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Original article

Floristic composition of Jandaf Mountain as biodiversity hotspot area in southwestern Saudi Arabia

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ABSTRACT

Arid environments around the world are characterized by lower plant diversity. However, some specific locations have relatively high species richness and have significant importance in terms of vegetation structure and plant diversity. Jabal Al-Jandaf is located in an arid area within the eastern side of mountainous region in the southwest of Saudi Arabia. It consists of valleys, lower plain and upper plain habitats with unique and diverse vegetation. These habitats range from 1000 m above sea level near the Tarj valley to 1910 m at the summit. In this study, we conducted a first survey of the floristic diversity at Jandaf Mountain. Furthermore, we applied the criteria of the Important Plant Area (IPA) and the High Conservation Value (HCV) approaches to assess whether the plant community at Jandaf Mountain qualifies as a significant conservation area. We found that the study area has great plant diversity with plant composition varying among the different habitats (e.g., valleys, upper and lower elevations) within the study area. We recorded 118 species from 97 genera belonging to 42 families, including endemic (e.g. *Aloe pseudorubroviolacea*), near-endemic (e.g. *Monolluma quadrangular*), and endangered species (e.g. *Dracaena serrulata*, *Combretum molle*, and *Moringa peregrine*). The plant diversity at Jandaf Mountain achieves the criteria outlined in the IPA and HCV approaches. Therefore, we conclude that Jandaf Mountain has a unique vegetation structure, and the area qualifies for conservation as a high value area for biodiversity and conservation of global significance.

1. Introduction

Mountainous areas often have high botanical significance in biodiversity and endemism, where species tend to be spatially limited to particular elevations or habitats (Noroozi et al., 2018). Within mountainous areas, each individual mountain and valley may have species that occur nowhere else in the world. For example, the mountains of Northwest Yunnan, China, were found to have a unique vegetation composition with high species richness (Sherman et al., 2007). Vegetation composition on mountains may also be stratified with different sets of species occurring across different elevations (Hall et al., 2009; Al-Namazi et al., 2021). The relative high diversity of these mountains gives them a high botanical importance and makes an absolute necessity for these habitats to be protected (Kollmair et al., 2005).

The mountains of Sarawat (part of the Asir Mountains in southwestern Saudi Arabia) hold the greatest proportion of plant species diversity compared to other habitats in Saudi Arabia (which represent about 60% of plant species; Collenette, 1999; Seraj et al., 2014). Vegetation and species distributions are strongly influenced by geological heterogeneity. A greater extent of spatial variation in rock and soil types often reflects a higher level of plant diversity (Elvidge and Lyon, 1985). This is particularly the case in the mountains of Saudi Arabia (Abulfatih, 1983). Thus, the plant community structure of the mountain environment is highly affected by topoclimatic complexity (Oldfather et al., 2016). The mountains of the Arabian Peninsula have great ecological significance for plant diversity due to the abundance of endemic and endangered species (Hall et al., 2009 Thomas et al., 2017; Al-Namazi et al.,

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2021). Jandaf Mountain within the Asir region has steep slopes and the surrounding valleys provide a biogeographic and bioclimatic refuge area for plant species. The vegetation of Jandaf Mountain is influenced by heterogeneity in elevation, hydrology, and moisture from the air current coming from the Red Sea. The mountain contains several habitats with distinct plant community structures due to the variation in local climate and conditions. These attributes highlight the ecological importance of Jandaf Mountain to plant diversity.

Several surveys have been conducted in the Asir mountainous region (e.g. Abulfatih, 1983; Hosni and Hegazy, 1996; Heneidy and Bidak, 2001; Al-Yemeni and Sher, 2010; Seraj et al., 2014; Ghazal, 2015). Although Wadi Tarj and the surrounding mountains (e.g. Jandaf Mountain) are already known to be habitats for endangered animal species such as the Arabian Gazelle (*Gazella arabica*, Boug et al., 2012), endemic and endangered plant species are likely to inhabit these mountains. However, no survey has yet been conducted on the vegetation of Jandaf Mountain.

We assess the eligibility of Jandaf Mountain for consideration as an important conservation area by applying the criteria of the Important Plant Area (IPA) based on the results of our survey (Plantlife International, 2002). Moreover, this study aims to make a checklist for all recorded plant species to contribute to the flora of Saudi Arabia, and highlights the importance of conserving Jandaf Mountain due to its unique botanical diversity.

2. Materials and methods

2.1. Study site

Jandaf Mountain is an isolated mountain surrounded by Tarj valley streams. It is located about 60 km west of Bisha city with the highest elevation at around 1900 m above sea level (a.s.l.) (located at 19°33′N, 42°20′E). The elevation ranges from 1400 m a.s.l. near the Tarj valley to 1910 m a.s.l. at the summit. The mountain extends for a distance of 13 km on the east-west axis and 7 km in the north–south axis (Fig. 1). Jandaf Mountain has an arid climate with an annual precipitation of 126 mm. The monthly average of the maximum temperature is 38 °C, while the monthly average of the minimum temperature is about 9 °C, and the average annual of mean temperature is about 25 °C (National Center for Meteorology (NCM, 2021), see Fig. 2).

Jandaf Mountain is a part of the Arabian shield which is made up of rocks of the Bisha complex, which consist of volcanic and plutonic rocks. Biotite Monzogranite covers the upper parts of the mountains. They are pale reddish gray to light-gray and medium coarse-grained. Tonalite and Diorite occur in the lower areas, which are metamorphic rocks and forms part of the Jeddah group (Ministry of Petroleum and Minerals, 1985). Jandaf Mountain descends steeply in three directions: north, east, and west. However, many gullies formed by water erosion (i.e., by ephemeral streams) hold significant vegetation cover (Fig. 1).

2.2. Field survey

The inventory study was conducted at the end of March 2018 across a 30 km^2 area. Two transects were laid out along the slopes of Jandaf Mountain. The first transect was placed on the west facing side of the mountain, while the second transect was on the east facing side. Ten (50 × 50 m^2) quadrats were laid out along each transect. In each quadrat, we recorded the density and frequency of each plant species. In addition, for each quadrat we recorded the location information such as latitude, longitude, and altitude.

2.3. Conservation criteria

Areas with high biodiversity and conservation value (i.e., high conservation value areas - HCVAs) have high species richness, with rare or endemic species. The Forest Stewardship Council (FSC) originally developed the High Conservation Value (HCV) approach in 1999 for use in forest management certification to identify areas eligible for conservation (Anderson, 2002; Jennings et al., 2003,

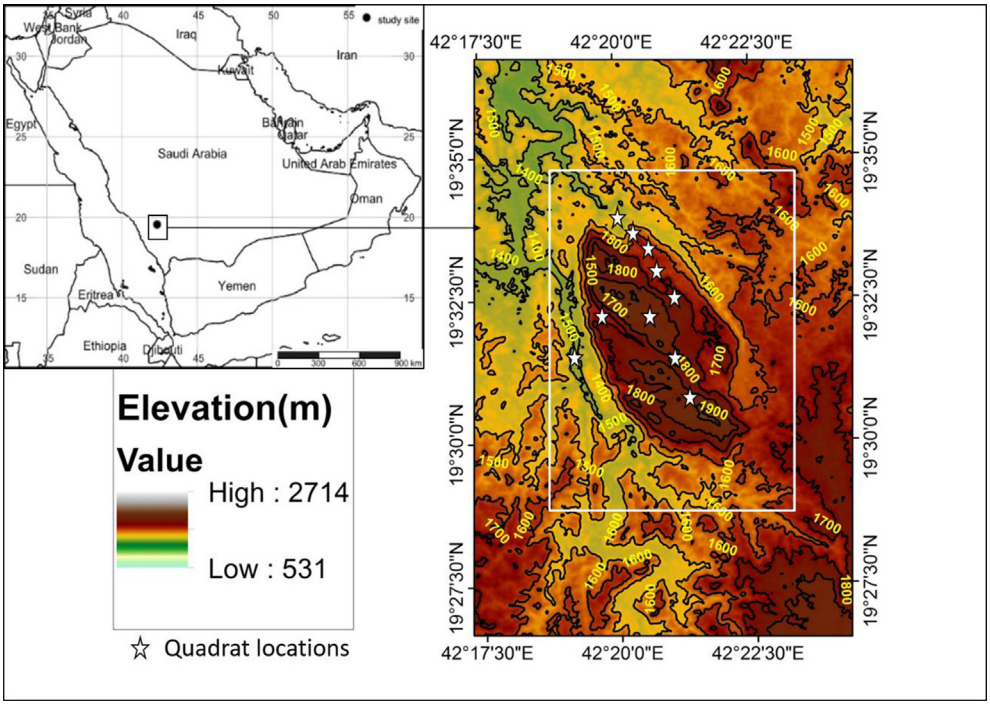

Fig. 1. Topographic map of the study site at Jandaf Mountain, Saudi Arabia. Elevation of the study area at Jandaf Mountain (indicated by white frame) ranges from 1400 to 1900 m a.s.l.

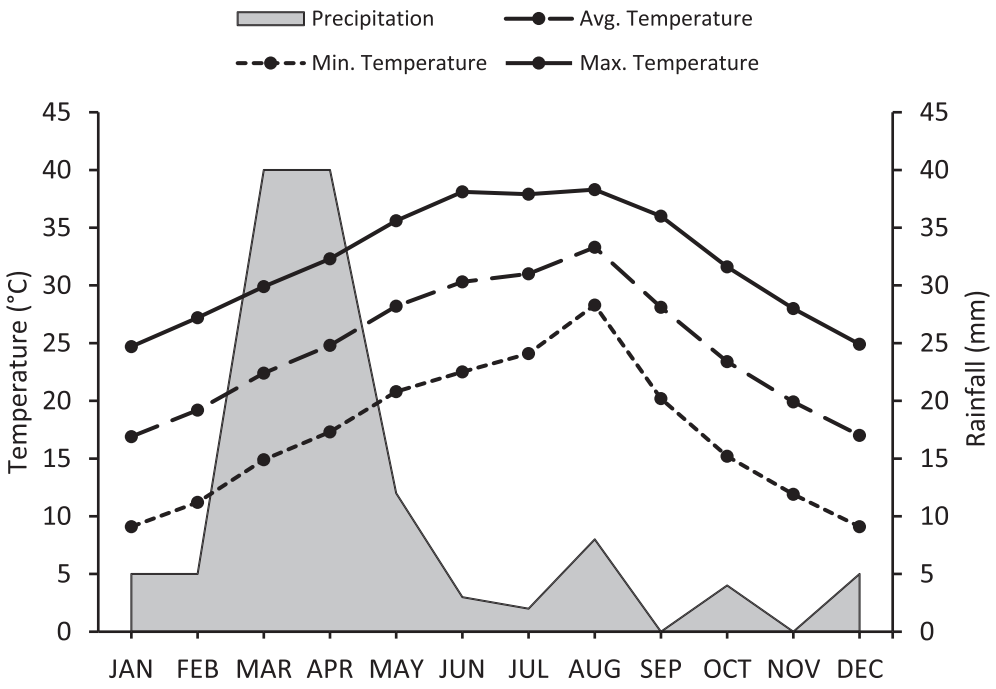

Fig. 2. Climate graph showing the monthly mean monthly maximum, average, and minimum temperatures (°C) and rainfall (mm) near the study site (Bishah weather station for the period from 2003 to 2017).

Judd et al., 2007); Brown et al., 2013). In addition, Plantlife International, which is a non-profit charity based in the UK, established the IPA program to meet the urgent need for the reduction of global plant diversity issues (Al-Abbasi et al., 2010). The approach of IPA was compatible with the regional inventories and plant diversity of European countries (Eken et al., 2004), and does not fit with other specific regions around the world (e.g., arid areas) due to some limitations in term of data availability (e.g. vegetation data, population size, and threats), that have been discussed by Knight et al. (2007) or technical limitations (global, regional, and local limitations) of conservation assessments according to Darbyshire et al. (2017). Therefore, the approach of IPA was adapted by Al-Abbasi et al. (2010) to be used for countries in the Arabian Peninsula (e.g., Saudi Arabia). We applied the criteria for High Conservation Value Areas (HCVA) and Important Plant Areas (IPA) using our survey data. Areas with values which are considered very significant at the national, regional, or global level can be significantly or critically important due to their high biological, ecological, social, or cultural values. These are defined to the following criteria (i.e., HCV(1) to HCV(6) for HCVA, and B-A to B-C for IPA). The specific criteria are presented in supplementary 1 and 2.

3. Results

Upon this survey, within all plotted quadrats, 118 plant species were recorded in Jandaf Mountain. The recorded plant species belong to about 97 genera and 42 plant families. Most of the Jandaf plant species were perennials (i.e., trees, shrubs, and iteroparous herbs) (Table 1). Although the plant cover was remarkably low across Jandaf Mountain, the plant density and species richness were high and valuable.

We applied the criteria of the Important Plant Areas (IPA, Plantlife International, 2004) to our survey results. We found that the vegetation diversity of Jandaf Mountain contains several endemic and near endemic plant taxa. For example, *Aloe pseudorubroviolacea* is a national endemic, *Monolluma quadrangula* is regionally endemic, and *Dracaena serrulata and Combretum molle* are regionally range-restricted taxa. Thus, the vegetation composition of Jandaf Mountain meets several of the criteria of IPA and HCVA (e.g. criterion A of the IPA criteria and HCV1 of HVCA criteria; see supplementary 1 and 2).

Furthermore, the study site has an exceptionally rich flora in a regional context in relation to its biogeographic zone. Thus, the small area of Jandaf Mountain has a high species richness within an arid environment (i.e., 118 species within a small arid area of Jandaf Mountain). This satisfies the criterion of IPA criteria (see supplementary 1). Moreover, the isolation and the steep slopes of Jandaf Mountain make it a refuge for a number of threatened and endangered species (e.g. *Aloe pseudorubroviolacea, Monolluma quadrangula, Dracaena serrulata*, and *Combretum molle*) which meet the criterion HVC3 of HVCA criteria (see supplementary 2).

Across the study area, the plant community structure varies depending on elevation. The elevation in the study site ranges from 1400 m in the valleys around Jandaf Mountain to about 1900 m at the mountain summit (Fig. 1). This variation is reflected in the vegetation type and plant diversity. Therefore, we classified the vegetation into several ecological zones depending on the elevation.

3.1. Wadi Tarj habitat

The valley habitat (e.g., Wadi Tarj) around Jandaf Mountain was located at elevations between 1400 and 1450 m a.s.l. This habitat has a high species richness and was dominated by *Ziziphus spina-christi, Acacia ehrenberrigiana, Leptadenia pyrotechnica, Abutilon bidentatum, Conyza pyrrhopappa,* and *Aerva javanica.* A few individuals of rare species such as *Moringa peregrina* and *Salix mucronata* have been recorded only in this habitat, these two species occur only in one quadrat with frequency of 0.05 for each species.

3.2. Lower plain

The plots surveyed in this habitat lies between 1450 and 1500 m a.s.l.; such plots at this altitude have the highest species richness (Fig. 3). The most dominant species in this habitat are

Table 1
Full list of plant species recorded in the study area with information on their families, life forms, density, and frequency. The life forms are represented by Ch: chamaephytes, G: geophytes, Ph: phanerophytes, and Th: therophytes. The conservation status of each species is represented by DD: Data Deficient species, LC: Least Concern, NE: Not Evaluated, EN: Endangered, NT: Near Threatened. The habitats of each species are represented by UPPER: upper plain, LOWER: lower plain, and VALLEY: Wadi Tarj.* indicates to the endemic species.

Family	Species	Growth form	Life form	Density/ha	Frequency	Status	Habitat
Acanthaceae	*Barleria bispinosa* (Forssk.)	shrub	Ch	4	0.6	DD	UPPER
	Barleria trispinosa (Forssk.) Brumm. & Wood	shrub	Ch	2	0.2	DD	UPPER
	Blepharis ciliaris (L.) B.l.Burtt	herb	Ch	2.4	0.4	LC	COMMON
Aizoaceae	*Aizoon canariense* L.	herb	Th	6	0.1	DD	LOWER
	Zaleya pentandra (L.) C. Jeffrey	herb	Th	2	0.3	DD	LOWER
Amaranthaceae	*Aerva javanica* (Burm. f.) Juss. ex Schult.	herb	Ch	2.8	0.4	LC	VALLEY
	Aerva lanata (L.) A. l. Juss. ex Schultes.	herb	Ch	2	0.1	LC	LOWER
	Alternanthera pungens Kunth.	herb	Ch	2.6	0.2	NA	LOWER
	Amaranthus hybridus L.	herb	Th	6.8	0.2	DD	VALLEY
	Salsola cyclophylla Baker.	shrub	Ch	2.1	0.3	NA	LOWER
	Celosia polystachya (Forssk.) C.C.Towns.	undershrub	Ch	2	0.1	NA	VALLEY
	Pupalia lappacea (L.) Juss	herb	Ch	4	0.4	LC	LOWER
Anacardiaceae	*Pistacia falcata* Becc. ex Martelli	tree	Ph	1.2	0.2	NA	UPPER
	Searsia retinorrhoea (=Rhus retinorrhoea)	tree	Ph	12	0.3	NA	UPPER
Apocynaceae	*Adenium obesum* (Forssk.) Roem. & Schult.	shrub	Ph	2.7	0.3	LC	UPPER
	Calotropis procera (Aiton) W.T.Aiton	shrub	Ph	11	0.2	LC	VALLEY
Asclepiadaceae	*Monolluma quadrangula* (Forssk.) Plowes *	Succulent herb	Th	0.3	0.05	NA	UPPER
	Desmidorchis retrospiciens (N.E.Br.) Ehrenb.	Succulent herb	Ch	0.8	0.2	NA	LOWER
	Gomphocarpus sinaicus Boiss.	undershrub	Ch	3.1	0.3	NA	LOWER
	Kanahia laniflora (Forssk.) R.Br.	herb	Th	2	0.2	LC	VALLEY
	Pergularia daemia (Forssk.) Chiov.	vine	Ch	6.1	0.3	LC	LOWER
	Leptadenia pyrotechnica (Forssk.) Decne.	shrub	Ph	3.6	0.5	LC	VALLEY
Asparagaceae	*Aloe pseudorubroviolacea* Lavranos & Collen. *	Succulent herb	Ch	0.4	0.1	NA	UPPER
	Dracaena serrulata Baker *	shrub	Ph	2	0.05	EN	UPPER
Asphodelaceae	*Asphodelus aestivus* Brot.	herb	Th	15	0.5	LC	LOWER
Asteraceae	*Conyza pyrrhopappa* Sch.- Bip. ex A. Rich.	undershrub	Ch	6	0.1	NA	VALLEY
	Centaurea schimperi DC.	herb	Ch	4.1	0.3	NA	LOWER
	Centaurea sinaica DC.	herb	Ch	4.6	0.4	NA	LOWER
	Crepis rueppellii Sch.-Bip.	herb	Ch	2	0.3	NA	VALLEY
	Ambrosia maritima L.	herb	Th	3.2	0.3	LC	VALLEY
	Echinops hystrichoides Kit-Tan	herb	Ch	3.6	0.2	NA	LOWER
	Heteroderis pusilla (Boiss.) Boiss.	herb	Th	1.6	0.2	NA	LOWER
	Launaea massauensis (Fresen.) Sch. Bip.	herb	Th	0.8	0.1	NA	VALLEY
	Onopordum heteracanthum C.A. May	herb	Ch	0.9	0.3	NA	LOWER
	Pluchea dioscoridis (L.) DC.	undershrub	Ch	2	0.2	LC	VALLEY
	Pulicaria glutinosa (Boiss.) Jaub. & Spach	herb	Ch	3.6	0.4	NA	LOWER
	Pulicaria undulata (L.) C.A. May	herb	Ch	3.6	0.3	NA	LOWER
	Pulicaria vulgaris Gaertn.	herb	Ch	1	0.1	LC	LOWER
Boraginaceae	*Arnebia hispidissima* (Lehm.) DC.	herb	Th	4.7	0.3	NA	LOWER
	Asperugo procumbens L.	herb	Th	0.4	0.1	NA	UPPER
	Echium longifolium Delile.	herb	Th	6	0.15	NA	UPPER
	Heliotropium aegyptiacum (Lehm.) DC.	herb	Th	6.2	0.4	NA	VALLEY
	Heliotropium arbainense Fresen.	herb	Th	1.2	0.2	NA	LOWER
Burseraceae	*Commiphora gileadensis* C. Christ.	tree	Ph	44.4	0.2	NA	COMMON
	Commiphora kataf Engl.	tree	Ph	4	0.15	NA	LOWER
Capparaceae	*Capparis cartilaginea* Decaisne	tree	Ph	1.1	0.1	LC	LOWER
	Maerua crassifolia Forssk.	tree	Ph	0.4	0.1	LC	LOWER
	Maerua oblongifolia (Forssk.) A.Rich.	shrub	Ch	0.1	0.1	NA	LOWER
Celastraceae	*Maytenus arbutifolia* (Hochst. ex A.Rich.) R.Wilczek	shrub	Ph	2	0.3	LC	UPPER
Combretaceae	*Combretum molle* R.Br. ex G. Don	tree	Ph	1.2	0.1	LC	UPPER
Convolvulaceae	*Seddera arabica* (Forssk.) Choisy	herb	Ch	0.8	0.1	NA	LOWER
Cucurbitaceae	*Citrullus colocynthis* (L.) Schrader	vine	Ch	1.9	0.2	NA	VALLEY
	Zehneria scabra (L.f.) Sond.	vine	Ch	1	0.2	NA	UPPER
	Corallocarpus epigaeus (Rottler) Hook.f.	vine	Ch	0.9	0.3	NA	UPPER
Cyperaceae	*Carex divisa* Huds	herb	Th	1.2	0.1	LC	LOWER
Ebenaceae	*Euclea schimperi* (A. DC.) Dandy	tree	Ph	0.4	0.05	LC	UPPER
Ephedraceae	*Ephedra foeminea* Forssk.	shrub	Ph	4.4	0.2	LC	LOWER
	Ephedra foliata Boiss. ex C.A. May	shrub	Ch	1.2	0.1	LC	UPPER
Euphorbiaceae	*Euphorbia cuneata* Vahl	shrub	Ch	2.4	0.2	LC	LOWER
	Ricinus communis L.	shrub	Ch	2	0.2	NA	VALLEY
Geraniaceae	*Erodium cicutarium* (L.) L'Her	herb	Th	1	0.15	NA	UPPER
	Erodium neuradifolium Del.	herb	Th	1.4	0.15	NA	UPPER
Fabaceae	*Acacia asak* (Forssk.) Willd.	tree	Ph	14.4	0.4	NA	COMMON
	Acacia gerrardii Benth.	tree	Ph	3	0.15	NA	LOWER
	Acacia ehrenbergiana Hayne	tree	Ph	8	0.15	LC	VALLEY
	Acacia tortilis (Forssk.) Hayne	tree	Ph	4.4	0.15	LC	VALLEY
	Acacia hamulosa Benth.	tree	Ph	1	0.1	LC	LOWER
	Astragalus spinosus (Forssk.) Muschl.	herb	Th	0.1	0.05	NA	VALLEY
	Indigofera articulata Gouan	undershrub	Ch	7.2	0.25	NA	COMMON
	Indigofera coerulea Roxb.	undershrub	Ch	0.9	0.15	LC	COMMON
	Indigofera spinosa Forssk.	undershrub	Ch	5.6	0.35	NA	COMMON

(*continued on next page*)

Table 1 (*continued*)

Family	Species	Growth form	Life form	Density/ha	Frequency	Status	Habitat
	Medicago minima (L.) L.	herb	Th	2.7	0.4	LC	COMMON
	Trigonella anguina Del.	herb	Th	3	0.4	NA	COMMON
Geraniaceae	*Grewia tembensis* Fresen	shrub / tree	Ph	3.2	0.5	NA	UPPER
	Grewia tenax (Forssk.) Fiori	shrub / tree	Ph	4	0.5	LC	UPPER
Juncaceae	*Juncus punctorius* L.f.	herb	Th	0.3	0.05	LC	VALLEY
Lamiaceae	*Mentha longifolia* ssp. *schimperi* (Briq.) Briq.	herb	Th	4.4	0.05	LC	VALLEY
	Lavandula pubescens Decne.	herb	Ch	1.2	0.3	NA	UPPER
	Marrubium vulgare L.	herb	Ch	2.2	0.2	NT	LOWER
	Ocimum forsskaolii Benth.	herb	Ch	0.1	0.05	NA	LOWER
	Otostegia fruticosa ssp. *schimperi* (Benth.) Sebald	herb	Ch	4.8	0.4	NA	UPPER
	Salvia merjamie Forssk.	herb	Ch	0.1	0.1	NA	UPPER
Malvaceae	*Abutilon bidentatum* A. Rich.	shrub	Ch	15.6	0.5	NA	VALLEY
	Hibiscus deflersii Schweinf. ex Cufod.	undershrub	Ch	0.8	0.05	NA	LOWER
	Hibiscus micranthus L.	undershrub	Th	6.4	0.25	NA	LOWER
	Hibiscus vitifolius L.	undershrub	Ch	1.6	0.2	NA	LOWER
Menispermaceae	*Cocculus pendulus* (J.R. & G. Forster) Diels	vine	Ph	0.4	0.05	NA	LOWER
Moraceae	*Ficus cordata* ssp. *salicifolia* (Vahl) C.C. Berg.	tree	Ph	2.4	0.4	LC	LOWER
	Ficus palmata Forssk.	tree	Ph	0.7	0.2	NA	UPPER
Moringaceae	*Moringa peregrina* (Forssk.) Fiori *	tree	Ph	0.8	0.05	NT	LOWER
Oleaceae	*Olea europaea* subsp. *cuspidata* (Wall. ex G. Don) Cif.	tree	Ph	1.2	0.3	NA	UPPER
Papaveraceae	*Argemone mexicana* L.	herb	Th	4.8	0.1	LC	VALLEY
Plantaginaceae	*Plantago boissieri* Hausskn. & Bornm.	herb	Th	17	0.35	NA	UPPER
Poaceae	*Panicum turgidum* Forssk.	grass	G	0.8	0.1	NA	LOWER
	Andropogon distachyos L.	grass	Th	6	0.5	NA	LOWER
	Aristida adscensionis L.	grass	Th	4	0.3	NA	UPPER
	Aristida congesta Roem. & Schults	grass	Th	3	0.25	NA	UPPER
	Aristida tricornis H. Scholz & Konig	grass	Th	3.5	0.3	NA	UPPER
	Avena barbata Pott ex Link	grass	Th	6	0.3	NA	VALLEY
	Cynodon dactylon (L.) Pers.	grass	G	3	0.2	LC	LOWER
	Eragrostis aspera (Jacq.) Nees	grass	Th	1.6	0.3	NA	UPPER
	Stipagrostis hirtigluma (Trin. Rupr.) de Wint.	grass	Th	4.8	0.4	NA	LOWER
	Themeda triandra Forssk.	grass	Th	5.6	0.6	NA	UPPER
	Tripogon purpurascens Duthie	grass	G	0.9	0.1	NA	VALLEY
	Phragmites australis (Cav.) Trin. & Steudel.	grass	Th	0.5	0.05	LC	VALLEY
Resedaceae	*Ochradenus baccatus* Del.	shrub	Ph	5.6	0.6	LC	UPPER
	Reseda sphenocleoides Defl.	herb	Th	1.2	0.3	NA	VALLEY
Rhamnaceae	*Ziziphus spina-christi* (L.) Desf.	tree	Ph	4.8	0.3	LC	VALLEY
Salicaceae	*Salix mucronata* Thunb.	tree	Ph	1.2	0.05	NA	VALLEY
Salvadoraceae	*Salvadora persica* L.	tree	Ph	2.8	0.3	LC	LOWER
Sapindaceae	*Dodonaea viscosa* L.	shrub	Ph	0.8	0.1	LC	UPPER
Solanaceae	*Lycium shawii* Roem. & Schult.	shrub	Ph	11.2	0.7	LC	LOWER
	Datura innoxia Mill.	herb	Ch	21	0.3	NA	LOWER
	Nicotiana glauca R.C. Graham	undershrub	Ph	6.4	0.15	LC	VALLEY
	Solanum incanum L.	undershrub	Ch	31	0.7	LC	COMMON
Stilbaceae	*Nuxia oppositifolia* (Hochst.) Benth.	tree	Ph	0.4	0.05	LC	LOWWER
Tamaricaceae	*Tamarix aphylla* (L.) Karst.	tree	Ph	1.2	0.1	LC	VALLEY
Zygophyllaceae	*Fagonia indica* Burm.f.	herb	Th	6	0.7	NA	COMMON

Commiphora gileadensis, Abutilon bidentatum, Rhus retinorrhoe, Commiphora kataf. and *Salvadora persica.* Several rare species have been found restricted in this habitat such as *Hibiscus deflersii* and *Nuxia oppositifolia* with low frequency about 0.05 for both species.

3.3. Upper plain

The elevations of this part of Jandaf Mountain were above 1500 m a.s.l. This area was largely inaccessible due to the height and the steep slopes. These factors contribute to reserve some endangered species such as *Dracaena serrulata* and *Aloe pseudorubroviolacea* which are endemic to the Arabian Peninsula. The most common species in this habitat are *Commiphora gileadensis, Otostegia fruticosa,* and *Rhus retinorrhoe*. The survey show that this part contained several rare species, which have a low frequency across the study area such as *Dracaena serrulata*, *Euclea schimperi*, and *Seddera arabica* with frequency 0.05, 0.05, and 0.1 respectively. These species are considered regional endemic (i.e. endemic to east Afromontane region and south west of Arabian Peninsula) and considered globally rare. Such species have been found the rarest species in this habitat.

4. Discussion

The result of the field survey illustrated that Jandaf Mountain is high in species diversity. The highest species richness nearest to Jandaf occurs in Asir (Bisha region), which has 140 species (Heneidy and Bidak, 2001). We recorded about 118 species (Table 1) within a small elevated area (30 km^2), compared to 140 species in Bisha and its vicinity, which is across a much larger area (about 250,600 km^2, e.g., Heneidy and Bidak, 2001). The variation in altitude at the small mountainous area is the main reason behind the high species richness of Jandaf Mountain (Al-Namazi et al., 2021).

The west side of Assarwat Mountains is usually more diverse than the east side due to the waves of fog that hit the west side (Al-Robai et al., 2019; Al-Namazi et al., 2021). Although Jandaf Mountain is an isolated mountain located to the east of the Assarwat Mountains and is affected by the harsh desert climate inland, it

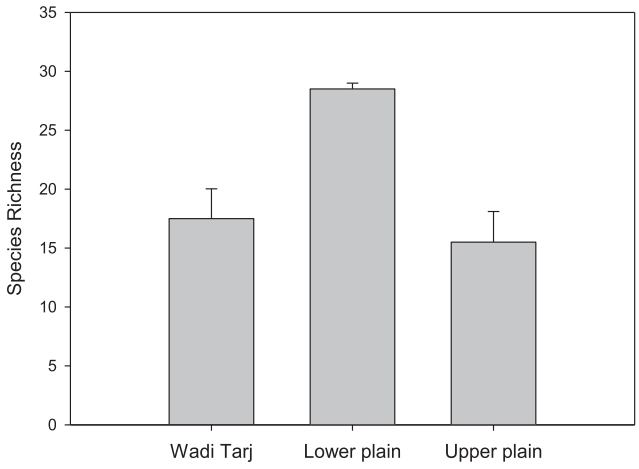

Fig. 3. The mean Species Richness ± (SE) in the three different elevation layers (N = 10, *df* = 9, F = 5.26, P = 0.40).

has relatively high plant diversity. Thus, the vegetation structure of Jandaf Mountain is dominated by the common species that grow in the Assrawat Mountains in addition to some species that often grow in the desert environment of Saudi Arabia such as *Acacia gerrardii, A. ehrenbergiana, A. tortilis, Calotropis procera, Maerua crassifolia*, *Ochradenus baccatus*, *Panicum turgidum*, and *Pulicaria undulata*. This also contributed to the enhanced species richness at this mountain.

Although there are many of common species that grow across a wide range of locations in the mountain, some species were found restricted to a specific elevation (see Table 1). Most of the rare and endangered species in the study area (e.g., *D. serrulata*, *A. pseudorubroviolacea,* and *M. quadrangula*) were restricted only to the highest elevation at Jandaf Mountain. Some other rare species such as *C. molle,* and *M. peregrina* were found only on the lower plain habitat. In contrast, the valley of Wadi Tarj is characterised by some species such as *S. mucronata*, *Z. spina-christi*, *P. australis*, *A. spinosus*, *Juncus punctorius*, and other species that could not be found growing anywhere else. The high level of specialisation contributes to the remarkable plant diversity.

The high plant biodiversity on this mountain qualifies for designation as an IPA. The first criterion (Criterion A) of the IPA (Al-Abbasi et al., 2010 see supplementary 1) is satisfied by the presence of several endemic and near-endemic plant species at Jandaf Mountain, such as *A. pseudorubroviolacea, M. quadrangula, D. serrulata, C. molle,* and *M. peregrina*. Furthermore, the species richness at this mountain satisfies Criterion B of the IPA. Satisfying these two criteria qualifies Janduf Mountain as an important plant area of the Arabian Peninsula. Our results also show that the vegetation of Jandaf Mountain satisfies several criteria of the HCVAs. The high species richness in Jandaf Mountain and the presence of some endemic and near-endemic species satisfies HCA1 and HCA3 (HCVA) see (supplementary 2). Satisfying these two criteria is sufficient support for the uniqueness of the vegetation type of this region.

About 20% of plant species across the world have been found to be threatened with extinction (Brummitt et al., 2015; Bachman et al., 2016). Thus, areas holding important plant diversity need urgent conservation effort (Darbyshire et al., 2017). Similarly, the unique vegetation of Jandaf is currently threatened by different factors, such as climate change (particularly drought), competition with other associated species, and most importantly human activities (such as overgrazing and clearing). *Dracaena serrulata*, for instance, was found to be very rare in Jandaf Mountain and is represented by only three individuals located in very remote inaccessible spots (i.e., it is restricted to the summit of upper plain). The main reason accounting for the rarity of *D. serrulata* is overcutting by the beekeepers for use as beehives for the production of honey. Therefore, the vegetation of Jandaf Mountain needs to be reserved to protect the habitats of endemic and endangered species inhabiting the mountain. Along with the Wadi Tarj, both areas are proposed to be protected as a Strict Nature Reserves (Category Ia) under the International Union for Conservation of Nature (IUCN; see Boug et al., 2012; Brummitt et al., 2015).

Different conservation methods should be conducted on the vegetation of the mountain of Jandaf based on the nature of species and habitat. For example, species that suffer overgrazing should be protected from grazing in order to re-establish populations (Al-Rowaily et al., 2015). Other species need to be propagated at botanical gardens or nurseries and then transplanted to the site for regeneration (Werden et al., 2018). In contrast, some species may not need any conservation efforts. For example, species that cannot be reached by herbivore animals or disturbance due to high elevation and inaccessibility of their habitat's topography are likely under less threat. In another example, the species that have defence mechanisms (e.g., chemical or physical defence) can escape the impact of herbivories and may be less impacted (Hanley and Lamont, 2002; Hanley et al., 2007; Agrawal and Konno, 2009), so they require less conservation effort than more vulnerable species.

Overall, our study found exceptional plant diversity at Jandaf Mountain, which suggests its designation as an important area for conservation would be crucial to the maintenance of biodiversity in the Arabian Peninsula. Future directions include studies on the gene flow and intraspecific differences among populations of the rare and vulnerable plant species.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sjbs.2022.03.003.

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