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The MIREN Road Survey Database: Standardized Vegetation Sampling to Advance Our Understanding of Biodiversity Responses in Mountain Systems Across the Globe

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ABSTRACT

Motivation: The database initiated by the Mountain Invasion Research Network (MIREN) is one of the few globally implemented standardized vegetation surveys in mountains. The focus is on collecting plant species occurrences at 5-year intervals along and adjacent to mountain roads spanning elevational gradients, with the goal of providing critical information about the ongoing spread of non-native plants and the potential impacts of climate and human-caused disturbance in the form of road infrastructure on mountain vegetation.

Main Types of Variables Contained: To date, the database contains almost 170,000 georeferenced records of plant species. Overall, 6854 vascular plant species were observed in 3364 plots across 25 regions, with many of these plots being revisited every 5 years. Each plot is identified by its coordinates, elevation and distance to the road. The status of each individual species (native, non-native or unknown) is determined in accordance with regional databases.

Spatial Location and Grain: Plant species were surveyed at 20 sample sites, placed at regular elevational intervals along each mountain road, with typically three roads selected per region. Each sample site is subdivided into three 2 m × 50 m plots, one parallel to the road and two perpendicular to it, extending into adjacent vegetation. The 25 studied regions cover all continents except Antarctica.

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For affiliations refer to page 6.

Time Period and Grain: Data were collected between 2007 and 2023, with surveys being repeated at 5-year intervals in a subset of regions. Three regions include four time-steps, while seven and three regions were sampled three times or twice, respectively. In most regions, long-term monitoring is ongoing.
Major Taxa and Level of Measurement: All vascular plant species.
Software Format: Data are available through a .csv file on Zenodo (https://doi.org/10.5281/zenodo.15749536).

1 | Introduction

Mountain areas exhibit disproportionately high biodiversity relative to their size, contain large portions of the globe's biodiversity (Chape et al. 2008; Payne et al. 2017) and sustain a broad range of ecosystem functions and nature's contributions to people (Martín-López et al. 2019; Mengist et al. 2020). However, these ecosystems are especially vulnerable to a range of global change drivers. For instance, there is a consensus that anthropogenically caused warming rates are elevation-dependent, with faster warming occurring at higher elevations (Gobiet et al. 2014; Pepin et al. 2022). Besides climate, human influence in mountain regions is significantly changing, mainly towards increasing land-use intensity resulting from, for example, expanding tourism (Pickering and Barros 2012). Whilst the negative consequences of intensified land use for natural plant communities and their diversity are well-known from other ecosystems (e.g., Allan et al. 2015; Felipe-Lucia et al. 2020), the rapid upward shift of many species following their climatic niche is a phenomenon unique to mountain systems (Elsen et al. 2020; Morueta-Holme et al. 2015; Rumpf et al. 2019; Vitasse et al. 2021). For example, understorey species in French mountain forests were reported to move upwards at a speed of 38 m per decade (Lenoir et al. 2008), and a study from Mt. Gongga in China documented significant upslope shifts since the 1950s of almost two thirds of plant species studied, including both herbaceous and woody life forms (Zu et al. 2021).

A specific consequence of the growing human influence on mountains is that formerly remote areas are increasingly penetrated by an expanding network of roads. Such infrastructure not only results in direct disturbance of mountain plant communities but also provides conduits for native and non-native plant species movements (Barros et al. 2022; Geppert et al. 2021; Lembrechts et al. 2017). Hence, species elevational range shifts might be visible first along mountain roads, making these shifts a potential harbinger of future changes in mountain environments. Moreover, non-native plants likely benefit from the altered microclimatic and hydrological conditions and increased soil nutrients along roadsides (Müllerová et al. 2011). This altered disturbance regime is ideal for species that possess weedy ruderal characteristics (Šerá 2010), which are often associated with non-native species (Baker 1974; Zhang et al. 2024).

Here, we present a unique empirical dataset based on standardized, repeated monitoring of vascular plant communities in and adjacent to roadsides in globally distributed mountain regions, each covering at least 500 m in elevation (Table 1). The survey protocol has been developed by the Mountain Invasion Research Network (MIREN, www.mountaininvasions.org; Haider et al. 2022; Kueffer et al. 2014). When founded in 2005, MIREN's main objective was to study patterns and processes of non-native plant invasions in mountains (Alexander et al. 2011; Seipel et al. 2012). Subsequently, MIREN expanded its scope to all vascular plant species to more broadly understand the effects of global change on mountain plant biodiversity and the elevational distribution of species (Haider et al. 2018). By 2023, the survey protocol had been implemented in 25 mountain regions across the globe, over a period of 16 years (Figure 1, Table 1). MIREN is an open network, with new regions joining and implementing the mountain road survey protocol. Sampling is conducted in permanent plots, which cover a broad range of climates and plant community types along the elevation gradients. The protocol targets parallel elevation gradients in anthropogenically disturbed sites next to the roads and in close-by (semi)natural vegetation. The survey is repeated every 5 years to support the detection of possible plant community changes and their drivers over time (Buhaly et al. 2025; Iseli et al. 2023).

2 | Methods

2.1 | Data Acquisition and Compilation

Data collection occurred in 25 different mountain regions across the globe, with each region aiming to survey three roads (elevational transects). Roads are generally spaced no more than 150 km apart within a region. Regions encompass most biomes and the majority of the global climatic niche occupied by mountains (Whittaker 1970; Figure 2). Road selection was based on elevation extent and public access. Ideally roads begin at the lowest elevation in the area and extend to the highest elevation possible. Further, roads must be open to vehicle traffic for at least parts of the year. Along each road, 20 sample sites are selected at evenly spaced elevational intervals. At each site, three 2 m × 50 m plots are arranged in a 'T', one parallel to the road and two perpendicular to the road, from the midpoint of the roadside plot, thus capturing the roadside vegetation and extending to the more natural area away from the road (Figure 3). Thereby, each region aims for a total of 180 plots (60 plots × 3 roads). Resampling occurs at 5-year intervals. To aid in resampling, GPS coordinates and photographs of each plot are captured at first sampling. Data collection includes the presence of all vascular plants, though earlier sampling years mostly cover only non-native species (Table 1). The standardized road survey protocol is detailed in Haider et al. (2022). Environmental

TABLE 1 | Overview of the 25 study regions, including their elevational range and year(s) of sampling of either non-native species only or all species. Footnotes indicate specific aspects of sampling which occurred in three regions for individual years.

Continent	Country	Region	Abbr.	Elevational range and extent	Non-native species only (years)	All species (years)
Africa	South Africa	Maloti-Drakensberg	ZAD	597 m (1945–2542 m a.s.l.)		2022
Africa	South Africa	Matroosberg	ZAM	770 m (1185–1955 m a.s.l.)		2022
Americas	USA	Blue Mountains, Oregon	ORE	1363 m (902–2265 m a.s.l.)	2007	2012
Americas	USA	Rocky Mountains, Montana	MTN	1512 m (1803–3315 m a.s.l.)	2007, 2017	2012, 2022[a]
Americas	Ecuador	Ecuadorian Andes	ECU	2850 m (1150–4000 m a.s.l.)		2012
Americas	Chile	Central Chilean Andes	CLC	1690 m (1895–3585 m a.s.l.)		2007, 2012, 2017
Americas	Chile	Chilean Andes, Maule region	CLM	1699 m (903–2602 m a.s.l.)		2019
Americas	Chile	Southern Chilean Andes	CLS	1412 m (274–1686 m a.s.l.)		2007, 2012, 2017[b]
Americas	Chile	Chilean Andes, Aysen region	CLA	754 m (346–1100 m a.s.l.)		2019
Americas	Chile	Chilean Andes, Patagonia	CLP	587 m (33–620 m a.s.l.)		2019
Americas	Argentina	Central Argentine Andes	ARC	2164 m (1755–3919 m a.s.l.)		2017, 2022
Americas	Argentina	South Argentine Andes	ARS	821 m (857–1678 m a.s.l.)		2015
Australia	Australia	Australian Alps, New South Wales	AUN	1745 m (380–2125 m a.s.l.)	2007	2012, 2017[c], 2022
Australia	Australia	Australian Alps, Victoria	AUV	1643 m (205–1848 m a.s.l.)		2012, 2017, 2022
Europe	Norway	Northern Scandes	NOR	691 m (13–704 m a.s.l.)		2012, 2017, 2022
Europe	Czech Republic	Krkonose Mountains	CZE	972 m (430–1402 m a.s.l.)		2022
Europe	Austria	European Alps	AUT	1439 m (682–2121 m a.s.l.)		2018
Europe	Switzerland	European Alps	CHE	1391 m (411–1802 m a.s.l.)	2007	2012, 2017, 2022
Europe	Italy	Central Apennine	ITA	1706 m (419–2125 m a.s.l.)		2022
Europe	Armenia	Caucasus Mountains	ARM	2040 m (1110–3150 m a.s.l.)		2017
Asia	China	Changbai Mountains	CNN	1537 m (1073–2610 m a.s.l.)		2018
Asia	India	Himalayas	IND	2064 m (1585–3649 m a.s.l.)		2012, 2017, 2022
Islands	USA	Hawaii	HWI	4145 m (30–4175 m a.s.l.)		2007, 2012
Islands	Spain	La Palma	ESL	2123 m (159–2282 m a.s.l.)		2013, 2019, 2023
Islands	Spain	Tenerife	ESP	2372 m (5–2377 m a.s.l.)		2008, 2018, 2022

Note: Abbr. = region abbreviations used in Figure 1. In most regions, in 2007, only data on non-native species were available since the original scope of MIREN was to study non-native plant invasions in mountains. Continents are sorted alphabetically; countries and regions within countries go from North to South.
[a]Note that one road (BP) had to be resurveyed 1 year later, in 2023, because of time constraints.
[b]Note that a fourth road (LL) was added in 2019.
[c]Note that in 2019, two roads (AS, AT) were expanded and six additional sites were added that reached beyond the previous maximum elevation (i.e., additional sites with numbers from 21 to 26). Further, a new road (AW) was established in 2019.

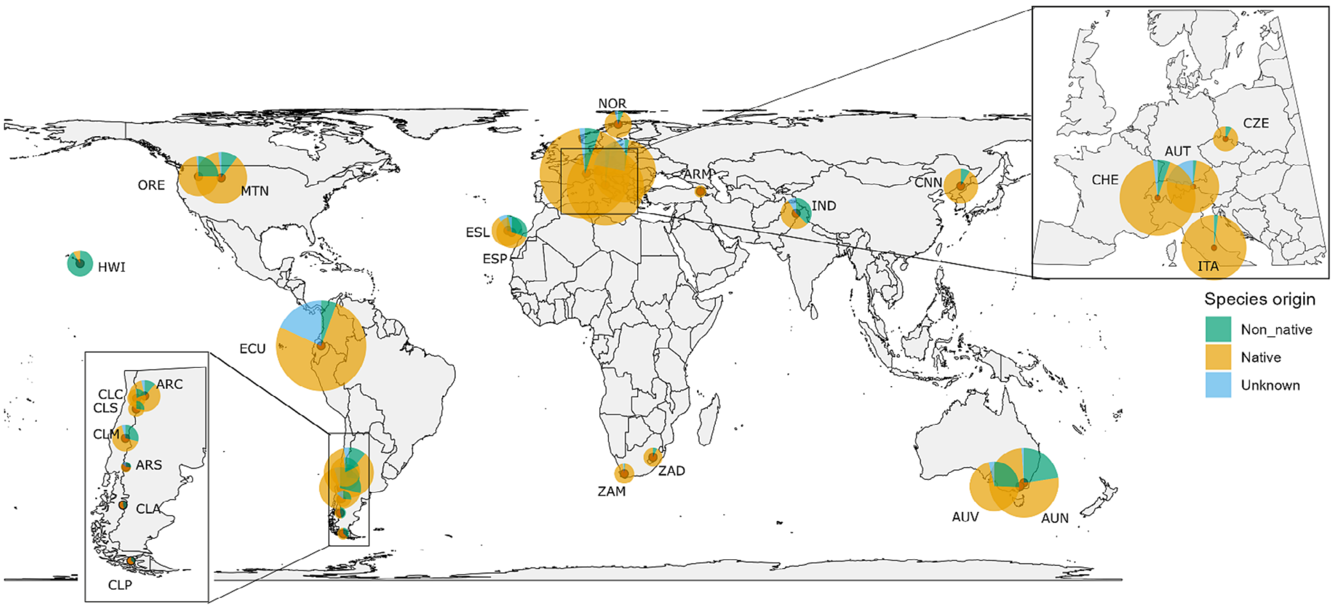

FIGURE 1 | Location of the regions that have implemented the standardized road survey protocol of the Mountain Invasion Research Network (MIREN). Pie charts are scaled by species richness, with colours indicating the proportion of native and non-native plant species.

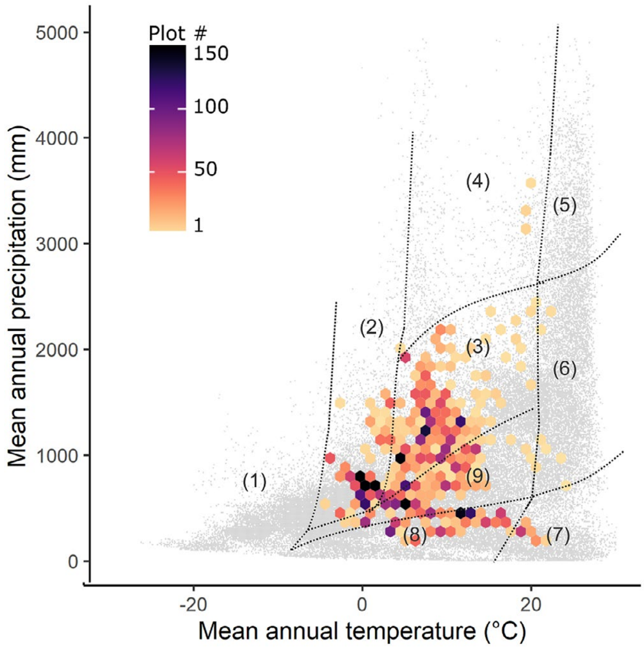

FIGURE 2 | Whittaker biome plot showing the mean annual temperature and precipitation of all 3364 plots in the database, as obtained from WorldClim 2.0 at a 1 km^2 resolution. Small grey dots in the background represent the mean annual precipitation and temperature of all mountain regions globally (except Antarctica), with 'mountain' defined following Körner et al. (2017). Dotted lines delineate Whittaker biomes: (1) Tundra, rocks and ice, (2) boreal forest, (3) temperate seasonal forest, (4) temperate rainforest, (5) tropical rainforest, (6) tropical savanna, (7) subtropical desert, (8) temperate grassland and (9) temperate woodland. Hexagon colours indicate the frequency of plots sampled per climate bin.

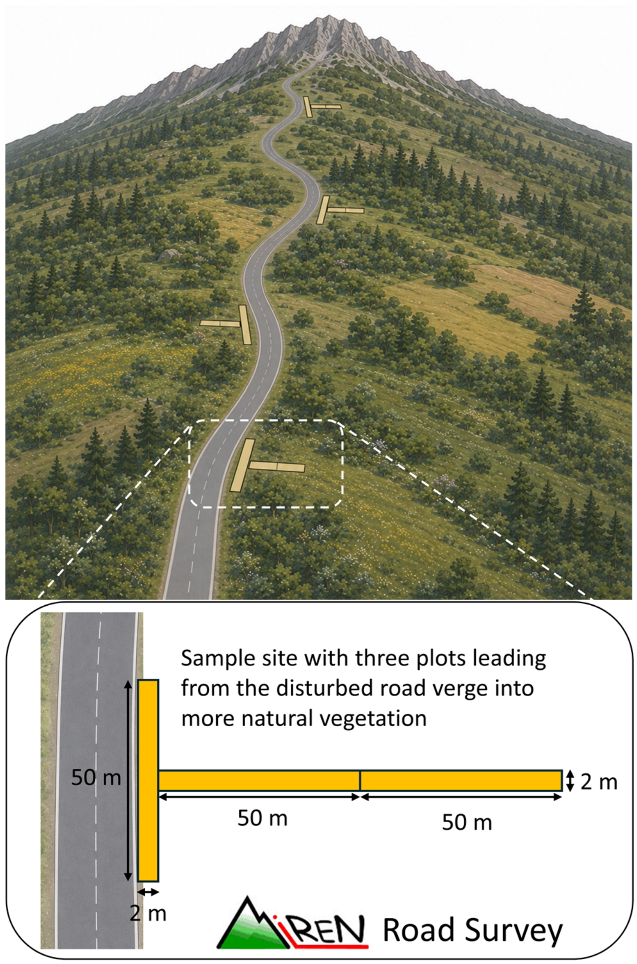

FIGURE 3 | Illustration of the sampling design. Along each mountain road, twenty sample sites are placed along the elevation gradient. Each sample site consists of one plot with the long side parallel to the road and two more plots leading perpendicularly from the road into more natural vegetation.

parameters such as disturbance intensity and forest cover were collected inconsistently between regions and sampling years and are therefore not included in this compilation (see also Haider et al. 2022).

TABLE 2 | Dataset structure.

Column name	Variable description	dwcTerm	dwcClass
Plot_id	Unique ID for each plot recorded in the form Region.Road.Site.Plot (e.g., MTN.BP.06.2). 'Region' is a three-letter code (e.g., MTN = Montana), and 'Road' a two-letter code (e.g., BP = Beartooth Pass Road). 'Site' is a number from 1 (lowest elevational point along the road) to 20 (highest elevational point). 'Plot' is a number from 1 to 3, with 1 the roadside plot, 2 the intermediate plot and 3 the interior plot	eventID	Event
Region	ID of the region	higherGeography	Location
Road	A two-letter code (e.g., BP = Beartooth Pass Road)	locality	Location
Site	A number from 1 (lowest elevational point along the road) to 20 (highest elevational point)[a]	locationRemarks	Location
Plot	'Plot' is a number from 1 to 3, with 1 being the roadside plot, 2 the intermediate plot (2–52 m from the road) and 3 the interior plot (52–102 m from the road)[b]	locationRemarks	Location
Year	Year in which observation was made	year	Event
Elevation	Elevation of the observation in metres above sea level	minimumElevationInMeters	Location
Latitude	Latitude of the observation in decimal degrees	decimalLatitude	Location
Longitude	Longitude of the observation in decimal degrees	decimalLongitude	Location
Accepted.Name.MIREN	Final species name after the taxonomic checking and harmonization procedure	scientificName	Taxon
Abundance	Abundance of the recorded species (ranging from 1 to 3)[c]	organismQuantity [organismQuantityType: abundance class]	Occurrence
Cover	Percentage cover of the recorded species (ranging from 1 to 8). Cover was not recorded in the first survey year in 2007 and 2008, respectively[d]	organismQuantity [organismQuantityType: cover class]	Occurrence
Status	Native or non-native status of the species within the region, based on regional sources. If no status could be assigned, an 'unknown' status was listed	establishmentMeans	Occurrence
Protocol	Version of the protocol used for the survey[e]	samplingProtocol	Event

Note: Data are provided as a .csv file and consist of a single data table, with a separate line for each species observation in a plot. Here, we additionally provide for all columns a Darwin Core term (dwcTerm) and the corresponding Darwin Core class (dwcClass) to enhance data interoperability.
[a]Note that there are three regions which established more than the 20 required sites per road. CHE started with site 0 in the first year of sampling, CZE established additionally site 21, and AUN expanded two of its roads (AS and AT) during the re-survey and added sites 21 to 26 in 2019.
[b]Note that in some locations, plots were destroyed, for example, through widening of the road or other construction works. In such cases, the original plot had to be abandoned, and a new plot was established instead, located as close as possible to the original plot. New plots are indicated by the letter 'A' after the plot number (e.g., '1A').
[c]Note that for the additional road AW, which was established in 2019 in AUN, only plant species cover was recorded, not abundance. Any additional NAs for abundance in the database result from missing data for some records.
[d]ECU did the first survey only in 2012 and recorded only abundance then, not cover. Any additional NAs for cover in the database result from missing data of some records.
[e]The main difference between protocol versions is the refinement of the cover classes. To compare cover values across years, classes of later protocol versions can be translated to earlier protocol versions.

2.2 | Data Curation and Quality Control

Regional teams conduct the surveying, clean and synthesize their data and submit them to MIREN data curators, who then perform further quality control. Geolocations are verified, species names are checked, and taxonomy is harmonized. Specifically, using the R-packages 'taxize' (Chamberlain et al. 2012; Chamberlain and Szöcs 2013) and 'WorldFlora' (Kindt 2020), species names are checked to remove synonyms and typological errors. Species without accepted names in the World Flora Online database are manually checked using the Taxonomic Name Resolution Service (Boyle et al. 2013) giving priority to the Tropicos database from Missouri Botanical Garden (https://tropicos.org) and the PLANTS database from the US Department of Agriculture (https://plants.usda.gov/). Nativity is assigned by the data collectors based on regional floras (see Appendix S1).

2.3 | Data-Use Guidelines

Detailed guidelines for data contribution and use are available on the MIREN website (www.mountaininvasions.org). Authorship is governed by the MIREN data-sharing agreement that is publicly available on the MIREN website. Upon publication, data become available open access, yet users are encouraged to inform the MIREN Steering Committee of their planned analyses to avoid overlap with ongoing projects and to involve regional data contributors in their paper if the database is a significant part of their analyses.

New regional datasets and resurveys not yet included in this publication are available upon request from the MIREN Steering Committee.

2.4 | Description of the Data

The data are provided as a single table .csv-file in long format, with a separate line for each observed species in a plot (Table 2). For each plot, the GPS coordinates and elevation are provided.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The MIREN road survey data can be downloaded from Zenodo (https://doi.org/10.5281/zenodo.15749536). New versions will be published at least every 5 years, since the monitoring is occurring every 5 years. There is no code associated with this data paper.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Appendix S1:** Regional references used to determine species status (native or non-native). For region abbreviations see Table 1 in the main text.