa-climate.org, CRU, crudata.uea.ac.uk, etc.). The TTT database fills a major geographical gap; it contains nearly twice as many high-latitude (≥55°N) observations as the TRY trait database for many key traits (Figure 3). Trait values in TTT are skewed towards individuals of smaller stature (height and leaf area) relative to values in TRY, likely reflecting improved sampling of the tundra’s coldest extremes (Figure 4).

The TTT database can be used to address wide-ranging theoretical and practical ecological questions. Multiple trait observations on individuals and species at numerous sites across the tundra biome enables the quantification of inter- and intraspecific trait
FIGURE 1  Trait observations span the Arctic, sub-Antarctic and alpine tundra. The size of the circle corresponds to the number of trait observations at a given location (minimum < 150, maximum > 2,500), while the colour of each circle indicates the measured trait. LDMC = leaf dry matter content; SLA = specific leaf area.

FIGURE 2  Frequency of observations across latitudes for the most commonly measured traits. More than 99% of the observations are georeferenced. The dashed line separates Southern and Northern Hemisphere observations. LDMC = leaf dry matter content.
TABLE 1  All traits contained in the Tundra Trait Team (TTT) database, including the number of total observations of each trait, the number of unique locations (rounded to the nearest tenth of a decimal degree) at which each trait was measured, and the total number of species for which each trait was measured. The mean, SD, median, and 95% quantiles for each trait are also provided. Leaf d13C and leaf d15N correspond to the leaf carbon isotope signature and the leaf nitrogen isotope signature, respectively.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Units</th>
<th># obs</th>
<th># locs</th>
<th># spp</th>
<th>Mean</th>
<th>SD</th>
<th>q2.5</th>
<th>Median</th>
<th>q97.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height, repro.</td>
<td>m</td>
<td>5,981</td>
<td>27</td>
<td>122</td>
<td>0.14</td>
<td>0.12</td>
<td>0.02</td>
<td>0.11</td>
<td>0.43</td>
</tr>
<tr>
<td>Height, veg.</td>
<td>m</td>
<td>25,453</td>
<td>146</td>
<td>643</td>
<td>0.21</td>
<td>0.38</td>
<td>0.01</td>
<td>0.09</td>
<td>1.39</td>
</tr>
<tr>
<td>Leaf dry matter content (LDMC)</td>
<td>g/g</td>
<td>7,981</td>
<td>55</td>
<td>755</td>
<td>0.33</td>
<td>0.15</td>
<td>0.10</td>
<td>0.32</td>
<td>0.66</td>
</tr>
<tr>
<td>Leaf area</td>
<td>mm²</td>
<td>11,498</td>
<td>55</td>
<td>688</td>
<td>696.4</td>
<td>4,048.2</td>
<td>4.4</td>
<td>163.0</td>
<td>3,975.2</td>
</tr>
<tr>
<td>Leaf carbon</td>
<td>mg/g</td>
<td>2,338</td>
<td>30</td>
<td>302</td>
<td>465.2</td>
<td>32.5</td>
<td>412.8</td>
<td>458.5</td>
<td>539.6</td>
</tr>
<tr>
<td>Leaf C:N ratio</td>
<td>ratio</td>
<td>1,026</td>
<td>13</td>
<td>182</td>
<td>26.1</td>
<td>13.9</td>
<td>11.8</td>
<td>22.0</td>
<td>66.5</td>
</tr>
<tr>
<td>Leaf d13C</td>
<td>ppt</td>
<td>342</td>
<td>4</td>
<td>18</td>
<td>−28.8</td>
<td>1.95</td>
<td>−32.6</td>
<td>−29.08</td>
<td>−24.7</td>
</tr>
<tr>
<td>Leaf d15N</td>
<td>ppt</td>
<td>274</td>
<td>3</td>
<td>18</td>
<td>−3.24</td>
<td>3.74</td>
<td>−9.48</td>
<td>−3.89</td>
<td>4.88</td>
</tr>
<tr>
<td>Leaf dry mass</td>
<td>mg</td>
<td>8,489</td>
<td>52</td>
<td>569</td>
<td>29.14</td>
<td>74.65</td>
<td>0.02</td>
<td>8.00</td>
<td>200.00</td>
</tr>
<tr>
<td>Leaf fresh mass</td>
<td>g</td>
<td>6,859</td>
<td>32</td>
<td>511</td>
<td>0.134</td>
<td>0.393</td>
<td>7 e⁻³</td>
<td>0.030</td>
<td>0.897</td>
</tr>
<tr>
<td>Leaf nitrogen</td>
<td>mg/g</td>
<td>3,153</td>
<td>45</td>
<td>399</td>
<td>23.23</td>
<td>9.33</td>
<td>7.87</td>
<td>22.73</td>
<td>44.61</td>
</tr>
<tr>
<td>Leaf N:P ratio</td>
<td>ratio</td>
<td>1,880</td>
<td>34</td>
<td>347</td>
<td>11.55</td>
<td>3.60</td>
<td>5.60</td>
<td>11.21</td>
<td>19.74</td>
</tr>
<tr>
<td>Leaf phosphorus</td>
<td>mg/g</td>
<td>1,881</td>
<td>34</td>
<td>346</td>
<td>2.360</td>
<td>1.055</td>
<td>0.761</td>
<td>2.166</td>
<td>4.807</td>
</tr>
<tr>
<td>Rooting depth</td>
<td>cm</td>
<td>62</td>
<td>1</td>
<td>9</td>
<td>36.81</td>
<td>17.75</td>
<td>9.05</td>
<td>36.50</td>
<td>70.80</td>
</tr>
<tr>
<td>Seed mass</td>
<td>mg</td>
<td>1,341</td>
<td>23</td>
<td>194</td>
<td>1.81</td>
<td>3.70</td>
<td>0.03</td>
<td>0.58</td>
<td>14.85</td>
</tr>
<tr>
<td>Specific leaf area (SLA)</td>
<td>mm²/mg</td>
<td>12,078</td>
<td>87</td>
<td>900</td>
<td>14.56</td>
<td>8.38</td>
<td>3.64</td>
<td>12.92</td>
<td>35.41</td>
</tr>
<tr>
<td>Stem specific density (SSD)</td>
<td>mg/mm³</td>
<td>926</td>
<td>18</td>
<td>39</td>
<td>0.62</td>
<td>0.16</td>
<td>0.31</td>
<td>0.61</td>
<td>0.92</td>
</tr>
<tr>
<td>Stem diameter</td>
<td>cm</td>
<td>408</td>
<td>10</td>
<td>13</td>
<td>0.36</td>
<td>0.92</td>
<td>0.01</td>
<td>0.01</td>
<td>3.14</td>
</tr>
</tbody>
</table>

Variation across scales. Linking trait observations with environmental data can facilitate our understanding of trait–environment relationships (Bjorkman et al. in press) and the role of environmental filtering in shaping plant communities (Asner, Knapp, Anderson, Martin, & Vaughn, 2016; Bernard-Verdier et al., 2012). Identifying trait–environment relationships can in turn inform predictions of plant and ecosystem responses to global change and help to establish Earth system model parameters in dynamic vegetation models (Wulschleger et al., 2014). We expect that making this dataset publicly available will contribute to future research in these and other unforeseen ways.

2 | METHODS

2.1 | Data acquisition and compilation

Data were submitted directly by the tundra researchers that collected them (see author list and Acknowledgments). These data represent a mix of previously collected data as well as new data collected as part of a multi-site field campaign. In some cases, the submitted trait data have contributed to publications (see Supporting Information Appendix S1 for reference list) but all values in the database are from primary sources (i.e. not extracted from publications). None of the data contained in the TTT database currently occur in other trait databases (e.g. TRY). All trait data in this version (v. 1.0) of the database are collected on plants growing in situ under natural conditions (i.e. data from experimental treatments were removed). Future updates to the database will also include trait data from experimental treatments (warming, grazing, nutrient addition, snow manipulation, etc.). This will be indicated accordingly in the ‘Treatment’ column.

2.2 | Data curation and quality control

All observations were checked to ensure logical latitude and longitude information and converted to standardized units of measurement. We also removed obviously erroneous or impossible values (e.g. leaf dry matter content values greater than 1 g/g). When possible, suspected errors were checked with the initial data providers and corrected. Species names were standardized to match the accepted names in The Plant List using the R package Taxonstand v. 2.0 (Cayuela, Granzow-de la Cerda, Albuquerque, & Golicher, 2012; column 'AccSpeciesName'), but the original names provided by data contributors are also included in the database (column 'OriginalName'). The original name may contain additional information about subspecies designations.

For those species with at least 10 observations of the same trait type, we additionally report an ‘error risk’ for each observation (see TRY database protocols for more information on the term ‘error...
risk’ in this context, https://www.try-db.org/TryWeb/TRY_Data_Release_Notes.pdf). The error risk was calculated as the number of standard deviations that a given value lies from the overall species mean for that trait. We also provide the script used to create the ‘cleaned’ version of the dataset as a GitHub repository (https://github.com/TundraTraitTeam/TraitHub), along with both the raw (uncleaned) and cleaned versions of the dataset. The cleaning script can be adapted to vary in its sensitivity to outliers. This script also includes code to output histograms that visually identify removed values per species for any traits of interest. It should be noted that this cleaning protocol is primarily useful for species with large numbers of observations of a given trait, and that much of the variation within a species may be due to environmental or other differences among sites (not error).

### 2.3 Data availability and access

The TTT database will be maintained at the GitHub repository (https://github.com/TundraTraitTeam/TraitHub). Trait data collection is ongoing; thus, we will periodically release updated versions of the database. A new version number will be assigned every time there is a database update, and old database versions will be archived for reference. A static version of the cleaned database (v. 1.0) will also be available at the Polar Data Catalogue (www.polardata.ca; CCI # 12,949) and additionally submitted to the TRY plant trait database (www.try-db.org) for inclusion in the next TRY version release. Data retrieved through TRY are fully public but are subject to the usage guidelines outlined in TRY. When using TTT data obtained through the Polar Data Catalogue or TRY, please cite this data paper as the original source.

### 2.4 Data use guidelines

Data are governed by a Creative Commons Attribution 4.0 International copyright (CC BY 4.0). Data are fully public but should be appropriately referenced by citing this data paper. Although not mandatory, we additionally suggest that data users contact and collaborate with data contributors (names provided in the ‘DataContributor’ column, contact information available through the TTT website: https://tundratraitteam.github.io/) whose datasets
have contributed a substantial proportion (e.g. 5% or greater) of trait observations used in a particular paper or analysis.

3 | DESCRIPTION OF DATA

The TTT database contains 91,970 observations on 18 plant traits measured in 207 locations across the tundra biome (Figures 1 and 2, Table 1). A ‘location’ is defined as a unique latitude-longitude combination, when both are rounded to the nearest tenth of a degree. The most frequently measured traits (>1,000 observations each) include plant height (both vegetative and reproductive), leaf area, specific leaf area, leaf fresh and dry mass, leaf dry matter content, leaf nitrogen content, leaf carbon content, leaf phosphorus content, leaf C:N, leaf N:P, seed mass, and stem specific density. In most cases, traits were measured on adult individuals at peak growing season, but some exceptions exist [e.g. Rhododendron caucasicum contains values of leaf dry matter content (LDMC) for both young and old leaves]. Most observations represent trait measurements at a single point in time, but several sites (e.g. Daring Lake, Alexandra Fiord and Qikiqtaaluk-Herschel Island, Canada, and several sites in Sweden) have measurements at the same site or on the same individual (Daring Lake) over time. Most observations (86%) represent a measurement on a single individual, while the rest represent plot or site means or maximums per species. This information is included in the ‘ValueKindName’ column (see Table 2). We have also retained information about the identity of each individual plant (‘IndividualID’) to facilitate analyses of within-individual trait-trait correlations.

In addition to the trait values themselves, nearly all observations (99.8%) contain information about latitude and longitude of the location where the measurement was taken (Figures 2 and 3). Elevation was also provided for most observations (70%). The high degree of georeferencing in the dataset enables the extraction of climate and other environmental data corresponding with each trait measurement. In addition, many data contributors provided information about the habitat type (‘SubsiteName’) in which each individual occurred. The full structure of the database is described in Table 2.

ACKNOWLEDGMENTS

This paper is an outcome of the sTundra working group supported by sDiv, the Synthesis Centre of the German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig (DFG FZT 118). ADB was supported by an iDiv postdoctoral fellowship and The Danish Council for Independent Research - Natural Sciences (DFF 4181-00565 to SN). ADB, IHM-S, HJDT and SAB were funded by the UK Natural Environment Research Council (ShrubTundra Project NE/M016323/1 to IHM-S) and SN by the Villum Foundation’s Young Scientists Programme.
**Table 2** Dataset structure. The cleaned Tundra Trait Team (TTT) dataset is provided as a csv file and consists of a single data table. The table structure is as follows.

<table>
<thead>
<tr>
<th>Column name</th>
<th>Description of variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>AccSpeciesName</td>
<td>Accepted species name as given by The Plant List (thepplantlist.org)</td>
</tr>
<tr>
<td>OriginalName</td>
<td>Original species name provided by the data contributor</td>
</tr>
<tr>
<td>IndividualID</td>
<td>ID number associated with each individual measured (as multiple traits were sometimes measured on the same individual)</td>
</tr>
<tr>
<td>Latitude</td>
<td>Latitude of the observation location in decimal degrees</td>
</tr>
<tr>
<td>Longitude</td>
<td>Longitude of the observation location in decimal degrees</td>
</tr>
<tr>
<td>Elevation</td>
<td>Elevation of the observation location in metres</td>
</tr>
<tr>
<td>SiteName</td>
<td>Name of the site where the observation was collected (as provided by the data contributor)</td>
</tr>
<tr>
<td>SubsiteName</td>
<td>Name of the subsite (nested within the SiteName) where the observation was collected (as provided by the data contributor). This frequently corresponds to a brief description of the habitat type</td>
</tr>
<tr>
<td>Treatment</td>
<td>Experimental treatment to which individuals were subjected. The current (v. 1.0) database contains only observations on naturally growing individuals (Treatment = ‘none’)</td>
</tr>
<tr>
<td>DayOfYear</td>
<td>Day of the year on which the measurement was made</td>
</tr>
<tr>
<td>Year</td>
<td>Year in which the measurement was made</td>
</tr>
<tr>
<td>DataContributor</td>
<td>Name of the original contributor of the data</td>
</tr>
<tr>
<td>ValueKindName</td>
<td>Specificity of the measurement; Single = single observation on an individual, Individual Mean = mean of multiple observations taken on a single individual, Plot mean = mean of multiple observations taken on individuals of the same species in a plot, Site specific mean = mean of multiple individuals of a species at the same site, Maximum in plot = maximum of all individuals of a species in a plot</td>
</tr>
<tr>
<td>Trait</td>
<td>Name of the trait measured using the TRY trait name convention, or the name reported by the data contributor when a trait is not included in TRY</td>
</tr>
<tr>
<td>Value</td>
<td>Value of the trait measured using the reported significant digits</td>
</tr>
<tr>
<td>Units</td>
<td>Unit of measurement for each trait (see also Table 1)</td>
</tr>
<tr>
<td>ErrorRisk</td>
<td>See description of the error risk variable in Data curation and quality control section, and <a href="https://www.try-db.org/TryWeb/TRY_Data_Release_Notes.pdf">https://www.try-db.org/TryWeb/TRY_Data_Release_Notes.pdf</a></td>
</tr>
<tr>
<td>Comments</td>
<td>Additional comments provided by the data contributor or collator, usually related to how the measurements were conducted</td>
</tr>
</tbody>
</table>
collection, and thank the governments, parks, field stations, and local and indigenous people for the opportunity to conduct research on their land.

REFERENCES


BIOSKETCHES

The Tundra Trait Team (https://tundratraitteam.github.io/) is an inclusive group of tundra ecologists involved in ongoing efforts to understand patterns of functional trait variation across scales, identify changes in functional traits in response to climate warming, and better understand the consequences of these changes for tundra ecosystem functioning. The TTT was founded by ADB and IHMS in association with members of the sTundra working group (German Centre for Integrative Biodiversity Research: iDiv) in an effort to increase the depth and breadth of trait data available for tundra plant species. The only requirement for membership of the TTT is the contribution of trait data; all are welcome to join. Please visit the website or contact one of the lead authors for more information.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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