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What determines the distribution of *Tulipa* species in Uzbekistan?

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ABSTRACT

Although the distribution of *Tulipa* species in Uzbekistan is well documented, there is no clear understanding of the importance of three classes of environmental variables, climate, soil type, and topography, as determinants of their distribution. We mapped the richness of *Tulipa* species in Uzbekistan, and conducted species distribution modeling to analyze the contribution of climate, soil type, and topography, to their predicted suitable ranges. The relationship between *Tulipa* species richness and altitude is best described by a hump-shaped curve, with a majority of the *Tulipa* species occurring at the altitude range of 700-2200 m. The climate was a major determinant of species distribution for the majority of the analyzed species, however, topography (slope angle and aspect) was equally or even more important for *T. tschimganica*, *T. borszczowii*, *T. butkovii*, *T. carinata*, *T. affinis*, *T. micheliana*, *T. sogdiana* and *T. korolkowii*. Soil was an important factor only for *T. uzbekistanica*, *T. butkovii* and *T. lanata*. The conservation implications of these results are discussed.

Key words: geospatial analysis, species richness, species range, species distribution modeling

Introduction

Tulips (*Tulipa* spp.) are among the most popular ornamental plants. Wild *Tulipa* species, due to the attractivity of their flowers and importance for breeding, have always been among the top priority conservation targets. Tulips appear in Red Lists of virtually all countries where they occur (Baitulin 2014; Khassanov 2019; Nowak et al. 2020; SAEPF et al. 2006).

Mountainous Central Asia is a recognized hotspot and center of diversity for the wild tulips (Botschantzeva 1962; Eker et al. 2014). To date, over 80 species are distributed in this region (Dekhkonov et al. 2022; WCVP 2022). Among the Central Asian countries, Uzbekistan is particularly rich in *Tulipa* species. Tojibaev & Beshko (2014) listed 34 *Tulipa* species as occurring in Uzbekistan, with six taxa being endemic to the country. The distribution of *Tulipa* species in Uzbekistan is well documented, however, there is no clear understanding of the importance of three classes of environmental variables, climate, soil type, and topography, in their distribution. Knowledge of the role of these factors as determinants of the *Tulipa* species range has very important practical implications. Tulips have always been high-priority species for conservation, and the conservation of *Tulipa* species both ex situ and in situ critically depends on this knowledge. For example, if topography (e.g. a particular slope angle and aspect) plays a critical role for a species, the necessary microenvironmental conditions for its living collection will hardly be possible to create in a botanical garden. On the contrary, if soil is the major determinant of a species range, creation of a particular soil microhabitat in a botanical garden will be a much easier task. For

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in situ conservation, knowledge of what environmental factor(s) determine the species range is vital in planning translocations, and in nature reserve decision-making (Volis 2022; Volis & Blecher 2022). Despite the importance of analysis of *Tulipa* species distribution, there have been only very limited attempts to understand the environmental requirements of the *Tulipa* species and the causes of their rarity (Dekhkonov et al. 2021; Wilson et al. 2021). The goal of this paper was two-fold: (i) to map the *Tulipa* species richness in Uzbekistan, and (ii) to understand the factors determining the distribution of *Tulipa* species in Uzbekistan.

Materials and Methods

Study area

The study area is Uzbekistan located in Central Asia between latitudes 37° and 46° N and longitudes 56° and 74° E. Approximately 12% of the country's total area are mountains and foothills and the rest of the territory is plains (Kuchkarov et al. 2018). Main mountainous regions are situated in the north-eastern (Ugam, Chatkal, Kurama, Fergana ranges), south-eastern (Turkestan and Alay), and southern (Hissar, Zeravshan, Babatag ranges) parts of the country. The climate is continental. The average summer temperature is around +40°C, while the average winter temperature is around −23°C (Baratov et al. 2002).

Data acquisition

We collected the herbarium specimens of 33 *Tulipa* species (34 taxa) from 2014 to 2021 at altitudes ranging from 50 to 3650 m, from mid-March to the end of July. Some areas were examined several times to ensure proper coverage. We took GPS coordinates and recorded the plant habitat and blooming time for each collected specimen. The 1300 collected specimens were deposited in National Herbarium of Uzbekistan (TASH). The other sources of the data used in this study were the previously published data (Botschantzeva 1962; Khasanov 2019; Tojibaev & Kadirov 2010), herbarium sheets stored in TASH, LE and MW (Thiers 2019), and also information from Global Biodiversity Information Facility (GBIF 2022) and Plantarium (2022). The species were identified according to (Zonneveld 2009) and (Tojibaev & Beshko 2014), and cross-checked by the World Checklist of Selected Plant Families (WCSP 2022) and Plants of the World (POWO 2022). Overall, more than 3500 specimens were examined.

Geospatial analysis and species distribution modeling

The species occurrence data were uploaded into ArcGIS 10.8 and used to create the species richness map. For all species we calculated area of occupancy (AOO) and extent of occurrence (EOO) in GeoCAT according to the guidelines of IUCN (2012). The elevation ranges were assessed based on geographic coordinates by GPS visualizer (https://www.gpsvisualizer.com). The information on AOO, EOO, elevation range and number of known populations for each species was visualized by creating radar charts in the fmsb package (Nakazawa 2019) in R. The importance of climate, topography, and soil in the *Tulipa* species distribution (except for *T. bactriana* which has a single occurrence record) was analyzed using the rJava package (Urbanek & Urbanek 2017) in R. This package performs species distribution modeling and calculates, using the permutation, a percentage contribution of each of the environmental variables in the final model. For climate, we used the 19 'Bioclim' variables from WorldClim v.1.4 (Hijmans et al. 2005) with a resolution of 30″ latitude/longitude (~1 km^2 at the ground level). For soil, we downloaded from the FAO website (https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/faounesco-soil-map-of-the-world/en/) the Digital Soil Map of the World. After extraction, the Uzbekistan soil map had 15 soil type categories. The elevation map downloaded from WorldClim v.1.4 was used to make slope and aspect maps. For the latter we utilized "slope" and "aspect" functions in ArcToolbox as implemented in ArcGIS v10.8 (Pawluszek et al. 2019). The slope map was produced using "percent_rise" classification. The resulting slope map had five categories (flat: 0-3%, very undulating: 3-10%, undulating: 10-20%, slightly steep: 20-32%, steep: >32%), and the aspect map had 9 categories (flat, north, northeast, east, southeast, south, southwest, west, northwest).

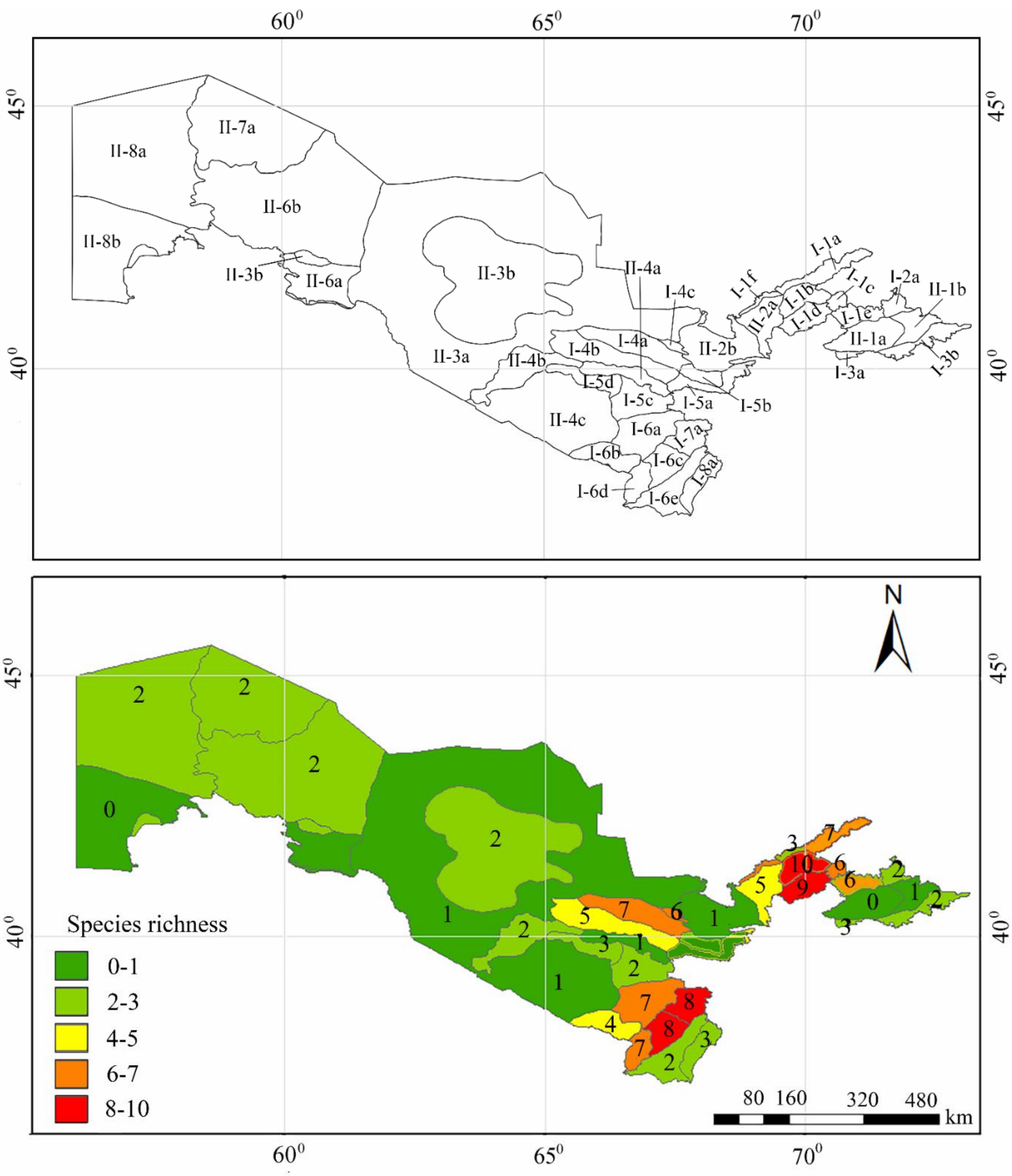

Fig. 1. Phytogeographical division of Uzbekistan according to Tojibaev et al. (2016) (top) and the *Tulipa* species richness map (below).

Table 1. The number of populations, conservation status in the Red Book of Uzbekistan, and information on the distribution of 33 *Tulipa* species in Uzbekistan. Phytogeographic regions correspond to those in Fig. 1.

Species	Phytogeographic regions	Elevation	No. of populations	Habitat	Red Book status
T. bactriana J. de Groot & Tojibaev	I-6e	420	1	P	N/E
T. korshinskyi Vved.	I-6a	2000-2580	1	M	N/E
T. biflora Pall.	II-8a	140-240	2	P	N/E
T. tschimganica Botschantz.	I-1b	1950-2130	2	M	N/E
T. hissarica Popov & Vved.	I-7a	2440-3560	2	M, A	2
T. borszczowii Baker	II-2a,b; II-3b	60-400	4	P, F	N/E
T. uzbekistanica Botschantz. & Sharipov	I-6b,d	1310-1930	5	M	1
T. orithyioides Vved.	I-6c; I-7a	2180-2990	4	M, A	1
T. talassica Lazkov	I-1e	1220-3340	7	M, A	N/E
T. mogoltavica Popov & Vved.	I-1b,d	570-1670	7	F, M	N/E
T. dasystemonoides Vved.	I-1a,c,b,d; I-5a	610-3240	12	P, A	N/E
T. butkovii Botschantz.	I-1b	1120-2640	14	F, M	N/E
T. intermedia Tojibaev & J.de Groot	I-1e	696-1258	11	F	2
T. scharipovii Tojibaev	I-1e	560-1010	13	F	2
T. tubergeniana Hoog	I-6c,d; I-7a; I-8a	1310-1930	13	M	3
T. ferganica Vved.	I-2a; I-3b	670-1200	7	F	2
T. vvedenskyi Botschantz.	I-1b,d,c,e	1080-2680	13	F, M	3
T. carinata Vved.	I-6c; I-7a	1130-3330	20	M, A	3
T. lanata Regel	I-6c,d; I-7a; I-8a	990-2600	18	F, M	3
T. fosteriana Irving	I-5c; I-6a	590-2400	21	F, M	2
T. ingens Hoog	I-6a,d,c; I-7a	1320-2580	37	M	3
T. dubia Vved.	I-1a,b,c,d	440-3030	25	P, A	3
T. affinis Botschantz.	I-3a; I-4a,b,c; I-5a,b	330-2600	32	P, M	3
T. micheliana Hoog	I-3a; I-4a,b,c; I-5a,b,c,d; I-6a,b,c	250-1630	40	P, F	3
T. greigii Regel	I-1a,f; II-2a	390-2430	40	P, M	N/E
T. sogdiana Bunge	I-4a; II-3a,b; II-4b,c,b; II-7a	60-720	37	P	N/E
T. dasystemon Regel	I-1a,b,c,d,e; I-5a; I-6a	610-3560	45	P, A	3
T. buhseana Boiss.	I-4a; II-6b; II-7a; II-8a	30-730	45	P	N/E
T. korolkowii Regel	I-1a,b,d,f; I-4a,b,c, I-5a,b; I-6a,b,c,d,e; I-7a; I-8a; II-2a	230-2810	56	P, M	3
T. kaufmanniana Regel	I-1a,b,c,d	360-3150	30	P, M	3
T. lehmanniana Mercklin	I-3a,b; I-4a,b; I-5d; II-4b	100-630	70	P	3
T. bifloriformis Vved.	I-1a,b,c,d,e,f; I-2a; II-2a	350-2760	60	P, M	N/E
T. turkestanica Regel	I-4a,b,c; I-5d, I-6a,b,d; I-7a; II-4a	340-3310	80	P, M	N/E

Abbreviations: P plain, F foothills, M mid mountain, A alpine, N/E not estimated

Results

Species richness

The information on the distribution of 33 *Tulipa* species in phytogeographic regions of Uzbekistan is provided in Table 1. The widest range have *Tulipa korolkowii* (in seven regions), *T. sogdiana* and *T. turkestanica* (in five regions). *T. micheliana, T. buhseana* and *T. lehmanniana* (in four regions) and *T. tubergeniana, T. lanata, T. affinis, T. dasystemon* and *T. bifloriformis* (in three regions). *T. borszczowii*, *T. orithyioides*, *T. dasystemonoides*, *T. ferganica*, *T. carinata*, *T. fosteriana*, *T. ingens* and *T. greigii* grow in two regions, and the remaining 14 species occur in only one region.

The species richness map produced by overlapping the species ranges on the map of phytogeographical regions of Uzbekistan is shown in Fig. 1. According to the map, the Western Tian Shan and Western Hissar are the most *Tulipa* species-rich regions, having 14 and 13 species, respectively. The Kuhistan and Hissar-Darvaz regions have 8 and 7 species, respectively, and the remaining regions from 1 to 5 species.

A relationship between altitude and species richness was found to be best described by a hump-shaped curve (Fig. 2). The highest species richness (> 15 species) is observed at the altitudes between 700 and 2200 m.

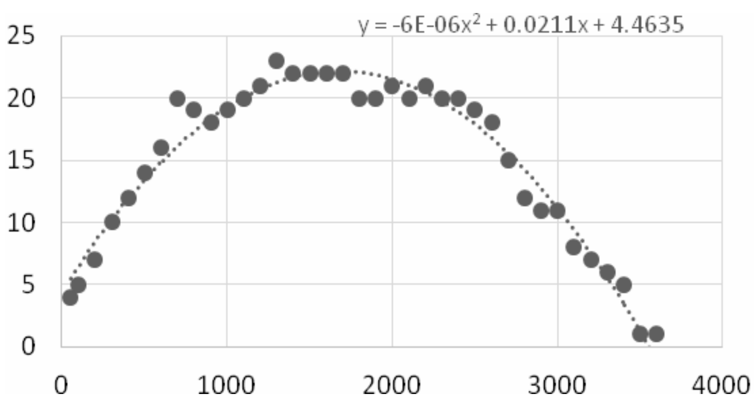

Fig. 2. The relationship between *Tulipa* species richness and elevation

Ecological determinants of species distribution

Topography (slope angle and aspect) was the primary determinant (> 50% contribution) of the distribution of 11 species (*T. biflora, T. tschimganica, T. hisssarica, T. borczszowii, T. butkovii, T. carinata, T. affinis, T. micheliana, T. sogdiana, T. korolkowii* and *T. turkestanica*), while climate was the primary determinant of all the remaining species subjected to SDM (Fig. 3). Topography significantly (from 10 to 50%) contributed to the explanation of the distribution of 11 species (*T. korshinskyi*, *T. tschimganica, T. talassica, T. mogoltavica, T. tubergeniana, T. ferganica, T. lanata, T. ingens, T. buhseana, T. kaufmanniana* and *T. lehmanniana*). Topography contributed little or nothing (less than 10%) to the explanation of the distribution of 9 species (*T. uzbekistanica, T. orithyioides, T. dasystemonoides, T. intermedia, T. scharipovii, T. vvedenskyi, T. fosteriana, T. dubia* and *T. bifloriformis*). Soil was the primary determinant for neither species, but it significantly contributed (> 10 %) to the explanation of the distribution of *T. uzbekistanica, T. butkovii* and *T. lanata.*

Tulipa species distribution inUzbekistan embraces four habitat categories defined by Sennikov et al. (2016) based on the altitude and corresponding vegetation: alpine (the yailau zone) (2800-3600 m), mid-mountain (the tau zone) (1200-2800 m), foothills (the adyr zone) (400-1200 m) and plains (the chul zone) (1-400 m) (Table 1). Ten *Tulipa* species grow in the alpine zone, 23 in mid-mountains, 21 in foothills, and 17 in plains. The Venn diagram (Fig. 4) shows that many species occur in more than one habitat category, and only 10 species occur in a single habitat (0, 3, 5, 2; alpine, mid-mountains, foothills, plains, respectively). Among the 22 species for which topography was found to be important, only five species occur in a single habitat (three in mid-mountains, and one in each foothills and plains).

Of 33 species, 12 had ≥ 30 populations, 10 had from 10 to 30 populations, and 11 had less than 10 populations per species. There was no preference for particular habitat categories for species with many or just a few populations. The elevation range spanned by the species distribution was found to be positively correlated with a number of populations ($r = 0.50$, $p < 0.05$) and AOO ($r = 0.57$, $p < 0.05$), but not with EOO ($r = 0.01$, $p > 0.5$).

Of 33 *Tulipa* species, 19 are included in the Red Book of Uzbekistan under the categories 1-3 (1: critically endangered, 2: endangered, 3: vulnerable or near threatened). The mean values ± SE of AOO, EOO, elevation range and the number of populations for these species are 110.5 ±17.7 km^2, 27111±8988 km^2, 1645±194 m, and 24.3±4.3 populations, respectively. These values did not differ significantly from the corresponding values for *Tulipa* species not included in the Red Book of Uzbekistan (without the recently discovered *T. bactriana* which is an extremely rare species but is not included in the Red Book yet) (99.2±32.4 km^2, 55860±21175 km^2, 1208±281 m, and 23.9±7.2 populations, respectively). Of 19 Red-Listed species, six grow in the alpine zone, 14 in mid-mountains, 11 in foothills, and 5 in plains. Only six species occur in a single habitat (3 in mid-mountains and 3 in foothills). A comparison of the Venn diagrams for the Red-listed and unlisted species (Fig. 4) shows minor differences. Three Red-listed species occur exclusively in foothills but neither unlisted species. Topography was the primary determinant of distribution (> 50% contribution) of 5, or important (10-50% contribution) for the distribution of 6 Red-listed species.

Discussion

Botschantzeva (1962) recognized in the genus *Tulipa* primary center of diversity (i.e. Central Asia) four sub-areas of diversity: Turan plains, Pamir-Alay Mountains, Western Tian Shan Mountains, and Central Asian highlands. Results of present study fully support Botschantzeva (1962). Interestingly, more than two-thirds of 33 *Tulipa* species that occur in Uzbekistan grow in several of the habitat categories defined by Sennikov et al. (2016), i.e. plains, foothills, and two mountain categories (alpine and mid-mountain). The highest *Tulipa* species richness in Uzbekistan is observed at altitudes between 700 and 2200 m, which corresponds to high foothills and mid-mountains. The climatic conditions observed at this altitude range apparently correspond to the conditions experienced by the genus ancestral lineage(s) or where the *Tulipa* species survived during the past climatic oscillations (glacial and interglacial periods). From here, the speciation of *Tulipa* in Central Asia apparently proceeded towards the dry (desert) and cold (alpine) environments. Besides climate, topography and soil can be the environmental factors that shape a species' distribution. Several studies have shown that topography is an important environmental factor influencing species distributions through its effects of sunlight, heat, and the spatial redistribution of water and nutrients, leading to the formation of specific microenvironmental conditions (Costa et al. 2005; Lassueur et al. 2006; Macek et al. 2019; Svenning et al. 2009). We found topography to be important not only for the species distributed

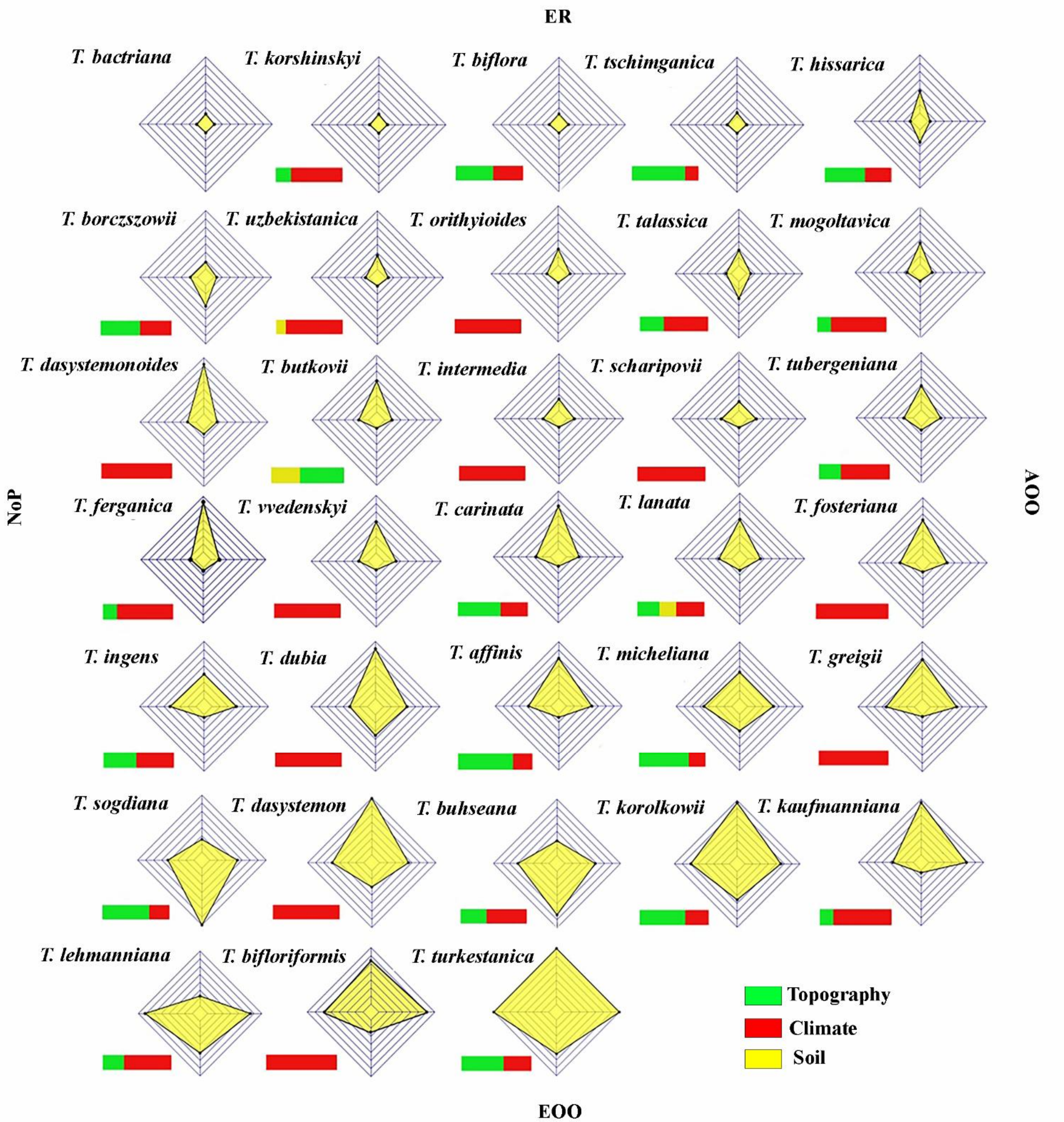

Fig. 3. The radar charts showing number of known populations (NoP, max=80), area of occupancy (AOO, max=344 km^2), extent of occurrence (EOO, max=224435 km^2), and elevational range (ER, max=2970 m); and barplots showing the contribution of three types of ecological factors (climate, topography and soil) to the explanation of the predicted by SDM tulip species distribution. The species are arranged by their AOO.

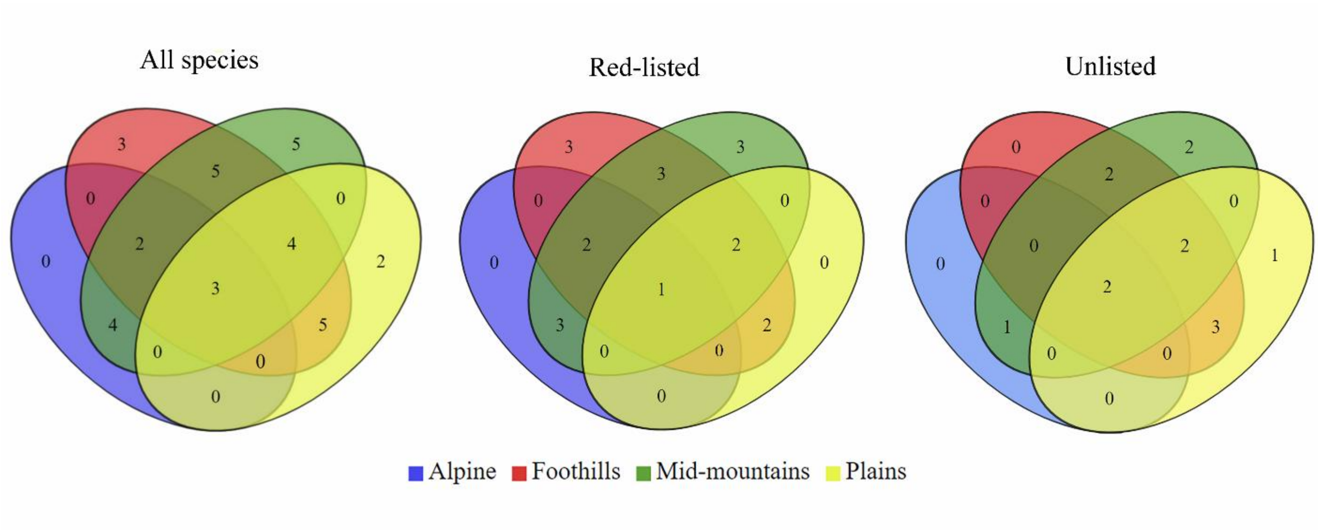

Fig. 4. Venn diagram showing the distribution of 33 *Tulipa* species in four habitats recognized by Sennikov et al. (2016).

exclusively in mountain areas, but also for those whose distribution spans mountains, plains and foothills, or foothills and plains. Topography was important for many species included in the Red Book of Uzbekistan, and for those that are of no conservation concern.

Knowing which of the 33 *Tulipa* species require specific topographic conditions has important conservation implications. Based on the results of SDM, we can conclude that maintaining the living collections of some species such as *T. hissarica, T. vvedenskyi, T. carinata, T. ingens, T. affinis, T. micheliana, T. korolkowii* in botanical gardens has little chance of success. On the other hand, the introduction of these species *in situ* must consider, the choice of microhabitats for planting, including environmental parameters as slope angle and aspect.

We found that the elevation range spanned by the species distribution is positively correlated with the number of populations. This means that *Tulipa* species with a broader ecological niche (specifically a broader climatic range a species can tolerate) have in general more populations and wider AOO.

In our study, we estimated the ranges (EOO and AOO) of all *Tulipa* species growing in Uzbekistan. This information is important for the determination of species conservation status. Besides the geographic range size, it is essential to know how it changes through time (Gaston & Fuller 2009). Unfortunately, we do not have any information about the geographic range size decline for *Tulipa* species. Hopefully, the reported species ranges in this paper will allow such calculations in the future. For several studied species, the current ranges are critically low. Although the AOO calculated using the IUCN (2012) guidelines for neither species (except for *T. bactriana*) was less than 20 km^2, these numbers are misleading, and in fact their ranges are less than 1 km^2 because the population sizes of *Tulipa* in mountainous habitats rarely exceed 1 ha and often are even much smaller (Tojibaev, unpublished data). It is necessary that for all Red-listed or at least critically endangered species, the extant populations are precisely measured for the geographic area occupied and the number of individuals to provide realistic estimates of species range sizes.

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