LOTVS: a global collection of permanent vegetation plots

Marta Gaia Sperandii[1], Francesco de Bello[1,2], Enrique Valencia[3], Lars Götzenberger[4,5], Manuele Bazzichetto[1], Thomas Galland[2], Anna E-Vojtkó[2,5], Luisa Conti[6,5], Peter B. Adler[7], Hannah Buckley[8], Jiří Danihelka[9,4], Nicola J. Day[10], Jürgen Dengler[11,12,13], David J. Eldridge[14], Marc Estiarte[15,16], Ricardo García-González[17], Eric Garnier[18], Daniel Gómez-García[17], Lauren Hallett[19], Susan Harrison[20], Tomas Herben[4,21], Ricardo Ibáñez[22], Anke Jentsch[23], Norbert Juergens[24], Miklós Kertész[25], Duncan M. Kimuyu[26,27], Katja Klumpp[28], Mike Le Duc[29], Frédérique Louault[28], Rob H. Marrs[29], Gábor Ónodi[25], Robin J. Pakeman[30], Meelis Pärtel[31], Begoña Peco[32], Josep Peñuelas[15,16], Marta Rueda[33], Wolfgang Schmidt[34], Ute Schmiedel[24], Martin Schuetz[35], Hana Skalova[4], Petr Šmilauer[36], Marie Šmilauerová[2], Christian Smit[37], Ming-Hua Song[38], Martin Stock[39], James Val[14], Vigdis Vandvik[40], Karsten Wesche[13,41,42], Susan K. Wiser[43], Ben A. Woodcock[44], Truman P. Young[45,27], Fei-Hai Yu[46], Amelia A. Wolf[47,27], Martin Zobel[31], Jan Lepš[2].

Affiliations:

[1] Centro de Investigaciones sobre Desertificación (CSIC-UV-GV), 46113, Valencia, Spain.

[2] Department of Botany, Faculty of Science, University of South Bohemia, České Budějovice, Czech Republic.

[3] Departamento de Biología y Geología, Física y Química Inorgánica, Escuela Superior de Ciencias Experimentales y Tecnología, Universidad Rey Juan Carlos, Móstoles, Spain.

[4] Institute of Botany of the Czech Academy of Sciences, Průhonice, Czech Republic.

[5] Institute of Botany, Czech Academy of Sciences, Třeboň, Czech Republic.

[6] Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Praha-Suchdol, Czech Republic.

[7] Department of Wildland Resources and the Ecology Center, Utah State University, Logan, UT, USA.

[8] School of Science, Auckland University of Technology, Auckland, New Zealand.

[9] Department of Botany and Zoology, Faculty of Science, Masaryk University, Brno, Czech Republic.

[10] School of Biological Sciences, Victoria University of Wellington, Wellington, New Zealand.

[11] Vegetation Ecology Group, Institute of Natural Resource Sciences (IUNR), Zurich University of Applied Sciences (ZHAW), Wädenswil, Switzerland.

[12] Plant Ecology Group, Bayreuth Center for Ecology and Environmental Research (BayCEER), University of Bayreuth, Bayreuth, Germany.

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

[14] Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, Australia.

[15] Centre for Ecological Research and Forestry Applications (CREAF), Cerdanyola del Vallès, Catalonia, Spain.

[16] CSIC, Global Ecology Unit CREAF-CSIC-UAB, Bellaterra, Catalonia, Spain.
[17] Instituto Pirenaico de Ecología (IPE-CSIC), Jaca-Zaragoza, Spain.
[18] Center in Ecology and Evolutionary Ecology (CEFE), French National Centre for Scientific Research (CNRS), Univ Montpellier, École pratique des Hautes Études (EPHE), Research Institute for Development (IRD), Montpellier, France.
[19] Environmental Studies Program and Department of Biology, University of Oregon, Eugene, Oregon, USA
[20] Department of Environmental Science and Policy, University of California, Davis, CA, USA. [21] Department of Botany, Charles University, Praha 2, Czech Republic.
[22] Department of Environmental Biology, University of Navarra, Pamplona, Spain.
[23] Department of Disturbance Ecology, Bayreuth Center of Ecology and Environmental Research (BayCEER), University of Bayreuth, Bayreuth, Germany.
[24] Research Unit Biodiversity, Evolution & Ecology (BEE) of Plants, Institute of Plant Science and Microbiology, University of Hamburg, Hamburg, Germany.
[25] Institute of Ecology and Botany, Centre for Ecological Research, Hungarian Academy of Sciences, Vácrátót, Hungary.
[26] Department of Natural Resources, Karatina University, Karatina, Kenya.
[27] Mpala Research Centre, Nanyuki, Kenya.
[28] Université Clermont Auvergne, French National Institute for Agriculture, Food, and Environment (INRAE), VetAgro Sup, UMR Ecosystème Prairial, Clermont-Ferrand, France.
[29] School of Environmental Sciences, University of Liverpool, Liverpool, UK.
[30] The James Hutton Institute, Craigiebuckler, Aberdeen, UK.
[31] Department of Botany, Institute of Ecology and Earth Sciences, University of Tartu, Tartu, Estonia.
[32] Terrestrial Ecology Group (TEG), Department of Ecology, Institute for Biodiversity and Global Change, Autonomous University of Madrid, Madrid, Spain.
[33] Department of Plant Biology and Ecology, Universidad de Sevilla, Sevilla, Spain.
[34] Department of Silviculture and Forest Ecology of the Temperate Zones, University of Göttingen, Göttingen, Germany.
[35] Community Ecology, Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Birmensdorf, Switzerland.
[36] Department of Ecosystem Biology, Faculty of Science, University of South Bohemia, České Budějovice, Czech Republic.
[37] Conservation Ecology Group, Groningen Institute for Evolutionary Life Sciences, Groningen, The Netherlands.
[38] Laboratory of Ecosystem Network Observation and Modelling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China.
[39] Wadden Sea National Park of Schleswig-Holstein, Tönning, Germany.

[40] Department of Biological Sciences and Bjerknes Centre for Climate Research, University of Bergen, Bergen, Norway.
[41] Botany Department, Senckenberg Natural History Museum Görlitz, Görlitz, Germany.
[42] International Institute Zittau, Technische Universität Dresden, Dresden, Germany.
[43] Manaaki Whenua – Landcare Research, Lincoln, New Zealand.
[44] UK Centre for Ecology & Hydrology, Crowmarsh Gifford, Wallingford, Oxfordshire, UK.
[45] Department of Plant Sciences, University of California, Davis, USA.
[46] Institute of Wetland Ecology & Clone Ecology / Zhejiang Provincial Key Laboratory of Plant Evolutionary Ecology and Conservation, Taizhou University, Taizhou, China.
[47] Department of Integrative Biology, University of Texas, USA.

* Correspondence:
Marta Gaia Sperandii, Centro de Investigaciones sobre Desertificación (CSIC-UV-GV), 46113, Valencia, Spain
ORCID: https://orcid.org/0000-0002-2507-5928
Email: marta.sperandii@ext.uv.es

Abstract

Analysing temporal patterns in plant communities is extremely important to quantify the extent and the consequences of ecological changes, especially considering the current biodiversity crisis. Long-term data collected through the regular sampling of permanent plots represent the most accurate resource to study ecological succession, analyse the stability of a community over time and understand the mechanisms driving vegetation change. We hereby present the LOng-Term Vegetation Sampling (LOTVS) initiative, a global collection of vegetation time-series derived from the regular monitoring of plant species in permanent plots. With 79 datasets from five continents and 7789 vegetation time-series monitored for at least six years and mostly on an annual basis, LOTVS possibly represents the largest collection of temporally fine-grained vegetation time-series derived from permanent plots and made accessible to the research community. As such, it has an outstanding potential to support innovative research in the fields of vegetation science, plant ecology and temporal ecology.

Keywords: ecoinformatics; ecological succession; ecosystem stability; global scale; permanent plots; plant communities; plant diversity; temporal analysis; time-series; vegetation.

1. Background

Anthropogenic changes are severely impacting ecosystems (Bradshaw et al. 2021). The rate of species loss has now exceeded background extinction rates (Pimm et al. 2014), leading many scientists to claim a sixth mass extinction (Pereira et al. 2012; Ceballos et al. 2015). At the same time, a considerable proportion of natural habitats has been lost (Convention on Biological Diversity 2020) and a number of ecosystem functions and services are seriously at risk (IPBES 2019).

The analysis of time-based patterns in biological communities, especially when focused on primary producers like plants, represents an opportunity to quantify the extent and the consequences of such changes in biodiversity (Dornelas et al. 2014; Gonzalez et al. 2016; Blowes et al. 2019). This research field has potential for: i) unravelling the mechanisms that drive and maintain biodiversity over time (Jones et al. 2017; Hillebrand et al. 2018); ii) shedding light on how external drivers (e.g. global changes) affect community dynamics in natural habitats (Bernhardt-Römermann et al. 2015; Newbold et al. 2015) and iii) assessing relationships between community stability over time and the delivery of ecosystem services (Isbell et al. 2018). Reliable answers to these questions can only be provided by drawing upon ecological data collected at several points in time using consistent sampling procedures. For plant communities, long-term data collected by regularly sampling permanent plots probably constitute the most precise approach to detect temporal changes at the local scale (Bakker et al. 1996; Damgaard 2019; de Bello et al. 2020). First, due to their geographical position being kept “fixed” in the field, permanent plots prevent relocation bias, i.e. the error derived from trying to find the original plot location. This bias is inherent in vegetation resurveys (Verheyen et al. 2018). Second, the repeated collection of vegetation data from permanent plots provides broad benefits to our understanding of vegetation change, including the means to track detailed successional trajectories, monitor species interactions over time and assess the stability of the community as a whole. For this reason, permanent plots have been listed among the six most important developments in vegetation science over the past three decades (Chytrý et al. 2019).

In recent decades, vegetation science has benefited from the development and maintenance of large vegetation databases (Dengler et al. 2011). Historical vegetation relevés performed by early vegetation ecologists, together with recent vegetation-plot data stemming from regional, but also national or continental research and survey projects, have been carefully assembled and digitally archived in the context of centralized initiatives (Chytrý et al. 2016; Wiser 2016; Bruelheide et al. 2019; Sabatini et al. 2021). Such global collections of vegetation-plot data are essential to investigate macroecological patterns and provide spatially meaningful answers to global issues, i.e. to effectively perform global-scale biodiversity research. In this context, a comparable effort specifically aimed at assembling and maintaining global databases built on time-series of vegetation data is urgently needed to lay a common ground for future studies focusing on i) providing global estimates of changes in plant diversity trends over time; ii) monitoring the conservation status of natural habitats over time or iii) assessing the stability of ecosystem functions and services. To the best of our knowledge, the BioTIME initiative (Dornelas et al. 2018) represents the most important global collection of biodiversity time-series so far, including abundance records measured in species assemblages belonging to the marine, freshwater and terrestrial environments. Yet, the powerful spatial representation of BioTIME has limitations that include: i) an often limited length and/or periodicity of the time-series, which particularly affects vegetation data (29 datasets with at least 6 data points); ii) a poor focus on vegetation and terrestrial plant biodiversity (96 datasets, corresponding to about 27% of the whole database). Given that a high number of ecosystem functions and services strongly depend on plants (Maestre et al. 2012; van der Plas 2019), we deem it crucial for the fields of vegetation science and ecology to be able to rely on a consistent and standardized collection of datasets including high-quality time-series measured at regular intervals and specific to plant communities.

Based on these premises, we hereby present the LOng-Term Vegetation Sampling (LOTVS) initiative, a growing global collection of vegetation time-series derived from the regular (mostly, annual) monitoring of plant species in permanent plots. By promoting the use, and supporting the visibility of high-quality temporal data collected using permanent plots, LOTVS ultimately aims to provide the tools to ask relevant ecological questions across a number of taxa, ecosystems and regions. The LOTVS collection provides a platform for aggregating the currently disconnected datasets sampled around the world based on permanent plots. As such, researchers are welcome to contribute to and, based on a scientific proposal (see section 3.2.), use the available collection of data.

2. Description of LOTVS

As of December 2021, LOTVS encompasses 79 datasets (Fig. 1) for a total of 7789 vegetation time-series, collected using permanent plots that were monitored for a minimum of six, and a maximum of 99 years (first quartile: 10; mean: 17.5; median: 16; third quartile: 23 years; see Fig 2). The vast majority of LOTVS time-series has a fine-grained temporal resolution: measurements in permanent plots were taken on 10% to 100% of the temporal interval (with 100% meaning that plots were sampled at least annually; first quartile: 82.8%; mean: 87.4%; median: 100%; third quartile: 100%). A description of the single datasets can be found in Valencia et al. (2020; Supplementary Material) and is now available on Zenodo as online metadata (https://doi.org/10.5281/zenodo.5807378; see section 3.3). At present, LOTVS includes vegetation time-series specifically focused on herbaceous species and shrubs mostly belonging to grassland habitats, followed by mixed vegetation types (i.e. savannas, shrub steppes, degraded stages of heathlands), shrublands (including heathlands), forest understoreys and wetlands (mostly salt marshes; Fig. 4A; see Box 1). We note that, in this context, mixed vegetation types consist of communities where grasses and shrubs co-exist in a mosaic landscape (naturally, or as the result of anthropogenic disturbance processes) or are just co-dominant. Forest plots exclusively monitoring long-term changes in tree species are, at the moment, excluded from LOTVS. The LOTVS collection contains data from five continents (Fig. 1; an interactive map can be also accessed here and through the proposal template available at https://doi.org/10.5281/zenodo.5807378), although Europe and North America are so far the most represented areas. While Europe is the leading continent in terms of datasets (38 out of 79), North America hosts the majority of plots (almost 70%, distributed across 30 datasets).

Habitat types	
Forest	Vegetated land with a tree canopy cover > 10% and covering an area of more than 0.5 ha.
Forest understorey	The vegetative layer of a forest, consisting of tree seedlings, shrubs and herbaceous vegetation growing below the forest canopy.
Grassland	Open vegetation dominated by graminoids and forbs, characterized by a low cover of woody species (i.e. trees and shrubs).
Heathland	Evergreen formation mostly composed of heathers, i.e. dwarf shrubs of the *Ericaceae* family
Salt marshes	Coastal wetlands dominated by salt- and flood-tolerant vegetation (mostly grasses, rushes and sedges).

Savannas	Vegetation typical of tropical and subtropical seasonally dry climates, normally characterized by an open canopy of scattered trees and an understorey dominated by grasses, often intermingled with large grassland patches.
Shrublands	Open vegetation dominated by shrubs or small (< 5 m tall) trees, often characterized by a single canopy layer.
Wetlands	Permanent or temporary areas of marsh, fen, peatland or water characterised by water that is static or flowing, fresh, brackish or salt.
Sampling method	
Biomass	Clipping, drying and weighing the aboveground phytomass present in a sampling unit (either as a whole or separately for each species).
Cover	Visual estimation of plant species cover in percentage (%) or through the use of cover-abundance classes.
Frequency	Estimation of species abundance based on recording the percentage of sub-units occupied by each species in a certain sampling unit. This can be done, e.g. by counting the number of contacts between each species and a pin.

Box 1. *Working definitions of the main habitat types and sampling methods mentioned. Habitat definitions were adapted from the Convention of Biological Diversity website (https://www.cbd.int/forest/definitions.shtml and https://www.cbd.int/drylands/definitions), from Goldstein & DellaSala (2020) and from the Ramsar Convention website (https://www.ramsar.org/about/the-convention-on-wetlands-and-its-mission).*

Datasets included in LOTVS span a wide climatic gradient, their mean annual temperature ranging between -11.5 and 20.1°C, and their mean annual precipitation between 140 and 2592 mm (source: WordClim 2; Fick & Hijmans 2017). As such, they are mostly included in the temperate seasonal forest, temperate grassland/desert and in the woodland/shrubland biomes (sensu Whittaker 1975; see Fig 3).

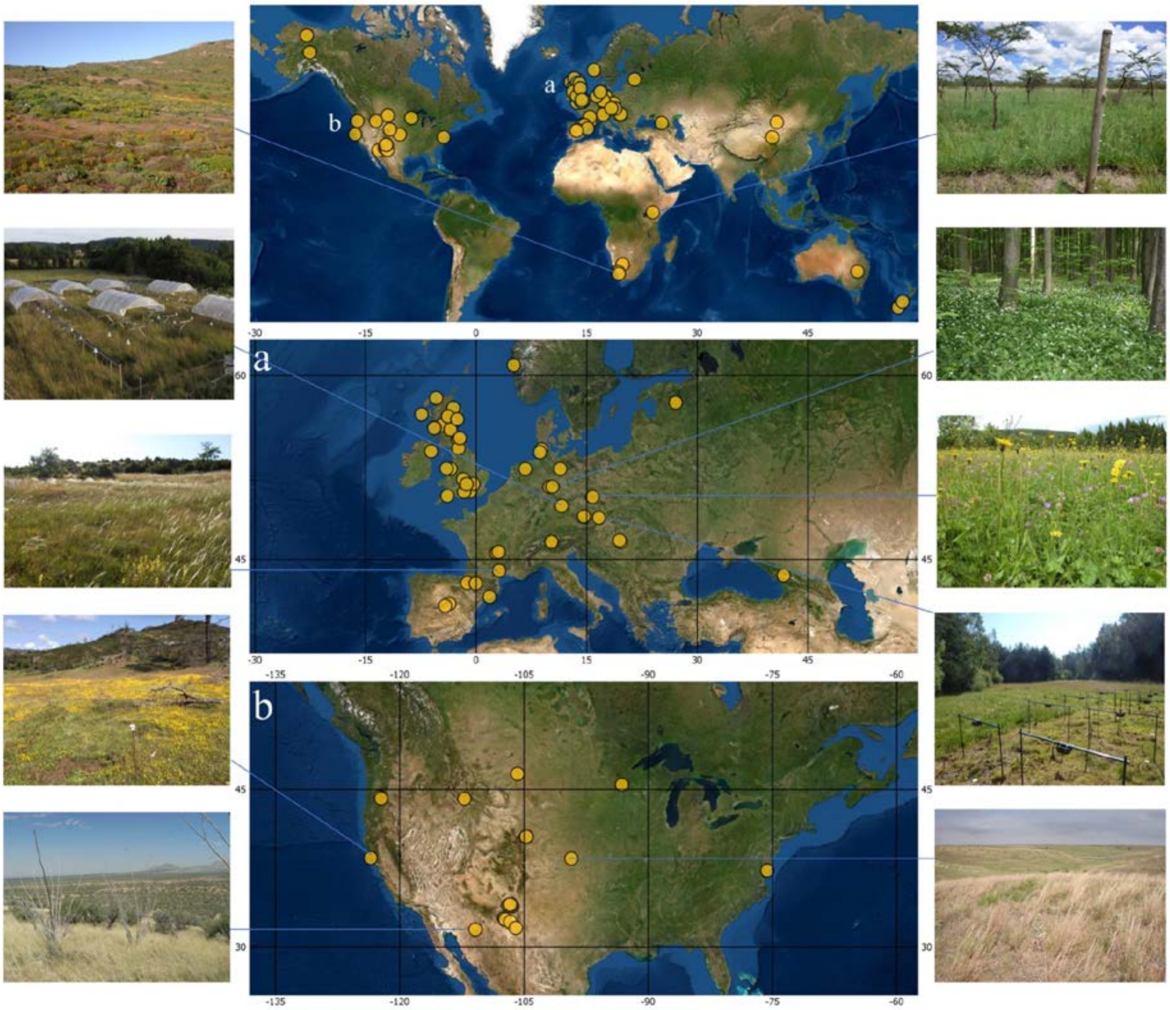

Fig. 1. *Map showing the geographical location of the 79 datasets included in LOTVS. A more detailed view is given for areas featuring a high density of datasets: a) Europe; b) North America. ESRI World Satellite Imagery was used as the base map. For a subset of sites, representative vegetation types are shown. Photos were taken at: (left, starting from the top): Soebatsfontein (South Africa), Bayreuth (Germany), Roquefort-sur-Soulzon (France), McLaughlin Natural Reserve (California, USA), Santa Rita Experimental Range (Arizona, USA); (right, starting from the top): Laikipia (Kenya), Göttinger Wald (Germany), Krkonoše Mountains (Czech Republic), Ohrazení (Czech Republic), Hays (Kansas, USA).*

.

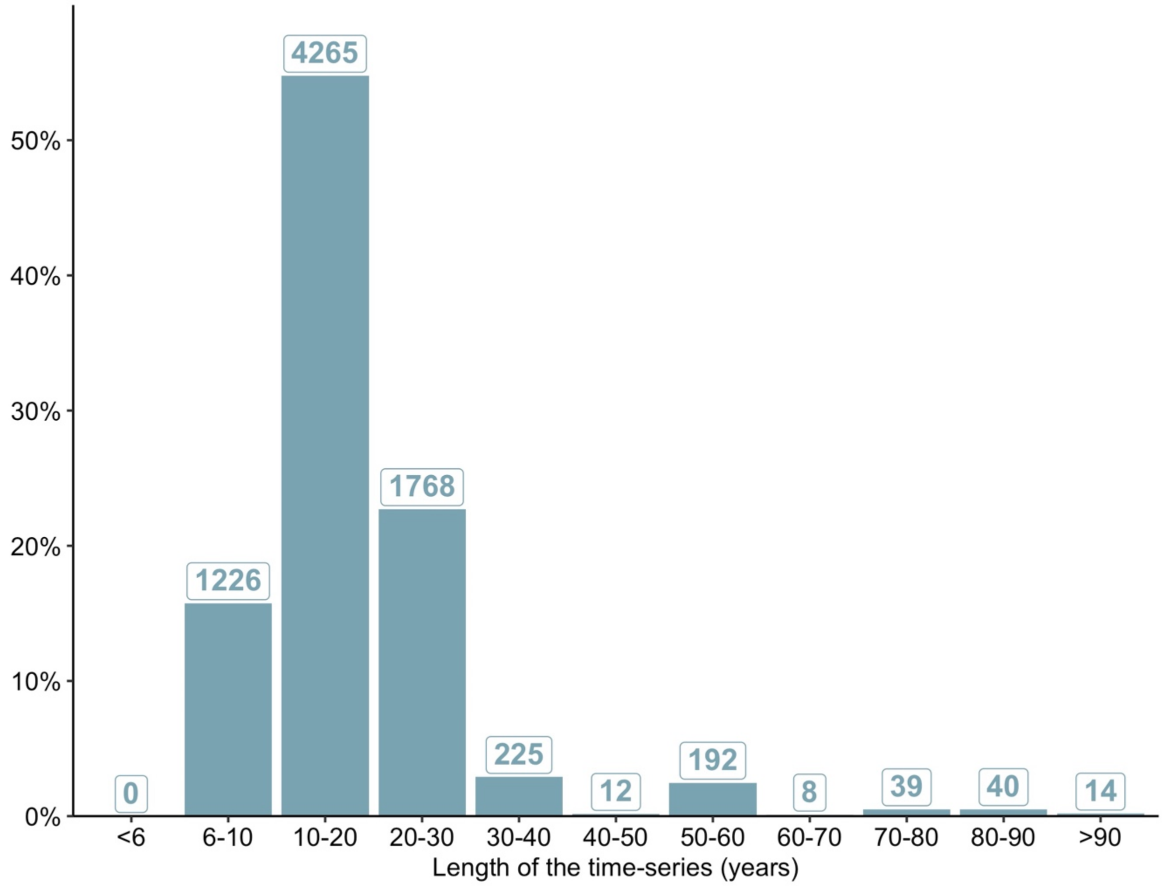

Fig. 2. *Distribution of the duration (in years) of the time-series included in LOTVS. The number of time-series within each class is reported above the bars.*

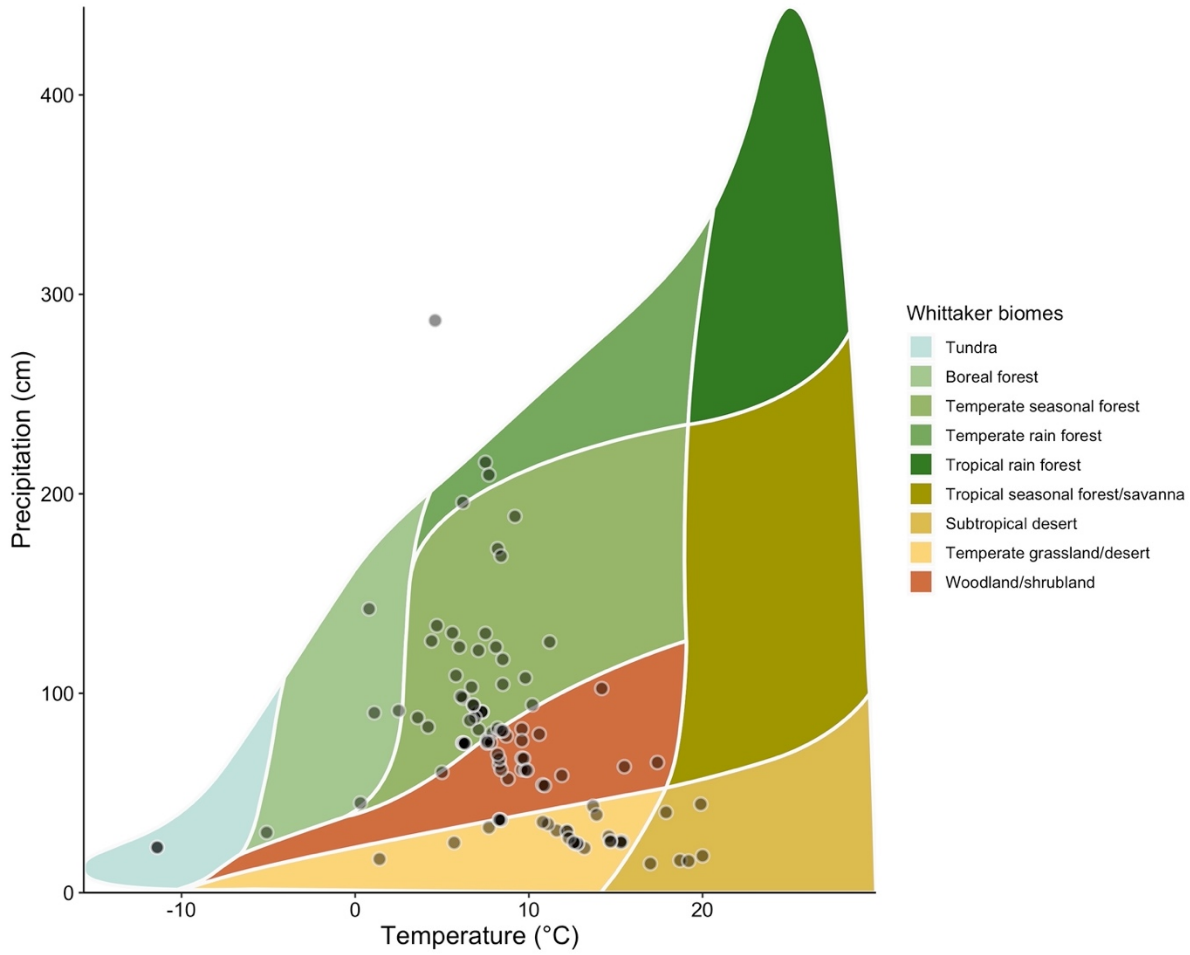

Fig. 3. *Climatic summary of the datasets included in LOTVS. Mean annual temperature and mean annual precipitation are plotted on the x and y axes, respectively. Each dot represents mean climatic conditions characterizing sites within each dataset. Dots are superimposed on Whittaker biomes (i.e. indicating potential vegetation; Whittaker, 1975), as redrawn from Ricklefs (2008). The plot was created using the R package "plotbiomes" (Stefan and Levin 2021).*

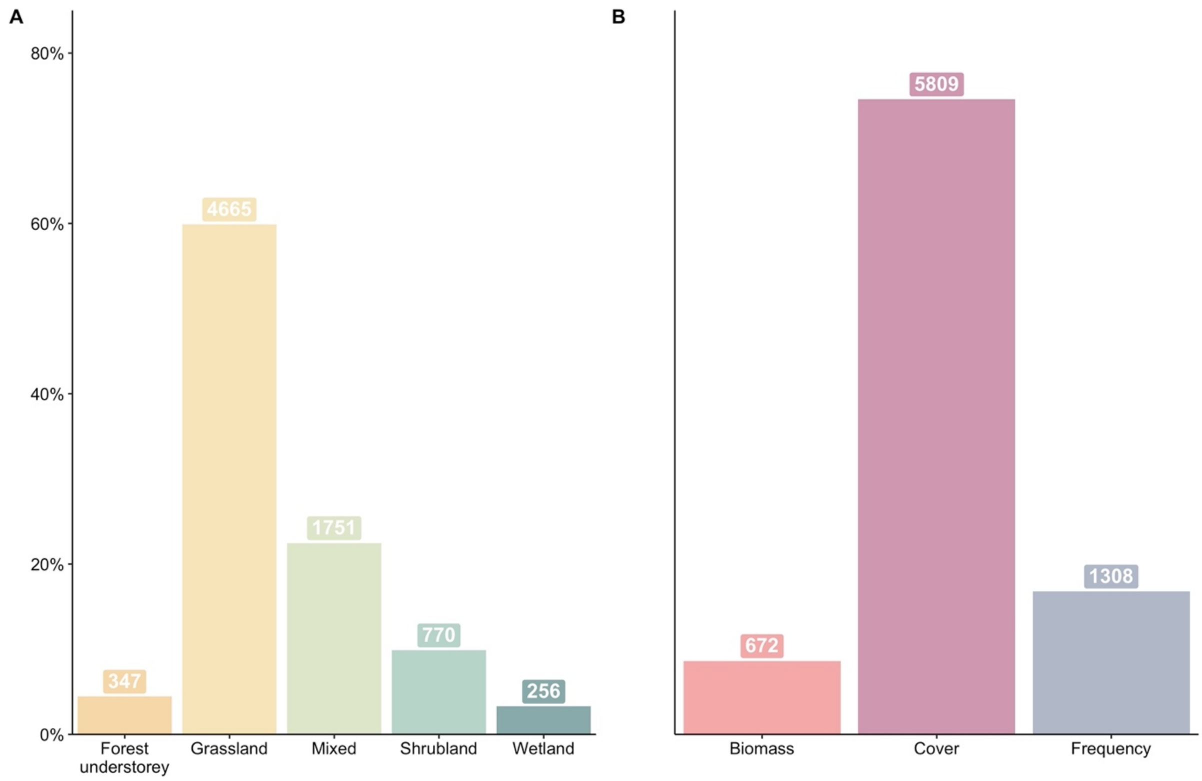

Fig. 4. *Habitat types (A) and sampling methods/approaches (B) covered in LOTVS. The number of time-series within each class is reported on top of the bars. See Box 1 for working definitions of habitat type and sampling methods.*

In almost half of the permanent plots included in LOTVS (48.5%), vegetation has been subjected to experimental treatments manipulating abiotic or biotic conditions. The most frequent treatment types are herbivore exclusion, fertilizer application and grazing intensification (applied to ~35, 24 and 17% of the treated plots, respectively; Fig. 5). Yet, even in the absence of such treatments, LOTVS includes plots subjected to regular management regimes, such as mowing or grazing, that are necessary to maintain traditional land-use in given habitats.

Permanent plots in the LOTVS collection are surveyed using different techniques. The vast majority (~85%) are quadrat plots, but line transects and quadrat plots arranged along a transect are also present. Plot size ranges from 0.04 to 400 m^2; ~ 80% of the plots range from 0.04 to 1.25 m^2, with 1 m^2 being the most frequent (49%) plot size in the collection. Information on plot size is missing for 90 plots, corresponding to 0.8% of the whole LOTVS collection. The method used to quantify species abundance also varies among the 79 datasets (Fig. 4B). The most frequent approach uses visual estimation of species cover (75%) followed by recording the frequency of individual species across a given number of subplots (17%) and third by the collection of aboveground biomass for each species in the plot (9%). In most cases, biomass clipping is intended to mimic mowing. All plots included in LOTVS were permanently marked in the field; geographic coordinates are available for either specific plots or for unique localities of each dataset. Besides estimating plant species abundance, some of the datasets within LOTVS also include information about bare ground cover or the abundance of other taxa (e.g. bryophytes, lichens).

Taxonomic standardization is fundamental when compiling vegetation databases. On the one hand, it is a necessary step to (i) addressing the issue of nomenclature redundancy caused by the multitude of synonyms characterizing botanical literature (Kalwij 2012) and (ii) performing comparative analyses across datasets; on the other hand, it allows a later integration of data with ancillary information linked to taxonomic entities, e.g. species functional traits. Original datasets included in LOTVS show considerable variation in the chosen taxonomical references reflecting different regional and national traditions as well as the time when the work was undertaken. As such, a taxonomic standardization was deemed necessary. To do this, we standardized the nomenclature of plant species following The Plant List, currently the most widely used global reference list (Kalwij 2012). This was done in R (R Core Team 2019) using the package "Taxonstand" (Cayuela et al. 2019), which allows the automatic standardization of plant names by running an internal query to The Plant List (http://www.theplantlist.org) and returning standardized species names, eventually resolving synonyms and homogenizing intraspecific taxonomic entities to the level of species. Nevertheless, a non-standardized version of the LOTVS collection, including (for each dataset) the original nomenclature of the species, is also available for potential users (see 3.2).

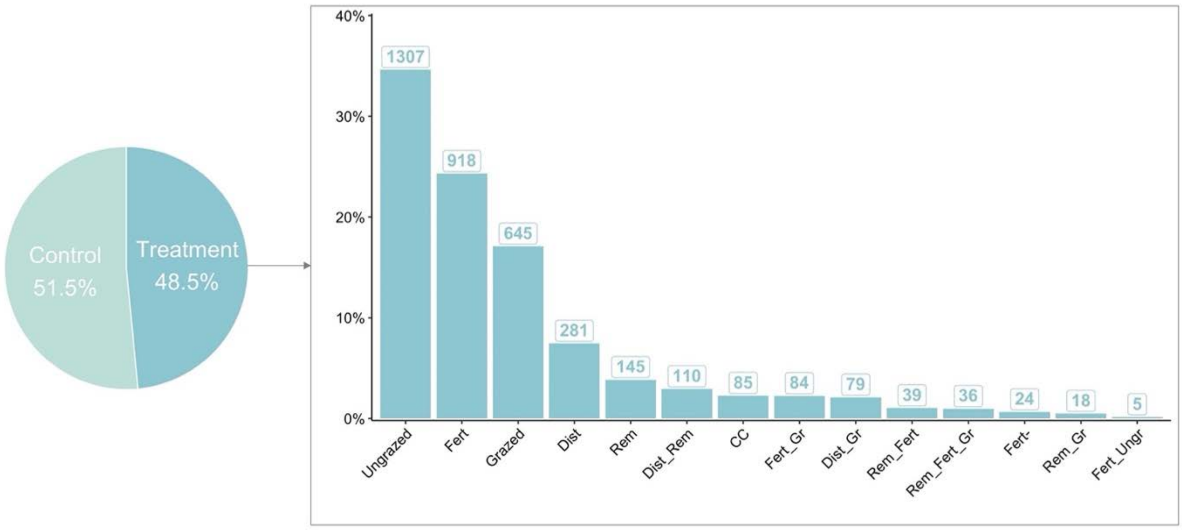

Fig. 5. *Left: pie chart describing the distribution of time-series included in the LOTVS collection according to the absence ("control") or presence ("treatment") of treatment. Right: distribution of the type of treatments present in LOTVS. The number of time-series within each treatment is reported on the top of the bars. Names for the treatments were abbreviated as follows: "Ungrazed": grazing exclosure; "Fert": fertilization; "Grazed": grazing; "Dist": disturbance; "Rem": removal of plant*

species; "Dist_Rem": disturbance + removal; "CC": climate change; "Fert_Gr": fertilization + grazing; "Dist_Gr": disturbance + grazing; "Rem_Fert": removal + fertilization; "Rem_Fert_Gr": removal + fertilization + grazing; "Fert-": decrease of productivity; "Rem_Gr": removal + grazing; "Fert_Ungr": fertilization + grazing exclosures.

3. Data usage

As an unprecedented collection of vegetation time-series, LOTVS has a huge potential to support timely and innovative research in the fields of vegetation science, plant ecology and temporal ecology. It should be noted, though, that installing and maintaining permanent plots is a very time- and resource-consuming task, and thus a powerful collection of vegetation plots such as LOTVS can only arise from collaborative efforts that stem from an impressive amount of work carried out by many data contributors, whose effort must be acknowledged. To this end, anyone can contribute to LOTVS with original data, as long as the data fully comply with LOTVS requirements (see section 3.2). At the same time, data included in LOTVS can be requested and, based on their accessibility level (see section 3.2), used following a simple procedure that is intended to support well-grounded research projects.

3.1. Contributing data

Detailed information on how to contribute to LOTVS, as well as specific data requirements can be found on the dedicated website https://lotvs.csic.es/contribute/. LOTVS welcomes datasets including vegetation time-series collected from permanent plots with a fixed (i.e. permanently marked) geographical position in the field, possibly replicated in space, maintained for a minimum of six years and sampled at annual intervals. In principle, the time-series should be continuous, i.e. no gaps should be present. However, exceptions are allowed, provided that observations for some years are only missing for a reduced number of plots. In cases of missing years for all of the permanent plots, the new dataset can only be incorporated to LOTVS if a) only a very limited number of years is missing and b) their distribution within the time-series is irregular, i.e. LOTVS is not intended to accept permanent plots that, according to their original scope, are only sampled every *n* years. Following these requirements, we are also not looking to include data collected in the context of so-called resurveying studies, where historic vegetation plots are revisited after a longer time period and re-recorded. In fact, these are the subject of other databases (e.g. the ReSurveyEurope initiative, http://euroveg.org/eva-database-re-survey-europe). Also, whereas data collected using different sampling approaches are welcomed (e.g. visual estimation of species cover, biomass, frequency, number of individuals), the sampling approach should be consistent over time. LOTVS does not plan, at present, to incorporate permanent plots that only record species occurrence (i.e. presence/absence data). To be included in LOTVS, permanent plots should be preferably representative of natural or semi-natural vegetation. The former can be defined as vegetation that developed in the absence of human influence and/or has long been left undisturbed by humans; as to the latter, its existence and maintenance depend on human practices (e.g. grazing or mowing) carried out for either production, conservation, or a mix of the two purposes. As such, time-series data recorded from artificial seed mixtures such as those sown in biodiversity experiments are not currently accepted.

3.2. Requesting data

Because of the effort needed to maintain permanent plots in time and collect temporal vegetation data (Mills et al. 2015), access to individual time-series or datasets included in LOTVS is governed by a data policy that allows data owners and contributors to remain in full control of their data if they so choose (see https://lotvs.csic.es/contribute/ for detailed information). The availability and access of single datasets depend on the choice of individual data owners and contributors, who decide the accessibility level of their data (from “restricted data”, i.e. data are only usable upon consent from data owners/contributors, that should be expressed each time their dataset is requested; to “free data” i.e. data that are freely available to use through the LOTVS platform). We note that about 65% of LOTVS datasets are publicly available, either because they belong to Long-Term Ecological Research (LTER) Programs, or because they were archived and published by their data owners. Also, several of the LOTVS datasets are publicly available in their own right, via contact with their owners. Depending on the accessibility level specified, data owners and contributors hold (or not, in case of freely usable data) the right to request authorship on eventual publications based on the proposal submitted by the applicants when they request the data. In all cases, to request data included in LOTVS, a short and sound scientific proposal describing the aims of the project and the type of data required should be prepared and submitted to the LOTVS’ Supervising Committee. This process is intended to i) minimize conceptual overlap of proposals addressing highly similar research questions and ii) make sure that all data owners are informed about the possible use of their data and are free to decline it if they wish so. To help potential users get familiar with the data and facilitate data requests, we provide both a metadata sheet describing the LOTVS datasets and a proposal template (both available on Zenodo: https://doi.org/10.5281/zenodo.5807378), that will be regularly updated every time new datasets are added to the LOTVS collection (or current datasets are updated). Together with a brief description of each dataset, the metadata sheet contains information on several features (e.g. accessibility level, number of plots, length of the time-series, habitat type, number of surveyed years, presence and type of treatments, data type) which, in our opinion, should guide the users in their data requests. The proposal template also includes a link to an interactive map displaying the geographical location of sampling sites within the LOTVS collection, along with key dataset features.

Perspectives

In its present form, LOTVS includes vegetation time-series for almost 8000 permanent plots installed and maintained in natural and semi-natural plant communities worldwide. Still, as we explained in section 2, the geographical representation of both individual datasets and permanent plots is not homogeneous; it is biased towards Europe and North America, and many habitats, such as forest understoreys, are strongly underrepresented. In order to promote a more equal representation in terms of geographical areas and habitats, one of the goals of this paper is to encourage new datasets including time-series recorded using permanent plots located in currently underrepresented continents such as Africa, Asia, Australia and South America. Similarly, time-series recorded in forest understoreys, tundra and coastal areas would be particularly welcome. Furthermore, we are very interested in datasets featuring spatial as well as temporal replication (minimum 6 years as mentioned above) to disentangle the differences between temporal and spatial changes. Finally, to broaden the range of potential applications of LOTVS (and in line with what has been done by other global initiatives, see Bruelheide et al. 2019), we are planning to integrate it with information on environmental variables (climate, micro-climate) and species functional traits. Such integration will eventually allow users complementary access to ancillary data crucial to explore the evolution of different facets of diversity over time (Monnet et al. 2014; Sperandii et al. 2021).

Conclusions

LOTVS possibly represents the largest collection of temporally fine-grained vegetation time-series made accessible to the research community derived from permanent plots addressing the study of plant communities through time. As such, LOTVS can be highly useful to perform timely research on a wide range of topics in the field of vegetation science: investigating patterns and drivers of ecological succession in natural plant communities, quantifying vegetation changes through time, as well as assessing community stability and identifying its driving mechanisms. At the same time, because it includes a considerable proportion of permanent plots subjected to some kind of treatment (e.g. grazing, fertilization etc.), LOTVS can also support the development of large-scale studies aiming to understand how temporal dynamics are affected by different treatments in the context of global changes. Last but not least, we believe LOTVS could also serve as a valuable resource to conduct methodological research addressing topics related to, for example, methods to quantify dissimilarity through time and their partitioning (Baselga 2010; Legendre & Condit 2015) or quantitative approaches to investigate community dynamics and more specifically, stability.

Funding information

The authors acknowledge institutional support as follows. Nicola J. Day: Te Apārangi Royal Society of New Zealand (Rutherford Postdoctoral Fellowship). Francesco de Bello: Spanish Plan Nacional de I+D+i (project PGC2018-099027-B-I00). Eric Garnier: La Fage INRA experimental station. Tomáš

Herben: GAČR grant 20-02901S. Anke Jentsch: German Federal Ministry of Education and Research (grant 031B0516C - SUSALPS) and Oberfrankenstiftung (grant OFS FP00237). Norbert Juergens: German Federal Ministry of Education and Research (grant 01LG1201N - SASSCAL ABC). Frédérique Louault and Katja Klumpp: AnaEE-France (ANR-11-INBS-0001). Robin J. Pakeman: Strategic Research Programme of the Scottish Government's Rural and Environment Science and Analytical Services Division. Meelis Pärtel: Estonian Research Council (PRG609) and European Regional Development Fund (Centre of Excellence EcolChange). Josep Peñuelas: Spanish Government (grant PID2019-110521GB-I00), Fundación Ramon Areces (grant ELEMENTAL-CLIMATE), Catalan Government (grant SGR 2017-1005), and European Research Council (Synergy grant ERC-SyG-2013-610028, IMBALANCE-P). Ute Schmiedel: German Federal Ministry of Education and Research (Promotion numbers 01LC0024, 01LC0024A, 01LC0624A2, 01LG1201A, 01LG1201N). Hana Skálová: GAČR grant 20-02901S. Karsten Wesche: International Institute Zittau, Technische Universität Dresden. Susan K. Wiser: New Zealand Ministry for Business, Innovation and Employment's Strategic Science Investment Fund. Ben A. Woodcock: NERC and BBSRC (NE/N018125/1 LTS-M ASSIST - Achieving Sustainable Agricultural Systems). Enrique Valencia: Program for attracting and retaining talent of Comunidad de Madrid (n° 2017-T2/AMB-5406). Truman P. Young: National Science Foundation (LTREB DEB 19-31224).

References

Bakker, J. P., Olff, H., Willems, J. H., & Zobel, M. 1996. Why do we need permanent plots in the study of long-term vegetation dynamics? *Journal of Vegetation Science* 7(2): 147-156. https://doi.org/10.2307/3236314

Baselga, A. 2010. Partitioning the turnover and nestedness components of beta diversity. *Global Ecology and Biogeography* 19(1): 134-143. https://doi.org/10.1111/j.1466-8238.2009.00490.x

Bernhardt-Römermann, M., Baeten, L., Craven, D., De Frenne, P., Hédl, R., Lenoir, J. et al. 2015. Drivers of temporal changes in temperate forest plant diversity vary across spatial scales. *Global Change Biology* 21(10): 3726-3737. https://doi.org/10.1111/gcb.12993

Blowes, S. A., Supp, S. R., Antão, L. H., Bates, A., Bruelheide, H., Chase, J. M. et al. 2019. The geography of biodiversity change in marine and terrestrial assemblages. *Science* 366(6463): 339-345. https://doi.org/10.1126/science.aaw1620

Bradshaw, C. J., Ehrlich, P. R., Beattie, A., Ceballos, G., Crist, E., Diamond, J. et al. 2021. Underestimating the challenges of avoiding a ghastly future. *Frontiers in Conservation Science*: 1-9. https://doi.org/10.3389/fcosc.2020.615419

Brondizio E.S., Settele J., Díaz S., & Ngo H.T.(Eds.). 2019. IPBES: Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services. Bonn, Germany: IPBES Secretariat.

Bruelheide, H., Dengler, J., Jiménez-Alfaro, B., Purschke, O., Hennekens, S. M., Chytrý, M. et al. 2019. sPlot–A new tool for global vegetation analyses. *Journal of Vegetation Science* 30(2): 161-186. https://doi.org/10.1111/jvs.12710

Cayuela, L., Macarro, I., Stein, A. and Oksanen, J. 2019. Taxonstand: Taxonomic Standardization of Plant Species Names. R package version 2.2. https://CRAN.R-project.org/package=Taxonstand.

Ceballos G., Ehrlich P.R., Barnosky A.D., García A., Pringle R.M., & Palmer T.M. 2015. Accelerated modern human–induced species losses: Entering the sixth mass extinction. *Science Advances* 1(5): e1400253. https://doi.org/10.1126/sciadv.1400253

Chytrý M., Hennekens S.M., Jiménez-Alfaro B., Knollová I., Dengler J., Jansen F. et al. 2016. European Vegetation Archive (EVA): an integrated database of European vegetation plots. *Applied Vegetation Science* 19(1): 173-180. https://doi.org/10.1111/avsc.12191

Chytrý M., Chiarucci A., Pärtel M. and Pillar V.D. 2019. Progress in vegetation science: trends over the past three decades and new horizons. *Journal of Vegetation Science* 30: 1–4. https://doi.org/10.1111/jvs.12697

Convention on Biological Diversity. 2020. Global Biodiversity Outlook. Montréal, QC: Secretariat of the Convention on Biological Diversity.

Damgaard C. 2019. A critique of the space-for-time substitution practice in community ecology. *Trends in Ecology & Evolution* 34: 416–421. https://doi.org/10.1016/j.tree.2019.01.013

de Bello F., Valencia E., Ward D., & Hallett L. 2020. Why we still need permanent plots for vegetation science. *Journal of Vegetation Science* 31(5): 679-685. https://doi.org/10.1111/jvs.12928

Dengler J., Jansen F., Glöckler F., Peet R.K., De Cáceres M., Chytrý M. et al. 2011. The Global Index of Vegetation-Plot Databases (GIVD): a new resource for vegetation science. *Journal of Vegetation Science* 22(4): 582-597. https://doi.org/10.1111/j.1654-1103.2011.01265.x

Dornelas M., Antao L.H., Moyes F., Bates A.E., Magurran A.E., Adam D. et al. 2018. BioTIME: A database of biodiversity time series for the Anthropocene. *Global Ecology and Biogeography* 27(7): 760-786. https://doi.org/10.1111/geb.12729

Fick S.E., & Hijmans R.J. 2017. WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, 37(12): 4302-4315. https://doi.org/10.1002/joc.5086

Goldstein, M.I., & DellaSala, D.A. 2020. Encyclopedia of the World's Biomes. Elsevier.

Gonzalez A., Cardinale B.J., Allington G.R., Byrnes J., Arthur Endsley K., Brown D.G. et al. 2016. Estimating local biodiversity change: a critique of papers claiming no net loss of local diversity. *Ecology* 97(8): 1949-1960. https://doi.org/10.1890/15-1759.1

Hillebrand H., Blasius B., Borer E.T., Chase J.M., Downing J.A., Eriksson B.K. et al. 2018. Biodiversity change is uncoupled from species richness trends: Consequences for conservation and monitoring. *Journal of Applied Ecology* 55(1): 169-184. https://doi.org/10.1111/1365-2664.12959

Jones S.K., Ripplinger J., & Collins S.L. 2017. Species reordering, not changes in richness, drives long-term dynamics in grassland communities. *Ecology Letters* 20(12): 1556-1565. https://doi.org/10.1111/ele.12864

Kalwij, J.M. (2012). Review of 'The Plant List, a working list of all plant species'. *Journal of Vegetation Science* 23(5): 998-1002. https://doi.org/10.1111/j.1654-1103.2012.01407.x

Legendre P., & Condit R. 2019. Spatial and temporal analysis of beta diversity in the Barro Colorado Island forest dynamics plot, Panama. *Forest Ecosystems* 6(1): 1-11. https://doi.org/10.1186/s40663-019-0164-4

Maestre F.T., Quero J.L., Gotelli N.J., Escudero A., Ochoa V., Delgado-Baquerizo M. et al. 2012. Plant species richness and ecosystem multifunctionality in global drylands. *Science* 335(6065): 214-218. https://doi.org/10.1126/science.1215442

Mills J.A., Teplitsky C., Arroyo B., Charmantier A., Becker P.H., Birkhead T.R. et al. 2015. Archiving primary data: solutions for long-term studies. *Trends in Ecology & Evolution* 30(10): 581-589. https://doi.org/10.1016/j.tree.2015.07.006

Monnet A.C., Jiguet F., Meynard C.N., Mouillot D., Mouquet N., Thuiller W., & Devictor V. 2014. Asynchrony of taxonomic, functional and phylogenetic diversity in birds. *Global Ecology and Biogeography* 23(7): 780-788. https://doi.org/10.1111/geb.12179

Newbold T., Hudson L.N., Hill S.L., Contu S., Lysenko I., Senior R.A. et al. 2015. Global effects of land use on local terrestrial biodiversity. *Nature* 520(7545): 45-50. https://doi.org/10.1038/nature14324

Pereira H.M., Navarro L.M., & Martins I.S. 2012. Global biodiversity change: the bad, the good, and the unknown. *Annual Review of Environment and Resources* 37: 25-50. https://doi.org/10.1146/annurev-environ-042911-093511

Pimm S.L., Jenkins C.N., Abell R., Brooks T. M., Gittleman J.L., Joppa L.N. et al. 2014. The biodiversity of species and their rates of extinction, distribution, and protection. *Science* 344: 987. https://doi.org/10.1126/science.1246752

R Core Team. 2019. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing. URL https://www.R-project.org/.

Ricklefs R.E. 2008. The economy of nature. New York: W.H.Freeman.

Sabatini F.M., Lenoir J., Hattab T., Arnst E., Chytrý M., Dengler J. et al. 2021. sPlotOpen – An environmentally-balanced, open-access, global dataset of vegetation plots. *Global Ecology and Biogeography*. https://doi.org/10.1111/geb.13346

Sperandii M.G., Barták V., Carboni M., & Acosta A.T.R. 2021. Getting the measure of the biodiversity crisis in Mediterranean coastal habitats. *Journal of Ecology* 109(3): 1224-1235. https://doi.org/10.1111/1365-2745.13547

Stefan V. and Levin S. 2021. plotbiomes: Plot Whittaker biomes with ggplot2. R package version 0.0.0.9001.

Valencia E., de Bello F., Galland T., Adler P.B., Lepš J., E-Vojtkó A. et al. 2020. Synchrony matters more than species richness in plant community stability at a global scale. *Proceedings of the National Academy of Sciences* 117(39): 24345-24351. https://doi.org/10.1073/pnas.1920405117

van der Plas F. 2019. Biodiversity and ecosystem functioning in naturally assembled communities. *Biological Reviews* 94(4): 1220-1245. https://doi.org/10.1111/brv.12499

Verheyen K., Bažány M., Chećko E., Chudomelová M., Closset-Kopp D., Czortek P. et al. 2018. Observer and relocation errors matter in resurveys of historical vegetation plots. *Journal of Vegetation Science* 29(5): 812-823. https://doi.org/10.1111/jvs.12673

Whittaker R.H. 1975. Communities and Ecosystems, 2nd ed. New York: Macmillan.

Wiser S.K. 2016. Achievements and challenges in the integration, reuse and synthesis of vegetation plot data. *Journal of Vegetation Science* 27(5): 868-879. https://doi.org/10.1111/jvs.12419