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Authors

Francesco Maria Sabatini^{1,2,†}, Jonathan Lenoir^{3,†}, Tarek Hattab⁴, Elise Aimee Arnst⁵, Milan Chytry⁶, Jürgen Dengler^{1,7,8}, Patrice De Ruffray⁹, Stephan M. Hennekens¹⁰, Ute Jandt², Florian Jansen¹¹, Borja Jiménez-Alfaro¹², Jens Kattge¹³, Aurora Levesley¹⁴, Valério D. Pillar¹⁵, Oliver Purschke¹⁶, Brody Sandel¹⁷, Fahmida Sultana¹⁸, Tsipe Aavik¹⁹, Svetlana Aćić²⁰, Alicia T.R. Acosta²¹, Emiliano Agrillo²², Miguel Alvarez²³, Iva Apostolova²⁴, Mohammed A.S. Arfin Khan²⁵, Luzmila Arroyo²⁶, Fabio Attorre²², Isabelle Aubin²⁷, Marijn Bauters^{28,29}, Yves Bergeron³⁰, Erwin Bergmeier³¹, Idoia Biurrun³², Anne D. Bjorkman^{33,34}, Gianmaria Bonari³⁵, Viktoria Bondareva³⁶, Jörg Brunet³⁷, Andraž Čarni^{38,39}, Laura Casella⁴⁰, Luis Cayuela⁴¹, Tomáš Černý⁴², Victor Chepinoga⁴³, János Csiky⁴⁴, Renata Ćušterevska⁴⁵, Els De Bie⁴⁶, André Luis de Gasper⁴⁷, Michele De Sanctis²², Panayotis Dimopoulos⁴⁸, Jiri Dolezal⁴⁹, Tetiana Dziuba⁵⁰, Mohamed Abd El-Rouf Mousa El-Sheikh^{51,52}, Brian Enquist⁵³, Jörg Ewald⁵⁴, Richard Field⁵⁵, Manfred Finckh⁵⁶, Sophie Gachet⁵⁷, Antonio Galán-de-Mera^{58,59,60}, Emmanuel Garbolino⁶¹, Hamid Gholizadeh⁶², Melisa Giorgis⁶³, Valentin Golub⁶⁴, Inger Greve Alsos⁶⁵, John-Arvid Grytnes⁶⁶, Gregory Richard Guerin⁶⁷, Alvaro G. Gutiérrez⁶⁸, Sylvia Haider^{69,70}, Mohamed Z. Hatim^{71,72}, Bruno Hérault^{73,74,75}, Guillermo Hinojos Mendoza⁷⁶, Norbert Hözel⁷⁷, Jürgen Homeier⁷⁸, Wannes Hubau^{79,80}, Adrian Indreica⁸¹, John Janssen⁸², Birgit Jedrzejek⁸³, Anke Jentsch⁸⁴, Norbert Jürgens⁵⁶, Zygmunt Kącki⁸⁵, Jutta Kapfer⁸⁶, Dirk Nikolaus Karger⁸⁷, Ali Kavgaci⁸⁸, Elizabeth Kearsley⁸⁹, Michael Kessler⁹⁰, Larisa Khanina⁹¹, Timothy Killeen⁹², Andrey Korolyuk⁹³, Holger Kreft⁹⁴, Hjalmar Kühl^{1,95}, Anna Kuzemko⁹⁶, Flavia Landucci⁹⁷, Attila Lengyel⁹⁸, Frederic Lens⁹⁹, Débora Vanessa Lingner¹⁰⁰, Hongyan Liu¹⁰¹, Tatiana Lysenko^{102,103,104}, Miguel D. Mahecha¹⁰⁵, Corrado Marcenò³², Vasiliy Martynenko¹⁰⁶, Jesper Erenskjold Moeslund¹⁰⁷, Abel Monteagudo Mendoza¹⁰⁸, Ladislav Mucina¹⁰⁹, Jonas V. Müller¹¹⁰, Jérôme Munzinger¹¹¹, Alireza Naqinezhad¹¹², Jalil Noroozi¹¹³, Arkadiusz Nowak^{114,115}, Viktor Onyshchenko¹¹⁶, Gerhard E. Overbeck¹¹⁷, Meelis Pärtel¹¹⁸, Aníbal Pauchard^{119,120}, Robert K. Peet¹²¹, Josep Peñuelas^{122,123}, Aaron Pérez-Haase^{124,125}, Tomáš Peterka⁹⁷, Petr Petřík¹²⁶, Gwendolyn Peyre¹²⁷, Oliver L. Phillips¹⁴, Vadim Prokhorov¹²⁸, Valerijus Rašomavičius¹²⁹, Rasmus Revermann^{130,131}, Gonzalo Rivas-Torres¹³², John S. Rodwell¹³³, Eszter Ruprecht¹³⁴, Solvita Rūsiņa¹³⁵, Cyrus Samimi¹³⁶, Marco Schmidt¹³⁷, Franziska Schrödt⁵⁵, Pavel Shirokikh¹⁰⁶, Jozef Šibík¹³⁸, Urban Šilc¹³⁹, Petr Sklenář¹⁴⁰, Željko Škvorc¹⁴¹, Ben Sparrow¹⁴², Marta Gaia Sperandii^{21,143}, Zvjezdana Stančić¹⁴⁴, Jens-Christian Svensson¹⁴⁵, Zhiyao Tang¹⁰¹, Cindy Q. Tang¹⁴⁶, Ioannis Tsiripidis¹⁴⁷, Milan Valachovič¹³⁸, Kim André Vanselow¹⁴⁸, Rodolfo Vásquez Martínez¹⁰⁸, Kiril Vassilev²⁴, Eduardo Vélez-Martin¹⁴⁹, Roberto Venanzoni¹⁵⁰, Alexander Christian Vibrans¹⁰⁰, Cyrille Violle¹⁵¹, Risto Virtanen^{1,152,153}, Henrik von Wehrden¹⁵⁴, Viktoria Wagner¹⁵⁵, Donald A. Walker¹⁵⁶, Donald Waller¹⁵⁷, Hua-Feng Wang¹⁵⁸, Karsten Wesche^{1,159,160}, Timothy Whitfeld¹⁶¹, Wolfgang Willner¹¹³, Susan K. Wiser⁵, Thomas Wohlgemuth¹⁶², Sergey Yamalov¹⁶³, Martin Zobel¹⁶⁴, Helge Bruehlheide^{1,2}

✉ — To whom correspondence should be addressed: francesco.sabatini@botanik.uni-halle.de

† — These authors contributed equally to this work

3. Université de Picardie Jules Verne, Unité de Recherche "Ecologie et Dynamique des Systèmes Anthropisés" (EDYSAN),
4 UMR 7058 CNRS, 1 Rue des Louvels, 80000, Amiens, France
5. MARBEC, University of Montpellier, CNRS, IFREMER and IRD, Sète, France
6. Manaaki Whenua - Landcare Research, PO Box 69040, 7640, Lincoln, New Zealand
7. Masaryk University, Faculty of Science, Department of Botany and Zoology, Kotlářská 2, 611 37, Brno, Czech Republic
8. Zurich University of Applied Sciences (ZHAW), Vegetation Ecology Group, Institute of Natural Resource Sciences (IUNR),
9 Grüentalstr. 14, 8820, Wädenswil, Switzerland
10. University of Bayreuth, Plant Ecology, Bayreuth Center of Ecology and Environmental Research (BayCEER),
11 Universitätsstr. 30, 95447, Bayreuth, Germany
12. Université de Strasbourg, Institut de biologie moléculaire des plantes-CNRS, 12, rue du Général-Zimmer, F-67084,
13 Strasburg, France
14. Wageningen Environmental Research, P.O.Box 47, 6700 AA, Wageningen, Netherlands
15. University of Rostock, Faculty of Agricultural and Environmental Sciences, Justus-von-Liebig-Weg 6, 18059, Rostock,
16 Germany
17. University of Oviedo, Research Unit of Biodiversity (CSIC/UO/PA), C. Gonzalo Gutiérrez Quirós s/n, 33600, Mieres, Spain
18. Max Planck Institute for Biogeochemistry, Hans Knöll Str. 10, 07745, Jena, Germany
19. University of Leeds, School of Geography, Woodhouse Lane, LS2 9JT, Leeds, United Kingdom
20. Universidade Federal do Rio Grande do Sul, Department of Ecology, Av. Bento Gonçalves 9500, 91501-970, Porto
21 Alegre, RS, Brazil
22. Medical School of the Martin-Luther University Halle-Wittenberg, Institute for Medical Epidemiology, Biometrics and
23 Informatics (IMEBI), Interdisciplinary Center for Health Sciences, Magdeburger Straße 8, 06112, Halle/Saale, Germany
24. Aarhus University, Aarhus, Denmark
25. Shahjalal University of Science & Technology, Forestry & Environmental Science, 3114, Sylhet, Bangladesh
26. University of Tartu, Department of Ecology and Earth Sciences, Department of Botany, Lai 40, Tartu 51005, Estonia
27. University of Belgrade, Faculty of Agriculture, Department of Botany, Nemanjina 6, 11080, Belgrade-Zemun, Serbia
28. Roma Tre University, Department of Sciences, V.le Marconi 446, 00146, Rome, Italy
29. Sapienza University of Rome, Department of Environmental Biology, P.le Aldo Moro 5, 00185, Rome, Italy
30. University of Bonn, Plant Nutrition, INRES, Karlrobert-Kreiten-Str., 53115, Bonn, Germany
31. Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences, Department of Plant and Fungal
32 Diversity and Resources, Acad. Georgi Bonchev 23, 1113, Sofia, Bulgaria
33. Shahjalal University of Science & Technology, Forestry & Environmental Science, Akhalia, 3114, Sylhet, Bangladesh
34. Universidad Autónoma Gabriel René Moreno, Dirección de la Carrera de Biología, Santa Cruz de la Sierra, Bolivia
35. Canadian Forest Service, Natural Resources Canada, Great Lakes Forestry Centre, 1219 Queen St. East, P6A 2E5, Sault
36 Ste Marie (Ontario), Canada
37. Ghent University, Department Green chemistry and technology, Isotope Bioscience laboratory (UGent-ISOFYS),
38 Coupure Links 653, 9000, Ghent, Belgium
39. Ghent University, Department Environment, Computational and Applied Vegetation Ecology (UGent-CAVELab), Coupure
40 Links 653, 9000, Ghent, Belgium
41. Université du Québec en Abitibi-Témiscamingue, Forest Research Institute, 445 boul. de l'Université, J9X5E4, Rouyn-
42 Noranda, Canada
43. University of Göttingen, Vegetation Ecology and Phytodiversity, Untere Karsthöle 2, 37073, Göttingen, Germany
44. University of the Basque Country UPV/EHU, Plant Biology and Ecology, P.O. Box 644, 48080, Bilbao, Spain
45. University of Gothenburg, Department of Biological and Environmental Sciences, Carl Skottsbergs gata 22B, 41319,
46 Gothenburg, Sweden
47. Gothenburg Global Biodiversity Centre, Carl Skottsbergs gata 22B, 41319, Gothenburg, Sweden
48. Free University of Bozen-Bolzano, Piazza Università, 5, 39100, Bolzano, Italy
49. Institute of Ecology of the Volga River Basin, Department of Phytodiversity Problems, Komzina, 10, 445003, Toljatty,
50 Russian Federation
51. Southern Swedish Forest Research Centre, Swedish University of Agricultural Sciences, Sundsvägen 3, 230 53 Alnarp,
52 Sweden
53. Research Center of the Slovenian Academy of Sciences and Arts, Institute of Biology, Novi trg 2, 1000, Ljubljana,
54 Slovenia
55. University of Nova Gorica, School for viticulture and enology, Vipavska 13, 5000, Nova Gorica, Slovenia
56. ISPRA - Italian National Institute for Environmental Protection and Research, Biodiversity Conservation Department, Via
57 Vitaliano Brancati, 60, 00144, Roma, Italy
58. Universidad Rey Juan Carlos, Department of Biology and Geology, Physics and Inorganic Chemistry, c/ Tulipán s/n,
59 29833, Móstoles, Spain
60. Czech University of Life Sciences Prague, Department of Forest Ecology, Faculty of Forestry and Wood Sciences,
61 Kamýcká 1176, 165 21, Praha 6 - Suchdol, Czech Republic
62. Central Siberian Botanical Garden SB RAS, Zolotodolinskaya Str. 101, 630090, Novosibirsk, Russian Federation
63. University of Pécs, Department of Ecology, Ifjúság u. 6., 7624, Pécs, Hungary
64. Faculty of Natural Sciences and Mathematics, Institute of Biology, Arhimedova 3, 1000, Skopje, Republic of Macedonia
65. Research Institute for Nature and Forest (INBO), Biotope Diversity, Havenlaan 88, bus 73, 1000, Brussels, Belgium
66. Universidade Regional de Blumenau, Rua Antonio da Veiga, 140, Blumenau, 89030-903, Brazil

- 1
2
3 48. University of Patras, Laboratory of Botany, Division of Plant Biology, Department of Biology, University Campus, 26504,
4 Patras, Greece
5 49. Institute of Botany, Czech Academy of Sciences, Department of Functional Ecology, Dukelska 135, 37901, Trebon, Czech
6 Republic
7 50. M.G. Kholodny Institute of Botany, National Academy of Sciences of Ukraine, Geobotany and ecology, Tereschenkivska,
8 1004, Kyiv, Ukraine
9 51. College of Science, King Saud University, Botany and Microbiology Department, P.O. Box 2455, 11451, Riyadh, Saudi
10 Arabia
11 52. Damanhour University, Botany Department, Faculty of Science, Damanhour, Egypt
12 53. University of Arizona, Ecology and Evolutionary Biology, 1041 E. Lowell St., AZ 85721, Tucson, United States
13 54. Hochschule Weihenstephan-Triesdorf, University of Applied Sciences, Hans-Carl-von-Carlowitz-Platz 3, 85354, Freising,
14 Germany
15 55. University of Nottingham, School of Geography, University Park, NG7 2RD, Nottingham, United Kingdom
16 56. University of Hamburg, Biodiversity, Ecology and Evolution of Plants, Institute for Plant Science & Microbiology,
17 Ohnhorststr. 18, 22609, Hamburg, Germany
18 57. Aix Marseille Univ, Avignon Université, CNRS, IRD, IMBE, Campus St-Jérôme Etoile, 13397, Marseille, France
19 58. Universidad CEU San Pablo, Laboratorio de Botánica, P.O. Box 67, 28660, Boadilla del Monte, Madrid, Spain
20 59. Universidad Privada Antonio Guillermo Urrelo, Laboratorio de Botánica, Jr. José Sabogal
21 60. Estudios Fitogeográficos del Perú, Herbario AQP, Sánchez Cerro 219, Manuel Prado, Paucarpata, Arequipa, Peru
22 61. Climpact Data Science (CDS), Nova Sophia - Regus Nova, 291 rue Albert Caquot, CS 40095, 06902, Sophia Antipolis
23 Cedex, France
24 62. University of Mazandaran, Department of Biology, Babolsar, Iran
25 63. Instituto Multidisciplinario de Biología Vegetal (IMBIV-CONICET), ECOLOGÍA VEGETAL Y FITOGEOGRAFÍA, Av. Vélez
26 Sársfield 1611, 5000, Córdoba, Argentina
27 64. Institute of Ecology of the Volga River Basin, Laboratory of Phytocoenology, Komzina, 10, 445003, Toljatty, Russian
28 Federation
29 65. The Arctic University Museum of Norway, UiT - The Arctic University of Norway, Tromsø, Norway
30 66. University of Bergen, Department of Biological Sciences, Postbox 7803, Bergen, Norway
31 67. University of Adelaide, School of Biological Sciences, North Terrace, 5005, Adelaide, Australia
32 68. Universidad de Chile, Departamento de Ciencias Ambientales y Recursos Naturales Renovables, Facultad de Ciencias
33 Agronomicas, Santa Rosa 11315, La Pintana, 8820808, Santiago, Chile
34 69. Martin Luther University Halle-Wittenberg, Institute of Biology, Am Kirchtor 1, 06108, Halle, Germany
35 70. German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Puschstraße 4, 04103, Leipzig, Germany
36 71. Wageningen University, Plant Ecology and Nature Conservation Group - Environmental Sciences Department, P.O. Box
37 Postbus 47, Droevedaalsesteeg 3, 6700 AA, Wageningen, The Netherlands
38 72. Tanta University, Botany and Microbiology Department - Faculty of Science, El Geish St., 31527, Tanta, Egypt
39 73. CIRAD, UPR Forêts et Sociétés, Yamoussoukro, Ivory Coast
40 74. University of Montpellier, Forêts et Sociétés, CIRAD, Montpellier, France
41 75. INP-HB, Institut National Polytechnique Félix Houphouët-Boigny, Yamoussoukro, Côte d'Ivoire
42 76. ASES Ecological and Sustainable Services, Pépinière d'Entreprises l'Espélidou, Parc d'Activités du Vinobre, 555 Chemin
43 des Traverses, Lachapelle-sous-Aubenas, 07200, Aubenas, France
44 77. University of Muenster, Institute of Landscape Ecology, Heisenbergstr. 2, 48149, Münster, Germany
45 78. University of Goettingen, Plant Ecology and Ecosystems Research, Untere Karspuele 2, 37073, Goettingen, Germany
46 79. Ghent University, Department Environment, Laboratory of Wood Biology (UGent-WoodLab), Coupure Links 653, 9000,
47 Ghent, Belgium
48 80. Royal Museum for Central Africa, Service of Wood Biology, Leuvensesteenweg 13, 3080, Tervuren, Belgium
49 81. Transilvania University of Brasov, Department of Silviculture, Sirul Beethoven 1, 500123, Brasov, Romania
50 82. Wageningen University and Research, Wageningen Environmental Research (Alterra), P.O.Box 47, 6700 AA,
51 Wageningen, Netherlands
52 83. University of Münster, Institute of Landscape Ecology, Heisenbergstr. 2, 48149, Münster, Germany
53 84. University of Bayreuth, Disturbance Ecology, Bayreuth Center of Ecology and Environmental Research, Universitaetsstr.
54 30, 95447, Bayreuth, Germany
55 85. University of Wrocław, Botanical Garden, Sienkiewicza 23, 50-335, Wrocław, Poland
56 86. Norwegian Institute of Bioeconomy Research, Holtvegen, 66, Tromsø, 9016, Norway
57 87. Swiss Federal Institute for Forest, Snow and Landscape Research WSL , Biodiversity and Conservation Biology,
58 Zürcherstrasse 111, 8903, Birmensdorf, Switzerland
59 88. Karabuk University, Faculty of Forestry, Kilavuzlar Köyü Öte Karsi Üniversite Kampüsü Merkez, 78050, Karabuk, Turkey
60 89. Ghent University, Department Environment, Computational and Applied Vegetation Ecology (UGent-CAVELab), Coupure
61 Links 653, 9000, Gent, Belgium
62 90. University of Zurich, Department of Systematic and Evolutionary Botany, Zollikerstrasse 107, 8008, Zurich, Switzerland
63 91. branch of the M.V. Keldysh Institute of Applied Mathematics of Russian Academy of Sciences, Institute of Mathematical
64 Problems of Biology of RAS, 1 Prof. Vitkevich, 142290.0, Pushchino, Russia
65 92. Universidad Autonoma Gabriel Rene Moreno, Museo de Historia Natural Noel Kempff Mercado, Santa Cruz de la
66 Sierra, Bolivia

- 1
2
3 93. Central Siberian Botanical Garden, Siberian Branch, Russian Academy of Sciences, Geosystem Laboratory,
4 Zolotodolinskaya str. 101, 630090, Novosibirsk, Russian Federation
5 94. University of Göttingen, Department of Biodiversity, Macroecology and Biogeography, Büsgenweg 1, 37077, Göttingen,
6 Germany
7 95. Max Planck Institute for Evolutionary Anthropology (MPI-EVA), Primateology, Puschstrasse 4, 04103, Leipzig, Germany
8 96. M.G. Kholodny Institute of Botany of the National Academy of Sciences of Ukraine, Department of Geobotany and
9 Ecology, 2, Tereshchenkivska str., 01601, Kyiv, Ukraine
10 97. Masaryk University, Department of Botany and Zoology, Kotlářská 2, 611 37, Brno, Czech Republic
11 98. Centre for Ecological Research, Institute of Ecology and Botany, Alkotmány u. 2-4., 2163, Vácrátót, Hungary
12 99. Naturalis Biodiversity Center, Research Group Functional Traits, Darwinweg 2, 2333 CR, Leiden, The Netherlands
13 00. Universidade Regional de Blumenau, Departamento de Engenharia Florestal, Rua São Paulo, 3250, 89030-000,
14 Blumenau, Brazil
15 01. Peking University, College of Urban and Environmental Sciences, Yiheyuan Rd. 5, 100871, Beijing, China
16 02. Komarov Botanical Institute RAS, Laboratory of Vegetation Science, Prof. Popov 2, 197376, Saint-Petersburg, Russian
17 Federation
18 03. Institute of Ecology of the Volga River Basin RAS - Branch of the Samara Scientific Center RAS, Laboratory of
19 Phytodiversity Problems, Komzin str. 10, 445003, Togliatti, Russian Federation
20 04. Tobolsk complex scientific station of Ural Branch RAS, Group of Ecology of Living Organisms, Academician Yu. Osipov
21 str. 15, 626152, Tobolsk, Russian Federation
22 05. Leipzig University, Remote Sensing Centre for Earth System Research, Talstr. 6b, 07745, Leipzig, Germany
23 06. Ufa Federal Scientific Center of the Russian Academy of Sciences, Institute of Biology, prospekt Oktyabrya, 69, 450054,
24 Ufa, Russian Federation
25 07. Aarhus University, Department of Bioscience, Grenaaej 14, 8410, Roende, Denmark
26 08. Jardín Botánico de Missouri Oxapampa, Bolognesi Mz-E-6, Oxapampa, Pasco, Peru
27 09. Murdoch University, Harry Butler Institute, 90 South Street, Building 390, 6150, Murdoch, Australia
28 10. Royal Botanic Gardens, Kew, Conservation Science, Wakehurst Place, RH17 6TN, Ardingly, West Sussex, United
29 Kingdom
30 11. AMAP, Université de Montpellier, CIRAD, CNRS, INRAE, IRD, 34000, Montpellier, France
31 12. University of Mazandaran, Department of Biology, P.O. Box 47416-95447, Mazandaran, Iran
32 13. University of Vienna, Department of Botany and Biodiversity Research, Rennweg 14, 1030, Vienna, Austria
33 14. Polish Academy of Sciences, Botanical Garden - Center for Biodiversity Conservation, Prawdziwka 2, 02-950, Warsaw,
34 Poland
35 15. University of Opole, Institute of Biology, Oleska St. 52, 45-052, Opole, Polska
36 16. National Academy of Sciences of Ukraine, M.G. Kholodny Institute of Botany, Tereshchenkivska 2, 01601, Kyiv, Ukraine
37 17. Universidade Federal do Rio Grande do Sul, Department of Botany, Av. Bento Gonçalves 9500, 91501-970, Porto Alegre,
38 Brazil
39 18. University of Tartu, Institute of Ecology and Earth Sciences, Lai 40, 51005, Tartu, Estonia
40 19. Universidad de Concepción, Laboratorio de Invashiones Biológicas (LIB). Facultad de Ciencias Forestales., Victoria 631,
41 4030000, Concepción, Chile
42 20. Institute of Ecology and Biodiversity (IEB), Chile
43 21. University of North Carolina, Department of Biology, CB3280, South Road, 27599-3280, Chapel Hill, NC, United States
44 22. CSIC, Global Ecology Unit CSIC-CREAF-UAB, Edifici C, Campus UAB, 08193, Bellaterra, Spain
45 23. CREAF, Edifici C, 08193, Cerdanyola del Valles, Espanya
46 24. University of Vic-Central University of Catalonia, Department of Biosciences, Carrer de la Laura, 13, 08500, Vic,
47 Barcelona, Spain
48 25. University of Barcelona, Department of Evolutionary Biology, Ecology and Environmental Sciences, Diagonal 643,
49 08028, Barcelona, Spain
50 26. Czech Academy of Sciences, Department of vegetation ecology, Institute of Botany, Zámek 1, 25243, Průhonice, Czech
51 Republic
52 27. University of the Andes, Department of Civil and Environmental Engineering, Carrera 1 Este No. 19A-40, Edificio Mario
53 Laserna, Piso 6 , 111711, Bogota, Colombia
54 28. Kazan Federal University, Institute of Environmental Sciences, Kremlevskaya 18, 420008, Kazan, Russian Federation
55 29. Nature Research Centre, Institute of Botany, Zaliuju Ezeru 49, 08406, Vilnius, Lithuania
56 30. University of Hamburg, Biodiversity, Ecology and Evolution of Plants/Institute for Plant Science & Microbiology,
57 Ohnhorststr. 18, 22609, Hamburg, Germany
58 31. Namibia University of Science and Technology, Faculty of Natural Resources and Spatial Sciences, Windhoek, Namibia
59 32. Universidad San Francisco de Quito, COCIBA, Diego de Robles, 170177, Quito, Ecuador
60 33. 7 Derwent Road, LA1 3ES, Lancaster, United Kingdom
61 34. Babeş-Bolyai University, Hungarian Department of Biology and Ecology, Faculty of Biology and Geology, Republicii
62 street 42., 400015, Cluj-Napoca, Romania
63 35. University of Latvia, Faculty of Geography and Earth Sciences, Jelgavas iela 1, LV 1004, Riga, Latvia
64 36. University of Bayreuth, Climatology, Bayreuth Center of Ecology and Environmental Research (BayCEER),
65 Universitätsstr. 30, 95447, Bayreuth, Germany
66 37. Stadt Frankfurt am Main - Der Magistrat, Palmengarten, Siesmayerstraße 61, 60323, Frankfurt am Main, Germany

- 1
2
3 38. Plant Science and Biodiversity Centre Slovak Academy of Sciences, Institute of Botany, Dubravská cesta 9, 84523,
4 Bratislava, Slovakia
5 39. Research Centre of Slovenian Academy of Sciences and Arts (ZRC SAZU), Institute of Biology, Novi trg 2, 1000, Ljubljana,
6 Slovenia
7 40. Department of Botany, Charles University, Benátská 2, 12801 Prague, Czech Republic
8 41. University of Zagreb, Faculty of Forestry, Svetosimunska 25, 10000, Zagreb, Croatia
9 42. University of Adelaide, TERN, North Terrace, 5005, Adelaide, Australia
10 43. CSIC-UV-GV, Centro de Investigaciones sobre Desertificación, Carretera Moncada-Náquera km 4.5, 46113.0, Moncada
11 (Valencia), Spain
12 44. University of Zagreb, Faculty of Geotechnical Engineering, Hallerova aleja 7, 42000, Varaždin, Croatia
13 45. Aarhus University, Department of Biology, Ny Munkegade 114, DK-8000, Aarhus C, Denmark
14 46. Yunnan University, School of Ecology and Environmental Science, Building Shixun, Chenggong Campus, Dongwaihuan
15 South Road, University Town, Chenggong New District, 650504, Kunming, China
16 47. Aristotle University of Thessaloniki, School of Biology, 54124, Thessaloniki, Greece
17 48. University of Erlangen-Nuremberg, Department of Geography, Wetterkreuz 15, 91058, Erlangen, Germany
18 49. Universidade Federal do Rio Grande do Sul, Department of Ecology, Av Bento Gonçalves 9500, 91501-970, Porto Alegre,
19 Brazil
20 50. University of Perugia, Department of Chemistry, Biology and Biotechnology, Borgo XX giugno 74, 06124, Perugia, Italy
21 51. Univ Montpellier, CNRS, EPHE, IRD, Univ Paul Valéry Montpellier 3, CEFE, 1919 route de Mende, 34293, Montpellier,
22 France
23 52. University of Oulu, Ecology and Genetics Research Unit, Biodiversity Unit, Kaitoväylä 5, 90014, Oulu, Finland
24 53. Helmholtz Center for Environmental Research - UFZ, Department of Physiological Diversity, Permoserstr. 15, 04318,
25 Leipzig, Germany
26 54. Leuphana University of Lüneburg, Institute of Ecology, Universitätsallee 1, 21335, Lüneburg, Germany
27 55. University of Alberta, Department of Biological Sciences, Biological Sciences Building, T6G2E9, Edmonton, Canada
28 56. University of Alaska, Institute of Arctic Biology, P. O. Box 7570000, 99775, Fairbanks, United States
29 57. University of Wisconsin-Madison, Botany, 430 Lincoln Drive, 53706, Madison, United States
30 58. Hainan University, Hainan Key Laboratory for Sustainable Utilization of Tropical Bioresources, College of Tropical
31 Crops, 58 Renmin Avenue, Meilan District, 570228, Haikou, China
32 59. Senckenberg Museum of Natural History Görlitz, Botany Department, PO Box 300 154, 02806, Görlitz, Germany
33 60. Technische Universität Dresden, International Institute Zittau, Markt 23, 02763, Zittau, Germany
34 61. Brown University, Department of Ecology and Evolutionary Biology/Brown University Herbarium, 34 Olive Street,
35 02912, Providence, United States
36 62. Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Forest Dynamics, Zürcherstrasse 111, CH-8909,
37 Birmensdorf, Switzerland
38 63. Ufa Scientific Centre, Russian Academy of Sciences, Laboratory of Wild-Growing Flora, Botanical Garden-Institute,
39 Mendeleev str., 195/3, 450080, Ufa, Russian Federation
40 64. University of Tartu, Institute of Ecology and Earth Sciences, Lai st 40, 51005, Tartu, Estonia
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Abstract

Assessing biodiversity status and trends in plant communities is critical for understanding, quantifying and predicting effects of global change on ecosystems. Vegetation plots record occurrence or abundance of all plant species present (community composition) in a delimited area of 0.01 to 40,000 m². Absences can be inferred, allowing analyses not possible with presence-only data. Recently the first global vegetation plot database was compiled ('sPlot'). However, this large dataset is environmentally and spatially unbalanced, and not open-access. We address both issues by (a) resampling the vegetation plots using a novel algorithm; (b) securing permission to openly release data from the holders of 104 specific datasets. We present the largest open-access vegetation plot dataset ever released: 91,205 plots globally, recording abundance of each vascular plant species (total 39,997 taxa). Plot-level data include location, date, size, biome, elevation, slope aspect, vegetation type and naturalness. Based on values for 18 traits per species from the 'TRY' database, community-weighted mean and variance of traits per plot are presented. The dataset can be used to explore plant community diversity patterns globally, as ground truth data in remote sensing applications or as baselines for biodiversity monitoring.

Abstract - Alternative for GEB (290/300 words)

Motivation: Assessing biodiversity status and trends in plant communities is critical for understanding, quantifying and predicting the effects of global change on ecosystems, among other applications. Vegetation plots record occurrence or abundance of all plant species present (community composition) in delimited local areas. These data also allow inferring absences, enabling many analyses not possible using the presence-only data provided by existing global plant datasets. Although very many vegetation plots have been recorded, most are not available to the global research community. A recent initiative, sPlot, compiled the first global vegetation plot database, and continues to grow and curate it. However, this large dataset is challenging to work with because it is extremely unbalanced spatially, and because the data are not open-access. Here, we address both these issues by (a) resampling the vegetation plots using a novel algorithm and (b) securing permission from data holders to openly release data (from 105 local to regional datasets). We thus present the largest open-access dataset of vegetation plots ever released. Our open-access dataset can be used to explore global patterns of diversity at the plant community level, as ground truthing data in remote sensing applications or as a baseline for biodiversity monitoring.

Main types of variable contained: 91,205 vegetation plots, recording cover or abundance of each vascular plant species in delimited areas. Besides geographic location, date, plot size, biome, elevation, slope, aspect, vegetation type, naturalness, coverage of various vegetation layers and source dataset, plot-level data also include community-weighted mean and variance of 18 plant functional traits from the 'TRY' database.

Spatial location and grain: global, 0.01-40,000 m².

Time period and grain: 1888-2015, recording dates.

Major taxa and level of measurement: 39,997 vascular plant taxa, plot-level records.

Software format: three main matrices (.csv), relationally linked.

Background & Summary

Biodiversity is facing a global crisis. As many as 1 million species are currently threatened with extinction, the vast majority due to anthropogenic impacts such as land-use and climate change (1, 2). In addition, the rates of biodiversity homogenization and redistribution are accelerating (3, 4; 5). Biological assemblages are becoming progressively more similar to each other globally, as local and endemic species go extinct and are replaced by more widespread and competitive native or alien species (1; 5). Many terrestrial and marine species are also shifting their geographical distribution as a response to climate change (4), including animals hosting pathogens transmissible to humans (6; 7). This has profound potential impacts on ecosystems and human health (8; 9).

Plant communities are no exception to this biodiversity crisis (10; 11; 5). This is particularly worrying since terrestrial vegetation accounts for 80% (450 Gt C) of the living biomass on Earth (12). Given the central role of vegetation in ecosystem productivity, structure, stability and functioning (11), assessing biodiversity status and trends in plant communities is paramount for other kingdoms of life and human societies alike.

Monitoring trends in plant biodiversity requires adequate data across a range of spatiotemporal scales (13, 14). Large independent collections of plant occurrence data do exist at the global or continental extent via the Botanical Information and Ecology Network (BIEN) (15), the Global Inventory of Floras and Traits (GIFT) (16) or the Global Biodiversity Information Facility (GBIF) (<https://www.gbif.org/>). However, these presence-only databases either neglect how individual plant species co-occur and interact locally to form plant communities, or are collected at spatial resolutions which preclude intersection with high resolution remote sensing data and are too coarse to assess biodiversity trends (e.g., one-degree grid cells) at the plant community scale (17).

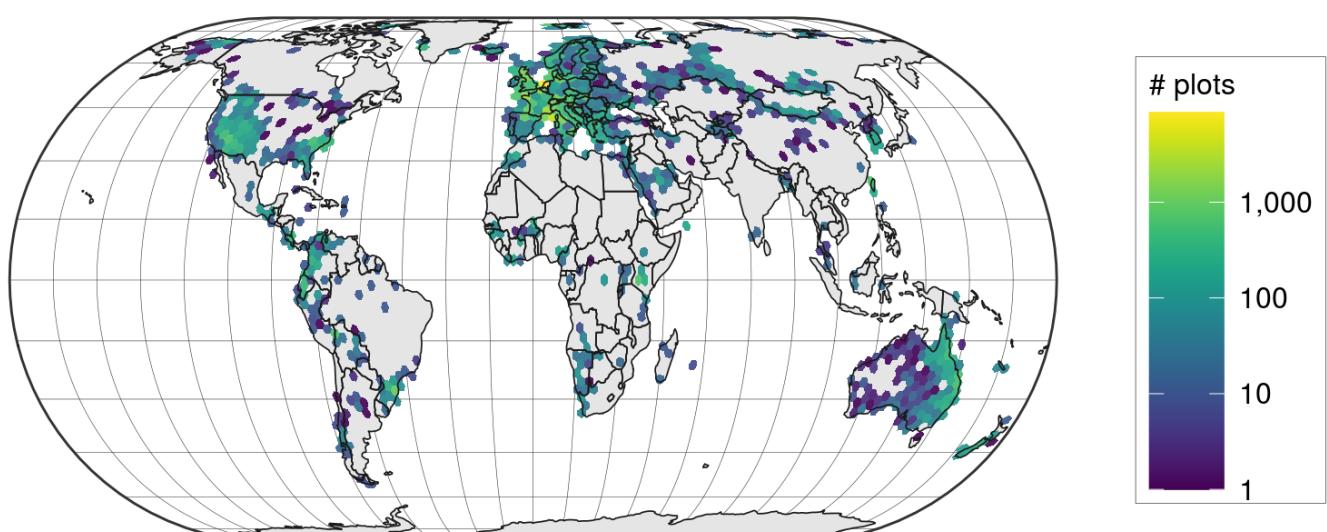
Yet, there is a long tradition among botanists to record the cover or abundance of each plant species that occurs in a vegetation plot location of a given size (i.e. surface area) at a given time (e.g. 18). Compared to presence-only data, vegetation-plot data (termed ‘presence-absence’ here) present many advantages. As all visible plant species are recorded, plots contain information on which plant species do, and do not, co-occur in the same locality at a given moment in time (19). This is important for testing hypotheses related to biotic interactions among plant species. Vegetation-plot data also provide crucial information on where and when a species was absent, therefore improving predictions from current species distribution models (20). Being spatially explicit, vegetation plots can be resurveyed through time to assess potential changes in plant species composition relative to a baseline (21; 22, 5). As they normally contain information on the relative cover or abundance of each species, vegetation plots are also more appropriate for detecting biodiversity changes than data representing only the occurrence of individual species (23).

Globally, however, vegetation-plot data are very fragmented, as they typically stem from a myriad of local research and survey projects (24). Consequently, these data often have either high fine-grain spatial resolutions but small spatial extents, or broad extents but coarse grains (25). Furthermore, with their disparate sampling protocols, standards and taxonomic resolutions, aggregating and harmonizing vegetation plot data proves extremely challenging (26). It is not surprising, therefore, that these data are rarely used in global-scale research on the biodiversity of plant communities (27; 28; 29).

The sPlot initiative tries to close this data gap. It consolidates numerous local to regional vegetation-plot datasets to create a harmonized and comprehensive global database of georeferenced terrestrial plant species assemblages (24). Established in 2013, sPlot (version 3) currently contains more than 1.9 million vegetation plots, and is fully integrated with the TRY database (30), from which it derives information on plant functional traits. The sPlot database is increasingly being used to study

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3 continental-to-global scale vegetation patterns, such as the relative contribution of regional vs. local
4 factors on the global patterns of fern richness ([31](#)), the mechanisms underlying the spread and
5 abundance of native vs. invasive tree species ([32](#)), and worldwide trait–environment relationships in
6 plant communities ([26](#)).
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9 Here, we provide an open-access data set composed of 91,205 vegetation plots, that represent the
10 entire environmental space covered by the sPlot database, to provide a standardized dataset for
11 ecological research. The environmental stratification of the sampling of these plots maximises the
12 benefits of this large dataset for a wide range of potential uses of the data. The selected vegetation
13 plots stem from 104 databases and span 115 countries (Figure 1). This resampled dataset (sPlot Open
14 - hereafter) is composed of: (1) plot-level information, including metadata and basic vegetation
15 structure descriptors; (2) the vascular plant species composition of each vegetation plot, including
16 species cover or abundance information when available; and (3) community-level functional
17 information obtained by intersection with the TRY database ([30](#)).
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66 **Figure 1:** Global map of sPlot Open (n = 91,205) and spatial distribution of vegetation plot density per hexagonal cell
67 with a spatial resolution of approximately 70,000 km². Map projection is Eckert IV.
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Methods

Vegetation plot data sources

We started from the sPlot database v2.1 (created in October 2016), which contains 1,121,244 unique vegetation plots and 23,586,216 species records stemming from 110 different vegetation-plot datasets of regional, national or continental extent. Some of the 110 datasets stem from regional or continental initiatives (see [24](#) for more information). For instance: 48 vegetation-plot datasets derive from the European Vegetation Archive (EVA) ([19](#)); three major African datasets derive from the Tropical African Vegetation Archive (TAVA); and multiple vegetation datasets in the USA and Australia derive from the VegBank ([33](#); [34](#)) and TERN's AEKOS ([35](#)) archives, respectively. Data from other continents (South America, Asia) or countries were contributed as separate standalone datasets. The metadata of each individual vegetation-plot dataset stored in sPlot are managed through the Global Index of Vegetation-Plot Databases [GIVD](#) ([36](#)), using the GIVD code as the unique dataset identifier.

Resampling method

Data in the sPlot database are unevenly distributed across continents and biomes (see [26](#)). Mid-latitude regions in developed countries (mostly Europe, the USA and Australia) are overrepresented, while regions in the tropics and subtropics are underrepresented, which is a typical geographical bias in biodiversity data (e.g., [37](#); [4](#)). To reduce this imbalance as much as possible, we performed a stratified resampling approach, using several environmental variables available at global extent as sampling strata. We considered 30 climatic and soil variables. For climate, we complemented the 19 bioclimatic variables from CHELSA v1.2 ([38](#)), as well as two variables reflecting the growing-season length (growing degree days above 1 °C - GDD1 - and 5 °C - GDD5), which were derived from CHELSA's monthly average temperatures. Specifically we summed the number of days of those months with average temperature greater than 1 °C or 5 °C, respectively. In addition, we considered an index of aridity and a layer for Potential Evapotranspiration from the Consortium of Spatial Information (CGIAR-CSI) ([39](#)). For soil, we extracted seven variables from the SOILGRIDS database ([40](#)), namely: soil organic carbon content in the fine earth fraction, cation exchange capacity, pH, as well as the fractions of coarse fragments, sand, silt and clay.

We stratified our sampling effort based on the following procedure. First, we ran a global principal component analysis (PCA) on a matrix of terrestrial grid cells by the 30 above-mentioned environmental variables. We considered the full environmental space of all terrestrial habitats on Earth at a spatial resolution of 2.5 arcmin, totaling 8,384,404 terrestrial grid cells, irrespective of whether a grid cell hosted vegetation plots from the sPlot database v2.1 or not. We then subdivided the PCA ordination space, represented by the first two principal components (PC1-PC2), which accounted for 47% and 23% of the total environmental variation in terrestrial grid cells, into a regular 100×100 grid. This PC1-PC2 two-dimensional space was subsequently used to balance our sampling effort across all PC1-PC2 grid cells for which vegetation plots were available. Before projecting vegetation plots from the sPlot database v2.1 onto this PC1-PC2 environmental space, we removed vegetation plots: a) from wetlands; b) from anthropogenic vegetation types; c) without geographical coordinates; and d) with a location uncertainty higher than 3 km for those having geographical coordinates. This resulted in a total of 799,400 out of the initial set of 1,121,244 vegetation plots. When projecting the 799,400 vegetation plots in the PC1-PC2 grid, we calculated how many vegetation plots occurred in each PC1-PC2 grid cell. For those grid cells with more than 50 vegetation plots ($n = 858$), we selected up to 50 vegetation plots using the heterogeneity-constrained random resampling algorithm from Lengyel et al. (2011) [[41](#)]. This approach optimizes the selection of a random subset of vegetation plots that encompasses the highest variability in species composition while avoiding peculiar and rare communities, which may represent outliers. We quantified the variability in plant

species composition among the 50 randomly selected vegetation plots by computing the mean and the variance of the Jaccard's dissimilarity index (42) between all possible pairs of these 50 vegetation plots ($n = 1,225$). More precisely, for a given PC1-PC2 grid cell containing more than 50 vegetation plots, we generated 1,000 random selections of 50 vegetation plots and ranked them according to the mean (ascending order) and variance (descending order) value. Ranks from both sortings were summed for each random selection, and the selection with the lowest summed rank was considered to provide the most balanced/even representation of vegetation types within the focal grid cell. Where a grid cell contained less than 50 plots, we retained all of them. In this way, we reduced the imbalance towards over-sampled climate types while ensuring that the resampled dataset represents the entire environmental gradient covered by the sPlot database. We repeated the resampling procedure three times to get three different possibilities of a heterogeneity-constrained selection of 50 vegetation plots per PC1-PC2 grid cell with, initially, more than 50 vegetation plots. Vegetation plots selected during the first iteration were our first choice, while we considered the vegetation plots additionally selected in the second and third iteration as reserves when asking for permission to release the data as open access to each dataset's contributor(s).

Permission to release the data as open access

The resampling procedure resulted in a preliminary potential selection of 98,383 vegetation plots (first choice) and 51,634 vegetation plots flagged as reserves (second or third choice for the subset of PC1-PC2 grid cells with more than 50 vegetation plots available). Since the sPlot database is a consortium of independent datasets whose copyright belongs to the data contributor, we used this preliminary potential selection to ask each dataset's custodian (i.e., either the owner of a dataset or its authorized representative in case of a collective dataset) for permission to release the data of each selected vegetation plot as open access. For 8,070 vegetation plots, permission could not be granted because, for instance, the data are unpublished, confidential or sensitive. For these vegetation plots, we used the reserve pool to randomly select replacements, for which such permission could be granted. We imposed the constraint that each candidate vegetation plot in the reserve pool should belong to the same environmental stratum, i.e., the same PC1-PC2 grid cell, of the confidential vegetation plot. Note that 2,380 PC1-PC2 grid cells (11.7% of total) had one or more confidential vegetation plots (median = 1, mean = 3.4, max = 171) that could not be replaced from the reserve pool.

Trait information

For each vegetation plot for which open access has been granted, we computed the community weighted means for eighteen plant functional traits derived from the TRY database v3.0 (30). These traits were selected among those that describe the leaf, wood and seed economics spectra (43; 44), and are known to either affect different key ecosystem processes or respond to macroclimatic drivers, or both (24). The eighteen plant functional traits (all concentrations based on dry weight) were: (1) leaf area [mm^2]; (2) stem specific density [g cm^{-3}]; (3) specific leaf area [m^2kg^{-1}]; (4) leaf carbon concentration [mg g^{-1}]; (5) leaf nitrogen concentration [mg g^{-1}]; (6) leaf phosphorus concentration [mg g^{-1}]; (7) plant height [m]; (8) seed mass [mg]; (9) seed length [mm]; (10) leaf dry matter content [g g^{-1}]; (11) leaf nitrogen per area [g m^{-2}]; (12) leaf N:P ratio [g g^{-1}]; (13) leaf $\delta^{15}\text{N}$ [per million]; (14) seed number per reproductive unit; (15) leaf fresh mass [g]; (16) stem conduit density [mm^{-2}]; (17) dispersal unit length [mm]; and (18) conduit element length [μm].

Because missing values were particularly widespread in the species-trait matrix, we employed a gap-filling procedure based on hierarchical Bayesian modeling (R package 'BHPMF', 45; 46). Gap-filling was performed at the level of individual observations. We then transformed to the natural logarithm all gap-filled trait values and averaged each trait by taxon (i.e., at species, or genus level). Additional information on the gap-filling procedure is available in [24].

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3 Community-weighted means (CWM) and variances (CWV) were calculated for every plant functional
4 trait j and every vegetation plot k as follows (47):
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$$CWM_{j,k} = \sum_i^{n_k} p_{i,k} t_{i,j} \quad (1)$$

$$CWV_{j,k} = \sum_i^{n_k} p_{i,k} (t_{i,j} - CWM_{j,k})^2 \quad (2)$$

19 where n_k is the number of species with trait information in vegetation plot k , $p_{i,k}$ is the relative
20 abundance of species i in vegetation plot k calculated as the species' fraction in cover or abundance of
21 total cover or abundance, and $t_{i,j}$ is the mean value of species i for trait j .
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Data Records

sPlot Open contains 91,205 vegetation plots (also called 'relevés') from 115 countries and all continents except Antarctica (Figure 1). This randomized selection comes from 105 constitutive datasets (Table 1). It only contains the species composition of vascular plants; information on the composition of bryophytes and lichens was discarded since it was only available for a minority of plots ($n = 4,963$ and $n = 3,045$, respectively). Information on the size (surface area) of the vegetation survey is available for 61,898 vegetation plots, and ranges between 0.01 and 40,000 m² (mean = 270 m²; median = 78.5 m²). Similarly, only for a minority of plots ($n = 17,757$) information on the exact group of plants sampled in the field is available (e.g., complete vegetation, only trees, only trees > 1 m height, and so on). However, as most data were collected using the phytosociological method, we deem safe to assume that, unless otherwise specified, plots contain information on all vascular plants. The average number of vascular plant species per vegetation plot ranges between 1 (i.e. monospecific stands) and 270 species (mean = 17.6; median = 13).

By capping the number of vegetation plots in overrepresented environmental conditions, the resampling procedure described above strongly reduced the bias in the distribution of vegetation plots within the environmental niche space. Yet, due to the lack or scarcity of data from some geographical regions, like the tropics, the spatial distribution of vegetation plots remains unbalanced across geographical regions (Figure 1). This is evident when comparing the number of plots across continents or biomes. Europe is by far the best represented continent, with 53,884 vegetation plots. In contrast, in Africa and South America the remaining plots after data edition and selection were 4,507 and 5,533 vegetation plots, respectively. The representation of biomes is also unbalanced (Figure 2). Despite these imbalances, all the Whittaker biomes are covered by sPlot Open, and our resampling algorithm has resulted in a much more balanced dataset than many other large global datasets that are available, such as GBIF.

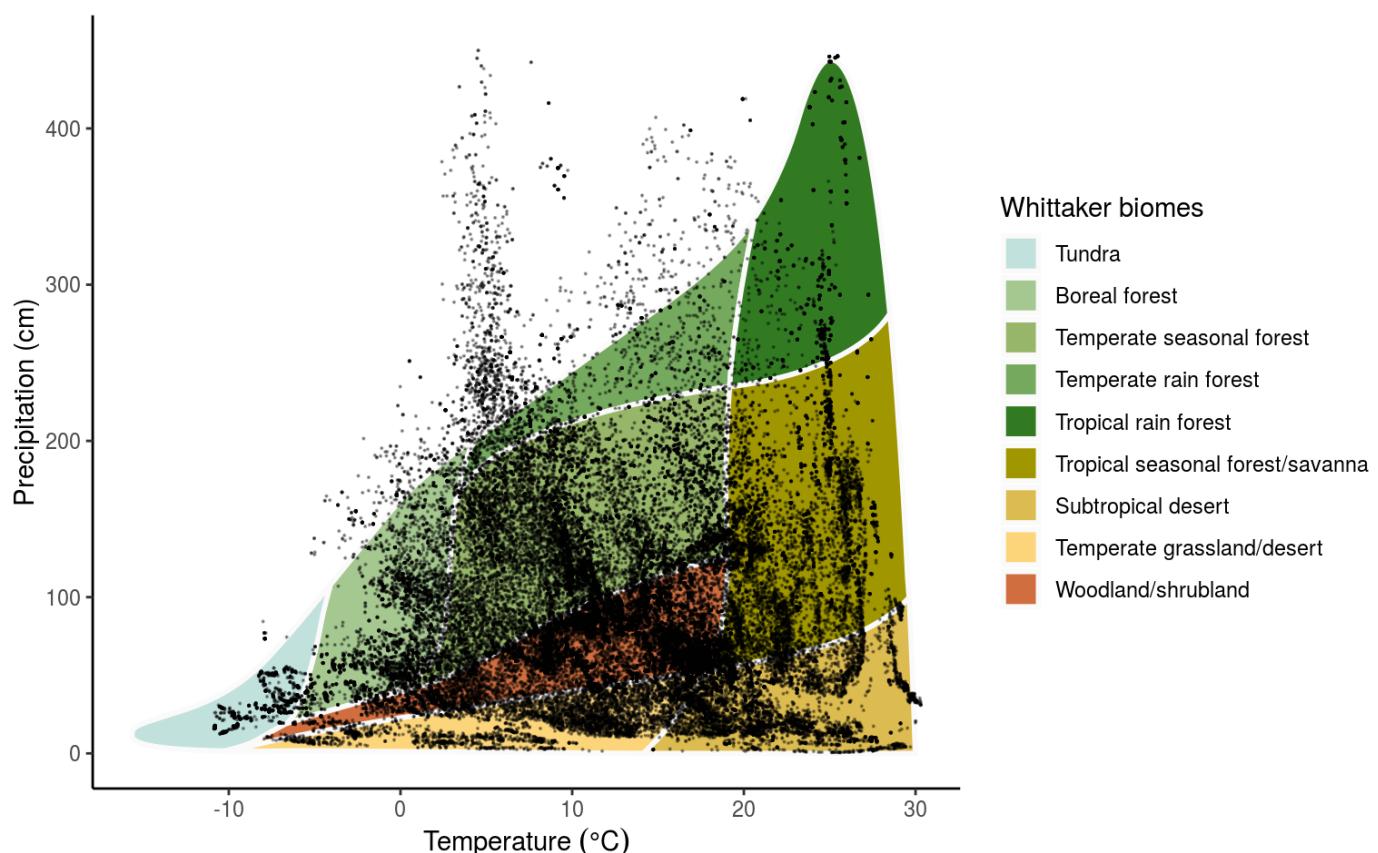


Figure 2: Distribution of all the vegetation plots provided by sPlot Open ($n = 91,205$) in the two-dimensional climatic space represented by mean annual temperature and mean annual precipitation superimposed onto Whittaker biomes

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3 ([48](#))
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5 Almost one third of vegetation plots in sPlot Open belong to forest (n = 25,740), two thirds to non-
6 forest vegetation (n = 58,145) vegetation, with 8 % of plots remaining unassigned (n = 7,320). When
7 not directly done by data providers, the assignment of plots to forests and non-forests was based on
8 multiple lines of evidence, including the plot-level information on the cover of the tree layer, as well as
9 traits of species composing a plot, such as growth form and height. In short, a plot record was
10 considered as forest if the cover of the tree layer, or alternatively, the sum of the (relative) cover of all
11 tree taxa (normalized to 100%), was greater than 25%. It was considered a non-forest record if the
12 sum of relative cover of low-stature, non-tree and non-shrub taxa was greater than 90%. For an
13 extensive explanation of this classification scheme, we refer the reader to Bruelheide et al. (2019)
14 [[24](#)]. Even if the proportion of forest vs. non-forest vegetation plots is relatively well-balanced, the
15 geographical distribution of vegetation plots belonging to different vegetation types is likely not
16 balanced in the geographical space, as it depends on the idiosyncrasies of the constitutive datasets
17 composing the sPlot database. For instance, the data from New Zealand only include plots collected in
18 non-forest ecosystems, while data from Chile only refer to forests. We urge potential users to carefully
19 read the description of each individual dataset in [GIVD](#), or to contact the custodians of each dataset
20 before using sPlot Open.
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Database Organization

sPlot Open is organized into three main matrices, relationally linked through the key column 'PlotObservationID'.

The '**header**' matrix contains plot-level information for the 91,205 vegetation plots provided in sPlot Open, including: metadata (e.g., plot ID, ownership, sampling date, geographical location, positional accuracy); sampling design information (e.g., the total surface area used during the vegetation survey); and a plot-level description of vegetation structure (e.g., vegetation type, percentage cover of each vegetation layer) and vegetation type. Plots in Europe are also classified according to the EUNIS habitat classification (column 'ESY'), based on the habitat classification expert system described in Chytrý et al. (2020) (49). For each vegetation plot, we further provide information on the dataset it originates from, based on the IDs used in [GIVD](#). A brief description of all the 43 variables in the header matrix is provided in Table 2.

The '**DT**' matrix contains data on the species composition of each plot. It is structured in a long format and contains 1,608,610 records from 39,997 vascular plant taxa, mostly resolved at the species level. For each record, we report both the taxon name as originally contributed by the data custodian (column '*Original_species*'), and the taxon name after taxonomic standardization (column '*Species*'). For each record, we report the species cover/abundance values. These follow different standards across the datasets constituting the sPlot database. We, therefore, provide both the cover/abundance value as reported in the original data (column '*Original_abundance*'), together with the abundance scale that was originally used (column '*Abundance_scale*'). This can take seven values: 'CoverPerc' = percentage cover, 'pa' = presence-absence, 'x_BA' = basal area (m^2/ha , only for woody species), 'x_IC' = individual count, i.e., number of individuals in plot, 'x_SC' = stem count, i.e., number of stems in plot, 'x_IV' = importance value index, 'x_PF' = presence frequency. The great majority of entries, however, use the percentage cover scale (n= 1,397,109). Finally, for each entry, we calculated a '*Relative_cover*', i.e., the cover/abundance of a given taxon divided by the total cover/abundance of all taxa in that vegetation plot.

The '**CWM_CWV**' matrix contains the community-weighted means and variances calculated for each of the 18 functional traits mentioned above. It also contains three additional columns. The column '*Species_richness*' returns the number of species recorded in each plot. The columns '*Trait_coverage_cover*' and '*Trait_coverage_pa*' return, respectively, the proportion of total cover and species in a plot for which functional trait information was available. Functional trait information was available for 20,932 species. The average proportion of species in each plot for which we have functional trait information is 0.88 (median = 1). For 47,177 plots, the coverage is complete, while for only one plot do we have no functional trait information for any of the species occurring in it. When considering relative cover, the average trait coverage is 0.89. As many as 68,234 and 74,388 plots have functional trait information for more than 80% of the species or 80% of relative cover, respectively.

sPlot Open contains two additional objects. The '**metadata**' matrix contains plot-level metadata, which provide information on the origin of each individual vegetation plot. This object contains 15 columns, with information on the dataset of origin (column '*GIVD_ID*' - [36](#)), author or surveyor names (columns '*Relevé_author*' and '*Relevé_coauthor*'), bibliographic references both at the dataset (column '*DB_BIBTEXKEY*') and plot level ('*Plot_Biblioreference*' and '*BIBTEXKEY*'), when available. Similarly, the column '*Project_name*' provides information on the project in which a vegetation plot was collected. When available, we also provide information on the numbering of the plots in the publication where they originally appeared (columns '*Nr_table_in_publ*', '*Nr_relevé_in_table*'), or in the dataset where they were initially stored ('*Original_nr_in_database*'). In the case of nested plots (n = 1,786), we also provide the original plot and subplot IDs (columns: '*Original_plotID*', '*Original_subplotID*'). The last two columns

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3 report plot-level '*Remarks*', and the unique identifier produced by Turboveg when the vegetation plot
4 was first stored ('*GUID*').
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7 Finally, the object '**references**', contains all the bibliographic references formatted according to a
8 BibTex standard. Each reference is tagged with a key corresponding to the fields '*DB_BIBTEXKEY*' and
9 '*BIBTEXKEY*' in the metadata. We further provide an R function ('*sPlotOpen_citation*') to create
10 reference lists, based on a selection of plots and/or datasets.
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13 Except for the 'reference' file (format .bib), all objects/matrices are provided in tab-delimited .txt files.
14 All objects, including the '*sPlotOpen_citation*' function, are also compiled inside an .RData object.
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Technical Validation

The original sPlot database has a nested structure and consists of several individual datasets, each validated and maintained by its respective dataset custodian. In many cases, individual datasets are also collections whose vegetation plots were provided by their respective owners (the person who performed the actual vegetation survey) or by someone who digitized the original data from the scientific published or grey literature. We obviously have no direct control over the individual vegetation plots that we provide here in sPlot Open. Yet, all these vegetation plots stem from trained professional botanists, or published scientific work, and are accompanied by detailed information on the sampling protocols used, thus ensuring data quality and reliability.

Before integration into the sPlot database, each dataset was further checked for consistency and, if it was in a different format, we converted it to a Turboveg 2 dataset (50). During this conversion, we checked that all datasets contained the required metadata information, and cross-checked that each plot was located within the geographic scopes of its respective dataset. All individual Turboveg 2 datasets were then integrated into a Turboveg 3 database, and exported to comma-separated files. Finally, we harmonized all the taxonomic names from all datasets, based on the sPlot's taxonomic backbone (51). This backbone matched all the taxonomic names (without nomenclatural authors) from all datasets in sPlot 2.1 and TRY v3.0 (30) to their resolved version based on the Taxonomic Name Resolution Service web application (TNRS version 4.0; 52; iPlant Collaborative, 2015). This allowed us to (1) harmonize all datasets to a common nomenclature, and (2) link the sPlot database to the TRY database (30). All taxa originally denoted at taxonomic ranks lower than species were aggregated at species level. Additional detail on the taxonomic resolution is reported in Bruelheide et al. (2019) [24], while a description of the workflow, including R-code, is available in Purschke (2017) [51].

Usage Notes

The sPlot Open database can be downloaded from <https://www.idiv.de> (link to PlantHub). Users are urged to cite the original sources when using sPlot Open in addition to the present paper, particularly when using data contained in BioTIME (53). For two datasets (AF-00-009, AF-CD-001), the identification of taxa at species level is still in progress. As most of the constitutive datasets remain under continuous development, sPlot Open users are encouraged to get in touch with the custodian(s) of the data they are planning to use (custodian names are reported in <https://www.idiv.de/sPlot>).

The data included in the present paper represent the subset of sPlot for which we were able to secure permission for making these data open. The additional data in sPlot are available under sPlot's Governance and Data Property Rules (www.idiv.de/sPlot). Using the full sPlot dataset is also recommended if a stratification is desired that is different from the environmental factors used here, for example by geographical region or plot size.

Code Availability

The R code used to produce sPlot Open from the sPlot 2.1 database is contained in the *sPlotOpen_code* GitHub repository: (https://github.com/fmsabatini/sPlotOpen_Code/). This manuscript was produced using the Manubot workflow (54). The code for reproducing this manuscript is stored in the *sPlotOpen_manuscript* GitHub repository: (https://github.com/fmsabatini/sPlotOpen_Manuscript).

Acknowledgements

We are grateful to thousands of vegetation scientists who sampled vegetation plots in the field or digitized them into regional, national or international databases. We also appreciate the support of the German Research Foundation for funding sPlot as one of the iDiv (DFG FZT 118, 202548816) research platforms, as well as for funding the position of Francesco Maria Sabatini and the organization of three workshops through the sDiv calls. We acknowledge this support with naming the database "sPlot", where the "s" refers to the sDiv synthesis workshops.

The study has been supported by the TRY initiative on plant traits (<http://www.try-db.org>). The TRY initiative and database is hosted, developed and maintained by J. Kattge and G. Bönnisch (Max Planck Institute for Biogeochemistry, Jena, Germany). TRY is currently supported by DIVERSITAS/Future Earth and the German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig. Jens Kattge acknowledges support by the Max Planck Institute for Biogeochemistry (Jena, Germany), Future Earth, the German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig and the EU H2020 project BACI, Grant No 640176.

Isabelle Aubin was funded through Natural Sciences and Engineering Research Council of Canada and Ontario Ministry of Natural Resources and Forestry. Yves Bergeron was funded through Natural Sciences and Engineering Research Council of Canada. Idoia Biurrun was funded by the Basque Government (IT936-16). Anne Bjorkman thanks the Herschel Island-Qikiqtaruk Territorial Park management, Catherine Kennedy, Dorothy Cooley, Jill F. Johnstone, Cameron Eckert and Richard Gordon for establishing the ecological monitoring programme. Funding was provided by Herschel Island-Qikiqtaruk Territorial Park. Luis Cayuela was supported by project BIOCON08_044 funded by Fundación BBVA. Milan Chytrý, Flavia Landucci, Corrado Marcenò and Tomáš Peterka were supported by the Czech Science Foundation (project no. 19-28491X). Brian Enquist thanks the following individuals and institutions for contributing data to sPlot via the SALVIAS database: Mauricio Bonifacino, Saara DeWalt, Timothy Killeen, Susan Letcher, Nigel Pitman, Cam Webb, The Missouri Botanical Garden, RAINFOR and the Amazon Forest Inventory Network. Alvaro G. Gutiérrez was funded by Project FORECOFUN-SSA PIEF-GA-2010-274798 and FONDECYT 1200468. Mohamed Z. Hatim thanks Kamal Shaltout and Joop Schaminée for supervision of the MSc thesis, and Joop Schaminée for support and funding from the Prince Bernard Culture Fund Prize for Nature Conservation. Jürgen Homeier received funding from BMBF (Federal Ministry of Education and Science of Germany) and the German Research Foundation (DFG Ho3296-2, DFG Ho3296-4). Borja Jiménez-Alfaro was funded by the Spanish Research Agency through grant AEI/10.13039/501100011033. Dirk N. Karger received funding from: The WSL internal grant exCHELSA and ClimEx, the Joint Biodiversa COFUND project 'FeedBaCks' and 'Futureweb', the Swiss Data Science Projects: SPEEDMIND, and COMECO, and the Swiss National Science Foundation (20BD21_184131). Attila Lengyel was supported by the National Research, Development and Innovation Office, Hungary (PD-123997). Tatiana Lysenko was funded by Russian Foundation for Basic Research (grant No. 16-04-00747a). Jérôme Munzinger was supported by the French National Research Agency (ANR) with grants INC (ANR-07-BDIV-0008), BIONEOCAL (ANR-07-BDIV-0006) & ULTRABIO (ANR-07-BDIV-0010), by National Geographic Society (Grant 7579-04), and with fundings and authorizations of North and South Provinces of New Caledonia. Arkadiusz Nowak received support from the National Science Centre, Poland, grant no. 2017/25/B/NZ8/00572. Gerhard E. Overbeck acknowledges support from Brazil's National Council of Scientific and Technological Development (CNPq, grant 310022/2015-0). Robert Peet acknowledges the support from the National Center for Ecological Analysis and Synthesis, the North Carolina Ecosystem Enhancement Program, the U.S. Forest Service, and the U.S. National Science Foundation (DBI-9905838, DBI-0213794). Josep Peñuelas would like to acknowledge the financial support from the European Research Council Synergy grant ERC-SyG-2013-610028 IMBALANCE-P. Petr Petřík and Jiri Dolezal acknowledge the support of the long-term research development project No. RVO 67985939 of the Czech Academy of Sciences. Oliver Phillips was funded by an ERC Advanced Grant (291585, "T-FORCES") and a Royal Society-Wolfson Research Merit Award. Valério D. Pillar has been supported by

the Brazil's National Council of Scientific and Technological Development (CNPq, grant 307689/2014-0). Solvita Rūsiņa was supported by the University of Latvia grant AAP2016/B041//Zd2016/AZ03 within the "Climate change and sustainable use of natural resources". Franziska Schrodt was supported by a University of Minnesota Institute on the Environment Discovery Grant, a German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig grant (50170649_#7) and a University of Nottingham Anne McLaren Fellowship. Jens Christian Svenning considers this work a contribution to his VILLUM Investigator project "Biodiversity Dynamics in a Changing World" funded by VILLUM FONDEN (grant 16549). Kim André Vanselow would like to thank W. Bernhard Dickoré for the help in the identification of plant species and acknowledge the financial support from the Volkswagen Foundation (AZ I/81 976) and the German Research Foundation (DFG VA 749/1-1, DFG VA 749/4-1). Evan Weiher was funded by NSF DEB-0415383, UWEC-ORSP, and UWEC-BCDT. Work by Karsten Wesche was supported by the German Research Foundation (DFG WE 2601/3-1,3-2, 4-1,4-2) and by the German Ministry for Science and Education (BMBF, CAME 03G0808A). Susan Wiser was funded by the NZ Ministry for Business, Innovation and Employment's Strategic Science Investment Fund.

This paper is dedicated to the memory of Dr. Ching-Feng (Woody) Li.

Author contributions

FMS wrote the first draft of the manuscript, with considerable input from JL and HB. JL and TH wrote the resampling algorithm. FMS set up the GitHub projects, curated the database, and produced the graphs. He also coordinated the sPlot consortium. SMH wrote the Turboveg software, which holds the sPlot database. JK provided the trait data from TRY and FS performed the trait data gap filling. HB secured the funding for sPlot as a strategic project of iDiv. All other authors contributed data and/or helped set up the database and/or helped develop the resampling algorithm. All authors contributed to revising the manuscript.

Competing interests

The authors declare no competing interests.

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6 *Biodiversity & Ecology* (2012-09-10) <https://doi.org/ghgt9j>
7 DOI: [10.7809/b-e.00207](https://doi.org/10.7809/b-e.00207)
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11 113. **Vegetation Database of the Volga and the Ural Rivers Basins**
12 Tatiana Lysenko, Olga Kalmykova, Anna Mitroshenkova
13 *Biodiversity & Ecology* (2012-09-10) <https://doi.org/ghgvc7>
14 DOI: [10.7809/b-e.00208](https://doi.org/10.7809/b-e.00208)
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18 114. **Vegetation Database of Tatarstan**
19 Vadim Prokhorov, Tatiana Rogova, Maria Kozhevnikova
20 *Phytocoenologia* (2017-09-27) <https://doi.org/ghgt84>
21 DOI: [10.1127/phyto/2017/0172](https://doi.org/10.1127/phyto/2017/0172)
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26 115. **Vegetation Database of Slovenia**
27 Urban Šilc
28 *Biodiversity & Ecology* (2012-09-10) <https://doi.org/ghgt9k>
29 DOI: [10.7809/b-e.00215](https://doi.org/10.7809/b-e.00215)
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33 116. **Slovak Vegetation Database**
34 Jozef Šibík
35 *Biodiversity & Ecology* (2012-09-10) <https://doi.org/ghgt9m>
36 DOI: [10.7809/b-e.00216](https://doi.org/10.7809/b-e.00216)
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40 117. **Ukrainian Grasslands Database**
41 Anna Kuzemko
42 *Biodiversity & Ecology* (2012-09-10) <https://doi.org/ghk7f3>
43 DOI: [10.7809/b-e.00217](https://doi.org/10.7809/b-e.00217)
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48 118. **The Tree Biodiversity Network (BIOTREE-NET): prospects for biodiversity research and
49 conservation in the Neotropics**
50 Luis Cayuela, Lucía Gálvez-Bravo, Ramón Pérez Pérez, Fábio de Albuquerque, Duncan Golicher,
51 Rakan Zahawi, Neptalí Ramírez-Marcial, Cristina Garibaldi, Richard Field, José Rey Benayas, ...
52 Regino Zamora
53 *Biodiversity & Ecology* (2012-09-10) <https://doi.org/ghgvck>
54 DOI: [10.7809/b-e.00078](https://doi.org/10.7809/b-e.00078)
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59 119. **Timberline meadows along a 1000-km transect in NW North America: species diversity and
60 community patterns**
61 Viktoria Wagner, Toby Spribille, Stefan Abrahamczyk, Erwin Bergmeier
62 *Applied Vegetation Science* (2014-01) <https://doi.org/f5mpvm>
63 DOI: [10.1111/avsc.12045](https://doi.org/10.1111/avsc.12045)
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69 120. **How resilient are northern hardwood forests to human disturbance? An evaluation using a
70 plant functional group approach**
71 I. Aubin, S. Gachet, C. Messier, A. Bouchard
72 *Ecoscience* (2007)
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76 121. **Vegetation and altitudinal zonation in continental West Greenland**
77 B. Sieg, B. Drees, F. J. A. Daniëls
78 *Meddelelser om Grønland Bioscience* (2006)
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3 122. **VegBank – a permanent, open-access archive for vegetation-plot data**
4 Robert Peet, Michael Lee, Michael Jennings, Don Faber-Langendoen
5 *Biodiversity & Ecology* (2012-09-10) <https://doi.org/ghgvcm>
6 DOI: [10.7809/b-e.00080](https://doi.org/10.7809/b-e.00080)
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10 123. **Vegetation-plot database of the Carolina Vegetation Survey**
11 Robert Peet, Michael Lee, Forbes Boyle, Thomas Wentworth, Michael Schafale, Alan Weakley
12 *Biodiversity & Ecology* (2012-09-10) <https://doi.org/ghgvn>
13 DOI: [10.7809/b-e.00081](https://doi.org/10.7809/b-e.00081)
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17 124. **The Alaska Arctic Vegetation Archive (AVA-AK)**
18 Donald A. Walker, Amy L. Breen, Lisa A. Druckenmiller, Lisa W. Wirth, Will Fisher, Martha K.
19 Raynolds, Jozef Šibík, Marilyn D. Walker, Stephan Hennekens, Keith Boggs, ... Donatella Zona
20 *Phytocoenologia* (2016-09-01) <https://doi.org/f877ht>
21 DOI: [10.1127/phyto/2016/0128](https://doi.org/10.1127/phyto/2016/0128)
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26 125. **VegPáramo, a flora and vegetation database for the Andean páramo**
27 Gwendolyn Peyre, Henrik Balslev, David Martí, Petr Sklenář, Paul Ramsay, Pablo Lozano, Nidia
28 Cuello, Rainer Bussmann, Omar Cabrera, Xavier Font
29 *Phytocoenologia* (2015-07-01) <https://doi.org/f7m9cj>
30 DOI: [10.1127/phyto/2015/0045](https://doi.org/10.1127/phyto/2015/0045)
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35 126. **The Floristic and Forest Inventory of Santa Catarina State (IFFSC): methodological and
36 operational aspects**
37 A. C. Vibrans, L. Sevgnani, D. V. Lingner, A. L. Gasper, S. Sabbagh
38 *Pesquisa Florestal Brasileira* (2010)
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42 127. **Plant Invasions in Protected Areas**
43 Springer Science and Business Media LLC
44 (2013) <https://doi.org/ghgt8v>
45 DOI: [10.1007/978-94-007-7750-7](https://doi.org/10.1007/978-94-007-7750-7)
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51 Jürgen Schultz
52 *Springer Science and Business Media LLC* (2005) <https://doi.org/ft52nn>
53 DOI: [10.1007/3-540-28527-x](https://doi.org/10.1007/3-540-28527-x)
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57 129. **A global inventory of mountains for bio-geographical applications**
58 Christian Körner, Walter Jetz, Jens Paulsen, Davnah Payne, Katrin Rudmann-Maurer, Eva M. Spehn
59 *Alpine Botany* (2016-12-19) <https://doi.org/f93fmr>
60 DOI: [10.1007/s00035-016-0182-6](https://doi.org/10.1007/s00035-016-0182-6)
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Supplementary Material

Table 1: List of databases contributing to the open access dataset extracted from the sPlot database. Databases are ordered based on their ID in the Global Index of Vegetation Databases (GVID ID).

GVID ID	Dataset name	Custodian	Deputy custodian	Nr. open-access plots	Ref
00-00-001	ForestPlots.net	Oliver L. Phillips	Aurora Levesley	108	55
00-00-003	SALVIAS	Brian Enquist	Brad Boyle	2860	
00-00-004	Vegetation Database of Eurasian Tundra	Risto Virtanen		600	
00-00-005	Tundra Vegetation Plots (TundraPlot)	Anne D. Bjorkman	Sarah Elmendorf	227	56
00-RU-001	Vegetation Database Forest of Southern Ural	Vasiliy Martynenko	Pavel Shirokikh	25	
00-RU-002	Database of Masaryk University's Vegetation Research in Siberia	Milan Chytrý		128	57
00-RU-003	Database Meadows and Steppes of Southern Ural	Sergey Yamalov	Mariya Lebedeva	99	
00-TR-001	Forest Vegetation Database of Turkey - FVDT	Ali Kavgaci		15	
AF-00-001	West African Vegetation Database	Marco Schmidt	Georg Zizka	184	58
AF-00-003	BIOTA Southern Africa Biodiversity Observatories Vegetation Database	Norbert Jürgens	Ute Schmiedel	562	59
AF-00-006	SWEA-Dataveg	Miguel Alvarez	Michael Curran	1211	
AF-00-008	PANAF Vegetation Database	Hjalmar Kühl	TeneKwetche Sop	942	
AF-00-009	Vegetation Database of the Okavango Basin	Rasmus Revermann	Manfred Finckh	202	60
AF-BF-001	Sahel Vegetation Database	Jonas V. Müller	Marco Schmidt	279	61
AF-CD-001	Forest Database of Central Congo Basin	Kim Sarah Jacobsen	Hans Verbeeck	97	62
AF-ET-001	Vegetation Database of Ethiopia	Desalegn Wana	Anke Jentsch	59	63
AF-MA-001	Vegetation Database of Southern Morocco	Manfred Finckh		266	64
AF-ZW-001	Vegetation Database of Zimbabwe	Cyrus Samimi		17	65
AS-00-001	Korean Forest Database	Tomáš Černý	Jiri Dolezal	766	66
AS-00-003	Vegetation of Middle Asia	Arkadiusz Nowak	Marcin Nobis	128	67
AS-00-004	Rice Field Vegetation Database	Arkadiusz Nowak		31	
AS-BD-001	Tropical Forest Dataset of Bangladesh	Mohammed A.S. Arfin Khan	Fahmida Sultana	82	
AS-CN-001	China Forest-Steppe Ecotone Database	Hongyan Liu	Fengjun Zhao	97	68
AS-CN-002	Tibet-PaDeMoS Grazing Transect	Karsten Wesche		27	69
AS-CN-003	Vegetation Database of the BEF China Project	Helge Bruehlheide		18	70

GIVD ID	Dataset name	Custodian	Deputy custodian	Nr. open-access plots	Ref
AS-CN-004	Vegetation Database of the Northern Mountains in China	Zhiyao Tang		70	
AS-EG-001	Vegetation Database of Sinai in Egypt	Mohamed Z. Hatim		98	71
AS-ID-001	Sulawesi Vegetation Database	Michael Kessler		24	
AS-IR-001	Vegetation Database of Iran	Jalil Noroozi	Parastoo Mahdavi	105	
AS-KZ-001	Database of Meadow Vegetation in the NW Tien Shan Mountains	Viktoria Wagner		3	72
AS-MN-001	Southern Gobi Protected Areas Database	Henrik von Wehrden	Karsten Wesche	688	73
AS-RU-001	Wetland Vegetation Database of Baikal Siberia (WETBS)	Victor Chepinoga		6	74
AS-RU-002	Database of Siberian Vegetation (DSV)	Andrey Korolyuk	Andrei Zverev	2150	75
AS-RU-004	Database of the University of Münster - Biodiversity and Ecosystem Research Group's Vegetation Research in Western Siberia and Kazakhstan	Norbert Hözel	Wanja Mathar	85	
AS-SA-001	Vegetation Database of Saudi Arabia	Mohamed Abd El-Rouf Mousa El-Sheikh		607	76
AS-TJ-001	Eastern Pamirs	Kim André Vanselow		174	77
AS-TW-001	National Vegetation Database of Taiwan	Ching-Feng Li	Chang-Fu Hsieh	897	
AS-YE-001	Socotra Vegetation Database	Michele De Sanctis	Fabio Attorre	190	78
AU-AU-002	AEKOS	Ben Sparrow		7443	35
AU-NC-001	New Caledonian Plant Inventory and Permanent Plot Network (NC-PIPPN)	Jérôme Munzinger	Philippe Birnbaum	98	79
AU-NZ-001	New Zealand National Vegetation Databank	Susan K. Wiser		983	80
AU-PG-001	Forest Plots from Papua New Guinea	Timothy Whitfeld	George D. Weiblen	53	81
EU-00-002	Nordic-Baltic Grassland Vegetation Database (NBGVD)	Jürgen Dengler	Łukasz Kozub	931	82
EU-00-011	Vegetation-Plot Database of the University of the Basque Country (BIOVEG)	Idoia Biurrun	Itziar García-Mijangos	1694	83
EU-00-013	Balkan Dry Grasslands Database	Kiril Vassilev	Armin Macanović	224	84
EU-00-016	Mediterranean Ammophiletea Database	Corrado Marcenò	Borja Jiménez-Alfaro	3713	85
EU-00-017	European Coastal Vegetation Database	John Janssen		1369	
EU-00-018	The Nordic Vegetation Database	Jonathan Lenoir	Jens-Christian Svensson	1755	86
EU-00-019	Balkan Vegetation Database	Kiril Vassilev	Hristo Pedashenko	211	87

					Nr. open- acces s plots	Ref
	GIVD ID	Dataset name	Custodian	Deputy custodian		
10	EU-00-020	WetVegEurope	Flavia Landucci		61	88
11	EU-00-022	European Mire Vegetation Database	Tomáš Peterka	Martin Jiroušek	1843	89
12	EU-AL-001	Vegetation Database of Albania	Michele De Sanctis	Giuliano Fanelli	99	90
13	EU-AT-001	Austrian Vegetation Database	Wolfgang Willner	Christian Berg	950	91
14	EU-BE-002	INBOVEG	Els De Bie		48	
15	EU-BG-001	Bulgarian Vegetation Database	Iva Apostolova	Desislava Sopotlieva	74	92
16	EU-CH-005	Swiss Forest Vegetation Database	Thomas Wohlgemuth		1409	93
17	EU-CZ-001	Czech National Phytosociological Database	Milan Chytrý	Ilona Knollová	579	94
18	EU-DE-001	VegMV	Florian Jansen	Christian Berg	5	95
19	EU-DE-013	VegetWeb Germany	Florian Jansen	Jörg Ewald	199	96
20	EU-DE-014	German Vegetation Reference Database (GVRD)	Ute Jandt	Helge Bruehlheide	286	97
21	EU-DK-002	National Vegetation Database of Denmark	Jesper Erenskjold Moeslund	Rasmus Ejrnæs	1181	
22	EU-ES-001	Iberian and Macaronesian Vegetation Information System (SIVIM) - Wetlands	Aaron Pérez-Haase	Xavier Font	292	
23	EU-FR-003	SOPHY	Emmanuel Garbolino	Patrice De Ruffray	13322	98
24	EU-GB-001	UK National Vegetation Classification Database	John S. Rodwell		5457	
25	EU-GR-001	KRITI	Erwin Bergmeier		43	
26	EU-GR-005	Hellenic Natura 2000 Vegetation Database (HelNatVeg)	Panayotis Dimopoulos	Ioannis Tsiripidis	777	99
27	EU-GR-006	Hellenic Woodland Database	Ioannis Tsiripidis	Georgios Fotiadis	4	100
28	EU-HR-001	Phytosociological Database of Non-Forest Vegetation in Croatia	Zvjezdana Stančić		213	101
29	EU-HR-002	Croatian Vegetation Database	Željko Škvorc	Daniel Krstonošić	688	
30	EU-HU-003	CoenoDat Hungarian Phytosociological Database	János Csiky	Zoltán Botta-Dukát	17	102
31	EU-IT-001	VegItaly	Roberto Venanzoni	Flavia Landucci	2712	103
32	EU-IT-010	Vegetation database of Habitats in the Italian Alps – HabitAlp	Laura Casella	Pierangela Angelini	155	104
33	EU-IT-011	Vegetation-Plot Database Sapienza University of Rome (VPD-Sapienza)	Emiliano Agrillo	Fabio Attorre	1003	105
34	EU-LT-001	Lithuanian Vegetation Database	Valerijus Rašomavičius	Domas Uogintas	119	

GIVD ID	Dataset name	Custodian	Deputy custodian	Nr. open-access plots	Ref
EU-LV-001	Semi-natural Grassland Vegetation Database of Latvia	Solvita Rūsiņa		306	106
EU-MK-001	Vegetation Database of the Republic of Macedonia	Renata Ćušterevska		10	
EU-NL-001	Dutch National Vegetation Database	Stephan M. Hennekens	Joop H.J. Schaminée	10223	107
EU-PL-001	Polish Vegetation Database	Zygmunt Kącki	Grzegorz Swacha	464	108
EU-RO-007	Romanian Forest Database	Adrian Indreica	Pavel Dan Turtureanu	60	109
EU-RO-008	Romanian Grassland Database	Eszter Ruprecht	Kiril Vassilev	44	110
EU-RS-002	Vegetation Database Grassland Vegetation of Serbia	Svetlana Aćić	Zora Dajić Stevanović	57	111
EU-RU-002	Lower Volga Valley Phytosociological Database	Valentin Golub	Andrey Chuvashov	149	112
EU-RU-003	Vegetation Database of the Volga and the Ural Rivers Basins	Tatiana Lysenko		96	113
EU-RU-011	Vegetation Database of Tatarstan	Vadim Prokhorov	Maria Kozhevnikova	94	114
EU-SI-001	Vegetation Database of Slovenia	Urban Šilc	Filip Kuzmič	435	115
EU-SK-001	Slovak Vegetation Database	Milan Valachovič	Jozef Šibík	893	116
EU-UA-001	Ukrainian Grasslands Database	Anna Kuzemko	Yulia Vashenyak	149	117
EU-UA-006	Vegetation Database of Ukraine and Adjacent Parts of Russia	Viktor Onyshchenko	Vitaliy Kolomiychuk	479	
NA-00-002	Tree Biodiversity Network (BIOTREE-NET)	Luis Cayuela		208	118
NA-CA-003	Database of Timberline Vegetation in NW North America	Viktoria Wagner	Toby Spribile	38	119
NA-CA-004	Understory of Sugar Maple Dominated Stands in Quebec and Ontario (Canada)	Isabelle Aubin		9	120
NA-CA-005	Boreal Forest of Canada	Yves Bergeron	Louis De Grandpré	44	
NA-GL-001	Vegetation Database of Greenland	Birgit Jedrzejek	Fred J.A. Daniëls	340	121
NA-US-002	VegBank	Robert K. Peet	Michael T. Lee	6456	122
NA-US-006	Carolina Vegetation Survey Database	Robert K. Peet	Michael T. Lee	2317	123
NA-US-014	Alaska-Arctic Vegetation Archive	Donald A. Walker	Amy Breen	467	124
SA-00-002	VegPáramo	Gwendolyn Peyre	Xavier Font	1591	125
SA-AR-002	Vegetation Database of Central Argentina	Melisa Giorgis	Alicia T.R. Acosta	42	
SA-BO-003	Bolivia Forest Plots	Michael Kessler	Sebastian Herzog	18	
SA-BR-002	Forest Inventory, State of Santa Catarina, Brazil (IFFSC Project)	Alexander Christian Vibrans	André Luís de Gasper	1345	126

GIVD ID	Dataset name	Custodian	Deputy custodian	Nr. open-access plots	Ref
SA-BR-003	Grasslands of Rio Grande do Sul, Brazil	Eduardo Vélez-Martin	Valério D. Pillar	271	
SA-BR-004	Grassland Database of Campos Sulinos	Gerhard E. Overbeck	Valério D. Pillar	111	
SA-CL-002	SSAForests_Plots_db	Alvaro G. Gutiérrez		163	
SA-CL-003	Chilean Park Transects - Fondecyt 1040528	Aníbal Pauchard	Alicia Marticorena	33	127
SA-EC-001	Ecuador Forest Plot Database	Jürgen Homeier		156	

Table 2: Description of the variables contained in the ‘header’ matrix, together with their range (if numeric) or possible levels (if nominal or binary), and the number of non-empty (i.e., non NA) records. Variable types can be n - nominal (i.e., qualitative variable), o - ordinal, q - quantitative, or b - binary (i.e., boolean), or d - date. . Additional details on the variables is in Bruelheide et al. (2019) [24]. GIVD codes derive from Dengler et al. (2011) [36]. Biomes refer to Schultz 2005 [128], modified to include also the world mountain regions by Körner et al. (2017)[129]. The column ESY refers to the EUNIS Habitat Classification Expert system described in Chytrý et al. (2020) [49].

Variable	Range/Levels	Unit of Measurement	Nr. non-NA Records	Type
GIVD_ID			91205	n
Dataset			91205	n
Continent	Africa, Asia, Europe, North America, Oceania, South America		91205	n
Country			91205	n
Biome	Alpine, Boreal zone, Dry midlatitudes, Dry tropics and subtropics, Polar and subpolar zone, Subtropics with year-round rain, Subtropics with winter rain, Temperate midlatitudes, Tropics with summer rain, Tropics with year-round rain		91205	n
Date_of_recording	1888-07-05 - 2015-02-03	dd-mm-yyyy	75971	d
Latitude	-54.73863 - 80.149116	° (WGS84)	91205	q
Longitude	-162.741433 - 179.590053	° (WGS84)	91205	q
Location_uncertainty	1 - 2500	m	91176	q
Relevé_area	0.01 - 40000	m ²	62063	q
Plant_recorded	All vascular plants, All trees & dominant understory, Dominant trees, Only dominant species, Dominant woody plants >= 2.5 cm dbh, All woody plants, Woody plants >= 1 cm dbh, Woody plants >= 2.5 cm dbh, Woody plants >= 5 cm dbh, Woody plants >= 10 cm dbh, Woody plants >= 20 cm dbh, Woody plants >= 1 m height, Not specified		91205	n
Elevation	-25 - 4819	m a.s.l.	52277	q
Aspect	1 - 360	°	30842	q
Slope	0 - 90	°	37817	q
is_forest	FALSE = 58145; TRUE = 25740		83885	b

Variable	Range/Levels	Unit of Measurement	Nr. non-NA Records	Type
ESY			55631	n
Forest	FALSE = 50071; TRUE = 23979		74050	b
Shrubland	FALSE = 62967; TRUE = 11083		74050	b
Grassland	FALSE = 26974; TRUE = 47076		74050	b
Wetland	FALSE = 55970; TRUE = 18080		74050	b
Sparse_vegetation	FALSE = 62728; TRUE = 11322		74050	b
Cover_total	1 - 313	%	24850	q
Cover_tree_layer	0.5 - 150	%	7270	q
Cover_shrub_layer	0.5 - 145	%	10209	q
Cover_herb_layer	0.2 - 180	%	26846	q
Cover_moss_layer	1 - 100	%	9685	q
Cover_lichen_layer	1 - 95	%	739	q
Cover_algae_layer	1 - 100	%	221	q
Cover_litter_layer	1 - 100	%	4510	q
Cover_bare_rocks	1 - 100	%	1904	q
Cover_cryptogams	1 - 95	%	593	q
Cover_bare_soil	0.1 - 99	%	1414	q
Height_trees_highest	1 - 99	m	6140	q
Height_trees_lowest	1 - 90	m	246	q
Height_shrubs_highest	0.1 - 9.9	m	2902	q
Height_shrubs_lowest	0.1 - 9	m	350	q
Height_herbs_average	0.1 - 440	cm	10161	q
Height_herbs_lowest	1 - 250	cm	2809	q
Height_herbs_highest	1 - 600	cm	1744	q
Naturalness	1 = Natural, 2 = Semi-natural		68179	o