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How to preserve narrow endemics in view of climate change? The Nuratau Mountains as the case

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ABSTRACT

Endemic species usually have higher risk of extinction than widespread species and therefore for endemics negative effects of climate change can be especially dramatic. The Nuratau Mountains, located in Uzbekistan, are rich in endemic species and are a part of the Mountains of Central Asia Global Biodiversity Hotspot and one of Key Biodiversity Areas. To understand the consequences of climate change for a group of endemic plant species found in this region, we conducted species distribution modelling (SDM) and produced species maps of habitat suitability, as well as maps of predicted endemic species richness under current and expected future climatic conditions. Based the obtained information, we assessed: i) how well the existing protected area in the region (Nuratau Nature Reserve) protects the local endemics and ii) what needs to be done to preserve these species in the face of expected future warming. Among the 27 species studied, 14 appear to be the true narrow endemics as their predicted range is largely or entirely limited to the Nuratau Mountains. The remaining species have a wide predicted range, of which the Nuratau Mountains are only a small part. Only seven species will have suitable habitat within the Nuratau Mountains and only five of them will have suitable habitat in the protected territory of the Nuratau Nature Reserve. For six species, there will be no suitable area throughout the study area. Surprisingly, 13 species will have a suitable habitat in the Kugitang Range, where the Surkhan Nature Reserve is located. We propose as the most appropriate climate change adaptation strategy for these Nuratau endemics to artificially increase their dispersal capacity via *in situ* introduction trials and the creation of new populations in the Surkhan Nature Reserve.

Key words: plant conservation, *in situ*, endemic species richness, climate change, Mountains of Central Asia Biodiversity Hotspot.

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Introduction

Many species have restricted ranges, and the phenomenon of endemism has been a subject of intensive research (Kruckeberg & Rabinowitz 1985; Major 1988; Anderson 1994; Hobohm 2014). Endemic species are generally defined as those with "small range, narrow habitat specificity" (Kruckeberg & Rabinowitz 1985), and such species usually have a higher likelihood of extinction than widespread species (Gaston 1998; McKinney & Lockwood 1999; Lamoreux et al. 2006). Defined in this way, endemism has been used as a criterion for the relative importance of areas for conservation (e.g. Fjeldså & Rahbek 1997; Myers et al. 2000; Kremen et al. 2008; Manish & Pandit 2019). Areas identified for conservation based on high levels of endemism have been shown to contain a greater proportion of overall species richness than species richness hotspots, and a greater proportion of threatened species than threat hotspots (Orme et al. 2005). Recognized causes of endemism are geological events that occurred discontinuously over time and space, as well as discrete habitats created by topographic, lithological, and pedological discontinuities at a finer scale.

Besides understanding the causes of endemism and rarity, it is important to analyze for endemic species the possible effects of climate change. The potential for extinction caused by climate change has been shown to be very high, and in general, the smaller the geographic extent of a species' distribution, the higher the fraction of range displacement due to warming (Thomas et al. 2004; Schwartz et al. 2006). Thus, areas of high endemism are likely to be particularly vulnerable to climate change (Malcolm et al. 2006; Dirnböck et al. 2011; Enquist et al. 2019; Manes et al. 2021). However, this general trend may not hold for some species, as narrowly distributed species are likely to be a mixed suite of species, and while many of them are stenotopic some once had much larger ranges but, due to anthropogenic activities, have only survived in the most inaccessible or well protected areas (Volis & Tojibaev 2021). This implies an individualistic approach in working out conservation programs for narrow endemics.

The Nuratau Mountains, located in Uzbekistan, are a part of the Mountains of Central Asia Global Biodiversity Hotspot (Myers et al. 2000) and are also listed as Key Biodiversity Area (CEPF 2017). This area is rich in endemic plants, with an endemism rate of 2.7%. Of the 1,180 native species from 444 genera and 81 families growing here, 32 species from 13 families are endemics (Appendix), of which 18 are listed in the national Red Data Book (Khasanov 2019). The only strictly protected area within Nuratau Mountains is Nuratau Nature Reserve (Category Ia IUCN) that has occurrence records of 20 out of 32 local endemics. Its total flora list includes 847 species from 364 genera and 75 families, or 66.01% of the plant diversity of the Nuratau Mountains and 70.29% of the flora of Nuratau Range.

The endemic flora of the Nuratau Mountains is a result of their specific geographic location, geological history and natural conditions that significantly differ from other mountain ranges of Central Asia. The Nuratau Mountains are one of the oldest mountains of Central Asia, almost unaffected by the Alpine orogeny. These rather low arid mountains are situated at the edge of the huge desert Kyzylkum, the proximity of which determines the low rainfall (compared to other mountains) in this region and the predominance of xerophitic vegetation. The characteristics of this area, such as low altitude, small area and already low rainfall, make the Nuratau Mountains particularly vulnerable to aridification predicted for Central Asia by all existing climatic models (Lioubimtseva & Henebry 2009). Particularly alarming is the fact that the only strictly protected area in this region, the Nuratau Nature Reserve, has an area of 177.52 km^2 covering a very small part (1.27%) of the territory of the Nuratau phytogeographical region (Tojibaev et al., 2017). To understand the consequences of climate change for a group of endemics occupying the Nuratau Mountains, we conducted species distribution modelling (SDM) and produced maps of habitat suitability for each species, as well as maps of predicted endemic species richness under current and expected in the future climatic conditions. From the information obtained we assessed i) how well the existing in the region protected area (Nuratau Nature Reserve) protects the local endemics, and ii) what should be done to preserve these species under the expected in the future warming.

From the information obtained we evaluate i) how well the existing protected area in the region (Nuratau Nature Reserve) protects local endemics, and ii) what should be done to preserve these species in the face of expected future warming.

Materials and Methods

Study area

The Nuratau Mountains are located at the north-western spurs of the Turkestan Range, one of the mayor ranges of the Pamir-Alay system in Central Asia. They are surrounded to the north, west and south-west by the huge desert Kyzylkum and stretch ca. 250 km in a sub-latitudinal direction along the right bank of the Zeravschan River. They occupy the area of ca. 14,000 km2. There are two parallel mid-altitude mountain ranges, Nuratau (about 200 km long, 2,169 m) to the north and Aktau (about 100 km long, 1,993 m) to the south, and several peripheral low mountains (Fig. 1). The latter include to the south Karatau (50 km long, 1,190 m), Karachatau (20 km long, 1,101 m), Khobduntau (35 km long, 1,672 m) and an insular mountain Kokcha (7 km long, 485 m), and to the north Pistalitau (32 km long, 557 m), Khanbandytag (16 km long, 476 m), Egarbelistag (15.5 km long, 618 m) and Balyklitau (17 km long, 581 m).

The Nuratau Range arose in the late Proterozoic – early Paleozoic as a result of the Baikal and the Caledonian orogeny. The southern branch, Aktau, was f ormed in the Paleozoic, during the Hercynian orogeny. At the time of transgressions of the Tethys Sea (Cretaceous –Paleogene), the Nuratau Mountains existed as isolated islands. The Nuratau Range is composed of shales, limestones, sandstones, dolomites, granites, granodiorites and diorites. The geological structure of the Aktau Range is represented mainly by limestones, marbles, granitoids, granodiorites, diorites, schists and sandstones. Mesozoic-Cenozoic deposits (conglomerates, limestones, sandstones, variegated beds, siltstones, dolomites, gypsum, marls and clays) predominate in the foothills, whereas the piedmont plain is composed by loess-like and sandy loams, marls, clays and pebbles (Atlas of the Uzbek SSR 1982; Tojibaev et al. 2017). The proximity to the Kyzylkum Desert, one of largest deserts in the world, has a great impact on the climate of the Nuratau Mountains and determines the generally xerophytic nature of its vegetation. The mean temperature in January and in July is 0°C and 27–30°C, respectively. The lowest and highest temperature recorded in this area is -30°C and 46.1°C, respectively. The mean annual temperature is 14°C, and the mean annual precipitation is 200–300 mm in the foothills and 300–480 mm in the montane zone (Alibekov & Nishanov 1978; Williams & Konovalov 2008). The rainfall occurs mainly in the winter and spring (the maximum precipitation falls in March–April), and the dry period is June–September. Phytogeographically, the Nuratau Mountains belong to the Nuratau dictrict of the Mountain Central Asian province of the Irano-Turanian region of Tethyan (ancient Mediterranean) Holarctic floristic subkingdom (Takhtadjan 1986; Kamelin 1990; Tojibaev et al. 2016, 2017). Due to the arid conditions of this area, more than 90% of the flora are herbaceous plants, and 33.3% of them are annuals. Four sites in this region are

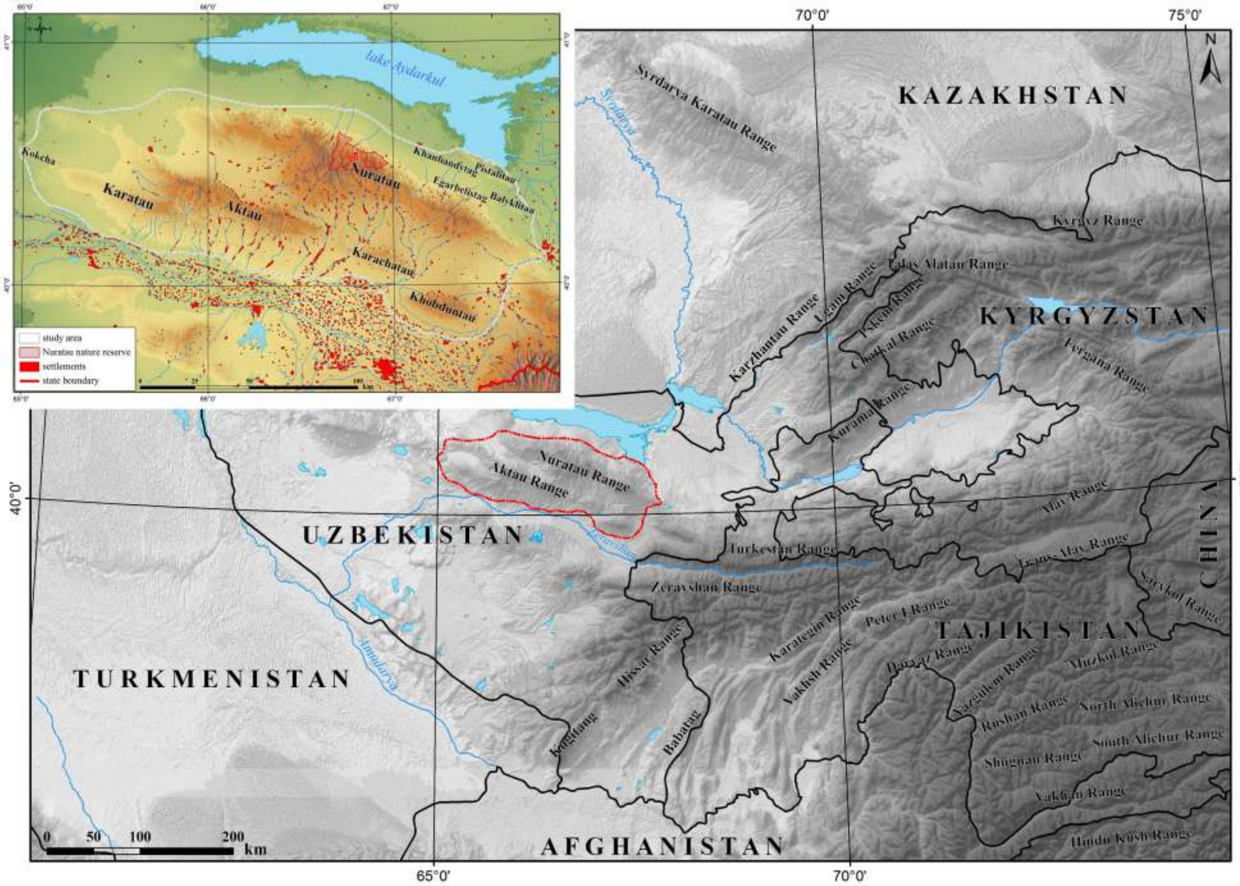

Fig. 1. Orographic map of the study region and surrounding it area.

among the 36 recognized Key Biodiversity Areas recognized in Uzbekistan; one of them (UZB 24 - Nuratau Ridge) is a priority KBA (CEPF 2017). Sites UZB 23 (Northern Piedmont Plain of Nuratau Ridge), UZB 25 (Koytash Ridge) and UZB 26 (Aktau Ridge) meet global KBA criterion B1 (endemic species), while site UZB 24 (Nuratau Ridge) also meets criterion A1 (globally threatened species) (IUCN 2016). In addition, the Nuratau Mountains are one of 25 conservation corridors within the Mountains of Central Asia Global Biodiversity Hotspot, important for maintaining their ecological and evolutionary processes (CEPF 2017). The main threats to populations of endemic plants in this region are grazing, agriculture, mining and quarrying which cause habitat degradation and loss, and aridification caused by the climate change.

Analysis

We used species distribution modelling to predict the geographic distribution of suitable habitat for 27 species endemic to the Nuratau Mountains. All occurrence records used come from herbarium specimens stored in TASH, LE, MW and the Nuratau Nature Reserve, and from field observations by Natalya Beshko. These records were subjected to SpThin (Aiello-Lammens et al. 2015) to thin the occurrence points to a minimal neighbour distance of 1 km. The modelled area had the following spatial extent: longitude from 65 to 74E and latitude from 36 to 44N. For climate, we used 19

"Bioclim" variables (Hijmans et al. 2005) summarizing the temperature and precipitation dimensions of the environment. They were obtained from WorldClim 1.4 (Hijmans et al. 2005) with a resolution of 30″ latitude/longitude (ca. 1 km^2 at ground level). MAXENT v3.3.3 (Phillips et al. 2006; Phillips & Dudik 2008) was used to generate an estimate of the probability of species presence ranging from 0 to 1, where 0 is the lowest probability and 1 is the highest. In the analyses, where possible, we used 25% of the occurrences for testing under the 'crossvalidate' option. Model predictions in ASCII grid layer format were loaded into ArcGIS 10.2 to produce predicted species distribution maps. The Maxent model was then "projected" by applying it to the climatic conditions expected in year 2070 to assess the impact of climate change on the study species future distribution. The values for 19 climatic variables were those developed within the framework of the Coupled Model Inter-comparison Project Phase5 (CMIP5), using Representative Concentration Pathway 8.5 (RCP8.5) (Moss et al., 2008) and the General Circulation Model CCSM4 (US National Center for Atmospheric Research). RCP8.5 was chosen from the four existing Representative Concentration Pathways (RCP2.6, RCP4.5, RCP6, and RCP8.5) because it assumes the highest CO_2 concentrations in 2100 relative to the current CO_2 baseline of 1986-2005, that is predicts the most extreme future climate change. The produced area suitability maps identified suitable ranges for the species studied under current and expected future climate.

Both, current and future climate predictions were summarized by summing the cell values. Calculation of species suitability values per cell employed a minimum training presence threshold which sets the omission rate (i.e. a proportion of occurrence localities incorrectly classified as unsuitable for a species) to zero. In other words, neither training sample in any replicate run is outside the predicted range. The use of this threshold is justified when the number of occurrence records is very small and they are 100% trusted. Thus, for each species acell had a value of either 0 (unsuitable) or 1 (suitable). The produced maps were endemic species richness maps in which each cell value corresponded to the number of species predicted to occur in a cell. In other words, none of the training samples from a repeated run are outside the expected range. The use of this threshold is justified when the number of occurrence records is very low and they are 100% reliable. Thus, for each species, a cell had a value of 0 (unsuitable) or 1 (suitable). The maps produced were endemic species richness maps in which each cell value corresponded to the predicted number of species in a cell. In addition to the SDM analysis, we estimated for each species with GeoCAT (Geospatial Conservation Assessment Tool, https://geocat.kew.org/) its area of occupancy (AOO) and extent of occurrence (EOO), and accessed all studied species for their conservation status based on IUCN criteria (IUCN 2012). These, together with the SDM results, were used to make conservation recommendations.

Results

Current climate predictions

Of the species analyzed, 12 had occurrence records in the Nuratau Range only, five in the Aktau Range and the low insular mountains to the east and west of it, and nine in both ranges. The area occupied by *Iris hippolyti* and *Ferula helenae* is confined to small geological outcrops (the insular low mountain Kokcha and the Karatau Range at the south-western spurs of the Aktau Range and the insular low mountains Pistalitau, Balyklytau and Egarbelistag north of the Nuratau Range, respectively). *Autumnalia innopinata* grows in two valleys of Karatau, south-western spur of the Aktau Range. The number or records per species varied, after thinning, from three to 42, being on average 14.6 ± 12.7 (SD) (Table 1).

The accuracy of niche model predictions was high for all species (AUC >0.95 for training

Table 1. Study species names, number of occurrence records, conservation status and a proposed solution for each species based on the maps of predicted suitable habitat.

Species	Occurrences thinned (1km)	EOO, km^2	AOO, km^2	Estimated total population size	UzbRDB status	Status assessed using IUCN Categories and Criteria (2012)	Proposed solution
Acantholimon nuratavicum	37	452	132	10,000–30,000	2	VU B2ab(ii,iii,iv,v); C2a(i)	seed banking
Acantholimon subavenaceum	7	35	24	500–1,000	2	EN C2a(i)	translocation (Surkhan NR)
Acantolimon zakirovii	4	43	20	300–500	none	EN B2ab(ii,iii,iv); C2a(i)	translocation (Surkhan NR)
Allium svetlanae	3	12	12	5,000–10,000	none	EN B2ab(i,ii,iii)	translocation (new PA)
Arctium pallidivirens	32	3467	136	10,000-30,000	2	VU B2ab(ii,iii,iv,v); C2a(i)	translocation (Surkhan NR)
Astragalus nuratensis	7	87	28	500–1,000	1	EN C2a(i)	seed banking
Autumnalia innopinata	3	12	12	300–500	1	EN B2ab(ii,iii,iv,v); C2a(i)	seed banking
Cousinia botschantzevii	30	6088	116	5,000–10,000	none	VU C2a(i)	translocation (Surkhan NR)
Cousinia pseudolanata	3	12	12	300–500	1	EN B2ab(i,ii,iii,iv); C2a(i)	translocation (Surkhan NR)
Dianthus helenae	32	6099	128	10,000-50,000	none	NT	translocation (Surkhan NR)
Dracocephalum nuratavicum	10	305	40	5,000–10,000	none	VU B2ab(ii,iii,iv,v); C2a(i)	augmentation (Nuratau NR), translocation (Surkhan NR)
Eremurus nuratavicus	4	50	16	500–1,000	1	EN B2ab(ii,iii,iv,v); C2a(i)	translocation (new PA)
Ferula helenae	5	67	20	1,000–2,000	2	EN B2ab(ii,iii,iv,v); C2a(i)	augmentation (Nuratau NR), translocation (new PA)
Ferula nuratavica	5	67	20	1,000–2,000	none	EN B2ab(i,ii,iii,iv); C2a(i)	translocation (new PA)

Helichrysum nuratavicum	26	2645	100	2,500-3,000	2	VU B2ab(ii,iii,iv,v); C2a(i)	seed banking
Iris hippolyti	3	12	12	250–300	1	EN B2ab(ii,iii,iv,v); C2a(i)	seed banking
Jurinea zakirovii	7	183	24	300–500	1	EN B2ab(ii,iii,iv,v); C2a(i)	translocation (Surkhan NR)
Lagochilus olgae	23	212	84	2,000-2,500	2	EN B2ab(ii,iii,iv,v); C2a(i)	seed banking
Lagochilus proskorjakovii	9	33	24	300–500	1	EN B2ab(ii,iii,iv,v); C2a(i)	translocation (Surkhan NR)
Lappula nuratavica	9	44	36	1,000–1,500	2	EN C2a(i)	translocation (Surkhan NR)
Lepidium olgae	3	12	16	1,000–1,500	2	EN B2ab(ii,iii,iv,v); C2a(i)	translocation (new PA)
Oxytropis pseudorosea	31	2184	104	2,000-2,500	2	EN B2ab(ii,iii,iv,v); C2a(i)	translocation (Surkhan NR)
Parrya nuratensis	20	2031	76	2,500-3,000	none	VU B2ab(ii,iii,iv,v); C2a(i)	translocation (Surkhan NR)
Phlomis nubilans	11	2905	164	50,000–100,000	3	VU B2ab(ii,iii,iv,v); C2a(i)	seed banking
Phlomoides anisochila	42	47	36	500–1,000	2	EN B2ab(ii,iii,iv,v); C2a(i)	augmentation (Nuratau NR), translocation (Surkhan NR)
Salvia submutica	25	852	96	2,000-2,500	2	EN B2ab(ii,iii,iv,v); C2a(i)	seed banking
Thymus subnervosus	5	120	24	2,000-2,500	none	EN B2ab(ii,iii,iv); C2a(i)	translocation (new PA)

Abbreviations: EN endangered, VU vulnerable, NT near threatened, PA protected area, NR nature reserve, UzbRDB Red Data Book of Uzbekistan and testing). The 27 species analyzed can be classified, based on their predicted under current climate range, into the following categories (Fig. 2).

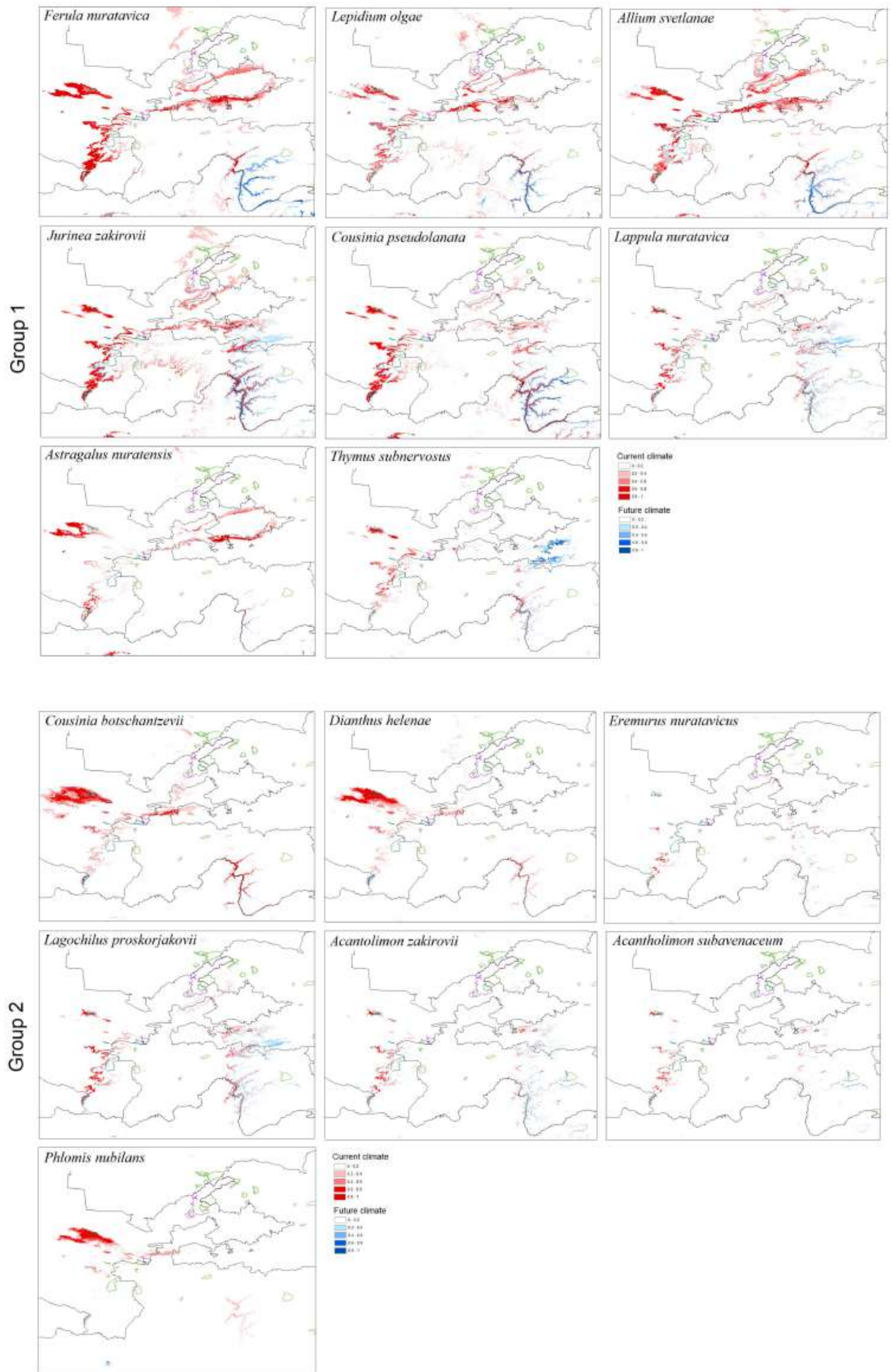

Fig. 2. Climatically suitable habitat predicted for 27 endemic species of the Nuratau Mountains under current and future (Rcp85) climate. Habitat suitability corresponds to the intensity of the color.

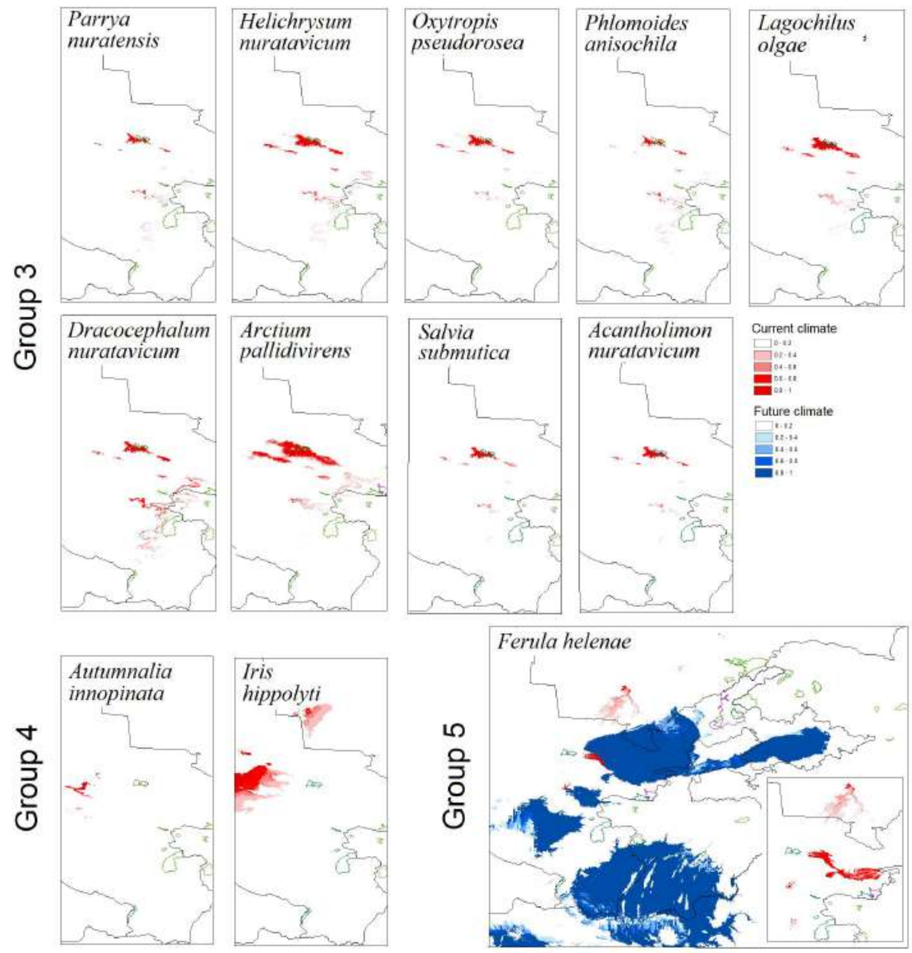

Fig. 2. (continued)

1. A potentially suitable range includes, in addition to the Nuratau and Aktau ranges, parts of the Zeravshan, Hissar and Kugitang ranges to the south, and of the Turkestan, Alay and Kurama ranges to the east and north (8 species – *Allium svetlanae*, *Astragalus nuratensis*, *Cousinia pseudolanata*, *Ferula nuratavica*, *Jurinea zakirovii*, *Lappula nuratavica*, *Lepidium olgae*, *Thymus subnervosus*).
2. The same as above but without the Alay range (*Cousinia botschantzevii* and *Dianthus helenae*) or without the Alay and Kurama ranges (*Phlomis nubilans*), or without the Turkestan range (*Eremurus nuratavicus* and *Lagochilus proskorjakovii*) or without the Turkestan and Kurama ranges (*Acantholimon subavenaceum* and *Acantolimon zakirovii*) (7 species).
3. A suitable range is confined to the Nuratau and Aktau ranges and parts of the Zeravshan and/or Turkestan and/or Hissar ranges (9 species – *Acantholimon nuratavicum*, *Arctium pallidivirens*, *Dracocephalum nuratavicum*, *Helichrysum nuratavicum*, *Lagochilus olgae*, *Oxytropis pseudorosea*, *Parrya nuratensis*, *Phlomoides anisochila*, *Salvia submutica*).
4. A suitable range is confined to south-western spurs of the Aktau range (*Autumnalia innopinata*) and some areas to the north (*Iris hippolyti*).
5. A suitable range is in foothills neighboring the Nuratau range (*Ferula helenae*).

The species comprising the first three groups are annuals, perennials and subshrubs occupying slopes above 700 m altitude, mainly between 1,300 to 2,100 m. One of these species occupies wet microhabitats such as swamp alluvial meadows and wet granite outcrops (*Allium svetlanae*). In contrast, the species from groups 4 and 5 occupy low mountain semi-deserts at an altitude below 800 m.

Of the two mountain ranges comprising the Nuratau Mountains, areas with high endemic species richness were primarily in the Nuratau Range, with very few such areas in the Aktau Range (Fig. 3). Surprisingly, large areas of high endemic species richness were found in the Zeravshan Range, indicating that its climatic conditions are similar to those of the Nuratau Mountains. In other mountain ranges south of the Nuratau Mountains, areas with high endemic species richness were present but their spatial extent was negligible.

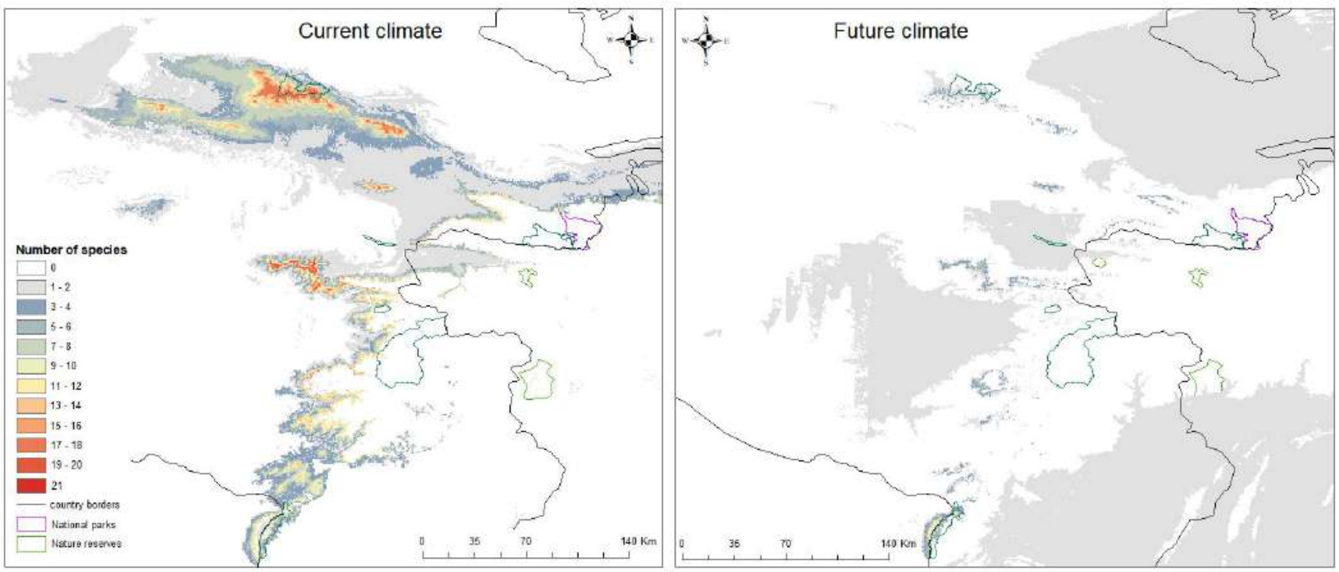

Fig. 3. Endemic species richness for the modelled area predicted under current and future (Rcp85) climatic conditions.

Among the 27 analysed species, all species from groups 3 and 4, and several species from group 2 (*Cousinia botschantzevii*, *Dianthus helenae*, *Phlomis nubilans*) appear to be the true Nuratau endemics because their predicted range is mostly or completely confined to the Nuratau Mountains. In contrast, all group 1 species and four out of seven species of group 2 have a wide predicted range, of which the Nuratau Mountains are only a small part.

Future climate predictions

The majority of Nuratau endemics will have no climatically suitable habitat under the Rcp85 scenario in the Nuratau Mountains or surrounding ranges (Fig. 2). Only seven species, *Dracocephalum nuratavicum*, *Cousinia botchanzevii*, *Arctium palidivirens*, *Phlomis nubilans*, *Oxytropis pseudorosea*, *Dianthius helenae* and *Ferula helenae*, will have suitable habitats within the Nuratau Mountains (Fig. 4). Among them, only the first five species will have suitable habitat in the only strictly protected area in this region (Nuratau Nature Reserve). For six species, *Acantholimon nuratavicum*, *Astragalus nuratensis*, *Autumnalia innopinata*, *Helichrysum nuratavicum*, *Lagochilus olgae*, and *Salvia* *submutica*, there will be no suitable area in the entire study area.

Surprisingly, under the Rcp85 scenario, 13 species will have suitable habitats in the Kugitang Range where the Surkhan Nature Reserve is located (Fig. 5).

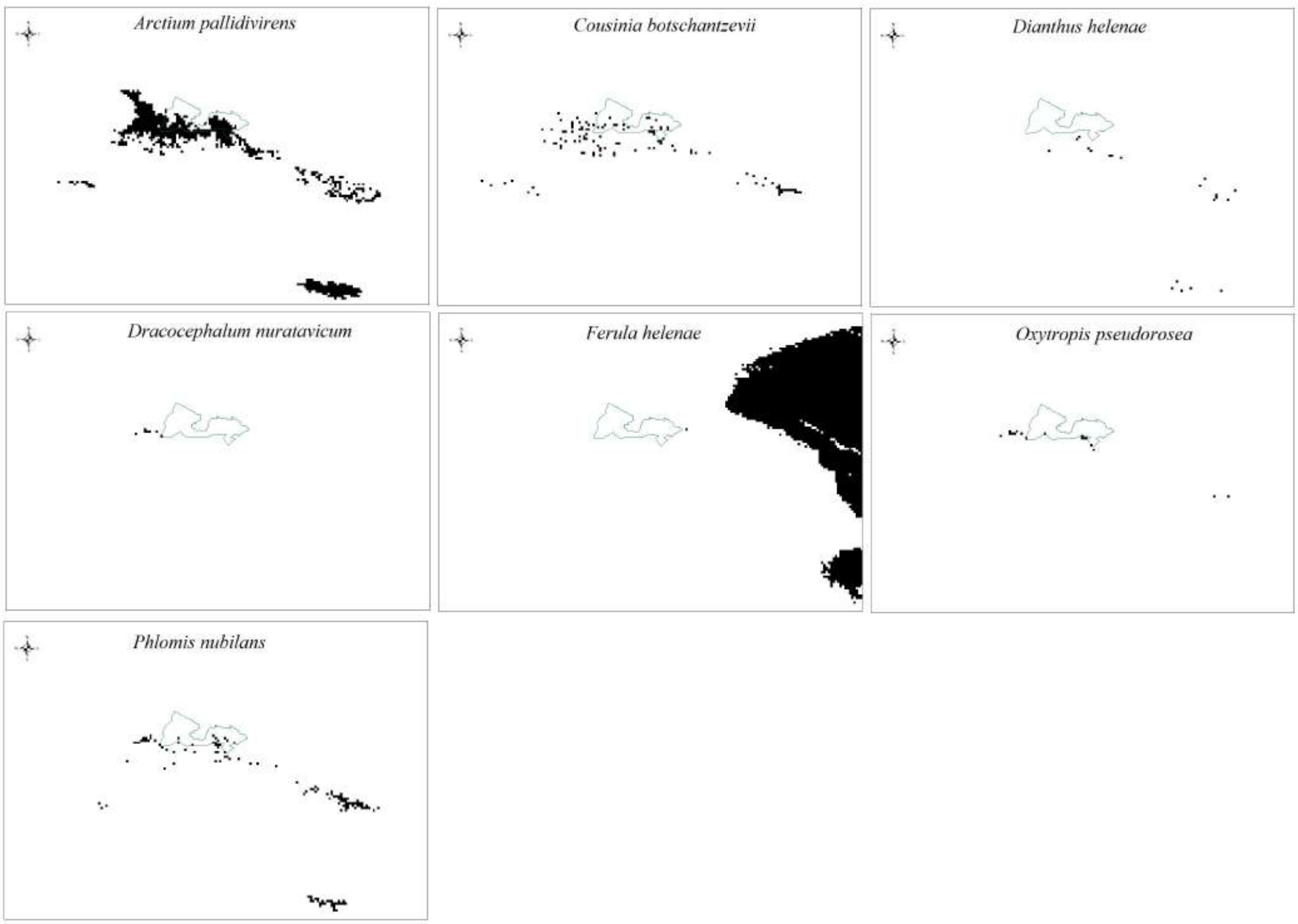

Fig. 4. Maps of suitable habitat under future (Rcp85) climatic conditions for those species that can be protected in Nuratau Nature Reserve.

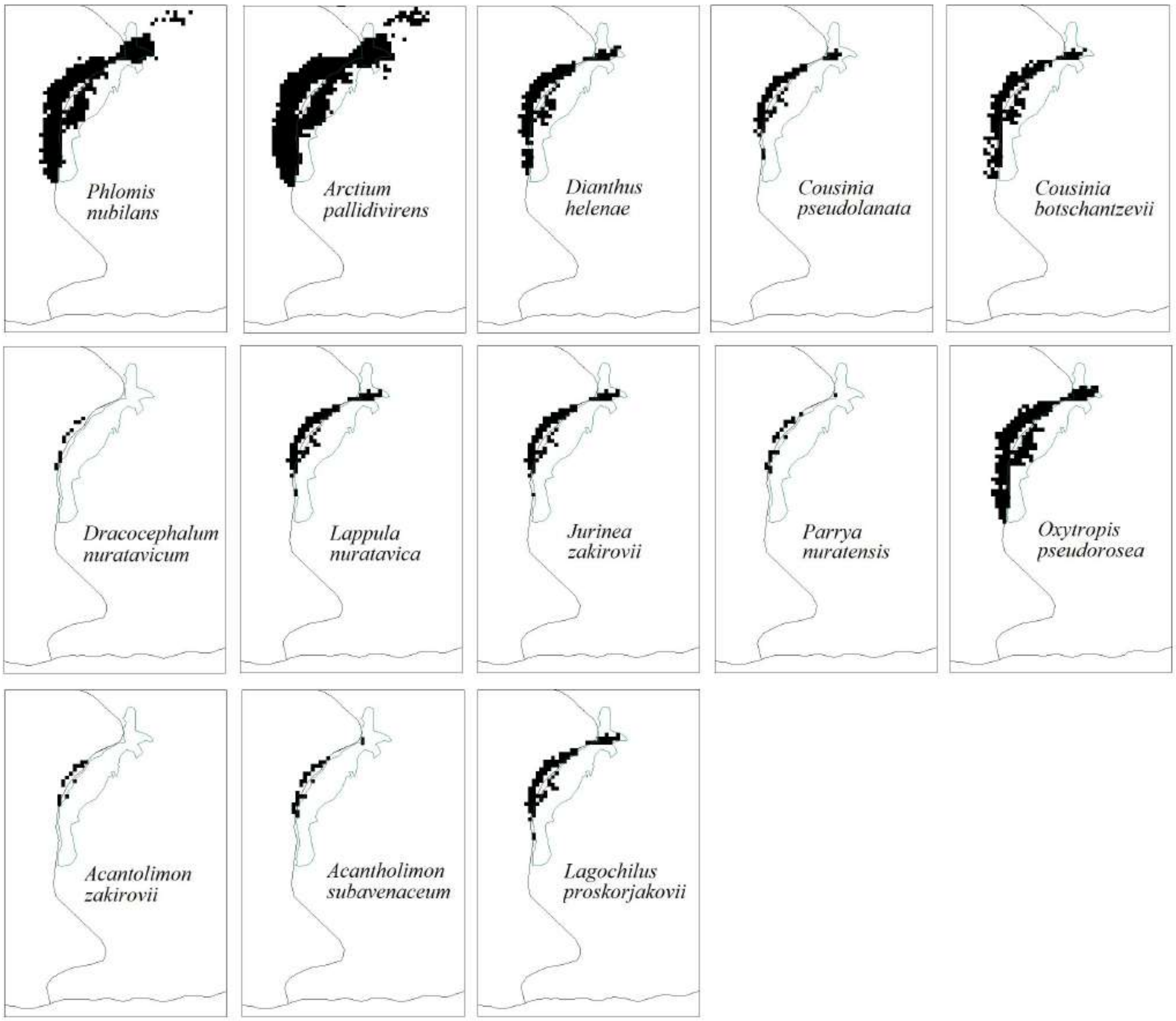

Fig. 5. Maps of suitable habitat under future (Rcp85) climatic conditions for those species that can be protected in Surkhan Nature Reserve.

Conservation implications

Based on population size, number of locations, AOO and EOO (IUCN 2012), all species studied fall into IUCN categories EN, VU or NT (19, 7 and 1 species, respectively, Table 1), which necessitates developing their conservation plans. Of the 27 endemic species, 20 occur in the Nuratau Nature Reserve. However, the endemic species richness map (Fig. 3) shows that areas with high predicted species richness cover less than half of the reserve territory, while large territories with potentially high species richness lie outside. This indicates that the design of the reserve is not optimal.

Taking into account the distribution of SDM-predicted suitable habitat under the climate change scenario, translocation to the Surkhan Nature Reserve is recommended for 13 species and to a new protected area – for 6 species. For two species that are predicted by SDM to retain their suitable habitat in the future in the Nuratau Mountains, but have a critically small AOO, we recommend augmentation of their extant populations. For seven species which, according to SDM, will have no suitable habitat anywhere in the study area, the only solution we have to propose is seed banking.

Discussion

As the climate warms, the climatically suitable range for species belonging to various taxonomic groups is predicted to shift towards higher latitudes and elevations (Parmesan & Yohe 2003; Parmesan 2006; Hickling et al. 2006), and among the world's ecosystems, mountain flora is particularly vulnerable to climate change (Beniston et al. 1996; Theurillat & Guisan 2001; Nogués-Bravo et al. 2007; Gottfried et al. 2012). Engler et al. (2011) predicted for 2632 plant species occupying European mountains that 36-55% of alpine species, 31-51% of subalpine species and 19-46% of montane species will lose more than 80% of their suitable habitat by 2070-2100. Dullinger et al. (2012) modelled the distribution of 150 high mountain plant species across the European Alps and found an average reduction in range size of 44-50% by the end of the 21st century. They also detected that population dynamics will lag behind climatic trends and that on average 40% of the range still occupied at the end of the 21st century will have become climatically unsuitable for the respective species, thus creating an extinction debt. No such study has been conducted in Central Asia. Even data on expected shifts of the altitudinal belt up mountain slopes in this region are available only for Kazakhstan and Kyrgyzstan, but not for Uzbekistan. In the mountains of Kazakhstan and Kyrgyzstan, the upper line of the steppe zone is expected to rise by 200-250 m, that of forests and meadows by 150 m, and the subalpine zone by 100 m. With global warming of 2 to 3°C, the steppe climate of the upper foothills of the Alatau Island ridge (North Tien Shan) will transform into a desert climate and the foothills currently covered with grasses and shrubs will turn into badlands (Dimeyeva et al. 2015). SDM predictions for endemic plants in the Nuratau Mountains were consistent with these expected dramatic changes in vegetation, being also dramatic and more severe than the predicted changes in European mountains. A factor that exacerbated the situation was the isolation of the Nuratau Mountains from other ranges. Species endemic to isolated mountain ranges are known to be particularly vulnerable as they are likely to face insurmountable barriers to dispersal and lack of suitable areas for range adjustment, which makes their chances of survival gloomy (Williams et al. 2003; Ohlemüller et al. 2008; Dirnböck et al. 2011).

In our study, of the 27 endemic species analyzed, 26 are predicted to have no suitable habitat in the area they currently occupy, and their potentially suitable areas been hundreds of kilometres away or not existent. Because the current ranges of these species are surrounded by environments that have been totally transformed or fundamentally unsuitable for them, they cannot be rescued by 'connecting up' the landscape between the area they occupy and potential habitats elsewhere. It is therefore impossible to disagree with Thomas (2011) who wrote that "increasing the dispersal capacity of endangered species might represent the most effective climate change adaptation strategy available to conservationists who wish to reduce extinction rates". In practical terms this means that we must begin the introduction trials of the target species outside their natural range. The locations can be in botanical gardens as a temporal solution, but most importantly, they must primarily include in situ locations. For 13 out of 26 Nuratau endemics, climatically suitable habitat for the future climate was predicted to be in the Surkhan Nature Reserve located in Kugitang Range. To divert these species from their current path to extinction, we need to start seed collecting, propagating and introduction of propagated material into the Surkhan Reserve area, ideally as a replicated experiment over a variety of microhabitats. Unlike these 13 species, for six species whose climate space has been projected to disappear entirely (*Acantholimon nuratavicum*, *Astragalus nuratensis*, *Autumnalia innopinata, Helichrysum nuratavicum, Lagochilus olgae, Salvia submutica*), the situation is much more dramatic, but some of these species could still survive if suitable conditions exist outside the region modelled, i.e. in eastern Tajikistan or Kyrgyzstan. In any case, a general climate change adaptation strategy for Nuratau endemics is to artificially increase their dispersal capacity via in situ introduction trials. Analysis of the suitable range under the current climate revealed several groups of species whose suitable range is much larger than that occupied and extends far away into the other mountain ranges that stretch across Uzbekistan, Kyrgyzstan and Tajikistan. At least some of these species apparently once had a wider range than today, but past climatic oscillations and, most importantly, human activity, have caused these species to become extinct outside of the Nuratau Mountains. Supporting this view is the fact that the area covered by vegetation is steadily decreasing in the Nuratau Mountains and that the plains and foothills surrounding this area are today almost entirely devoid of vegetation due to the tremendous grazing pressure. Even within the Nuratau Nature Reserve, domestic livestock grazing is common and signs of ecosystem degradation are visible across most of its territory. Thus, the involvement of humans in the disappearance of many species that are now Nuratau endemics from other places seems highly plausible. For these species, introduction trials have a higher probability of success than for species whose predicted suitable range is narrowly confined to the Nuratau Mountains.

In conclusion, the analyzed case of a group of endemics inhabiting isolated mountain system surrounded by environments that are fundamentally unsuitable for them demonstrate that for the vast majority of these species the effects of predicted warming will be catastrophic, and that the environments suitable for them under the predicted future climate will be both far away and very localized spatially. This implies that the most appropriate climate change adaptation strategy for narrow endemics is creation of populations in carefully chosen (using SDM predictions and expert knowledge) new locations, and seed banking when no such locations are predicted to exist.

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Appendix. Full list of the Nuratau Mountains endemic plant species and the information about their life form, habitat, type of endemism, origin time and number of occurrence records.

Species	Family	Life form	Habitat	Altitude range, m.s.l.	Occurrence records
Acantholimon nuratavicum Zakirov	Plumbaginaceae	pulvinate subshrub, chamaephyte	dry stony, shistaceous, fine-earth-shistaceous slopes, plateaus and watersheds, communities of mountain xerophytes and mountain steppes, rarely open xerophilous shrublands	1300-2100	87
Acantholimon subavenaceum Lincz.	Plumbaginaceae	pulvinate subshrub, chamaephyte	dry stony, shistaceous, fine-earth-shistaceous slopes, plateaus and watersheds, communities of mountain xerophytes and mountain steppes, rarely open xerophilous shrublands	1400-2000	13
Acantolimon zakirovii Beshko	Plumbaginaceae	pulvinate subshrub, chamaephyte	dry stony, shistaceous, fine-earth-shistaceous slopes, plateaus and watersheds, communities of mountain xerophytes and mountain steppes, rarely open xerophilous shrublands	1500-2100	6
Allium aktauense F.O. Khass. & Esankulov	Amaryllidaceae	bulbous perennial, geophyte	stony and shistaceous slopes and watersheds	1400-1600	1
Allium habibii F.O. Khass.	Amaryllidaceae	bulbous perennial, geophyte	shady places under rocks	800-1000	1
Allium svetlanae Vved. ex Filim.	Amaryllidaceae	bulbous perennial, geophyte	swamp alluvial meadows, wet granite rocks	1200-1500	5
Arctium pallidivirens (Kult.) S. Lopez, Romanschenko, Susanna & N. Garcia	Asteraceae	perennial, hemicryptophyte	dry stony, shistaceous, fine-earth slopes, open xerophilous shrublands, mountain steppes	700-1800	50
Astragalus nuratensis Popov	Fabaceae	perennial, hemicryptophyte	stony slopes, rocks, dry riverbeds	700-1800	7

Astragalus saidii F.O.Khass. & Esankulov	Fabaceae	perennial, hemicryptophyte	stony slopes, rocks	1000-1300	1
Autumnalia innopinata Pimenov	Apiaceae	perennial, monocarpic, hemicryptophyte	dry stony and shistaceous slopes, open xerophilous shrublands, low mountain semidesert	650-800	8
Cousinia botschantzevii Juz. ex Tscherneva	Asteraceae	biennial, therophyte	stony, shistaceous, fine-earth slopes, open xerophilous shrublands, mountain steppes	900-2100	32
Cousinia pseudolanata Popov ex Tscherneva	Asteraceae	perennial, hemicryptophyte	dry stony and shistaceous slopes, screes, open xerophilous shrublands, petrophytes	1500-2000	8
Dianthus helenae Vved.	Caryophyllaceae	perennial, hemicryptophyte	stony, shistaceous, fine-earth slopes, open xerophilous shrublands, mountain steppes	700-2100	34
Dracocephalum nuratavicum Adylov	Lamiaceae	subshrub, chamaephyte	dry stony, shistaceous slopes and watersheds, rocks, communities of petrophytes, mountain xerophytes and mountain steppes	1300-2100	18
Eremurus nuratavicus Khohkr.	Asphodelaceae	perennial, geophyte	stony and fine-earth slopes, mountain steppes	1800-2100	6
Ferula helenae Rakhmankulov & Melibaev	Apiaceae	perennial, monocarpic, hemicryptophyte	stony, shistaceous and fine-earth slopes, open xerophilous shrublands, low mountain semidesert	500-800	6
Ferula nuratavica Pimenov	Apiaceae	perennial, polycarpic, hemicryptophyte	stony slopes, rocks	900-1600	5
Helichrysum nuratavicum Krasch.	Asteraceae	perennial, hemicryptophyte	stony, shistaceous, fine-earth slopes, rocks, open xerophilous shrublands, mountain steppes	1500-2100	37
Iris hippolyti (Vved.) Kamelin	Iridaceae	bulbotuberous perennial, geophyte	stony, shistaceous, fine-earth slopes, open xerophilous shrublands, low mountain semidesert	400-800	5
Jurinea zakirovii Iljin	Asteraceae	perennial, hemicryptophyte	stony, shistaceous, fine-earth slopes, open xerophilous shrublands, mountain steppes	1500-2100	11
Lagochilus olgae Kamelin	Lamiaceae	subshrub, chamaephyte	stony, shistaceous slopes, open xerophilous shrublands, mountain steppes	1300-1800	42
Lagochilus proskorjakovii Ikramov	Lamiaceae	subshrub, chamaephyte	dry stony, shistaceous slopes and watersheds, rocks, screes, communities of petrophytes, mountain xerophytes and mountain steppes	1400-2100	24

Lappula nuratavica Nabiev & Zakirov	Boraginaceae	annual, biennial, therophyte	stony slopes, rocks	1500-2100	18
Lepidium olgae (R.M.Vinogr.) Al-Shehbaz & Mumm.	Brassicaceae	perennial, hemicryptophyte	stony, shistaceous slopes, open xerophilous shrublands	1000-1400	9
Oxytropis pseudorosea Filim.	Fabaceae	perennial, hemicryptophyte	stony, shistaceous, fine-earth slopes, open xerophilous shrublands, mountain steppes, mountain xerophytes	1200-2100	71
Parrya nuratensis Botsch. & Vved.	Brassicaceae	subshrub, chamaephyte	stony, shistaceous, fine-earth slopes, rocks, open xerophilous shrublands, mountain steppes, petrophytes	1300-2100	28
Phlomis nubilans Zakirov	Lamiaceae	perennial, hemicryptophyte	stony, shistaceous, fine-earth slopes, open xerophilous shrublands, mountain steppes	800-2100	68
Phlomoides anisochila (Pazij & Vved.) Salmaki	Lamiaceae	perennial, hemicryptophyte	stony, shistaceous slopes, watersheds, rocks, mountain steppes, communities of mountain xerophytes and petrophytes	1600-2100	33
Salvia submutica Botsch. & Vved.	Lamiaceae	perennial, hemicryptophyte	stony, shistaceous slopes, watersheds, rocks, mountain steppes, communities of mountain xerophytes and petrophytes, rarely open xerophilous shrublands	1300-2100	67
Silene nuratavica Kamelin	Caryophyllaceae	perennial, hemicryptophyte	stony slopes, rocks	1000-1500	2
Thymus subnervosus Vved., Nabiev & Tulyag.	Lamiaceae	subshrub, chamaephyte	stony and fine-earth slopes, rocks, mountain steppes, petrophytes	1400-2000	6
Vicoa krascheninnikovii Kamelin	Asteraceae	perennial, hemicryptophyte	stony slopes, rocks	100-1200	1