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DATA PAPER

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

Anne D. Bjorkman[1,2,3] | Isla H. Myers-Smith[1] | Sarah C. Elmendorf[4,5,6] | Signe Normand[2,7,8] | Haydn J. D. Thomas[1] | Juha M. Alatalo[9] | Heather Alexander[10] | Alba Anadon-Rosell[11,12,13] | Sandra Angers-Blondin[1] | Yang Bai[14] | Gaurav Baruah[15] | Mariska te Beest[16,17] | Logan Berner[18] | Robert G. Björk[19,20] | Daan Blok[21] | Helge Bruelheide[22,23] | Agata Buchwal[24,25] | Allan Buras[26] | Michele Carbognani[27] | Katherine Christie[28] | Laura S. Collier[29] | Elisabeth J. Cooper[30] | J. Hans C. Cornelissen[31] | Katharine J. M. Dickinson[32] | Stefan Dullinger[33] | Bo Elberling[34] | Anu Eskelinen[35,23,36] | Bruce C. Forbes[37] | Esther R. Frei[38,39] | Maitane Iturrate-Garcia[15] | Megan K. Good[40] | Oriol Grau[41,42] | Peter Green[43] | Michelle Greve[44] | Paul Grogan[45] | Sylvia Haider[22,23] | Tomáš Hájek[46,47] | Martin Hallinger[48] | Konsta Happonen[49] | Karen A. Harper[50] | Monique M. P. D. Heijmans[51] | Gregory H. R. Henry[39] | Luise Hermanutz[29] | Rebecca E. Hewitt[52] | Robert D. Hollister[53] | James Hudson[54] | Karl Hülber[33] | Colleen M. Iversen[55] | Francesca Jaroszynska[56,57] | Borja Jiménez-Alfaro[58] | Jill Johnstone[59] | Rasmus Halfdan Jorgesen[60] | Elina Kaarlejärvi[14,61] | Rebecca Klady[62] | Jitka Klimešová[46] | Annika Korsten[32] | Sara Kuleza[59] | Aino Kulonen[57] | Laurent J. Lamarque[63] | Trevor Lantz[64] | Amanda Lavalle[65] | Jonas J. Lembrechts[66] | Esther Lévesque[63] | Chelsea J. Little[15,67] | Miska Luoto[49] | Petr Macek[47] | Michelle C. Mack[52] | Rabia Mathakutha[44] | Anders Michelsen[34,68] | Ann Milbau[69] | Ulf Molau[70] | John W. Morgan[43] | Martin Alfons Mörsdorf[30] | Jacob Nabe-Nielsen[71] | Sigrid Schøler Nielsen[2] | Josep M. Ninot[11,12] | Steven F. Oberbauer[72] | Johan Olofsson[16] | Vladimir G. Onipchenko[73] | Alessandro Petraglia[27] | Catherine Pickering[74] | Janet S. Prevéy[57] | Christian Rixen[57] | Sabine B. Rumpf[33] | Gabriela Schaepman-Strub[15] | Philipp Semenchuk[30,76] | Rohan Shetti[13] | Nadejda A. Soudzilovskaia[75] | Marko J. Spasojevic[77] | James David Mervyn Speed[78] | Lorna E. Street[1] |

Katharine Suding[4] | Ken D. Tape[79] | Marcello Tomaselli[27] | Andrew Trant[80] | Urs A. Treier[2,7,8] | Jean-Pierre Tremblay[81] | Maxime Tremblay[63] | Susanna Venn[82] | Anna-Maria Virkkala[49] | Tage Vowles[19] | Stef Weijers[83] | Martin Wilmking[13] | Sonja Wipf[56] | Tara Zamin[44]

[1]School of GeoSciences, University of Edinburgh, Edinburgh, UK

[2]Ecoinformatics and Biodiversity, Department of Bioscience, Aarhus University, Aarhus, Denmark

[3]Senckenberg Gesellschaft für Naturforschung, Biodiversity and Climate Research Centre (BiK-F), Frankfurt, Germany

[4]Department of Ecology and Evolutionary Biology, University of Colorado, Boulder, Colorado

[5]National Ecological Observatory Network, Boulder, Colorado

[6]Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado

[7]Arctic Research Center, Department of Bioscience, Aarhus University, Aarhus, Denmark

[8]Center for Biodiversity Dynamics in a Changing World (BIOCHANGE), Department of Bioscience, Aarhus University, Aarhus, Denmark

[9]Department of Biological and Environmental Sciences, Qatar University, Doha, Qatar

[10]Department of Forestry, Forest and Wildlife Research Center, Mississippi State University, Mississippi

[11]Department of Evolutionary Biology, Ecology and Environmental Sciences, University of Barcelona, Barcelona, Spain

[12]Biodiversity Research Institute, University of Barcelona, Barcelona, Spain

[13]Institute of Botany and Landscape Ecology, Greifswald University, Greifswald, Germany

[14]Center for Integrative Conservation, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Xishuangbanna, China

[15]Department of Evolutionary Biology and Environmental Studies, University of Zurich, Zurich, Switzerland

[16]Department of Ecology and Environmental Science, Umeå University, Umeå, Sweden

[17]Environmental Sciences, Copernicus Institute of Sustainable Development, Utrecht University, Utrecht, The Netherlands

[18]School of Informatics, Computing, and Cyber Systems, Northern Arizona University, Flagstaff, Arizona

[19]Department of Earth Sciences, University of Gothenburg, Gothenburg, Sweden

[20]Gothenburg Global Biodiversity Centre, Göteborg, Sweden

[21]Department of Physical Geography and Ecosystem Science, Lund University, Lund, Sweden

[22]Martin Luther University Halle-Wittenberg, Institute of Biology / Geobotany and Botanical Garden, Halle (Saale), Germany

[23]German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Leipzig, Germany

[24]Adam Mickiewicz University, Institute of Geoecology and Geoinformation, Poznan, Poland

[25]University of Alaska Anchorage, Department of Biological Sciences, Anchorage, Alaska

[26]Technische Universität München, Freising, Germany

[27]Department of Chemistry, Life Sciences and Environmental Sustainability, University of Parma, Parma, Italy

[28]The Alaska Department of Fish and Game, Anchorage, Alaska

[29]Department of Biology, Memorial University, St. John's, Newfoundland and Labrador, Canada

[30]Department of Arctic and Marine Biology, Faculty of Biosciences, Fisheries and Economics, UiT- The Arctic University of Norway, Tromsø, Norway

[31]Systems Ecology, Department of Ecological Science, Vrije Universiteit, Amsterdam, The Netherlands

[32]Department of Botany, University of Otago, Dunedin, New Zealand

[33]Department of Botany and Biodiversity Research, University of Vienna, Vienna, Austria

[34]Center for Permafrost (CENPERM), Department of Geosciences and Natural Resource Management, University of Copenhagen, Copenhagen, Denmark

[35]Department of Physiological Diversity, Helmholtz Centre for Environmental Research - UFZ, Leipzig, Germany

[36]Department of Ecology and Genetics, University of Oulu, Oulu, Finland

[37]Arctic Centre, University of Lapland, Rovaniemi, Finland

[38]Swiss Federal Research Institute WSL, Birmensdorf, Switzerland

[39]Department of Geography, University of British Columbia, Vancouver, British Columbia, Canada

[40]Faculty of Science and Technology, Federation University, Ballarat, Victoria, Australia

[41]Global Ecology Unit, CREAF-CSIC-UAB, Bellaterra, Catalonia, Spain

[42]CREAF, Bellaterra, Cerdanyola del Vallès, Catalonia, Spain

[43]Department of Ecology, Environment and Evolution, La Trobe University, Bundoora, Australia

[44]Department of Plant and Soil Sciences, University of Pretoria, Pretoria, South Africa

[45]Department of Biology, Queen's University, Kingston, Ontario, Canada

[46]Institute of Botany of the Czech Academy of Sciences, Třeboň, Czech Republic
[47]Faculty of Science, Centre for Polar Ecology, University of South Bohemia, Ceske Budejovice, Czech Republic
[48]Biology Department, Swedish Agricultural University (SLU), Uppsala, Sweden
[49]Department of Geosciences and Geography, University of Helsinki, Helsinki, Finland
[50]Biology Department, Saint Mary's University, Halifax, Nova Scotia, Canada
[51]Plant Ecology and Nature Conservation Group, Wageningen University & Research, Wageningen, The Netherlands
[52]Center for Ecosystem Science and Society, Northern Arizona University, Flagstaff, Arizona
[53]Biology Department, Grand Valley State University, Allendale, Michigan
[54]British Columbia Public Service, Surrey, British Columbia, Canada
[55]Climate Change Science Institute and Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee
[56]Institute of Biological and Environmental Sciences, University of Aberdeen, Aberdeen, UK
[57]WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland
[58]Research Unit of Biodiversity, (CSIC/UO/PA), University of Oviedo, Oviedo, Spain
[59]Department of Biology, University of Saskatchewan, Saskatoon, Saskatchewan, Canada
[60]Department of Geosciences and Natural Resource Management, University of Copenhagen, Copenhagen, Denmark
[61]Department of Biology, Vrije Universiteit Brussel (VUB), Ixelles, Belgium
[62]Department of Forest Resources Management, Faculty of Forestry, University of British Columbia, Vancouver, British Columbia, Canada
[63]Département des Sciences de l'environnement et Centre d'études nordiques, Université du Québec à Trois-Rivières, Trois-Rivières, Quebec, Canada
[64]School of Environmental Studies, University of Victoria, Victoria, British Columbia, Canada
[65]School for Resource and Environmental Studies, Dalhousie University, Halifax, Nova Scotia, Canada
[66]Centre of Excellence Plants and Ecosystems (PLECO), University of Antwerp, Antwerp, Belgium
[67]Department of Aquatic Ecology, Swiss Federal Institute of Aquatic Science and Technology, Dubendorf, Switzerland
[68]Department of Biology, University of Copenhagen, Copenhagen, Denmark
[69]Research Institute for Nature and Forest (INBO), Brussels, Belgium
[70]Department of Biological and Environmental Sciences, University of Gothenburg, Gothenburg, Sweden
[71]Department of Bioscience, Aarhus University, Roskilde, Denmark
[72]Department of Biological Sciences, Florida International University, Miami, Florida
[73]Department of Geobotany, Lomonosov Moscow State University, Moscow, Russia
[74]Environment Futures Research Institute, Griffith University, Southport, Queensland, Australia
[75]Environmental Biology Department, Institute of Environmental Sciences, CML, Leiden University, Leiden, The Netherlands
[76]Division of Conservation Biology, Vegetation Ecology and Landscape Ecology, Department of Botany and Biodiversity Research, University of Vienna, Vienna, Austria
[77]Department of Evolution, Ecology, and Organismal Biology, University of California Riverside, Riverside, California
[78]NTNU University Museum, Norwegian University of Science and Technology, Trondheim, Norway
[79]Institute of Northern Engineering, University of Alaska Fairbanks, Fairbanks, Alaska
[80]School of Environment, Resources and Sustainability, University of Waterloo, Waterloo, Canada
[81]Département de biologie, Centre d'études nordiques and Centre d'étude de la forêt, Université Laval, Quebec City, Quebec, Canada
[82]Centre for Integrative Ecology, School of Life and Environmental Sciences, Deakin University, Burwood, Victoria, Australia
[83]Department of Geography, University of Bonn, Bonn, Germany

Correspondence
Anne D. Bjorkman, Senckenberg Biodiversity and Climate Research Centre, 60325 Frankfurt, Germany.
Email: annebj@gmail.com

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Abstract

Motivation: The Tundra Trait Team (TTT) database includes field-based 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

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content, leaf nitrogen, carbon and phosphorus content, leaf C:N and N:P, seed mass, and stem specific density.

Spatial location and grain: Measurements were collected in tundra habitats in both the Northern and Southern Hemispheres, including Arctic sites in Alaska, Canada, Greenland, Fennoscandia and Siberia, alpine sites in the European Alps, Colorado Rockies, Caucasus, Ural Mountains, Pyrenees, Australian Alps, and Central Otago Mountains (New Zealand), and sub-Antarctic Marion Island. More than 99% of observations are georeferenced.

Time period and grain: All data were collected between 1964 and 2018. A small number of sites have repeated trait measurements at two or more time periods.

Major taxa and level of measurement: Trait measurements were made on 978 terrestrial vascular plant species growing in tundra habitats. Most observations are on individuals (86%), while the remainder represent plot or site means or maximums per species.

Software format: csv file and GitHub repository with data cleaning scripts in R; contribution to TRY plant trait database (www.try-db.org) to be included in the next version release.

KEYWORDS

alpine, Arctic, plant functional traits, tundra

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 (Siefert 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

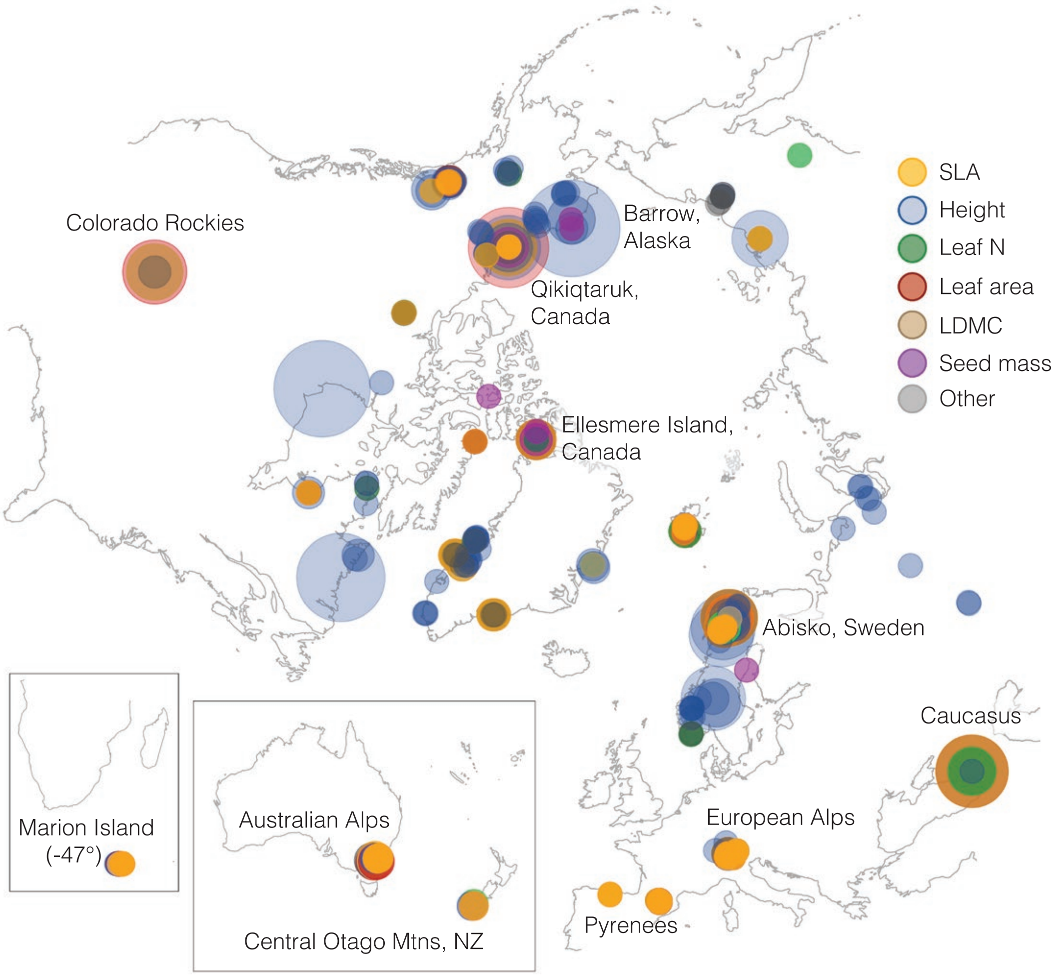

FIGURE 1 Trait observations span the Arctic, sub-Antarctic and alpine tundra. The size of the circle corresponds to the number of trait observations at a given location (minimum < 150, maximum > 2,500), while the colour of each circle indicates the measured trait. LDMC = leaf dry matter content; SLA = specific leaf area

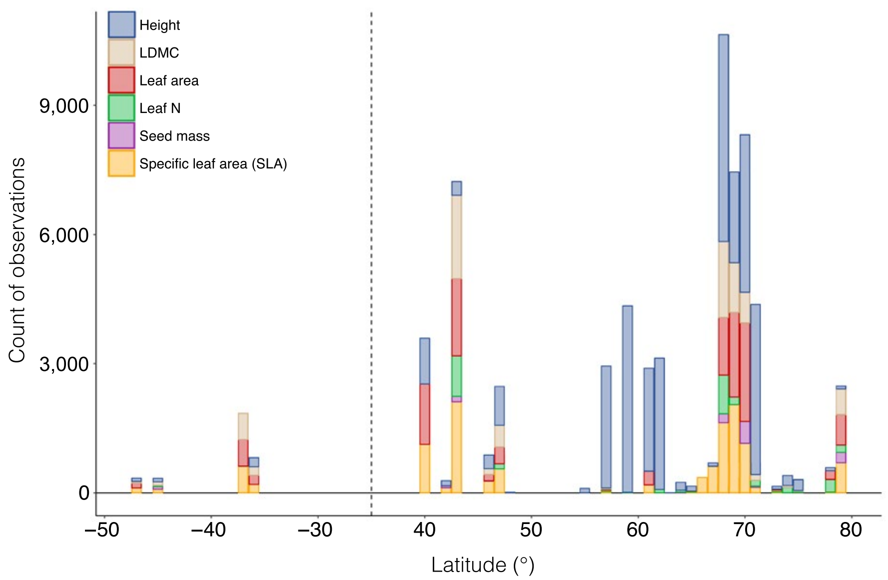

FIGURE 2 Frequency of observations across latitudes for the most commonly measured traits. More than 99% of the observations are georeferenced. The dashed line separates Southern and Northern Hemisphere observations. LDMC = leaf dry matter content

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

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

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 (Wullschleger 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

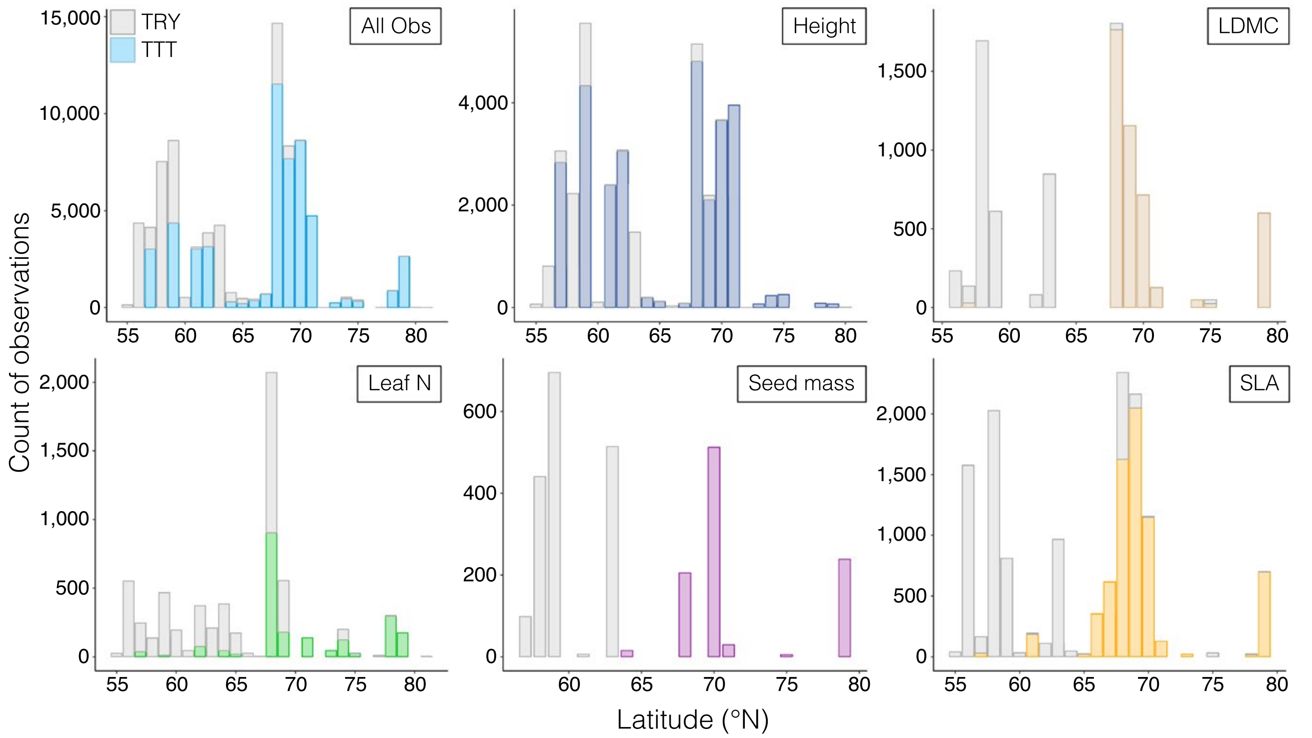

FIGURE 3 Histogram of all observations above 55°N contained in the Tundra Trait Team (TTT; coloured bars) and TRY (grey bars; try-db.org) databases. Bars are stacked, such that the height of the bar corresponds to the total number of observations (TRY + TTT) for that latitude. The first panel ('All Obs') contains all observations for height, specific leaf area (SLA), leaf N, leaf C, leaf P, leaf dry matter content (LDMC), seed mass, leaf area and stem specific density, while subsequent panels show observations for key individual traits. The TTT database more than doubles the number of high-latitude observations available for most traits; this is especially true in Arctic (i.e. above 65 °N) locations. The total number of georeferenced observations for these nine traits ('All Obs') is 27,802 and 52,179 for TRY and TTT, respectively. Coordinates for individual TRY trait observations are freely available on the TRY Data Portal (https://www.try-db.org/TryWeb/dp.php; 'Data Explorer' → 'Detailed information for 1 trait' → Choose trait and query 'Measurement table sorted by species'). TRY trait observations correspond to trait ID numbers 3106 and 3107 (height), 11, 3115, 3116, and 3117 (SLA), 1, 3108, 3110 and 3112 (leaf area), 13 (leaf C), 14 (leaf N), 15 (leaf P), 47 (LDMC), 4 (stem specific density) and 26 (seed mass)

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

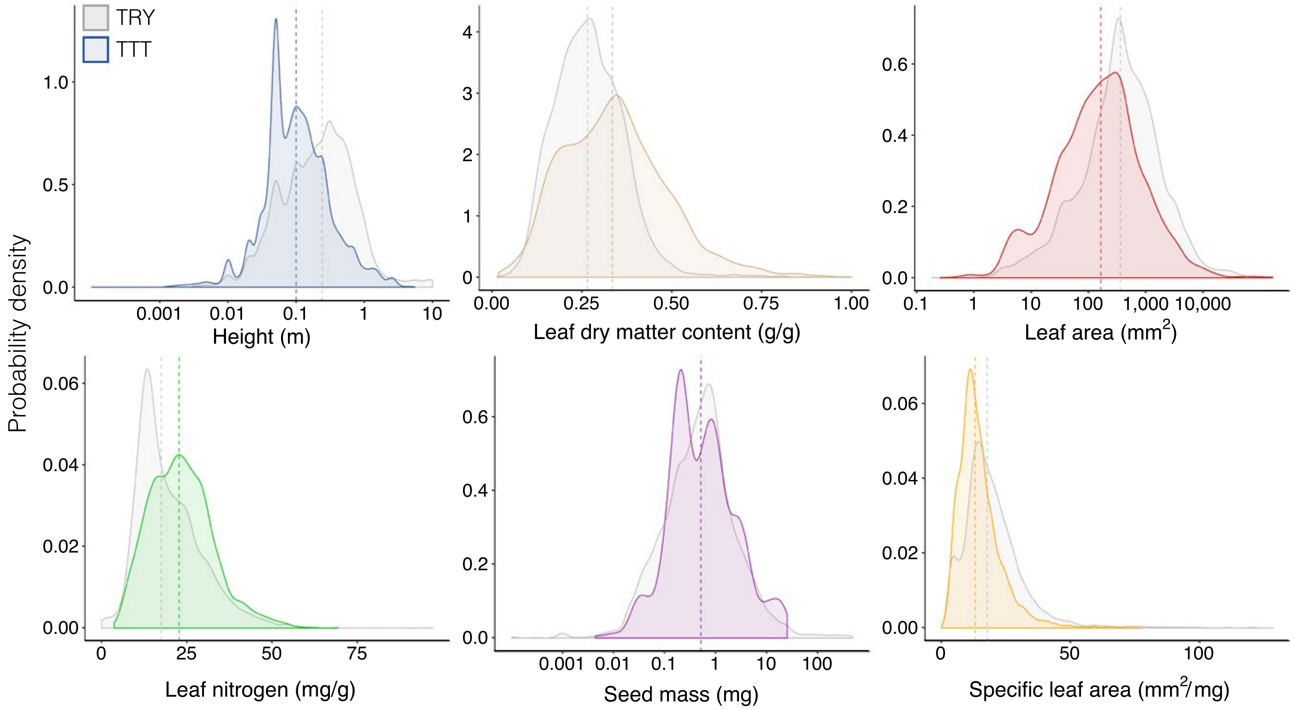

FIGURE 4 Density plots of trait values in the Tundra Trait Team (TTT; coloured) and TRY (grey) databases for all species that occur in both TTT and TRY (754 species in total). The *x* axes for height, leaf area and seed mass are on the log scale. Vertical dashed lines represent the median trait value for each database. TRY trait observations correspond to trait ID numbers 3106 and 3107 (height), 47 (leaf dry matter content, LDMC), 1, 3108, 3110 and 3112 (leaf area), 14 (leaf N), 26 (seed mass), and 11, 3115, 3116 and 3117 (specific leaf area, SLA). See Supporting Information Appendix S2 for the reference list of TRY datasets used in this comparison

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 Qikiqtaruk-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.

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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

Column name	Description of variable
AccSpeciesName	Accepted species name as given by The Plant List (theplantlist.org)
OriginalName	Original species name provided by the data contributor
IndividualID	ID number associated with each individual measured (as multiple traits were sometimes measured on the same individual)
Latitude	Latitude of the observation location in decimal degrees
Longitude	Longitude of the observation location in decimal degrees
Elevation	Elevation of the observation location in metres
SiteName	Name of the site where the observation was collected (as provided by the data contributor)
SubsiteName	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
Treatment	Experimental treatment to which individuals were subjected. The current (v. 1.0) database contains only observations on naturally growing individuals (Treatment = 'none')
DayOfYear	Day of the year on which the measurement was made
Year	Year in which the measurement was made
DataContributor	Name of the original contributor of the data
ValueKindName	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
Trait	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
Value	Value of the trait measured using the reported significant digits
Units	Unit of measurement for each trait (see also Table 1)
ErrorRisk	See description of the error risk variable in Data curation and quality control section, and https://www.try-db.org/TryWeb/TRY_Data_Release_Notes.pdf
Comments	Additional comments provided by the data contributor or collator, usually related to how the measurements were conducted

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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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