Acta Societatis Botanicorum Poloniae

ORIGINAL RESEARCH PAPER Acta Soc Bot Pol 83(2):123–135 DOI: 10.5586/asbp.2014.010
Received: 2013-12-08 Accepted: 2014-04-14 Published electronically: 2014-07-04

Distribution, ecology and conservation status of *Dionysia involucrata* Zaprjag., an endangered endemic of Hissar Mts (Tajikistan, Middle Asia)

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Abstract

Dionysia involucrata Zaprjag. (Primulaceae) is known as critically endangered endemic species of Hissar Mountains in Tajikistan. It is reported from few localities mainly in Varzob River valley and its tributaries. The species inhabits steep or overhanging faces of granite rocks in narrow river gorges. During the research all known populations of *D. involucrata* were examined in respect of the habitat conditions and species composition of vegetation plots. We analyzed the population extent of the species in its range in Tajikistan and the main threats in order to assess its conservation status. The detrended correspondence analysis was performed on a matrix of 65 relevés and 49 species (vascular plants and mosses), to classify the phytocoenosis with domination of *D. involucrata* according to their floristic composition in relation to other petrophytic vegetation units. Using our field data regarding present extent of occurrence and area of occupancy we conclude that the threat category of *D. involucrata* should be reassessed from critically endangered to endangered. The species shows decline tendency in extent of occurrence, area of occupancy as well as in number of locations. The vegetation plots with domination of *D. involucrata* have relatively high level of separateness due to different species composition. We define the new association – *Dionysietum involucratae* – representing chasmophytic vegetation of submontane and montane zone in Middle Asia (ca. 1000–1600 m a.s.l.). The plots of *Dionysietum involucratae* were found mainly on granite rocks, on very steep or overhanging faces, on southwestern or southern exposition. The association is rather poor in species with inconsiderable contribution of mosses. Despite the diagnostic species, *Campanula incanescens*, *Carex koshewnikowii* and *Scutellaria hissarica* were the most abundant and frequent taxa within the researched patches of vegetation.

Keywords: endangered species; Pamir Alai Mts; cliff vegetation; chasmophytes; petrophytes; phytosociology; syntaxonomy; Tadzhikistan

Introduction

The loss of biodiversity is of primary concern to the international scientific community, the government agencies responsible for the sustainable use of natural resources at global level and non-governmental organizations alike. The precise evaluation of the conservation status of a particular species is a requirement crucial to the successful prevention its extinction. To this end, the determination of threat degree or, alternatively, the expectation of survival of taxa to which a special significance is attributed is crucial. The biogeographical and ecological features of rare or endemic taxa have been the subject of preferential attention by conservationists [1,2] because they appear to be more exposed to threats. One way of risk assessment is to assign a given taxon to a particular standardized threat category. The IUCN red list categories [3] were defined for this purpose.

Tajikistan is a typical mountainous country located in the central part of the Pamir Alai mountain system. Its vascular plant flora is relatively species-rich, including around 4550 taxa [4]. Results of recent studies have shown that this number is not final, as some taxa new to the Tajik flora have been reported [5–9]. Approximately 30% of vascular plant species known from Tajikistan are generally accepted as endemics [4]. It is worth mentioning that Pamir Alai, belongs to the

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Handling Editor: Zygmunt Dajdok

central Asian mountain system recognized by Conservation International as one of thirty-four biodiversity hotspots [10] and as one of the eleven most important focal point of future plant diversity studies and conservation [11]. At the same time, with very nearly the lowest adaptive capacity to climate instability, Tajikistan is regarded as one of the most sensitive country to climate change in the world [12], and the high risk of climate change is one of the most critical factors in the degradation of its vegetation [13]. Although recently several papers concerning Tajik vegetation have been published [7,14–20], comprehensive research on its vegetation cover is necessary.

Alpine rock communities are considered as most unique and interesting plant formations in the mountainous areas of Holarctic and the Mediterranean provinces. Despite not being species-rich, they have drawn attention of botanists because they often consist of numerous specialists adapted to harsh and extreme environments [21–24]. Rocky habitats in central Asia are a refuge for a great many stenochorous plant species, probably on account of their high separateness and marginal position within the Irano-Turanian province. The taxa most frequent in rock vegetation patches in the central Asia include: *Campanula incanescens*, *Poa relaxa*, *Carex koshewnikowii* and *Artemisia rutifolia*. They also consist of other angiosperms such as: *Scutellaria* spp., *Campanula* spp., *Asperula* spp., *Dionysia* spp., *Parietaria* spp., *Penthanema* spp., *Silene* spp. and ferns, including: *Cystopteris fragilis*, *Adiantum capilli-veneris*, *Cryptogramma stelleri*, *Asplenium viride*, *A. ruta-muraria* [16].

The genus *Dionysia* Fenzl is spread throughout the Irano-Turanian and Mediterranean areas of Eastern Europe and southwestern Asia. It includes forty-nine species [25,26]. Most of them are adapted to the harsh, chasmophytic habitat conditions. They create fruticulose, loose or dense tufts and cushions and have reduced leaves, all of which are adjustments to growth under extreme conditions such as vertical niches or overhanging cliff walls at higher altitudes. However, they are not truly xerophytic, but require a certain amount of water and shade, which is provided by these niches [25,27]. Representatives of the genus *Dionysia* grow mainly on granite or dolomite rock faces where the amount of soil, if any, is very scarce and has a markedly low nutrient content. They prefer a Mediterranean-like climate with considerable alpine influences, especially in mean annual and minimum temperatures falling down to −2°C and −23°C respectively. Despite the fact that the members of *Dionysia* are very similar to those from the genus *Primula*, they can be relatively easily recognized by their powdery or woolly farina, long corolla tube and the capsule, which splits into 5 valves towards the base. In Tajikistan, the genus *Dionysia* includes two species. Besides *D. involucrata*, *D. gandzhinae* R. Kam. is also known from southern part of the country. The second species is very narrow endemic as well, known to date only from the locus classicus, which is located in the vicinity of Gandzhina village [28]. In the western part of Hissar Range, another narrow vicariant endemic belonging to the genus, *Dionysia hissarica* Lipsky, was reported. It grows on rock faces in southeastern Uzbekistan [29]. *Dionysia involucrata* is associated with loose rocky communities. However, until now, there has been insufficient investigation into the syntaxonomy of the species. No research on the plant communities and species of saxatile habitats has previously been conducted in the central Asian countries like Tajikistan, Kyrgyzstan, and Uzbekistan. In synthetic works, the rock vegetation has been usually described very briefly as "petriphyton" without the use of any classification methods (e.g. [30]). Only a few studies clarify questions of composition and zonation of rock or scree vegetation [31–33]. However, as they provide no distributional and ecological data, they are of minor importance in the analysis of rocky vegetation and chasmophytic species of Tajikistan.

Although *Dionysia involucrata* appears in several floristic studies [28,30,34], little is known about its ecology and endangerment. Given the extreme rarity of the species and the marked scarcity of data concerning its ecology and present distribution, we aimed to conduct the first-ever assessment of the endangerment and conservation status in accordance with IUCN guidelines and recommendations. In order to facilitate the evaluation, we analyzed the extent of population occurrence (EOO), the area of occupancy (AOO) and the total range. In this paper we also present the coenological condition of the species within the syntaxonomical system of submontane and montane saxatile vegetation of the Pamir-Alai mountain system.

Material and methods

Study species

Dionysia involucrata Zaprjag. (Family: Primulaceae, sect. Dionysiastrum Smoljan., subsect. Involucratae) is a small, 5–10 cm tall, glandular perennial. Its leaves are flat or slightly involute, 4–12 mm long, slightly dentate, with conspicuous, flabellate venations, densely glandular. The leaf veins are raised and farina powdery. Flowers occur in a stalked 3- to 5-flower umbel. The bracts are foliaceous and 2–4 cm long, usually longer than the leaves. Calyx is 7–9 mm long, with teeth three-quarters longer than the tube. Corolla is dark pink to light violet, with tube 3–4 times longer than the calyx, 2–3 cm in diameter, with emarginate lobes, homostylous and glandular-hairy (Fig. 1). Flowering period starts in April, and usually lasts for 3 months. Fruit ripens in June and July. An adult plant produces around 5–15 seeds in each capsule, giving approximately 150 seeds per year.

Dionysia involucrata is endemic to the central section of the Hissar Range located in Tajikistan, where it is restricted to several localities in the rocky gorges of the Varzob River and its tributaries. It was found between 1200 and 2500 meters above sea level: near the mouth of the Mayhura River (Fig. 2, location No. 1), the Sioma Valley (2), the Varzob Valley between Gushark and Kabuty (3), Pugus (4), between Dzhirinodsoy and the mouth of the Takob River (5), near Gazhni (6), in the Khondara Valley (locus classicus; 7), the Zamchurud Valley (8), Shaftimighon (9) and the Horongkong Valley (10), [4,28,29,34,35] (the numbers refer to Fig. 2).

This endemic species is considered to be both rare and critically endangered in Tajikistan [36]. However, it has never been included in the world red data book [37]. The main threats to the population have been attributed to too

Fig. 1 *Dionysia involucrata* Zaprjag. in Tajikistan. **a,b** Cushions of *D. involucrata* on pink granite rocks. **c** Flowering individual of *D. involucrata* near Gushark. **d** Young cushion of *D. involucrata* with typical leaves rosette near Pugus. **e** The association of *Dionysietum involucratae* in Takob valley.

intensive grazing and direct collection by professional and amateur botanists [36].

Study area

The Hissar Range covers approximately 10 000 km^2 and is situated in north-western part of Tajikistan and eastern part of Uzbekistan, between E 39°06′–39°32′ and N 66°55′–70°48′ (Fig. 2, Fig. 3). This is a typical mountainous area, situated between 850 meters above sea level, in the Varzob River Valley near Dushanbe, and 4886 at the Gaznok peak. The subranges within the Hissar Mountains are: the Osmontal, the Kugizaranga, the Sanginavishta, the Hodzhadaizi and the Odzhuk, along with several smaller ones. The Range is situated in the Mediterranean climate zone. However, the altitude and relief mean that the mountainous character of the climate has a strong influence on the area. According to a recent bioclimatic classification, which primarily considers precipitation and temperature values, the study area should be classified under the Mediterranean macrobioclimate type. This climate type is characterized by a summer drought lasting for at least two consecutive months during which mean precipitation is at least two times smaller than mean temperature value [38]. In the case of Dushanbe, four months in the summer period match this condition (Fig. 4). Other bioclimatic features of the study area also classify it to the Mediterranean macrobioclimate. The annual average

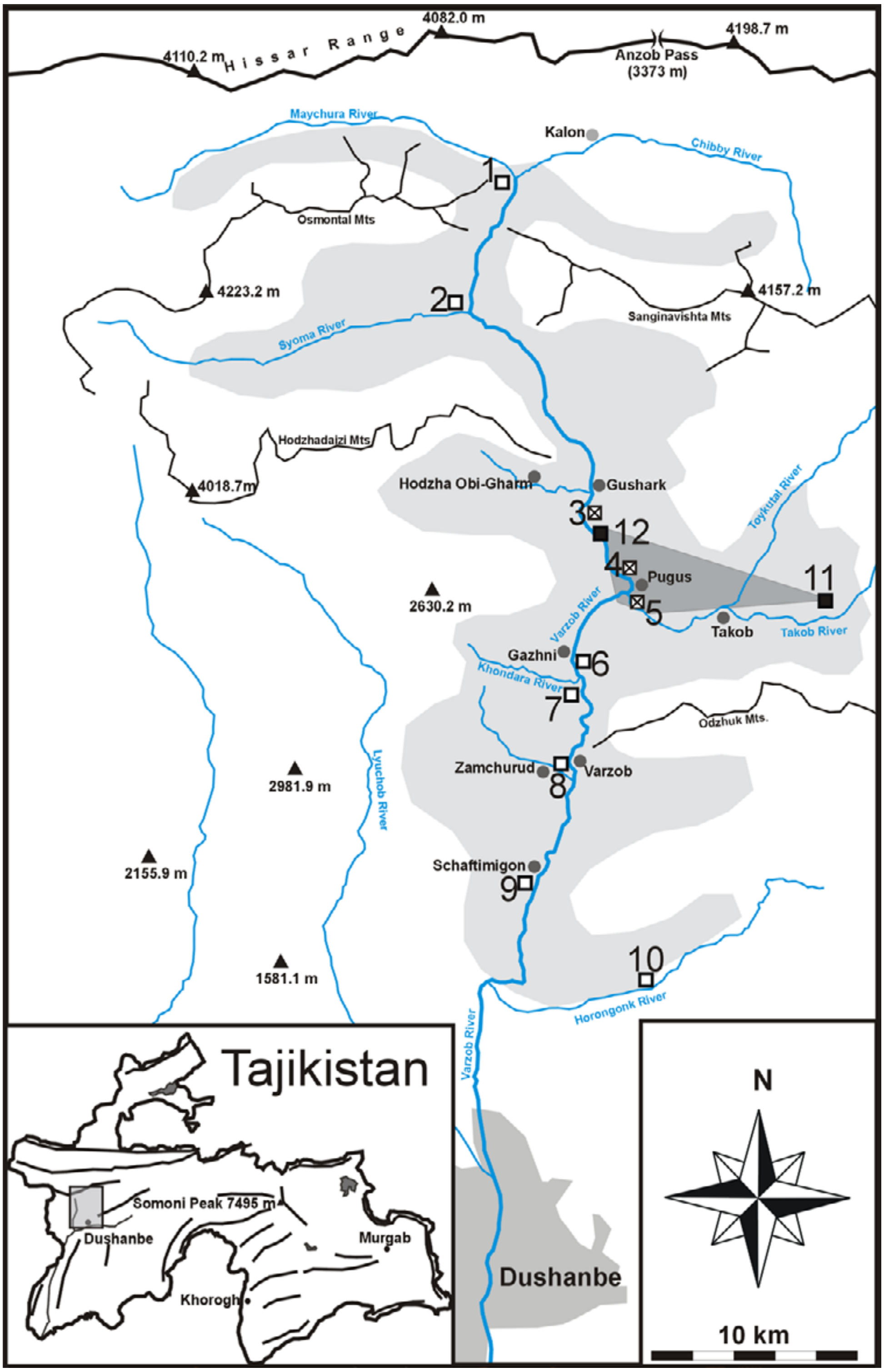

Fig. 2 The location of the study area with the distribution of *Dionysia involucrata* in the Hissar Mts. Location numbers are in accordance with the text and Tab. 1: white square – historical location; crossed square – confirmed historical location; dark square – new location. With hell grey the extent of occurrence, and with medium grey the area of occupancy were highlighted.

temperature is below 25°C (12°C) and the compensated thermicity index is lower than 580, at 542.8). The relatively high index of continentality (*Ic* = 25) demonstrates the considerable influence of the continental climate (sub-continental zone). Generally, this area of the country is characterized by high insolation, a low percentage of cloud cover, high-amplitude annual temperatures, low humidity and low precipitation. In the subtropical regions of Tajikistan, the average temperatures in June are around 30°C. In the temperate zone, which in Tajikstan mainly comprises the high mountains, the climate is much harsher, with average temperatures of between 9.7°C and 13.5°C in July. Annual precipitation in Tajikistan ranges from approximately 70 mm in the Pamirs to around 600 mm in the Hissar Range. The

Fig. 3 The location of Tajikistan in the Middle Asia.

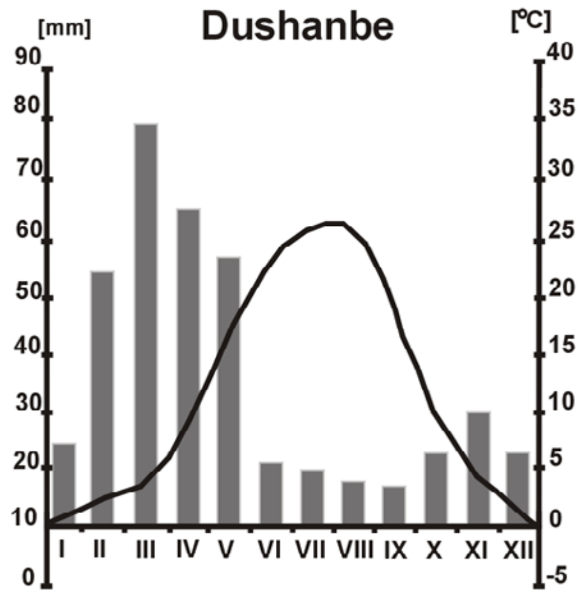

Fig. 4 Climatic characterization of the study area according to the Dushanbe weather station.

lower perpetual snow limit occurs at an altitude of 3500 to 3600 meters above sea level in the western part of the country, and at one of 5800 meters in its eastern regions [39,40]. These climatic and bioclimatic conditions determine the vegetation types and plant formations in the study areas, where deciduous and juniper forests, xerothermophilous swards and shrubs dominate in the lowlands and the montane belt.

The field studies were conducted in Tajikistan, on a potential area of *Dionysia involucrata* occupancy. The historical range of *Dionysia involucrata* and the adjacent areas in the Varzob River basin were investigated, with a particular emphasis on the valleys of the Takob, Gharm-Chashma, Khondara, Horongkong and Mayhura rivers, as well as several smaller ones. They are all located within the central section of the Hissar range of the Pamir Alai mountain system. Altogether, approximately 100 square km were investigated (Fig. 2, Tab. 1). The sites were phytosociologically examined in respect of the habitat conditions (rock type, elevation, insolation) and species composition of vegetation plots.

Data and analyses

The field studies were conducted in 2008–2013. The phytosociological data were sampled in 2012. A total of 17 relevés were made during the course of the research. The plot size used to sample the vegetation was established in such a way as to represent the full floristic composition. It varied from 0.5 to 2 m^2, depending on the plant density and homogeneity of the vegetation cover. All the vascular plants and cryptogams were recorded for each plot. The plant species were recorded in line with the Braun-Blanquet method employing the 7-degree scale (r, +, 1, 2, 3, 4, 5) [41]. The percentage values of the summarized species cover were computed automatically using the Juice program [42] and square rooted during ordination analyses. For the species from different layers (herb and moss), the total cover was calculated on the assumption that species covers can overlap and that they do so independently. Within the moss layer, the covers were assumed to be mutually exclusive. The geographical coordinates, elevation above sea level, substrate type, aspect and slope inclination for each relevé were recorded. The rock type was determined by an analysis of the lithology, pore geometry, mineralogical components, texture, permeability, hardness and pH carried out by a

Tab. 1 A list of localities of *Dionysia involucrata* found during field studies in 2008–2013.

No.	Location	Lat/Long	Area of occupancy (m^2)	Population size (cushions)	Altitude
3	To the S from Gushark	38°53′55″N 68°49′48″E	50	45	1300
4	Varzob River Valley near Pugus	38°51′23″N 68°50′29″E	270	750	1100
5	Lower section of Takob River Valley	38°49′57″N 68°52′76″E	185	500	1220
11	Varmanik (middle section of Takob River Valley)	38°50′10″N 68°56′38″E	15	20	1600
12	Varzob River Valley between Pugus and Gushark	38°52′13″N 68°50′0″E	130	350	1250

professional geologist (see acknowledgments). Hydrogen ion concentrations were measured in aqueous rock solution, using an Elmetron CP-105 pH meter.

The newly presented syntaxon is proposed in accordance with the "International code of phytosociological nomenclature" [43]. Works by Valachovič et al. [44], Dimopoulos et al. [45] and Nowak et al. [16] were taken into account when distinguishing and ranking the association. The association concept follows Willner [46]. It is based on distinctiveness of floristic composition of the association. The main diagnostic taxon is *Dionysia involucrata*. As differential one in relation to other communities of closely related habitats (community of *Scutellaria hissarica* and of *Tylosperma lignosa*) the *Scutellaria adenostegia* has been indicated.

In order to identify differences in the species composition of the vegetation patches with *Dionysia involucrata* and other phytocoenoses developing on rock faces in submontane and montane zone, the relevés collected during our field studies were compared with 48 relevés sampled by authors in western Pamir Alai Mts. To conduct the ordination analyses, we employed detrended correspondence analysis (DCA) to test the gradient length of the data using and subsequently elected to use unimodal techniques. The 17 relevés we gathered in this study were pooled with the 48 relevés of other communities (Fig. 5). To identify the differences between the vegetation patches, all the relevés were analyzed using the DCA functions of the Canoco software package [47].

Species nomenclature follows Czerepanov [48] for vascular plants and Ochyra [49] for mosses. The plant material collected during the field studies was deposited in the Middle Asian Mountains Herbarium hosted in OPUN (Opole University, Poland) and KRA (Jagiellonian University, Poland).

Threat evaluation

For the assessment of the current conservation state of *Dionysia involucrata*, we adopted the newest version of the IUCN guidelines for species endangerment evaluation [3]. We analyzed the total potential range, EOO and AOO as the most readily available and important data. To determine the AOO and EOO an exhaustive bibliographical survey was carried out and the herbarium specimens deposited in St. Petersburg (LED: Varzob River valley, leg. Stepanchenko and Stockij, Hissar Mts., 1954.06.25; Varzob River valley, leg. Gubanow I.A., 1963), Tashkent (TASH: Hissar range, Khondara River valley, leg. Krasovskaja, 1982.08.31; Kohondara River alley, leg. Baranova, 1985.05.12; Khondara River valley, leg. Sharapov, 1982.08.31) and Dushanbe (TAD: Khondara valley, Hissar range, leg. Pisjaukova, June 1950).

The extent of occurrence was defined as the area contained within the shortest continuous, imaginary boundary, which can be drawn to encompass all the known, inferred or projected sites of the current occurrence of a taxon. The area of occupancy was defined as the area within the EOO, which is presently occupied by a given taxon.

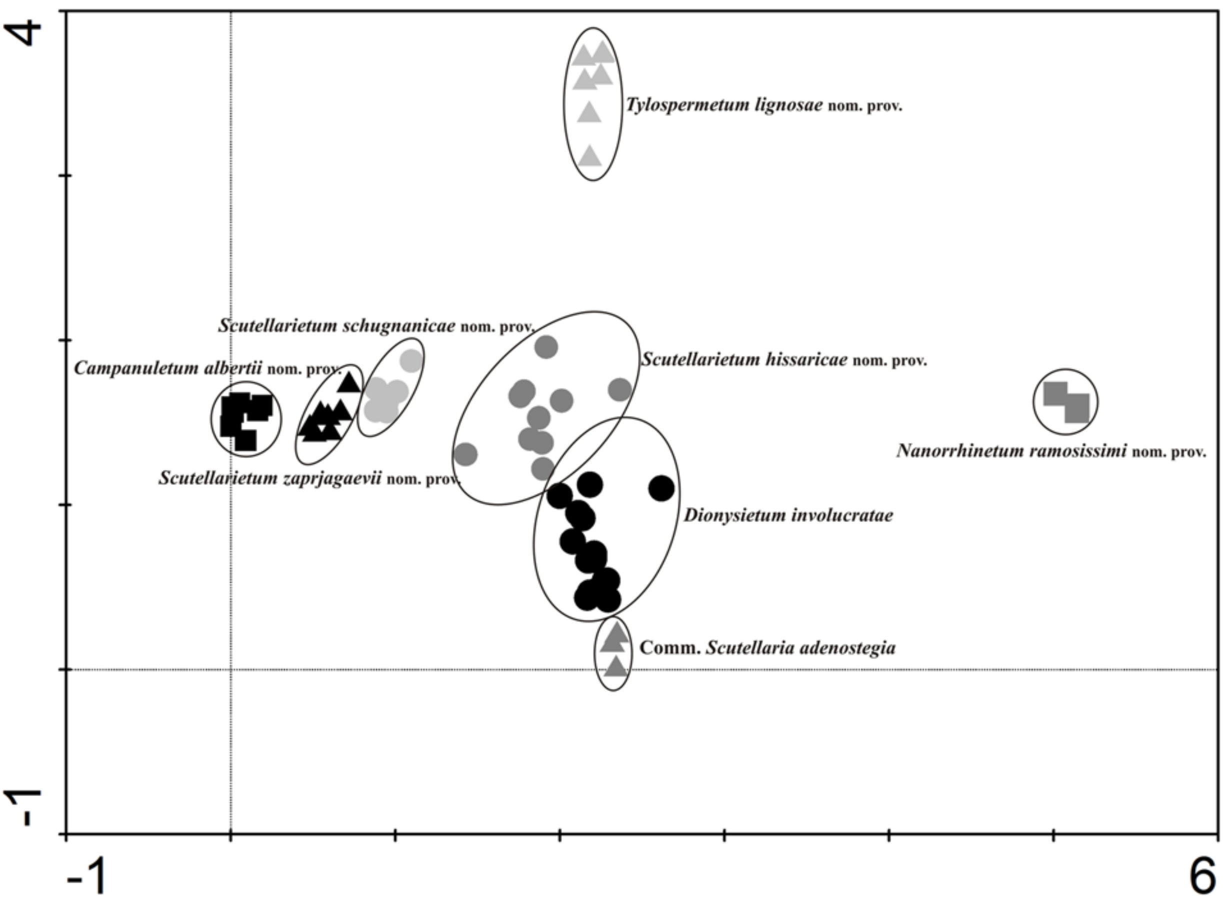

Fig. 5 DCA ordination for all samples of rock faces communities of submontane zone collected by authors in western Pamir Alai Mts in Tajikistan ($N = 65$).

Results

Historical range and present distribution

Dionysia involucrata was previously known from 10 locations in the Varzob River Valley in the Hissar Mountains, within the following limits: north, Mayhura River Valley (39°01′51.8″N; 68°46′29.7″ E); and south, the Horongonk River Valley (38°38′38.5″N; 68°50′52.1″E). All of the locations were checked during the study. A total of 5 populations of *Dionysia involucrata* were found, including two which were previously unknown. The current distribution of the species is generally restricted to the central section of the Varzob Valley, at an altitude of between 1100 and 1600 meters above sea level (Tab. 1). All recorded populations were established on pink granite rock, with the exception of the Takob Valley, where the individuals of *D. involucrata* grow on compact limestone.

Status of endangerment

The total range of *Dionysia involucrata* as known from the literature, herbarium and field data, is no larger than 2285 km^2. Our results show that the present EOO of *D. involucrata* is 11 km^2 and the current AOO is 650 m^2. In accordance with the IUCN categories and criteria, the taxon should be assessed as endangered (EN), because (***i***) the EOO is much lower than 5000 km^2 (criterion B1); (***ii***) the AOO is much lower than 500 km^2 (criterion B2) and, simultaneously, the taxa has only five extant locations [criterion B(a)] while a continuing decline in the EOO, AOO, as well as in the number of locations is observed [criteria B(b)i,ii,iv].

Most of the populations examined were large, with three of the five exceeding 350 individuals. The largest populations consist of more than 700 specimens. A total of over 1700 established plants were recorded (Tab. 1), meeting criterion C, small population size, for the EN category. Seedlings were frequent. Juvenile, mature, flowering and fruiting plants were observed in all the populations.

Ecology and syntaxonomical position

The plots of phytocoenosis with *Dionysia involucrata* were clearly distinguished in the results of the numerical classification of all relevés sampled in the rock habitats of the montane zone of the Pamir Alai Mountains in Tajikistan (Fig. 5). The plots are distinctively separated according to species composition (eigenvalue of first axis – 0.897, of the second – 0.786). Within eight of the distinguished groups, association with the domination of *D. involucrata* takes a central position. Given the structural differences, habitat separateness and floristic composition, this community could be defined as association. Despite insufficient investigation of the whole submontane zone of Tajikistan, the other groups probably should be identified also as associations: *Tylospermetum lignosae* nom. prov., *Scutellarietum hissaricae* nom. prov., *Nanorrhinetum ramosissimi* nom. prov., *Scutellarietum zaprjagaevii* nom. prov., *Scutellarietum schugnanicae* nom. prov., *Campanuletum albertii* nom. prov. and comm. of *Scutellaria adenostegia*. However, further investigations are still needed. The species composition of the plots in question determines the classification of *Dionysietum involucratae* association into the *Campanuletalia incanescentis* M. Nobis, A. Nowak & A. Nobis 2013 within the *Asplenietea trichomanis* class [7,16]. All the communities mentioned, as well as *Dionysietum involucratae* association, should be delimited within a new alliance of rock face vegetation in the subalpine and montane zone of the Pamir Alai Mountains. In view of the most frequent and abundant species, the proposed name for this syntaxon is *Caricion koshewnikovii* nom. prov.

Dionysietum involucratae ass. *nova*

Typus relevé: Tab. 2, relevé 2.

Diagnostic species: *Dionysia involucrata*.

The plots of *Dionysietum involucratae* association were found in all the extant location of the main diagnostic species in the valleys of the Varzob and Takob rivers, within the western Hissaro-Darvasian geobotanical subregion. Obviously, the association has a present distribution range even narrower than that of the diagnostic species and belongs to the endemic vegetation types of Tajikistan. It was found in montane and subalpine zones at the relatively low altitudes of 1085 to 1575 meters above sea level. The association prefers granite rocks of a relatively low cohesion index and acidity (pH 6.0 to 6.5). Only in Varmanik it was also found on compact limestone with fine crevices and fissures. The community develops on rock faces, mainly on southwestern and southern aspects with almost vertical, or even overhanging, inclinations, the approximate mean being 100° (Fig. 6). Owing to the scarce contribution of the species, the association is characterized by a moderate vegetation cover. In general, the total cover of the herb layer ranged between 15 and 55%, with mean value of approximately 25% (Tab. 2). The phytocoenosis is also characterized by a moderate number of species as far as rupicolous vegetation is concerned, having from two to seven taxa in one relevé (with the average number of species amounting 4). Mosses provide an insignificant contribution to the association and their total cover is no greater than 1%. Despite the diagnostic taxon, *Campanula incanescens*, *Carex koshewnikowii* and *Scutellaria hissarica* have the highest values of constancy and abundance among the vascular plants. In the moss layer, the most important contributors are *Grimmia pulvinata* and *Bryum argenteum*.

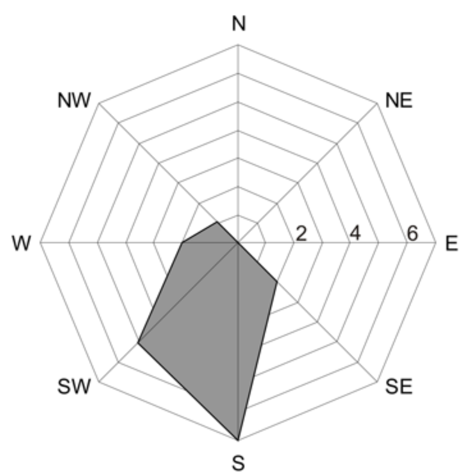

Fig. 6 Exposition of *Dionysietum involucratae* plots.

Tab. 2 *Dionysietum involucratae* in Hissar Mts (Tajikistan).

Relevé number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Day	8	8	8	8	8	8	16	19	8	8	8	8	8	8	8	8	8	C
Month	6	6	6	6	6	6	6	8	6	6	6	6	6	6	6	6	6	O
Year	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	N
Aspect	SW	S	S	S	SW	SW	W	NW	SE	W	SW	SE	S	S	S	SW	S	S
Inclination (degrees)	90	120	120	100	90	85	110	80	85	80	85	75	100	150	150	90	125	T
Altitude (m)	1226	1085	1229	1250	1560	1575	1090	1100	1250	1226	1230	1262	1250	1085	1229	1227	1236	A
Cover of shrub layer (%)	-	-	-	-	-	-	-	-	-	-	-	5	5	-	-	-	-	N
Cover of herb layer (%)	30	30	30	25	20	35	55	35	25	15	25	20	20	30	30	30	15	C
Cover of moss layer (%)	0.5	-	-	-	-	-	-	-	0.5	-	1	0.5	0.5	0.5	-	-	-	Y
Relevé area (m^2)	0.5	1	1	1	1	1	2	1	1	0.5	0.5	2	1	1	1	0.5	1	
pH	-	-	6	-	-	6	-	-	6	-	-	-	-	-	6.5			
Rock type	Gr	Gr	Gr	Gr	Gr	Gr	Gr	Gr	Gr	Gr	Gr	Gr	Gr	Gr	Li	Gr	Gr	
Number of species	6	4	3	5	5	3	3	5	5	3	6	7	5	4	2	3	2	
Diagnostic species																		
Ass. *Dionysietum involucratae*																		
Dionysia involucrata	3	3	2	2	2	3	4	3	2	2	2	2	2	3	1	3	2	V
All. *Caricion koshewnikowii*																		
Carex koshewnikowii	+	+			+	+		2	1	1	1	+				+	+	IV
Scutellaria hissarica	+			+	+		+	+	+									II
*Scutellaria adenostegia**										+	1			+				I
Tylosperma lignosa							+	+										I
O. *Campanuletalia incanescentis*																		
Campanula incanescens	+	+	2	1				+	+		+	+	+	+	+	+		IV
Cl. *Asplenietea trichomanis*																		
Grimmia pulvinata d											+	+	+	+				II
Parietaria judaica		+	+															I
Others																		
Bryum argenteum d	+								+		+							I
Spiraea baldshuanica b												1	1					I
Bromus tectorum				+		+												I
Spiraea baldshuanica c												+	+					I

Sporadic species: *Allium* sp. 4; *Echinops nanus* 1; *Gagea* sp. 5; *Pseudosedum condensatum* 12; *Steptorhamphus crambifolius* 5.

Locations of samples (according to the numbers of releves): 1, 3, 4, 9, 10, 12, 13, 17 – Takob (385038; 685014); 2, 14 – Varzob (384524; 684856); 5, 6 – Takob (385018; 685505); 7 – Varzob (384525; 684855); 8 – Varzob (384651; 684914); 11, 16 – Takob (385037; 685014); 15 – Varmanik (385010; 685638). Rock type: Gr – granite, Li – limestone. * Differential species.

Based on this study, we propose the following syntaxonomical classification of the *Dionysietum involucratae* ass. *nova* in Tajikistan:

Class: *Asplenietea trichomanis* (Br.-Bl. in Meier et Br.-Bl. 1934) Oberdorfer 1977
- Order: *Campanuletalia incanescentis* M. Nobis, A. Nowak et A. Nobis 2013
  - Alliance: *Caricion koshewnikowii* nom. prov.
    - Ass. *Dionysietum involucratae* A. Nowak, M. Nobis, S. Nowak & A. Nobis.

Discussion

Potential and present distribution of the species

According to Ovchinnikov [34], *Dionysia involucrata* is a long-standing element of what is known as Turanic flora of Irano-Mediterranean origin with highly stenochorous current distribution. The species meets the criteria of endemism [4] and is confined mostly to the granite rocks of the Varzob River Valley in the Hissar Mountains. The area belongs to the Hissaro-Darvasian geobotanical subregion, which is known as the richest as far as vascular plant endemics are concerned [4].

The small population located on limestone near Varmanik is rather ephemeral and untypical in character and could probably be defined as a sink part of the metapopulation [50]. Our field studies and extensive consultations with a geologist and botanists indicated no loose granite outcrops in the subalpine and montane zone in Tajikistan. There is thus little possibility of finding other populations of *D. involucrata* beyond its known historical range. The explanation for this absence can be found in the habitat conditions. This stenochorology is more typical for closely related species from the *Dionysia* genus, such as *D. hissarica*, *D. balsamea*, *D. paradoxa*, *D. lacei*, *D. saponacea*, *D. gandzhinae*, *D. hedgei*, *D. freitagii*, *D. viscidula*, *D. microphylla* and others. They are often confined to just one mountain range [25,35,51] and contribute significantly to the high endemism of isolated mountains within the Irano-Turanian province [4,21–23,52]. This kind of stenochory in chasmophytic plant communities is also observed in many other mountainous areas, especially with Mediterranean-type climates, such as the Bokkoya Mountains in northern Morocco [53,54], as well as on Gibraltar [55], on Crete and mainland Greece [45], in the Caucasus and the mountains of central Asia [22,56], in the Taurus Mountains in Turkey [57,58] and in Galicia in Spain [59]. Both *Dionysia involucrata* and other members of that genus undoubtedly corroborate the importance of rocky environments for the conservation of biodiversity (e.g. [4,60,61]). The specificity and diversity of the rock and scree habitats of Tajikistan is already known to be responsible for the extreme abundance of stenochorous plant species. This results from the extra-zonal nature of these habitats and their very different conditions in terms of humidity, type of substrate rock, insolation, temperature and inclination [4]. Another explanation for the chorological pattern is the concept defining highly distinct rock habitats as isolated, terrestrial "islands" serving as evolutionary traps. The surrounding dispersal barriers, genetic drift and founder effect work effectively on these isolated rock habitats [62–64].

Endangerment status of *Dionysia involucrata*

According to the red data book of Tajikistan, *Dionysia involucrata* was known from three locations and was considered as a critically endangered plant endemic to Tajikistan [36]. However, this assessment neither employs the approach suggested by the IUCN [3] nor takes into account all the previously known populations. For this reason, the re-evaluation of the endangerment status of *D. involucrata* with the use of the available data on spatial distribution, critical habitat and threat processes was vital. There is a global flora published for the region and there are also local checklists that give consideration to all the published and herbarium data on the distribution of the *D. involucrata* [28,34]. Despite this, the available data of use in order for the categorization process to be accomplished, such as fluctuations or the decline of, mature individuals, demographic tendency and so forth are either limited or even non-existent. At present, it is therefore possible neither to conduct an analysis of changes in population sizes, nor to evaluate the probability of the risk of species extinction in a given period of time. The methodology proposed by IUCN [3] requires precise information for the application of some criteria, although it does also enable decisions to be made on the basis of measurable parameters. In this case, only the EOO, the AOO and the present population size could be taken into account.

The detectability of *Dionysia involucrata* appears to be both unhampered by spatial or temporal distribution and unlimited by the biology and morphology of the species. Cushions of the species occupy the rock faces at medium heights and can be seen with the naked eye almost year round, with no need to employ alternative survey techniques. Despite some discrepancies concerning the precise location of the historical populations in relation to the extant ones, we can assess that the species is known from twelve locations, seven of which are probably extinct. *D. involucrata* also has a very narrow EOO of less than 5000 km^2 and an AOO of less than 650 m^2. This distributional feature makes it possible to evaluate the threat status of the species and permits the conclusion that the "endangered" is an appropriate category and should be considered as global. Nevertheless, in order to make this assessment more comprehensive, it seems reasonable to conduct further sampling, not only to ascertain the fluctuations or decline in the numbers of mature individuals more fully, but also to enable ecological and population genetic studies with a view to determining the species' capacity for dispersal among habitat patches and the minimum patch size and connectivity needed to support viable populations.

There is no evidence for the causes of *Dionysia involucrata* decline. Rasulova and Junusov [36] either, apart from suggestions that the withdrawal of the species is related to intensive grazing of goats and sheep and collection by botanists or tourists. The populations growing on the low-lying and accessible ledges of rock walls on flat slopes are, indeed, exposed to be grazed, primarily by goats or sheep. These livestock species are still the main source of livelihood in central Tajikistan and their farming causes considerable environmental degradation. Neither the pressure exerted by tourism on the population of *D. involucrata* in the Hissar mountains nor collection for scientific purposes seem to be relevant in this case, since the numbers and frequency of research studies and tourist expeditions in the Varzob River basin are still quite low. However, with their large attractive flowers, which do embrace values of beauty and ornamentation, *Dionysias* could be threatened by indiscriminate collection.

Another threat is related to road construction and modernization in the Varzob River basin over the few years. The populations of *Dionysia involucrata* occupy walls in closest vicinity of the river and the communication routes running alongside it. The granite quarrying or the fires lit by workers during the modernisation and broadening of these roads could have a negative impact on those populations. This is all the more significant in that *D. involucrata* is not protected by a species conservation law in Tajikistan and the currently existing populations are not included in the aerial protection system. Even though steering the formulation and implementation of public conservation policies in order to encompass the extant location of the species within protected areas is not a full guarantee of effective protection, it might at least increase the chances of halting the withdrawal of the species in Tajikistan [65–68].

Given the high conservation priority and threat status of *Dionysia involucrata*, as well as the difficulties involved in counteracting the threats in situ, we recommend the possibility of ex situ conservation, either by means of seed-banking or by taking measures to cultivate the species in ex-situ collections, due to the difficulties of counteracting the threats.

Position of *Dionysietum involucratae* in the syntaxonomical system of rock vegetation in the Pamir Alai Mountains

Syntaxonomical richness in mountainous areas with the Mediterranean type of macrobioclimate is known to be markedly high in both Europe and Asia (e.g. [45,56,58,59,69–80]). Because of the considerable structural differences between chasmophytic flora and other vegetation types, a separate *Asplenietea trichomanis* (Br.-Bl. in Meier et Br.-Bl. 1934) Oberdorfer 1977 class was designed for rock face, fissure, cleft, crevice and rock ledge communities [68,81]. *Dionysietum involucratae* association undoubtedly belongs to this class. It is also certain that, on account of the considerable frequency and abundance of diagnostic taxa, as well as of Irano-Turanian distributional-types species, the vegetation plots surveyed should be classified in the *Campanuletalia incanescentis* order [7,16]. The order includes phytocoenoses characterized by a high share of petrophytic taxa such as *Campanula incanescens*, *C. lehmanniana*, *Stipa zeravshanica*, *Poa relaxa*, *Scutellaria hissarica*, *Artemisia rutifolia* and others.

However, the ordination of the *Dionysietum involucratae* association at the alliance level still requires further research, particularly on the rocky vegetation of the montane and submontane belt. Recent studies of rupicolous vegetation in the Hissar, Zeravshan, Turkestan and Darvaz Mountains suggests that the new alliance, *Caricion koshewnikowii* nom. prov., needs to be established in order to differentiate the vegetation plots of chasmophytic vegetation developed in the lower altitudinal range of the Pamir Alai Mountains [16]. This type of phytocoenoses is distinctly different from *Asperulo albiflorae-Poion relaxae* [16] on account of both the floristic composition and the habitat conditions, with their mainly lower altitudinal amplitude, higher soil amount and precipitation. For example, in the alpine and nival belts, the most frequently spotted plants are *Asperula albiflora*, *A. czukavinae*, *Lophanthus virescens*, and *Poa relaxa*. In relevés sampled for *Dionysietum involucratae* association and other communities from the subalpine and montane zones, the *Carex koshewnikowii*, *Campanula incanescens*, *Scutellaria hissarica*, *Scutellaria zaprjagaevii*, *Scutellaria adenostegia* and *Syntrichia ruralis* reach the highest levels of abundance and frequency.

Dionysia involucrata has a high diagnostic syntaxonomical value and occurs almost exclusively within its own association. In only a few cases was it also spotted in a community of *Tylosperma lignosa*, the species with a broader distribution in southwest Asia, ranging from western Tajikistan to northern Iran and also occurring on granite rocks. Other sampled phtocoenoses with the optimum of occurrence on limestone and shale outcrops are devoid of any contribution on the part of *Dionysia*. The association is thus clearly related and depends on specific habitat conditions, these primarily consisting of an acidophilous substrate, relatively high precipitation, particularly in the spring period (Fig. 4) and very steep, often overhanging, rock walls. The fact that cushions of *Dionysietum involucratae* have never been observed in large numbers on rock ledges or on mountain tops also seems to be significant. The association prefers rock outcrops in deep gorges where exposure to sunlight is limited by the relatively long daily period in the shade.

Concluding remarks

The chasmophytic vegetation located in central Asia, in one of the world's most important biodiversity hotspots as far as the impact of global change and susceptibility to degradation is concerned, is under considerable threat [10–13]. Many of the species that occur in this environment are in severe danger, as human-caused threats, particularly goat grazing and collecting, are leading to habitat degradation and population damage [4]. Our study has revealed information regarding the geographical distribution and ecological requirements of *D. involucrata*, one of the most threatened and least known species in the region. We hope that this information will be used in conservation measures implemented for this endangered species. Although we shifted the threat category of *D. involucrata* from CR to EN, this species needs further monitoring and conservation on account of the continuing shrinkage of the distribution range. It has to be pointed out that the downgrading of the endangerment status is due neither to effective conservation action nor to the result of any increase in population size, but rather to precise re-evaluation of the species. Still, these isolated populations are particularly important from the ecological, genetic and evolutionary viewpoint and require more attention from conservation biologists [82].

We have also pointed out that *Dionysia involucrata* creates its own phytocoenosis and grows in similar habitats along the rock outcrops of the Varzob River Valley and its tributaries. The population of *D. involucrata* is mainly sensitive to goat grazing. However, the recent increase in the level of activity in the modernization of Tajikistan's road system may well be contributing considerably to species decline as well. We therefore recommend both further population studies on the species and the possibility of ex situ conservation, either by means of seed cryopreservation and/or by cultivating the species in garden collections.

Acknowledgments

We are very grateful to V. Plašek Ph.D., D.Sc. for his help in moss species determination. Special thanks to Prof. A. Bodzioch for determination of rock samples. We thank also two anonymous reviewers who considerably improve the text. The authors wish also to thank F. Abdurahimova from the Nature Protection Team Dushanbe for assistance and help in organizing expeditions. The project was partially funded by the Polish Ministry of Science, grant No. N304 377838/2010.

Authors' contributions

The following declarations about authors' contributions to the research have been made: project idea, field research: ASN, MN; data analysis, preparing the manuscript: ASN, MN, SN, AN.

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