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 consequences of the 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. From the obtained information 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 future warming. Among 27 studied species, 14 appear to be the true narrow endemics because their predicted range is mostly or totally confined to the Nuratau Mountains. The remaining species have a wide predicted range of which the Nuratau Mountains are only a small part. Majority of the Nuratau endemics will have no climatically suitable habitat under the Rcp85 scenario in the Nuratau Mountains or surrounding ranges. Only seven species will have suitable habitats within the Nuratau Mountains and only five of them will have suitable habitat within the protected territory of the Nuratau Nature Reserve. For six species there will be no suitable area in the whole study area. Surprisingly, 13 species will have a suitable habitat in the Kugitang Range where Surkhan Nature Reserve is located. We suggest as the most appropriate climate change adaptation strategy for these Nuratau endemics the artificial increasing their dispersal capacity via in situ introduction trials and the creation of new populations in Surkhan Nature Reserve.

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 usually defined as those with "small range, narrow habitat specificity" (Kruckeberg & Rabinowitz 1985) and such species usually have higher probabilities 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). The areas identified for conservation on the basis of high levels of endemism were shown to contain a greater proportion of overall species richness than did the species richness hotspots and a greater proportion of threatened species than did the threat hotspots (Orme et al. 2005). The recognized causes of endemism are geological events that occurred discontinuously over time and space, and discrete habitats created by topographic, lithological, and pedological discontinuities at the finer scale.

Besides understanding the causes of endemism and rarity, it is important to analyze for endemic species the possible effects of climate change. It has been shown that extinction potential of climate change is very high, and in general the smaller the geographic extent of a species distribution, the higher the fraction of range displacement as a consequence of warming (Thomas et al. 2004; Schwartz et al. 2006). Therefore, 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 certain species because narrowly distributed species are probably a mixed suite of species, and while many of them are stenotopic some once had much larger ranges but due to anthropogenic activities survived only in the most inaccessible or well protected areas (Volis & Tojibaev 2021). This implies 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 also included in the list of Key Biodiversity Areas (CEPF 2017). This area is rich in endemic plants with the rate of endemism 2.7%. Out of 1180 native species from 444 genera and 81 families that grow there, 32 species from 13 families are endemics (Appendix), and 18 of them are included 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.

Endemic flora of the Nuratau Mountains is a result of their specific geographic location, geological history and natural conditions that significantly differ from the 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, and the proximity of this desert is responsible for low (in comparison with the other mountains) precipitation in this region and predominance of xerophitic vegetation. Such features of this area as low altitude, small area and already low precipitation make the Nuratau Mountains especially vulnerable to aridification predicted for Central Asia by all existing climatic models (Lioubimtseva & Henebry 2009). Especially disturbing fact is that the only strictly protected area in this region, the Nuratau Nature Reserve, is 177.52 km^2 covering very small part (1.27%) of the Nuratau phytogeographical district territory (Tojibaev et al., 2017).

To understand consequences of the climate change for a group of endemics occupying 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 obtained information 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.

Materials And Methods

Study area

The Nuratau Mountains are located at the north-western spurs of the Turkestan Range, one of mayor ranges of the Pamir-Alay system in Central Asia. They are surrounded from the north, west and south-west by the huge desert Kyzylkum and stretch ca. 250 km in the sub-latitudinal direction along the right bank of the Zeravschan River. They occupy the area of ca. 14,000 km^2. There are two parallel medium-altitude mountain ranges, Nuratau (about 200 km long, 2,169 m) on the north and Aktau (about 100 km long, 1,993 m) on 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 formed 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 Nuratau dictrict of Mountain Central Asian province of the Irano-Turanian region of Tethyan (Ancient Mediterranean) floristic subkingdom of Holarctic (Takhtadzhi a n 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 among the 36 recognized Key Biodiversity Areas in Uzbekistan; one of them (UZB 24 - Nuratau Ridge) is a priority KBA (CEPF 2017). The 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 the 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 plant in this region are grazing, agriculture, mining and quarrying leading to the habitat degradation and loss, and the aridification caused by the climate change.

Analysis

We used species distribution modelling to predict the geographic distribution of suitable habitat for 27 endemic species of the Nuratau Mountains. All the occurrence records used are from the herbarium specimens stored in TASH, LE, MW and Nuratau Nature Reserve, and from the field observations by Natalya Beshko. These records were subjected to SpThin (Aiello-Lammens et al. 2015) to thin the occurrence points to a minimal neighbor distance of 1 km. The modelled area had the following spatial extent: longitude from 65 to 74°E, and latitude from 36 to 44°N. For climate, we used 19 “Bioclim” variables (Hijmans et al. 2005) summarizing 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 that varies from 0 to 1, where 0 is the lowest and 1 is the highest probability. In analyses, when possible, we used 25% of the occurrences for testing under the 'crossvalidate' option. Model predictions in ASCII grid layer format have been uploaded to 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 under the framework of the Coupled Model Inter-comparison Project Phase5 (CMIP5), using Representative Concentration Pathway 8.5 (RCP8.5) (Moss et al., 2008) and General Circulation Model CCSM4 (US National Center for Atmospheric Research). The RCP8.5 was chosen among 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, i.e. predicts the most extreme future climate change. The produced maps of area suitability identified the suitable for the study species ranges under the present and expected in the future climate.

Both, current and future climate predictions were summarized by summing the cell values. The 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 a cell 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 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). The latter, together with the SDM results, were used to make conservation recommendations.

Results

Current climate predictions

From the analyzed species, 12 had occurrence records in Nuratau Range only, five in Aktau Range and the low insular mountains 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 (insular low mountain Kokcha and range Karatau at the south-western spurs of Aktau Range and insular low mountains Pistalitau, Balyklytau and Egarbelistag north of Nuratau Range, respectively). *Autumnalia innopinata* grows in two valleys in Karatau, south-western spur of 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).

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)

Abbreviations: EN endangered, VU vulnerable, NT near threatened, PA protected area, NR nature reserve, UzbRDB Red Data Book of Uzbekistan

Species	Occurrences thinned (1km)	EOO, km²	AOO, km²	Estimated total population size	UzbRDB status	Status assessed using IUCN Categories and Criteria (2012)	Proposed solution
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

Abbreviations: EN endangered, VU vulnerable, NT near threatened, PA protected area, NR nature reserve, UzbRDB Red Data Book of Uzbekistan

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
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							

The accuracy of niche model predictions was high for all species (AUC > 0.95 for both training and testing). The analyzed 27 species can be classified, according to their predicted under current climate range, into the following categories (Fig. 2).

1. A potentially suitable distribution area includes, in addition to Nuratau and Aktau ranges, parts of Zeravshan, Hissar and Kugitang ranges to the south, and of 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 Alay Range (*Cousinia botschantzevii* and *Dianthus helenae*) or without Alay and Kurama ranges (*Phlomis nubilans*), or without Turkestan Range (*Eremurus nuratavicus* and *Lagochilus proskorjakovii*) or without Turkestan and Kurama ranges (*Acantholimon subavenaceum* and *Acantolimon zakirovii*) (7 species).
3. Suitable range is confined to Nuratau and Aktau ranges and parts of 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. Suitable range is confined to south-western spurs of Aktau Range (*Autumnalia innopinata*) and some areas upnorth (*Iris hippolyti*).
5. Suitable range is in foothills neighboring Nuratau range (*Ferula helenae*).

The species comprising the first three groups are annuals, perennials and subshrubs occupying slopes at the altitudes above 700 m, mostly in the range from 1300 to 2100 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 semideserts at the altitude below 800 m.

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

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

Future climate predictions

Majority of the Nuratau endemics will have no climatically suitable habitat under the Rcp85 scenario in the Nuratau Mountains or surrounding them 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). Of them, only the first five species will have suitable habitat within 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 whole study area.

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

Conservation implications

Based on population size, number of locations, AOO and EOO (IUCN 2012), all study species fall into either EN, VU or NT category of IUCN (19, 7 and 1 species, respectively, Table 1), which necessitates developing their conservation plans. From the 27 analyzed endemic species, 20 occur in Nuratau Nature Reserve. However, endemic species richness map (Fig. 3) shows that areas with the 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 reserve design is not optimal.

Taking into account the distribution of the SDM-predicted suitable habitat under the climate change scenario, translocation to 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 are predicted by SDM to 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 from a variety of 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 distribution of 150 high mountain plant species across the European Alps and found on average range size reductions of 44–50% by the end of the 21st century. He also detected that population dynamics will lag behind climatic trends and that an average of 40% of the range still occupied at the end of the 21st century will have become climatically unsuitable for the respective species, creating an extinction debt. No such studies have been conducted in Central Asia. Even the data on expected altitudinal belt shifts upward the mountain slopes in this region we have only for Kazakhstan and Kyrgyzstan but not for Uzbekistan. In mountains of Kazakhstan and Kyrgyzstan, it is expected that the upper line of steppe belt is going to rise by 200–250 m, forest and meadows – by 150 m, and subalpine belt – by 100 m. With global warming by 2–3°C, the steppe climate of the upper foothill level of Ile Alatau ridge (North Tien Shan) will transform into a desert one and the foothills that currently are covered with herbs and shrubs will turn into badlands (Dimeyeva et al. 2015). The SDM predictions for the Nuratau Mountains endemic plants were consistent with these expected dramatic changes in vegetation, being also dramatic and more severe than predicted changes in European mountains. A factor that exacerbated the situation was an isolation of the Nuratau Mountains from the other chains. It is known that species that are endemic to the isolated mountain ranges are specially vulnerable because they are likely to face the insurmountable barriers to dispersal and lack of suitable area for their range adjustment, which makes their chances of survival gloomy (Williams et al. 2003; Ohlemüller et al. 2008; Dirnböck et al. 2011).

In our study, from the 27 analyzed endemic species, 26 were 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 are 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. Therefore, it is 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 need to start 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 include *in situ* locations. For 13 out of 26 Nuratau endemics the climatically suitable habitat under expected in the future climate was predicted to be in 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 the propagated material into the Surkhan reserve area, ideally as the replicated experiment over a variety of microhabitats. In contrast to 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 might still be able to 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 the artificial increasing their dispersal capacity via in situ introduction trials.

Analysis of the suitable range under current climate revealed several groups of species which suitable range is much larger that the 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 larger range than today but the past climate oscillations and most importantly, human activity, caused extinction of these species outside the Nuratau Mountains. What supports this view is the fact that the area covered by vegetation is steadily decreasing in the Nuratau Mountains, and the plains and foothills surrounding this area are nowadays almost completely devoid of vegetation due to tremendous grazing pressure. Even within Nuratau nature reserve, grazing by domestic livestock is common and signs of ecosystem degradation can be seen in most of its territory. Thus, involvement of the humans in disappearance of many species which today are the Nuratau endemics from other places seems highly plausible. For these species introduction trials have a higher probability of success than for those species which 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.

Declarations

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Ethical Approval

N/A

Competing interests

The authors declare no competing interests

Authors' contributions

Data preparation, NB; analyses, writing SV; figure preparation and text editing NB and SV

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Data are available on request

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Figures

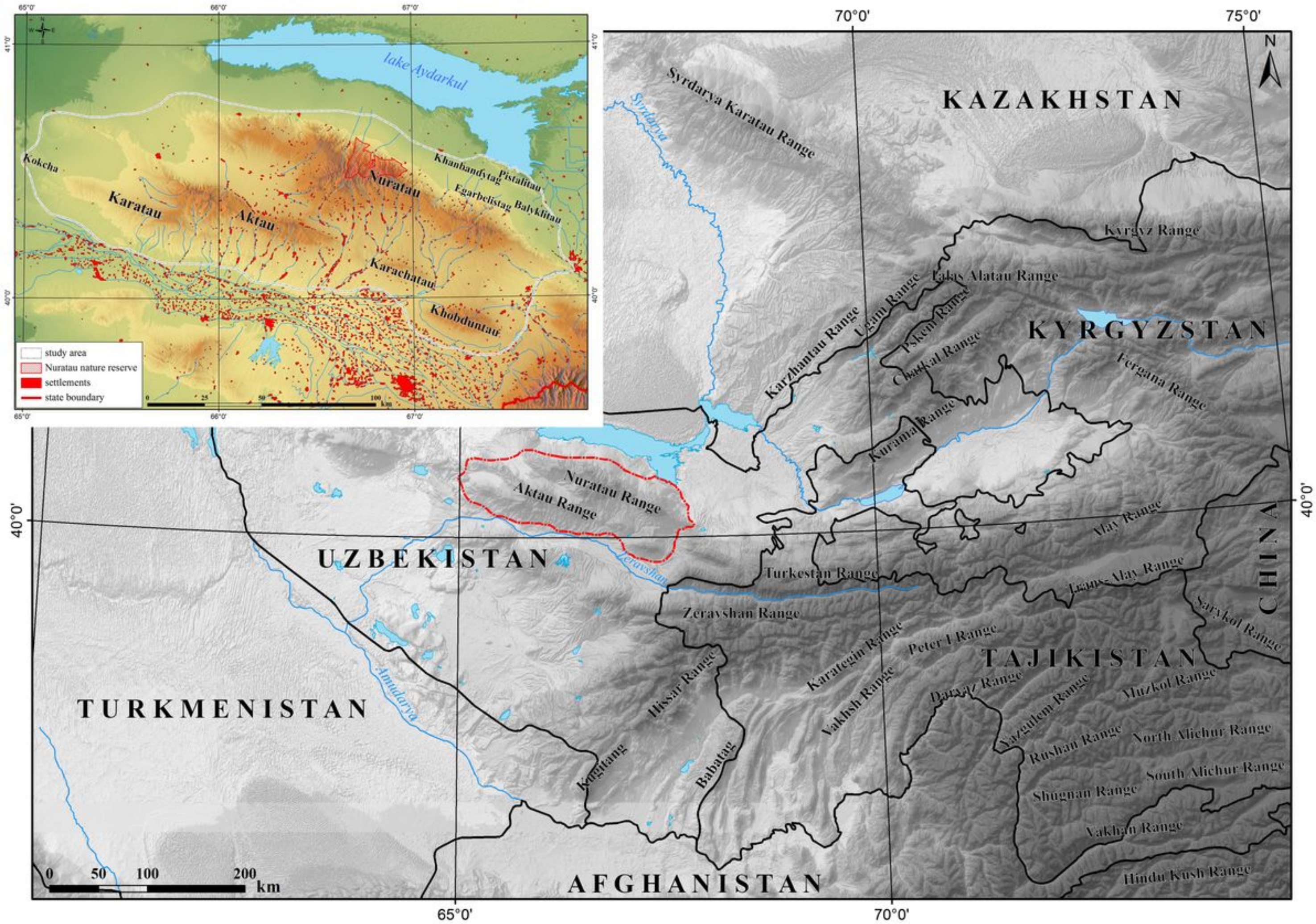

Figure 1

Orographic map of the study region and surrounding it area.

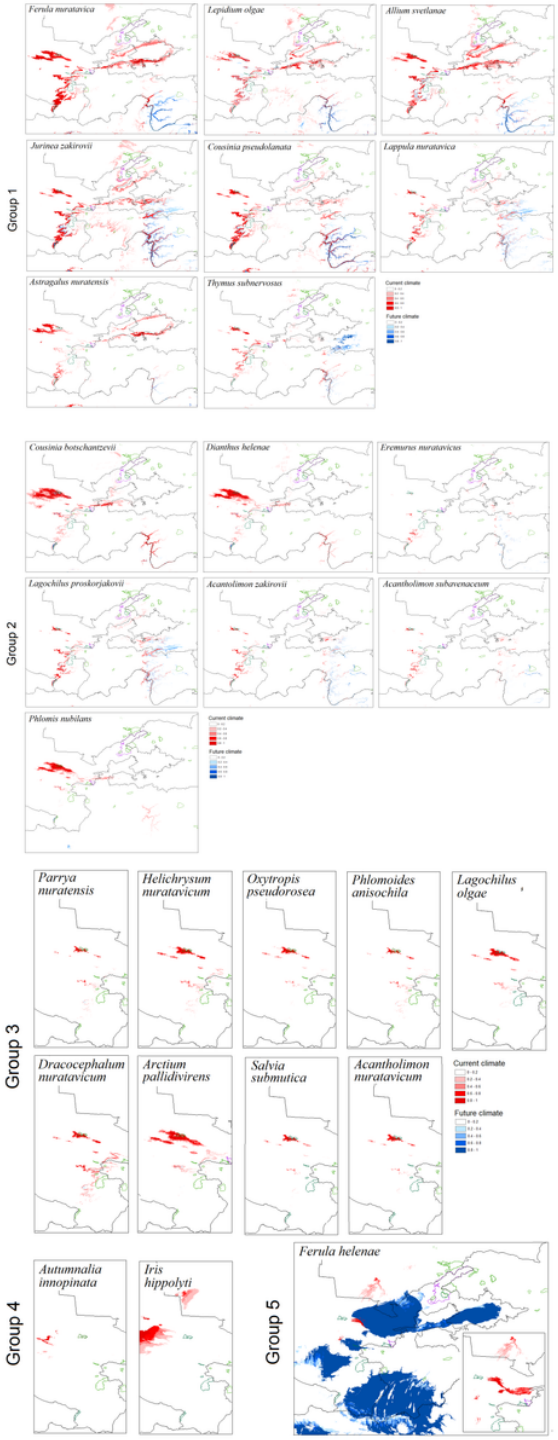

Figure 2

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.

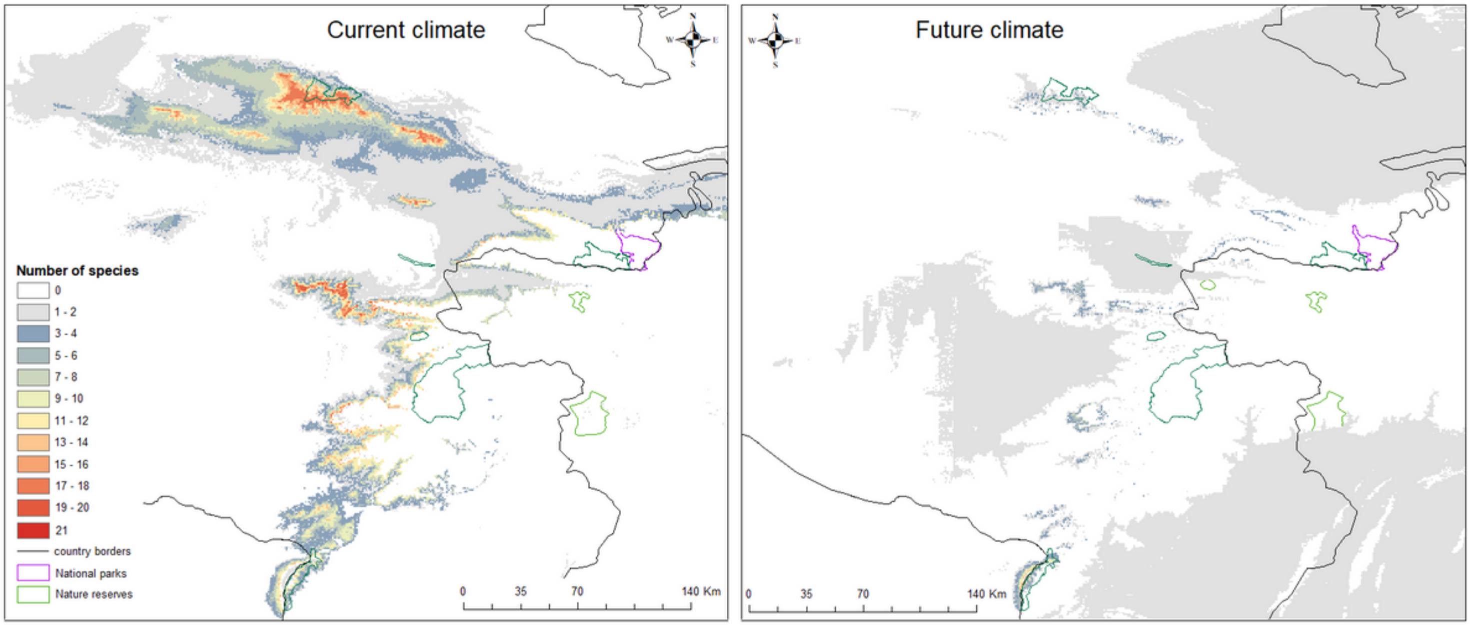

Figure 3

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

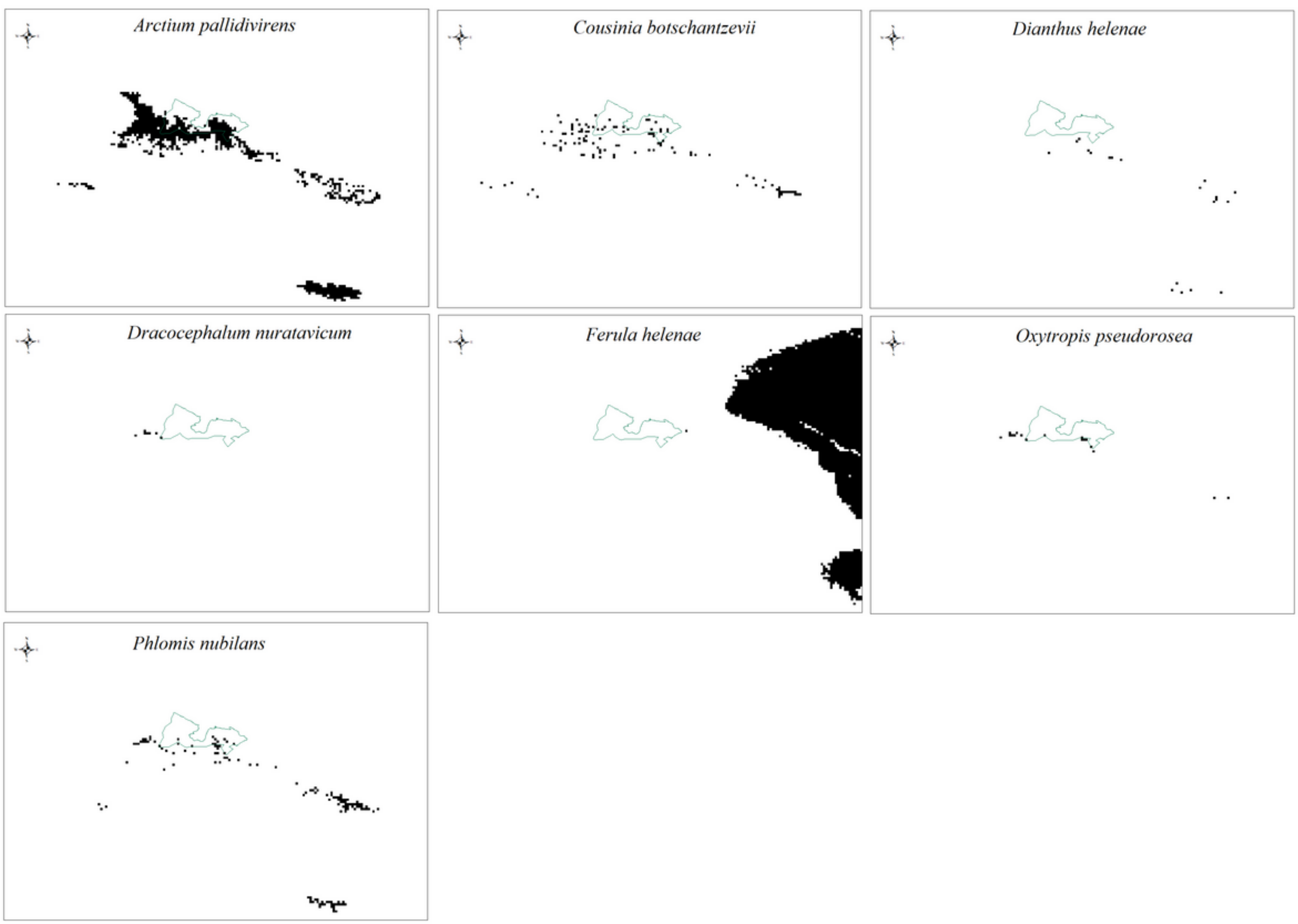

Figure 4

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

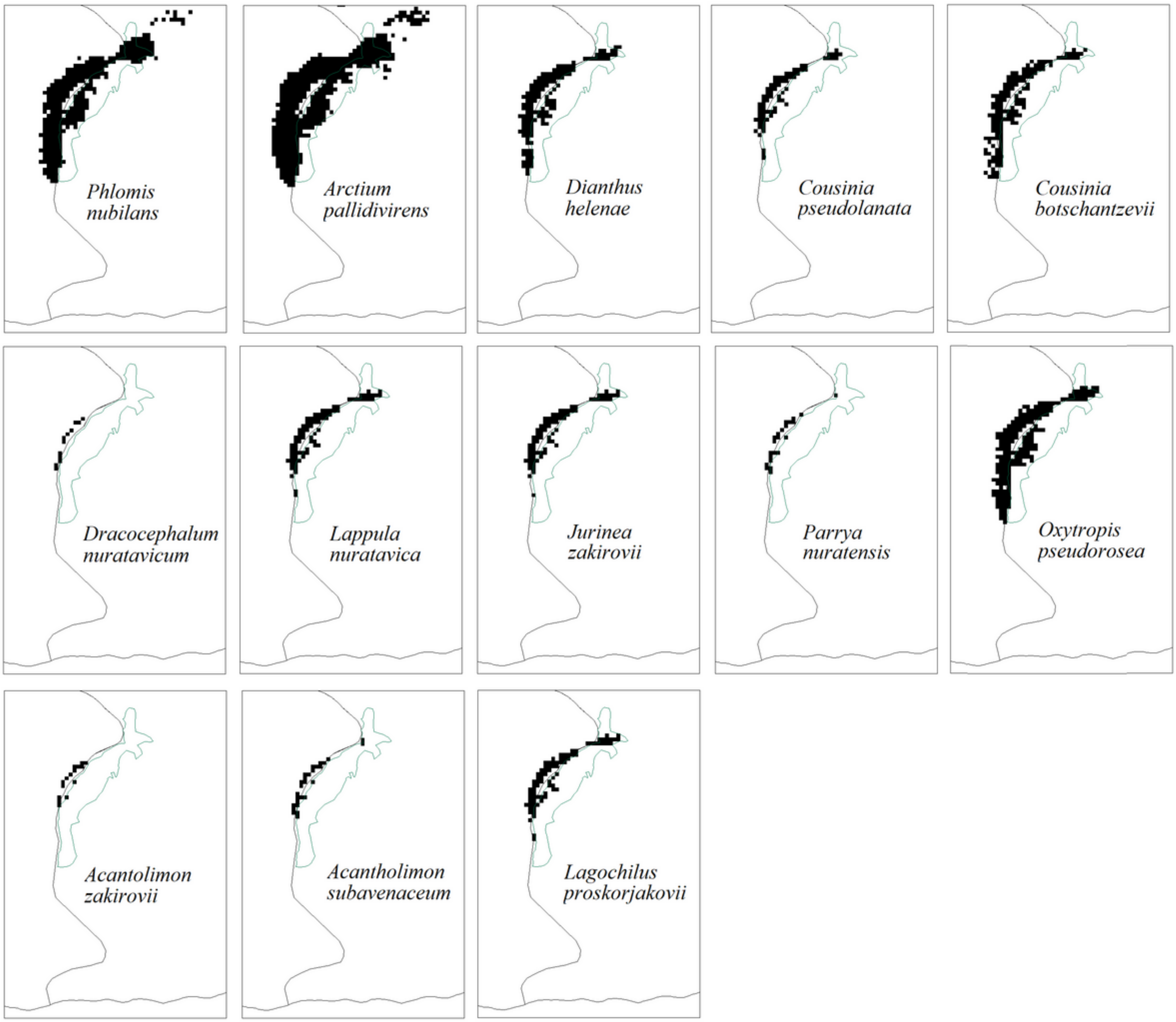

Figure 5

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