GRACE Resurvey of Central European Grassland Vegetation to study the Impacts of Country-Level Landscape Dynamics on Biodiversity

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Data Availability Statement

The datafiles are available at https://github.com/adamtclark/GRACE_resurveydata.

Abstract

Grasslands harbor high species diversity and are strongly influenced by local management and land-use histories. In countries of Central Europe, these ecosystems were severely impacted by different agricultural policies on both sides of the former Iron Curtain in the second half of the 20th century,, reshaping grassland extent and habitat quality. These land-use changes turned border regions into a natural experiment for studying the impacts of landscape structure and management on grassland plant communities. Here, we provide 401 historical vegetation plots, each paired with its recent resurvey, along the border region between Austria, the Czech Republic and Slovakia. The dataset, collected as part of the GRACE project (GRAssland Communities Experiment), spans 95 years, with the first surveys conducted between 1930 and 2020 and resurveys conducted between 2024 and 2025. The resurvey design was structured to balance representation across both countries and to capture the macroclimatic gradient of the region. The resulting vegetation-plot dataset (available at https://github.com/adamtclark/GRACE_resurveydata to be populated after review) provides valuable insights into the development of initially similar grassland communities impacted by divergent country-level landscape dynamics in Central Europe since the mid-20th century.

Key words: Austria, central european grasslands, collectivization, Czech Republic, historical military maps, plant community, Slovakia, vegetation change, vegetation plot

Introduction

Roughly half of European grassland habitat types are considered threatened, making them among the most threatened terrestrial habitat groups in Europe (Janssen et al., 2016). Grasslands provide a variety of valuable ecosystem services and account for 30% of the total utilised agricultural area in the EU, connecting them closely to local culture and economies (Eurostat, 2025; Schils et al., 2022). These habitats often face shifts from regional management tradition to either abandonment or intensification of land use, which cause a decline in their quality and biodiversity (Häberlin and Dengler, 2025; Klinkovská et al., 2025; Petermann and Buzhdygan, 2021). In Central Europe, grasslands also harbour an especially high diversity of vascular plants and can even exceed the species density of tropical rainforests at small spatial scales (Wilson et al., 2012).

Temporal biodiversity and community composition changes in grasslands can be driven by environmental shifts, as well as by historic and current landscape structures, and their management and land-use histories (Häberlin and Dengler, 2025; Němec et al., 2022). The changes of grasslands in Central Europe is shaped by agricultural intensification, especially due to the advent of industrialised agriculture after the mid-20th century (Němec et al., 2022; Skokanová et al., 2020). Similarly, the introduction of agricultural collectivization in parts of Eastern Europe led to divergent trajectories of the initially similar landscapes in neighbouring countries, especially in terms of the average parcel size and spatial structure (Clout, 1971; Tochitch, 1959). This regime reduced land parcelization and led to large, homogeneous agricultural fields through the aggregation of land ownership and management. In countries where collectivization did not take place, changes in parcel sizes and land ownership were comparatively modest, leaving a mosaic landscape of small, heterogeneous parcels (Němec et al., 2022). These sudden land-use changes have turned border regions into a natural experiment for studying the impacts of shifts in landscape structure and management on plant communities (Batáry et al., 2017; Šálek et al., 2021).

In this paper, we present an open-access dataset of resurveyed vegetation plots from the border region between Austria, the Czech Republic and Slovakia (AT-CZ-SK border) and provide an ecological analysis of the main temporal trends in the data. Data collection and processing were conducted within the Grassland Communities Experiment (GRACE), which focuses on the impacts of landscape composition change on grassland plant communities along the AT-CZ-SK border (Clark et al., 2026; Keil et al., 2025; Midolo et al., 2025b, 2025a). This border region gives valuable information on the impacts of landscape homogenization on grassland communities due to rapid collectivization in the 1950s that affected just one side of the border, i.e., the former Czechoslovakia (Clout, 1971; Tochitch, 1959).

The dataset consists of paired historical vegetation survey data collected over the past century, including 401 plots from the European Vegetation Archive, specifically from the Austrian, Czech and Slovak vegetation databases (Chytrý et al., 2016; Chytrý and Rafajová, 2003; Šibík, 2012; Willner et al., 2012), with corresponding resurvey data collected in 2024 and 2025 within GRACE. We thus provide a taxonomically standardized vegetation-plot time series for all 401 plots, as well as detailed plot-level metadata and photographs of the current vegetation. In addition, we include information on the average agricultural parcel sizes around each plot to quantify the effect of collectivization policies on landscape structure. We also assess temporal plant diversity change at the local scale, as well as species turnover between and within countries. We provide a complete list of plant species recorded in the historical and present-day survey and explore which species were lost or gained through time. This analysis, therefore, seeks to present summary statistics on temporal biodiversity trends on each side of the border.

Methods

Study Area

The study area covers grasslands within a 50 km buffer along each side of the border between Austria and the Czech Republic, forming part of the former Austrian (-Hungarian) Empire (1804−1918), which maintained similar management and landscape structure until the mid 20th century (see Figure 1A-B). Note that the study region includes a small section of western Slovakia (former Czechoslovakia) but excludes south-eastern Germany, which was not part of Austria-Hungary. The area ranges from from 48.1° N to 49.5° N and from 13.3° E to 17.6° E, with an elevational gradient ranging from 1350 m above sea level in the west to 100 m in the east. The climatic gradient ranges from cold-wet in the mountainous western region to warm-dry in the eastern region of the Pannonian lowlands (see Figure 1E-F). The collectivization policies in the mid-20th century led to the rapid restructuring of agriculture in former Czechoslovakia but not in Austria, causing a diverging development of land structure after 1948 (Clout, 1971; Tochitch, 1959). Present-day landscape structure consists of large, homogeneous parcels in the Czech Republic and Slovakia, whereas in Austria, the historical landscape structure dominated by small agricultural fields has been retained to a much greater extent (Němec et al., 2022; Skokanová and Eremiášová, 2013). These differences are illustrated in Figure 1A, where the average parcel size of agricultural land around each survey plot is shown for each vegetation plot location (see “Effect of parcel size” in the methods below), as well as in Figure 1C, where the distribution of average parcel size is shown across countries. However, the amount of protected areas at large- and small-scale, is higher in the Czech Republic than in Austria, and stronger urbanization around cities has occurred along the Austrian side of the study area, especially in regions near Vienna and Linz (Krausmann, 2001; Němec et al., 2022; Pesaresi, 2023; Skokanová and Eremiášová, 2013).

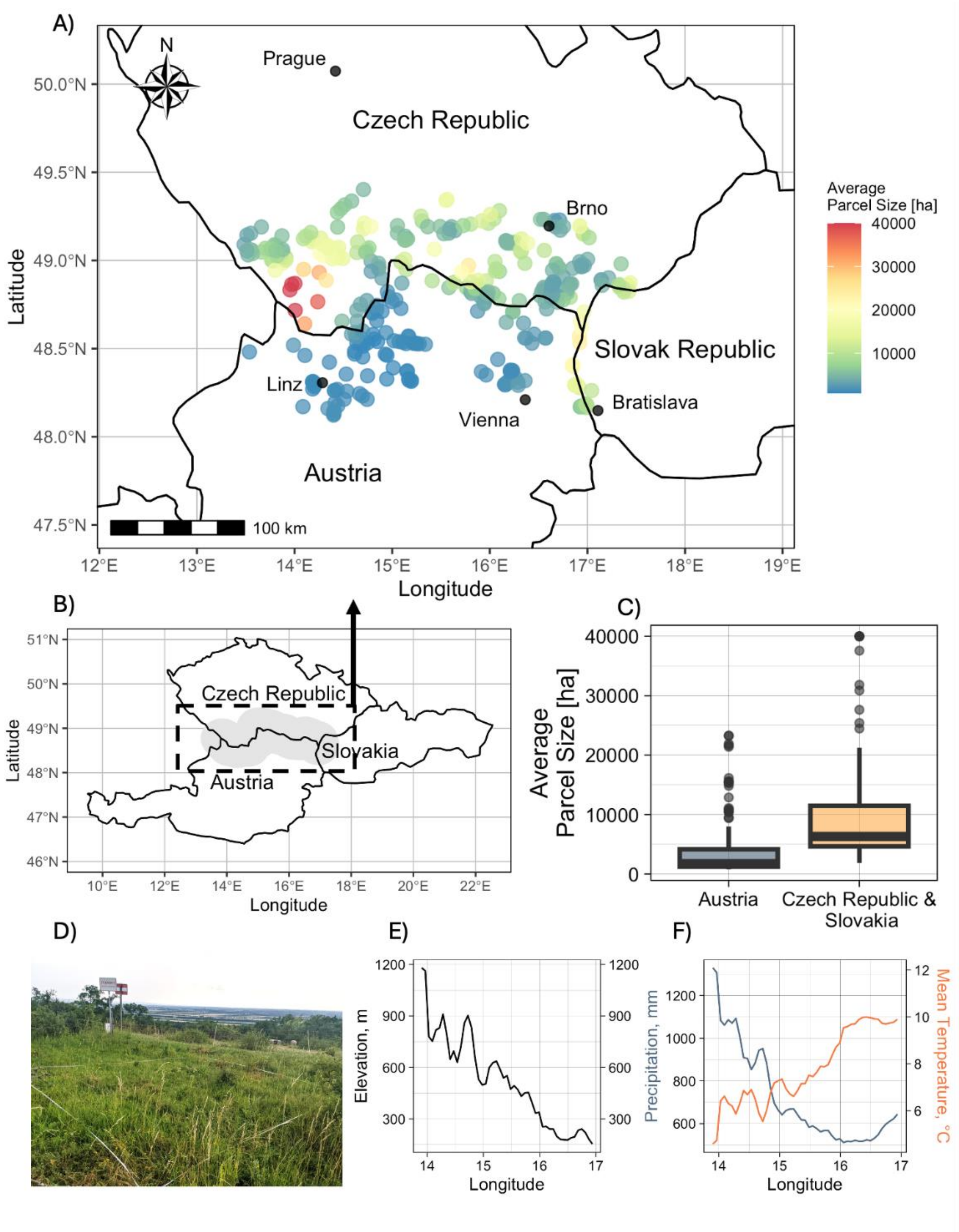

Figure 1 Study area showing the location of the resurvey vegetation plots and the change in elevation and climate from west to east along the AT-CZ-SK border. A) The resurvey plots (coloured points, n = 401) were selected within B) a 50-km distance from the AT-CZ-SK border (grey area); the colour of the points in A) indicates the average agricultural parcel size [ha] in which the plot was located. C) Boxplots showing the distribution of the average agricultural parcel size [ha] across countries. D) Field picture of a resurvey vegetation plot located at the AT-CZ border. The longitudinal gradient of the study area shows E) the elevation, F) the mean annual temperature in °C (orange) and the precipitation in mm (blue). The values for the parcel size can be found in the supplementary information (see "Average_Parcel_Size.csv").

Plot Selection

The historical vegetation plots resurveyed during the fieldwork campaign were chosen in 2024 and 2025 within a 50 km buffer along the AT-CZ-SK border. We selected plots from a total of 12,869 grassland vegetation plots present in the study area and sampled between 1930 and 2020. The source of the data was the European Vegetation Archive (EVA) (project no. 147, data version April 2022). Among these plots, we only considered those eligible for resurvey based on the following criteria: 1) the original plot size was known and ranged from 1 to 100 m^2; 2) sampling year was known; 3) the coordinate uncertainty was either ≤100 m or unknown (this information was missing for the majority of plots in the study area, and we therefore assumed that location uncertainty was in a reasonable distance to allow resurvey). We applied a stratified random resampling procedure using a cluster analysis based on Gower's distance to handle different data types, by using the *daisy* function of the “cluster” R package (version 2.1.4) (Maechler et al., 2021). We based this cluster analysis on eight environmental variables (Elevation, Mean annual temperature, Annual precipitation, Total available soil water content, Aspect, Slope, Soil type and Protection type), which were extracted from WorldClim, WDPA, OECM, and EU-DEM database based on EVA coordinates (Copernicus Land Monitoring Service, 2016; Fick and Hijmans, 2017; UNEP-WCMC, 2019). Then, to ensure that environmentally similar plots were selected in each country, we selected the number of clusters (= 7) that minimized the mean difference in plot counts between Austria and the Czech Republic for each cluster. We then randomly selected plots within each cluster and country. As a result, plots spanned a wide range of environmental conditions and geographic locations, balanced across both sides of the AT-CZ-SK border.

Resurvey campaign

Following this approach and a manual check of the selected historical plots by our author team, a subset of 527 plots present in the EVA database was selected for resurvey. In 2024, 255 of these plots could be reliably relocated and resurveyed - however, many of the remaining 272 historical plots could not be reliably located or accessed. In 2025, to ensure that at least one plot could be resurveyed in each of the geographic regions selected by the stratified randomized sampling routine, 146 additional resurveys were conducted within a 1.5-km diameter buffer centered around each of the 272 plots that could not be surveyed in 2024. Within each buffer, the surveyor was free to choose any historical grassland plot that could be reliably relocated. In total, 401 plots were ultimately resurveyed, with at least one plot in each of the 1.5-km buffers (fewer than 527 plots were necessary due to spatial overlap between the buffers). See Table 1, and datafiles “Historical_Metadata.csv” and “Resurvey_Metadata.csv” in the supplementary information available at https://github.com/adamtclark/GRACE_resurveydata, for more details.

To resurvey each of the 401 historical vegetation plots, we followed a common field sampling protocol, which also includes data sheets as well as safety information for botanists. The sampling protocol and the survey form are available in the supplementary information (“GRACE_Protocol” and “GRACE_Survey_Form”). Below, we provide a shortened summary of the protocol, but we encourage anyone aiming to replicate our methods to study the full protocol.

We started by localizing the original plot's position in the field. If the original plot location was highly uncertain (e.g., due to a lack of accurate coordinates), we selected the most probable location using location descriptions, aerial photographs of the site, and searches for remnants of historical plant communities. For reference, we also report the distance between the original coordinates and location uncertainty from the historical database, vs. the location that was ultimately chosen for the resurvey (as a rough index of the reliability of these historical coordinates). The resurvey plots include two scales of data collection: “primary plots” (“GRACE_Protocol” in the supplement available at https://github.com/adamtclark/GRACE_resurveydata), which match the size of the original survey area, and 1 m^2 “subplots”, nested in the southwestern corner of each primary plot. Species occurrences and percentage covers were recorded in both the primary plot and the subplot. A magnetic marker was buried in the southwestern corner of each plot (except where prohibited by local conservation rules – see “Resurvey_Metadata.csv” in the supplement), to ensure that the exact plot location can be found again for future resurveys. Soil samples were taken from the centre and from each of the four corners of the primary plot and archived for use in future studies. The plot was photographed from above and from each compass direction (see database provided as supplement – https://github.com/adamtclark/GRACE_resurveydata). In addition to vegetation data, we also collected GPS coordinates and environmental data, including the current management, specific landscape degradation, and the approximate distance from the historical plot. For more details on the resurvey in 2024 and 2025, see the GRACE survey protocol provided in in the supplementary information, which was followed by each surveyor during the resurvey.

Data Cleaning

Species

The vascular plant species list from the resurveyed plots underwent three stages of taxonomic cleaning to harmonize species records. First, we used the U.Taxonstand (version 1.2.8) package in R (Zhang and Qian, 2023) to correct for spelling errors and to standardize the species names to Turboveg 2 (Hennekens and Schaminée, 2001) regional taxonomic concepts (following the 2025 Austrian taxonomic standard and the

2015 Czech/Slovak standard). All species names that included spelling mistakes were double-checked by a human expert to ensure that fuzzy logic matches were sensible. Second, the species names were translated to the “matched concept” used in EVA – this is a single taxonomic list standardized across Europe by local experts to ensure that differences in naming conventions do not lead to mistakes when comparing species lists across countries. Finally, these “matched concepts” were further refined by matching them to the nomenclature standardization from the EUNIS-ESy expert system (Chytrý et al., 2025, 2020) – this system uses broader concepts for some taxa than the “matched concept” approach, and, e.g., groups many subspecies together to further reduce the impacts of country-level differences in taxonomic systems. For the historical surveys, we likewise translated the matched concept to the EUNIS-ESy system to make it comparable to the resurvey data.

Vegetation Cover and Layer Data

Because the historical EVA data have been collected from many different studies and surveyors, they used different cover scales, which needed to be standardized into a continuous cover scale for subsequent comparisons. For each species cover value, continuous cover data was generated by drawing a random sample from a uniform distribution, where the minimum and maximum are defined by the range of the cover groups of the corresponding cover scale. To generate comparable values from the continuous cover estimates in the resurveys, we first transformed the continuous cover values into the corresponding cover scale used in the historical survey, and then applied the same approach of random unified sampling. The package “goeveg” in R (version 0.7.6) was used to identify the minimum and maximum values for each category across the different cover scales. In the resulting dataset, we include values for both the original cover estimates, and the standardized uniform samples (see “Historical_Species_Data.csv” and “Resurvey_Species_Data.csv” in the supplementary information available at https://github.com/adamtclark/GRACE_resurveydata).

We unified the layer codes for the historic and resurvey data with those of the Turboveg 2 layers, as listed in Appendix S1. When no layer was listed in the survey, we assigned the survey to the “herb” layer (6).

Analysis

Species diversity. Alpha diversity of vascular plants for each historical plot and primary resurvey plot were calculated separately using species richness (S) and species-equivalent estimates for the Shannon Diversity Index (exp(H´)) and the Simpson Diversity Index (1/D). The Gini Index was calculated to measure species dispersion in each historical and resurvey plot, with 0 reflecting a totally even distribution and 1 the most unequal distribution.

Temporal species turnover. To estimate the temporal species turnover between the historical and the primary resurvey plot, the Jaccard Similarity Index for each paired plot ID was calculated as follows:

Eq. 1 $$\text{Jaccard Similarity Index} = \frac{Species\ Hist \cap Species\ RS}{Species\ Hist \cup Species\ RS}$$

where ∩ represents the intersection and ∪ the union of the historical ("Species Hist") and resurvey ("Species RS") species lists.

Species losses and gains. We calculated the number of species lost or gained in the resurvey plots relative to the historical surveys, as well as the number of persistent species and net species change (= gained - lost species). The significance of the differences in biodiversity indices between countries and surveys was determined using a Bayesian Generalized Linear Multivariate Multilevel Model to account for differences in plot size. The significance of the Jaccard Similarity Index, as well as net species change, was determined using a two-sample Wilcoxon test. For all tests, a two-sided 95% confidence interval was chosen. The plots located in Slovakia were only six and were included in one group with plots from the Czech Republic. We performed a sensitivity analysis by testing for significant differences in biodiversity indices for a subset of plots (n = 297), which consists of all plots with the historical survey conducted between 1975 and 2020 only.

Species-specific trends. We tested the changes at the species level by fitting a linear model based on presence/absence and cover data. The slope was extracted and set to 1 if the trend was positive and to 0 if it was negative. We calculated the probability of an increase in species incidence and cover using a binomial test. Species that had a significant probability of increase > 0.5 are referred to as "Winners", and Species which had a significant probability of increase < 0.5 are referred to as "Losers". This analysis was done across the whole dataset.

Effect of parcel size. We estimated the average agricultural parcel size for each resurvey site as the parcel size retrieved from the IFSGRID dataset (dataset C17) (Lampach et al., 2025; Statistical Office of the European Communities, 2025). The data is reported in a multi-resolution grid (Quadtree-based method) containing the parcel size as geo-reference data (Skøien et al., 2024). The data is reported with a minimum grid size of 1km and is aggregated to increasingly larger resolutions (e.g. 5 km and 10 km) to fulfil data confidentiality rules. For each plot location, we drew a circular buffer with a diameter of 20 km to extract the parcel size data. To estimate the average parcel size within each buffer, the parcel size of each grid cell was weighted by the relative land area of the grid cell in each buffer and summed together afterwards.

Results

Categorical Data

In total, 401 vegetation plots were resurveyed along the AT-CZ-SK border in 2024 and 2025. Of these plots, 162 were in Austria, 233 in the Czech Republic, and 6 in Slovakia. More plots were surveyed in 2024 (n=255) than in 2025 (n=146). In about 80% of the plots, a magnet was placed, soil was sampled and photographs were taken; details for each country are summarized in Table 1.

Table 1. Number of vegetation plots for the whole survey area, as well as categorized by country. Note that the number of pictures corresponds to the number of plots that have at least one picture of the survey plot.

	Austria	Czech Republic	Slovakia	Whole area
# Whole resurvey	162	233	6	**401**
# 2024	117	133	5	**255**
# 2025	45	100	1	**146**
# Magnet placed	91	222	6	**319**
# Pictures	90	222	6	**318**
# Soil samples	96	228	6	**330**

The status of the current plant community in the resurvey vegetation plot relative to the historical community is shown as the proportion of plots per country (see Figure 2A and Table 1). Note that this information is reported for 97 Austrian plots and for 238 Czech and Slovak plots. Across all plots, the community type remained unchanged between the original survey and the resurvey in a majority of cases. Recall that this categorization was made based on each surveyor's determination in the field, meaning that it is potentially more subjective than a quantitatively based community assessment. A table containing the absolute and relative plot numbers shown in Figure 2A is provided in Appendix S1. Cases where the community changed completely or only changed marginally (listed as "Similar to Historical Community" by the surveyor in the field) are listed in Figure 2B. For plots where the community was assessed as changed, the most common reasons listed by surveyors were that the plot was overgrown or fenced, though differences were also attributed to a variety of other drivers, such as disturbance, ruderalization, or imprecise historical coordinates. The reason "imprecise historical coordinates" is listed in a higher proportion of plots in the category "New Community" in comparison to "Similar to Historical Community". Note that each plot can have several reasons listed for community change. A complete list of absolute and relative plot numbers for each reason for community change shown in Figure 2B is provided in Appendix S3.

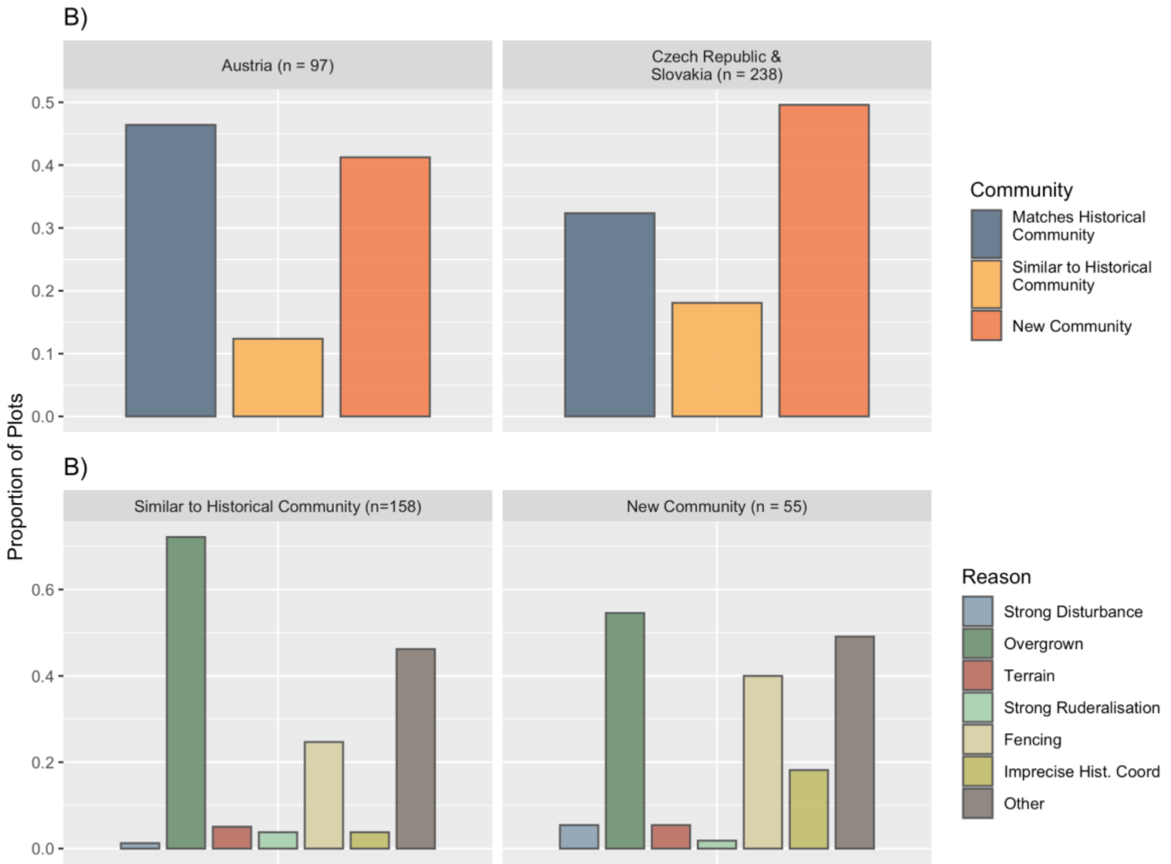

Figure 2 Plant community changes between the historical surveys and resurveys. A) The proportion of vegetation plots across each country categorized by the status of the present plant community in comparison to the historical community. This information was reported for 97 plots in Austria and for 238 plots in the Czech Republic and Slovakia. B) Proportion of plots in which the community changed, categorized by the possible reasons for a community change as recorded by the surveyors in the field. In total, 55 vegetation plots were identified as having a new community type, 158 showed a similar community compared to the historical one and 122 matched the historical community. Each vegetation plot can have multiple reasons listed as a community change.

The current management type and information on landscape degradation were noted by the surveyors at each resurvey site. The proportions of plots that were assigned to one or more of the nine management strategies (“Abandoned", "Burned", "Conservation Area", "Fertilised", "Grazed", "Irrigated", "Low Intensity", "Mowed" and "Other") are shown in Figure 3A. The category “Other” summarized management, including riverbank and fallow. Across both sides of the border, “Abandoned” and “Mowed” were noted in a high proportion of plots. The Czech Republic and Slovakia showed a higher proportion of plots within protected and abandoned areas in comparison to Austria. The proportion of plots within countries assigned to one or more of the 10 categories of landscape degradation is shown in Figure 3B. The proportion of plots without signs of landscape degradation is lower in Austria than in the Czech Republic and Slovakia. The category “Other” includes degradation noted as “Insufficient Management” and “Oligotrophication”, as well as degradation resulting from railway construction, succession, drainage and soil degradation. A complete list of all absolute and relative numbers of plots shown in Figure 3 can be found in Appendix S4-5.

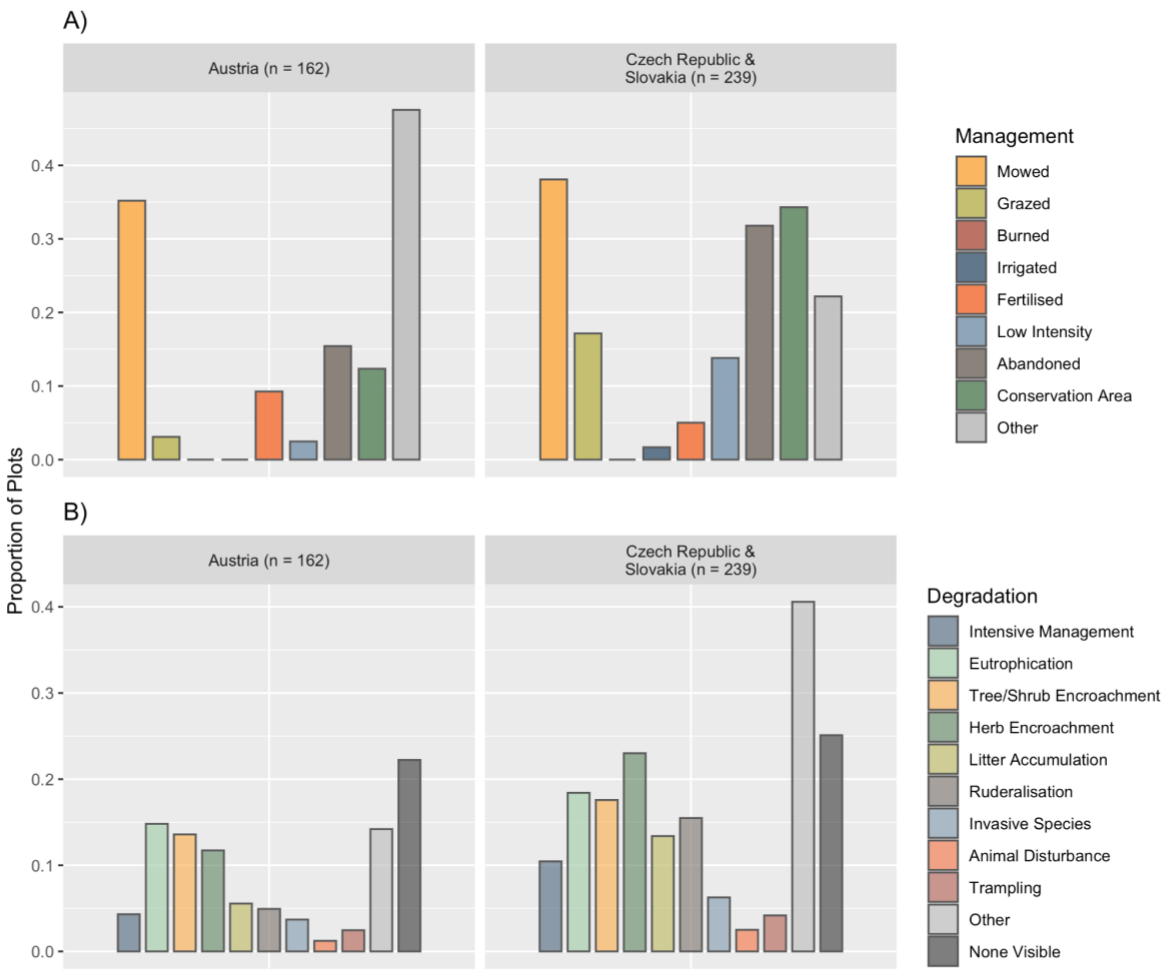

Figure 3 Bar plots showing specific management methods and landscape degradation at resurvey sites. A) The proportion of plots within the countries labelled with a specific management type. B) The proportion of plots within countries noted with a specific landscape degradation. In total, 162 plots were surveyed in Austria, 239 in the Czech Republic and Slovakia. Note that each plot can be labelled with more than one management type and landscape degradation.

Historical surveys of the selected 401 vegetation plots were conducted between 1930 and 2020, mostly between 1955 and 2020 (see Figure 4A). The vegetation plots selected in Austria (n=162) were mostly surveyed post-1975, except for one plot surveyed in 1936. To show how plot location uncertainty relates to the time elapsed since the first survey, Figure 4B shows the distance between the coordinates for the historical vegetation plot listed in the EVA database vs. the new coordinates of the resurvey plot against the year of the original survey. Note that there is no significant relationship between the location distance and original survey year, and that in most cases, differences are relatively small (< 300 m). However, most resurveys labelled in the field as occurring at “approximately the same coordinates” refer to plots originally surveyed between 1990 and 2020. The exact coordinates for the historical and current plot positions can be found in the supplementary information (available at https://github.com/adamtclark/GRACE_resurveydata, see “Plot_Coordinates.csv”).

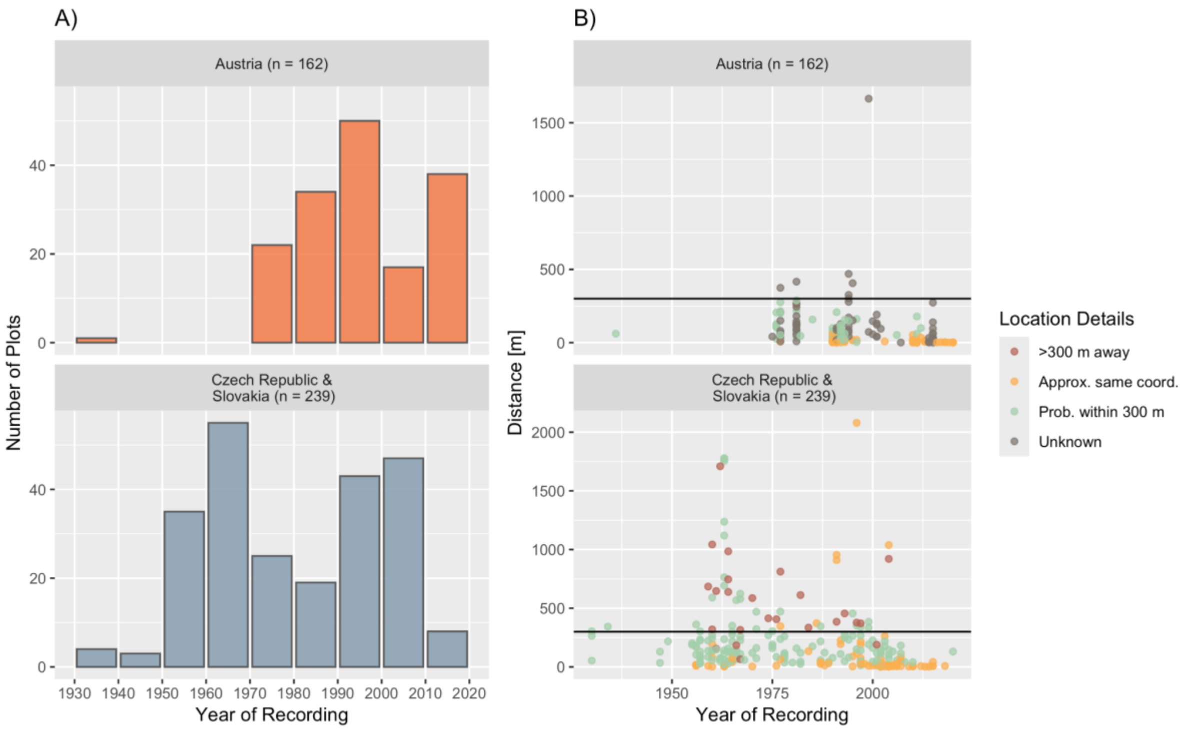

Figure 4 Distribution of the year in which original surveys were conducted, and its relation to relocation uncertainty. A) Numbers of vegetation plots by the periods when the historical plot was recorded, categorized by country (Year of Recording). The year of recording ranges from 1930 to 2020. B) The calculated distance [m] between the historical and resurvey plot location plotted against the year of the first recording. Points are coloured according to the distance estimated by the surveyors in the field. The black horizontal line marks a distance of 300 m.

Biodiversity and total species change

Comparing the species richness of the historical survey with the resurvey shows a significant temporal increase in the Czech and Slovak plots (see Fig. 5A). The present-day species richness in the Czech Republic and Slovakia is significantly higher than in Austria, as shown in Figure 5A. The Gini index of evenness shows a significant increase in all countries, and higher present-day values for the plots in the Czech Republic and Slovakia in comparison to those in Austria (see Fig. 5B). A significant temporal decrease in Shannon Diversity Index and Simpson Diversity Index for the plots in Austria is shown in Figure 5C and D. Additionally, Austria shows significantly lower values of the Shannon Diversity Index and Simpson Diversity Index in the historical and resurvey plots in comparison to the Czech Republic and Slovakia (see Fig. 5C-D). A list of all biodiversity metrics for each plot is available in the supplementary information at https://github.com/adamtclark/GRACE_resurveydata ("Biodiversity_Metrics.csv"). When comparing biodiversity indices for a subset of plots surveyed only between 1975 and 2020, we again found significant increases in species richness and the Gini index in Czech and Slovak plots (see Appendix S6).

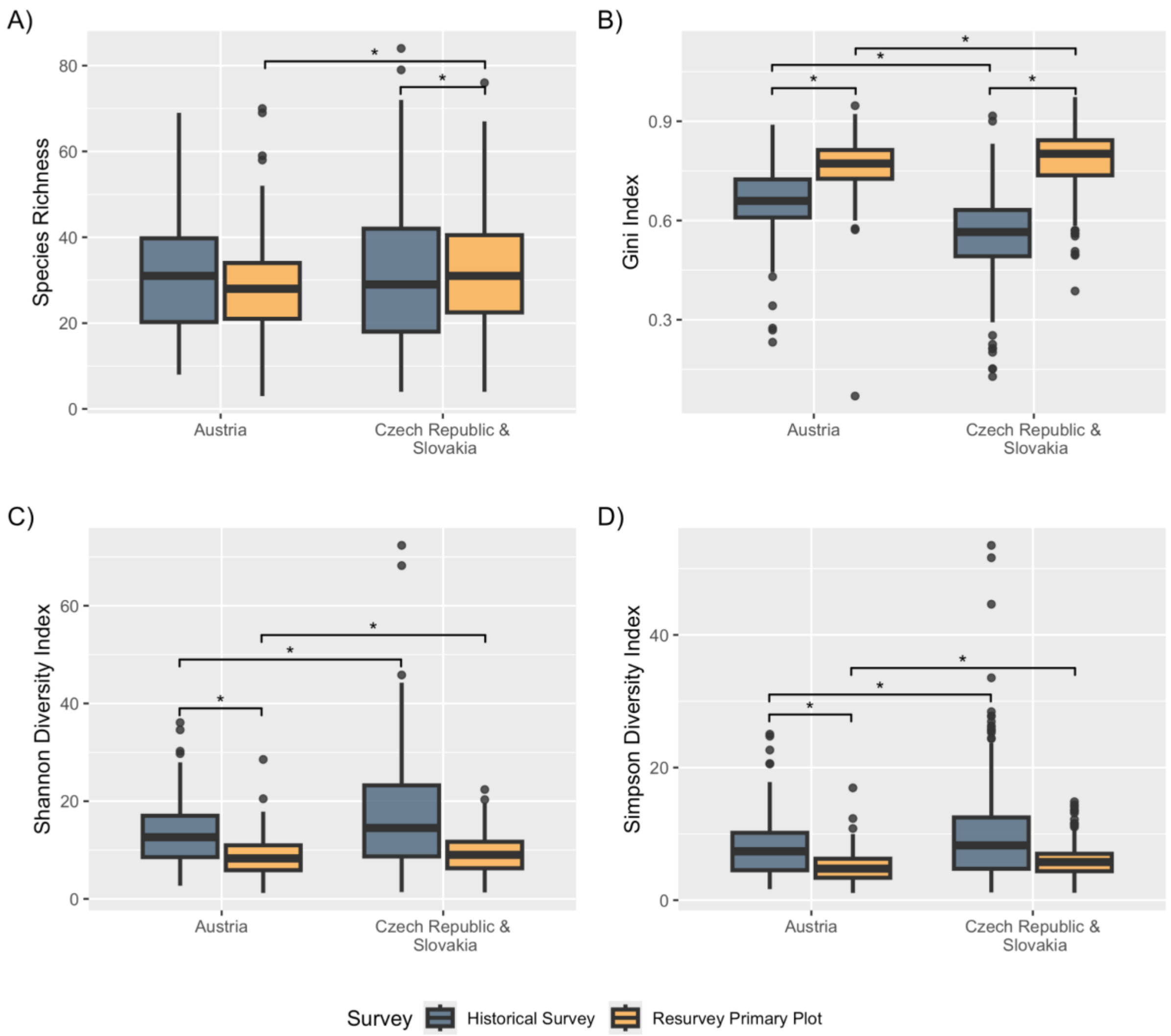

*Figure 5 Boxplots summarizing the distribution of A) Species richness, B) Gini Index of evenness (the higher the Gini Index, the less even the community), species equivalents of C) Shannon Diversity Index and D) Simpson Diversity Index for the historical and resurveyed primary plots (n=401), categorized by country. These biodiversity indices are calculated for the historical plots (blue), as well as for the primary resurvey plots (orange). These indices are plotted separately for Austria (n=162) and the Czech Republic and Slovakia (n=239). The significant differences correspond to the following classes: *,<0.05; ** ,<0.01; ***, <0.001. Non significant results are not indicated in the figure.*

The Jaccard Similarity Index, to estimate the temporal species turnover between the historical and the resurvey plot, is significantly higher in Austria than in the Czech Republic and Slovakia (see Fig. 6A). The number of gained species in Austria are significantly lower than in the Czech Republic and Slovakia, while the number of persistent species are significantly higher in Austria (see Fig. 6B). The net species change presented in Figure 6C shows significantly lower values for Austria than in the Czech Republic and Slovakia. Note that the Czech and Slovak plots cover a longer time period for the historical survey (1930-2020) with respect to the majority of Austrian plots (1975-2020). The values presented in Figure 5 can be found in the supplementary information (https://github.com/adamtclark/GRACE_resurveydata, see "Species_Turnover.csv"). Conducting a sensitivity analysis for a subset of plots surveyed only between 1975 and 2020 showed significantly higher numbers of gained species and lower numbers of lost species in the Czech Republic and Slovakia than in Austria (see Appendix S7).

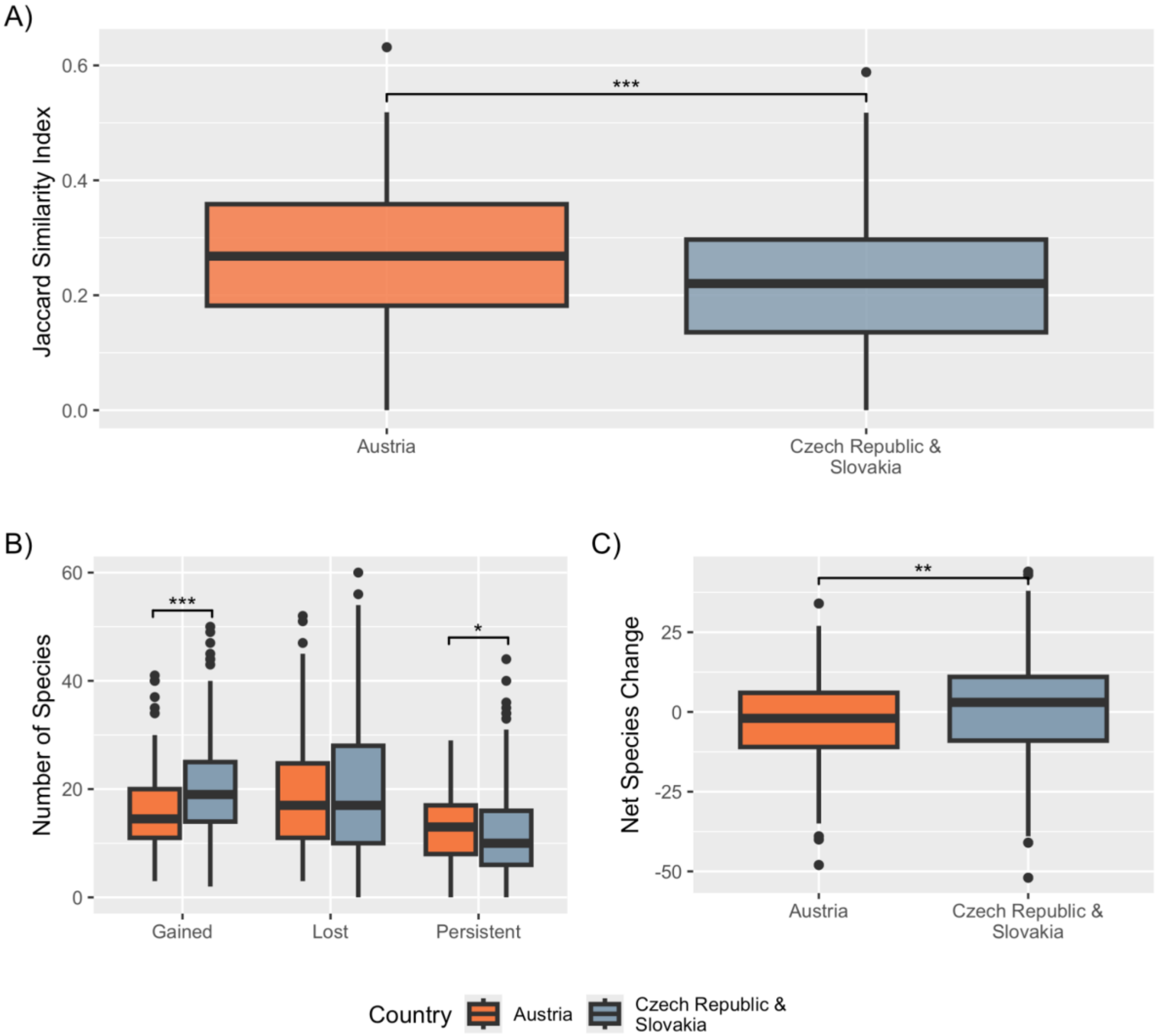

*Figure 6 Boxplots summarize the distribution of A) Jaccard Similarity Index between historical and resurveyed plots, B) the number of gained, lost and persistent species in time and C) the net species change by country. These indices were calculated for each plot (n=401), consisting of the historical and primary resurvey plot data. The significant differences correspond to the following classes: *,<0.05; ** ,<0.01; ***, <0.001. Non significant results are not indicated in the figure. The Jaccard index is a proportion, i.e., a value of 0.2 indicates that only 20% of species are present in both time periods, and 80% are either lost or gained.*

Species-specific trends

Across the whole dataset, 1304 taxa were identified and we found significant increases in incidence for 171 taxa and significant decreases for 79 taxa ($p < 0.05$). In total, 59 taxa showed a significant increase and 79 a significant decrease in both incidence and cover. Competitive graminoids that grow in nutrient-rich environments (e.g. *Poa pratensis* and *Carex hirta*) increased significantly in both incidence and cover, while taxa found in wet grasslands (*Agrostis canina*, *Caltha palustris* and *Valeriana dioica*) significantly decreased. However, *Cerastium pumilum* (including *C. pumilum* subsp.

glutinosum), significantly increased both in incidence and cover (Fig. 7). Across the whole dataset, 112 taxa showed a significant increase in cover but not in incidence. A complete species list with the probability of increase in incidence and cover can be found in the supplementary information at https://github.com/adamtclark/GRACE_resurveydata (see “Winner_Loser_Incidence.csv” and “Winner_Loser_Cover.csv”).

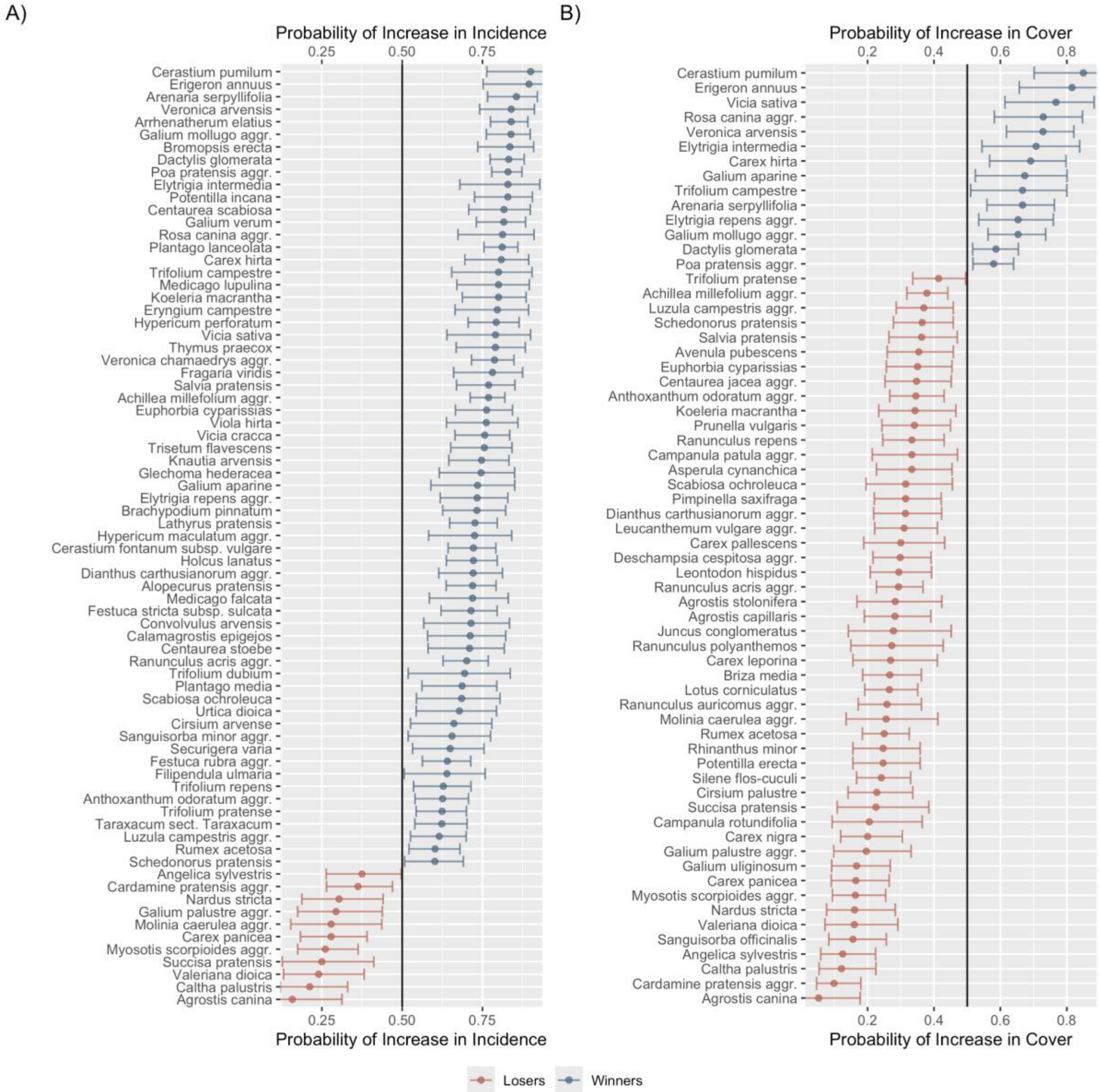

Figure 7 Probability of increase in species incidence (A) and abundance (B) across all countries. The points show the probability of a positive change estimated with a binomial test for each species, with error bars indicating a 95% confidence interval. The colors refer to Winners (blue, probability of increase >0.5) and Losers (red, probability of increase <0.5). Only species that showed a change in incidence and abundance in at least 30 plots and this change was significant (p < 0.05) according to the binomial test are presented in the figure.

Discussion

Biodiversity trends

Our results show higher present-day species richness and lower evenness in the Czech Republic and Slovakia than in Austria. Moreover, plots in the Czech Republic and Slovakia have higher numbers of gained species and are more often reported to be under conservation or abandoned than Austrian plots. However, the species list of the winner taxa is dominated by strong competitive graminoids and generalist species, which contribute to the species gain in the Czech Republic and Slovakia (Figure 7). Nevertheless, it is important to note that changes reported for Austria occurred, on average, over a shorter time period than for the Czech Republic and Slovakia. Our results align with research conducted on grasslands in the Czech Republic, where an increase of strong competitors and nutrient-demanding species over time was reported (Klinkovská et al., 2025).

European grasslands were characterized as nutrient-poor in the past, but turned into a suitable habitat for competitive grasses through time (Midolo et al., 2025b). Eutrophication and the abandonment of livestock grazing pose major threats to natural habitats, leading to increasing numbers of generalists (Calvin et al., 2023; Klinkovská et al., 2024). In addition, new plant communities were reported more often for the plots in the Czech Republic and Slovakia, which might be correlated with land aggregation in the 20th century as well. Habitat transformation may prevent species occurring in the original habitat from being persistent through time, leading to higher species turnover in regions where collectivization took place (Němec et al., 2022). However, to disentangle the effects of eutrophication, succession, and habitat disturbance on European grasslands, further analyses of our dataset will be needed in the future.

Limitations

Our dataset is not free from biases related to resurvey plot location uncertainty, which is common in resurveys of non-permanent plots (Boch et al., 2022; Morrison, 2016). However, we used aerial photographs of the areas around the most likely locations of historical plots and searched for remnants of historical plant communities. Another common and substantial bias in resurveys is the observation error, arising from different surveyors and methodologies across the study period, which could induce pseudoturnover in our dataset (Lepš and Hadincová, 1992; Morrison, 2016). Furthermore, categorizing vegetation cover into classes may increase observational bias (Dengler and Dembicz, 2023; McNellie et al., 2019). To ensure that both the historical and the resurvey cover data were subject to the same degree of added uncertainty in subsequent analysis, we transformed the categorical cover classes into continuous vegetation cover. Moreover, our dataset is limited by the fact that each historical plot was resurveyed only once, resulting in no time series of repeated resurveys. In addition, our dataset spans a wide range of historical sampling years, which are not evenly distributed across plots. A more general reconstruction and quantification of temporal landscape changes and a classification of grassland habitat types across the full region would help address most of these factors, but is outside of the scope of this article.

Novelty and implications

Our work provides a high-quality vegetation-plot resurvey dataset as an open-access resource, consisting of 401 plots distributed along the AT-CZ-SK border and spanning 95 years. This timespan captures divergent grassland developments of initially similar landscapes, which were caused by socio-economic changes in the 20th century, leading to a land use change ranging from a small habitat patchwork in the south to large collectivized fields in the north. Our dataset also spans a longitudinal gradient, running from wet uplands in the west to dry lowlands in the east. The structure of the resurvey was designed to balance these two gradients (i.e environmental changes from west to east, and landscape changes from north to south), creating a unique opportunity to test hypotheses about the effects of landscape and environmental change on grassland plant biodiversity. An important aspect of the resurvey is the placement of magnetic markers creating permanent plots and sharing a unified field collection protocol. This gives the possibility to increase the temporal scale of this dataset in the future and to add additional plots following the same method on the selected sites at the AT-CZ-SK border.

In addition to the vegetation-plot time series, we provide summary statistics, including historical and present-day local-scale diversity and plot-level species turnover. In combination with detailed environmental and plant data collected at various spatial scales, this dataset enables a more detailed analysis of biodiversity change than is possible in most other resurvey studies. Understanding the impact of historical management and current agricultural practices on central European grasslands is crucial for developing future conservation strategies and effective management. This work contributes to a deeper understanding of how historical socio-economic legacies influence plant diversity change, a topic driving current research on biodiversity change in Central Europe.

Relevant Research

This work is conducted within the GRACE project (FWF grant DOI: 10.55776/I6578, GAČR project number: 24-14299 I) and therefore provides a substantial dataset for ongoing research on landscape dynamics and its interaction with grassland plant communities at the AT-CZ border (Clark et al., 2026; Keil et al., 2025; Midolo et al., 2025a, 2025b). Current research at the Research Institute for Landscape and Ornamental Gardening in Brno (VUKOZ) aims to link the resurvey data with landscape changes by using historical maps covering > 150 years of landscape change. This gives deeper insights into the relationship of grassland plant communities with land-use change processes. Working groups at the CZU in Prague and the University of Graz are currently using this dataset for causal inference analysis and constructing species area relationships to disentangle the effects of climate, elevation and historical land use on biodiversity changes.

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Author contributions

VH wrote the paper with contribution from ATC, GM, MC, PK, FE and ESM; VH, ATC, GM, MC, PK, FE, and ESM conceived of the idea for the project and planned the study; EP contributed to the research idea; PK, DB, FW, VK, ZP collected data and commented on the manuscript; BC, EJ, GH, HS, JP, MV, MM, NT, VS collected data.

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Supplementary Information

Additional supporting information may be found online:
https://github.com/adamtclark/GRACE_resurveydata

Appendix S1. Layer description in Turboveg 2 for categories 0-9.
Appendix S2. Absolute and relative plot numbers grouped by community change categories.
Appendix S3. Absolute and relative plot numbers grouped by reasons listed for community change.
Appendix S4. Absolute and relative plot numbers grouped by management type.
Appendix S5. Absolute and relative plot numbers grouped by type of degradation.
Appendix S6. Boxplots summarizing biodiversity indices for a subset of historical and resurveyed primary plots.
Appendix S7. Boxplots summarizing temporal turnover for a subset of historical and resurveyed primary plots.

Datafiles

GRACE_Protocol.pdf
GRACE_Survey_Form.pdf
Resurvey_Species_Data.csv
Historical_Species_Data.csv
Resurvey_Metadata.csv
Historical_Metadata.csv
Average_Parcel_Size.csv
Plot_Coordinates.csv
Biodiversity_Metrics.csv
Species_Turnover.csv
Winner_Loser_Incidence.csv
Winner_Loser_Abundance.csv