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Original article

Natural plant species inventory of hotspot areas in Arabian Peninsula: Southwest Al-Baha region, Saudi Arabia

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ABSTRACT

Plant hotspot areas are the areas that are very rich in plant species diversity. These areas have a priority for conservation. To highlight the plant diversity for nature conservation purposes a case study in Al Baha region, Saudi Arabia is presented, in which the importance of the natural vegetation and flora of one of the hotspot areas of Saudi Arabia is evaluated through the explanation of its natural plant species. A survey study has been conducted in an area of 167.6 km2, a 97 sample each with 20X20 m were laid out covering the whole ecological zones of the study site. Data of flora, vegetation cover and topography were gathered from each sample site. The study revealed about 319 plant species belonging to 228 genera and 75 families. Two species were found endemic to Saudi Arabia, 14 were endemics to Arabian Peninsula, and five were regional endemics that are only found in East Africa and Arabian Peninsula, while 39 species are rare and endangered.

1. Introduction

The Mountains in southwestern Saudi Arabia (i.e. Sarawat), are considered as one of the richest biodiversity areas in the Arabian Peninsula and comprises a large number of endemic, endangered and threatened plant species (Abuzinada et al. 2005; Qushas, 2007). Biodiversity hotspots play a leading role in international and national nature conservation strategies (Hobohm et al., 2016). The study area is located on the Sarawat Mountains and within The Eastern Afromontane Hotspot area (Mallon, 2011). This area has rich biodiversity and is considered as one of the richest plant diversity areas in the Arabian Peninsula (Al-Aklabi et al. 2016; Al-Zandi et al. 2018). It also supports high rates of endemism, large numbers of rare species and a few endangered plant species with restricted distributions on inaccessible slopes facing the Red Sea (Al-Khulaidi et al. 2018). Some of the monotypic trees can be remnants of past forests and ancient heritage (Aronson et al. 2016), where many forest elements have destroyed and declined due to climate change and human activities.

Many studies on plant diversity of ecological sites in Saudi Arabia were conducted (e.g. Ghazanfar and Fisher 1998; Hegazy et al. 1998; Chaudhary and Al-Jowaid 1999; Hall et al. 2011; El-Sheikh, 2013; Alatar et al. 2015). The outcome of some of them (e.g. Collenette 1985, 1999; Thomas et al. 2017) takes into account the endemism and endangered plant species. However, a few of them highlighted the important areas of plant diversity in Saudi Arabia (e.g. Al-Abbasi et al. 2010; Llewellyn et al. 2010; Hall et al. 2010, 2011; Thomas et al. 2017).

The flora and the vegetation of the study area are a mixture of different climatic conditions and of different elements of Saharo-Arabian or Saharo-Sindian, Sudanian region, and Mediterranean region (Al-Khulaidi 2013; Al-Aklabi et al. 2016). This due to a variation in rainfall from dry at low altitude and relatively wet at high altitude and due to different types of landscape and altitude ranges from 650 to 2350 m. (Fig. 2). Few vegetation studies were conducted in Al-Baha region covering part of the study area (Al-Aklabi et al. 2016; Al-Zandi et al. 2018; Al-Khulaidi et al. 2018a; Al-Robai et al. 2019).

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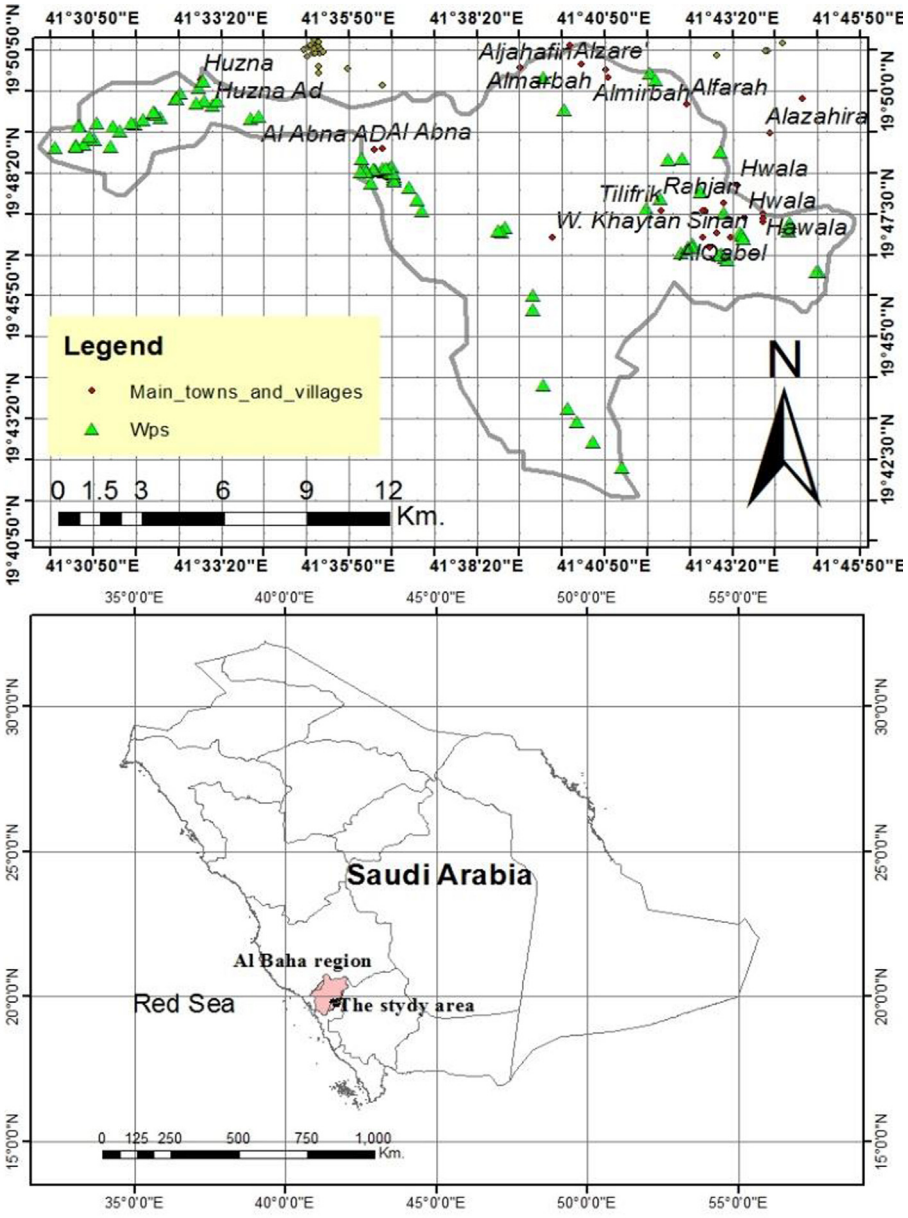

Fig. 1. The location of the study area.

In this study, we aim to highlight the important plant area in Albaha region. Our research will include an inventory for the plant diversity of the targeted study area. In addition, the study aims to highlight the hotspot areas that have the highest plant species richness and further plant biodiversity among the studied zones.

2. Materials and methods

2.1. The study area

The study was conducted in the period from April 2017 to July 2018, near Baljurashi city in the southwest of Al-Baha region, (between 19.41: 19.50 North and between 41.29 and 41.44 East), The study area covers the ecological zones located around Hawala, Jabal Uthrob, Al Abna and Huzna areas (Fig. 1). These areas stretch parallel to Tihamah plain and extend for approximately 68 km. from Assollubat fault in the south to Huznah escarpment in the north. The altitude ranges between 300 and 2350 m above sea level (masl). The slopes and the plateaus directed sharply to Tihamah plain, and become lower and gradually slope eastward. Deep wadis and drainage lines cut the mountains, and flow toward the Tihama foothills. Tihamah foothills area border the eastern and western sides of Jabal Uthrub escapement, which is covered by rocks, gravels, and rock outcrops.

In general, the Arabian Shield, where the study was conducted is composed of a stable Craton of predominantly late Precambrian metavolcanic and plutonic rocks. Its surface is composed of around 50% plutonic rocks, and 50% volcanic sedimentary rocks. Granit consists of about 70% of plutonic rocks. Most rocks in Hawalah area are Amphibolite, Biotite, Tonalite, Gabbro, Andesite, and Granite (Brown et al., 1989).

The landscape variation strongly influences the flora, composition, structure of the vegetation communities and vegetation types. The variation of landscape in particular that facing the west and effected by fog provides a vegetation edge microclimate ecosystem

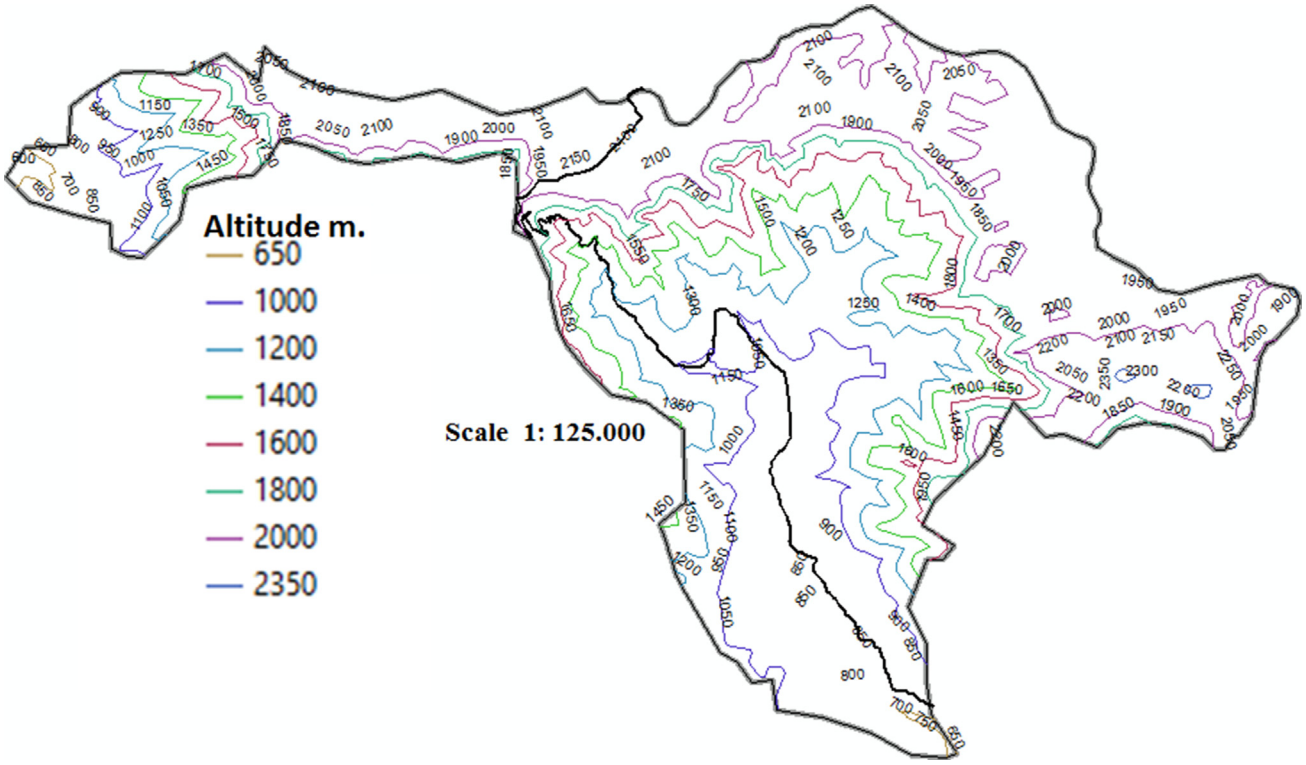

Fig. 2. The altitude of the study area.

(Young and Mitchell, 1994), which supports unique flora, vegetation composition and structure with endemic, rare plant species. The altitude of the study area ranges between 600 and 2240 masl (Fig. 2). The terraces are confined nearly to the high altitude areas, most of these terraces are neglected for years, and as a result, they became covered by natural vegetation dominated by *Vachellia origena (=Acacia origena)* with associated species such as *Juniperus procera, Asphodelus fistulosus, Achillea biebersteinii, Nepeta deflersiana, Tripteris vaillantii, Hyparrhenia hirta, Eragrostis papposa* and others.

The Geographic Information System GIS (Arc Map software) was used to generate maps of the endemic, near-endemic, rare, endangered species, plant density and plant richness throughout the study area. Diversity indices were applied using a MultiVariate Statistical Package (MVSP) software and by using Simpson's and Shannon's method to identify the more diverse sample sites. The total number of samples was 97 samples, each with a size of 20X20 m. and dispersed randomly in an area of 167.6 km 2, with the assurance that the samples covered all ecological zones and topographic units of the study area.

2.2. Plant population parameters

2.2.1. Density: Number of individuals of each species counted in each sample site

The numbers of individuals of each species in each site were then converted to a number of individuals per hectare. This is achieved by dividing the total number of individuals by the total areas surveyed in the different landforms.

2.2.2. Frequency: Frequency was calculated by dividing the number of plots in which a species occurs into the total number of plots sampled Al-Zandi et al, 2018

2.2.3. Endemism: The endemic plant species is defined for this study as the plant that only occurs in Saudi Arabia; the near-endemic species are those that occur only in the Arabian Peninsula (mainly Saudi Arabia and Yemen)

The distribution of endemic and near-endemic species are based on Collenette 1985); Wood 1997 and Al-Khulaidi 2013.). The Regional endemics in the study area are the plants that occur only in the Arabian Peninsula and East Africa (Somalia, Ethiopia, Djibouti, Sudan, Kenya, Uganda, Tanzania) (Fig. 3). The distribution

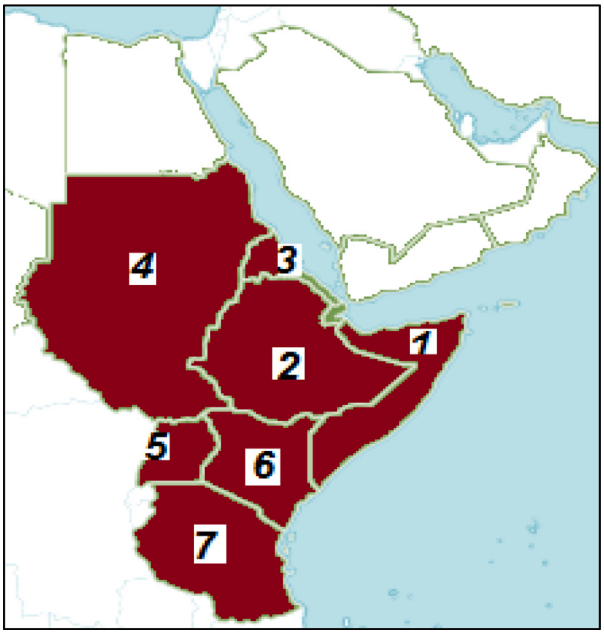

Fig. 3. Eastern Africa, 1 Somalia, 2 Ethiopia, 3 Djibouti, 4 Sudan (North & South), 5 Uganda, 6 Kenya, 7 Tanzania.

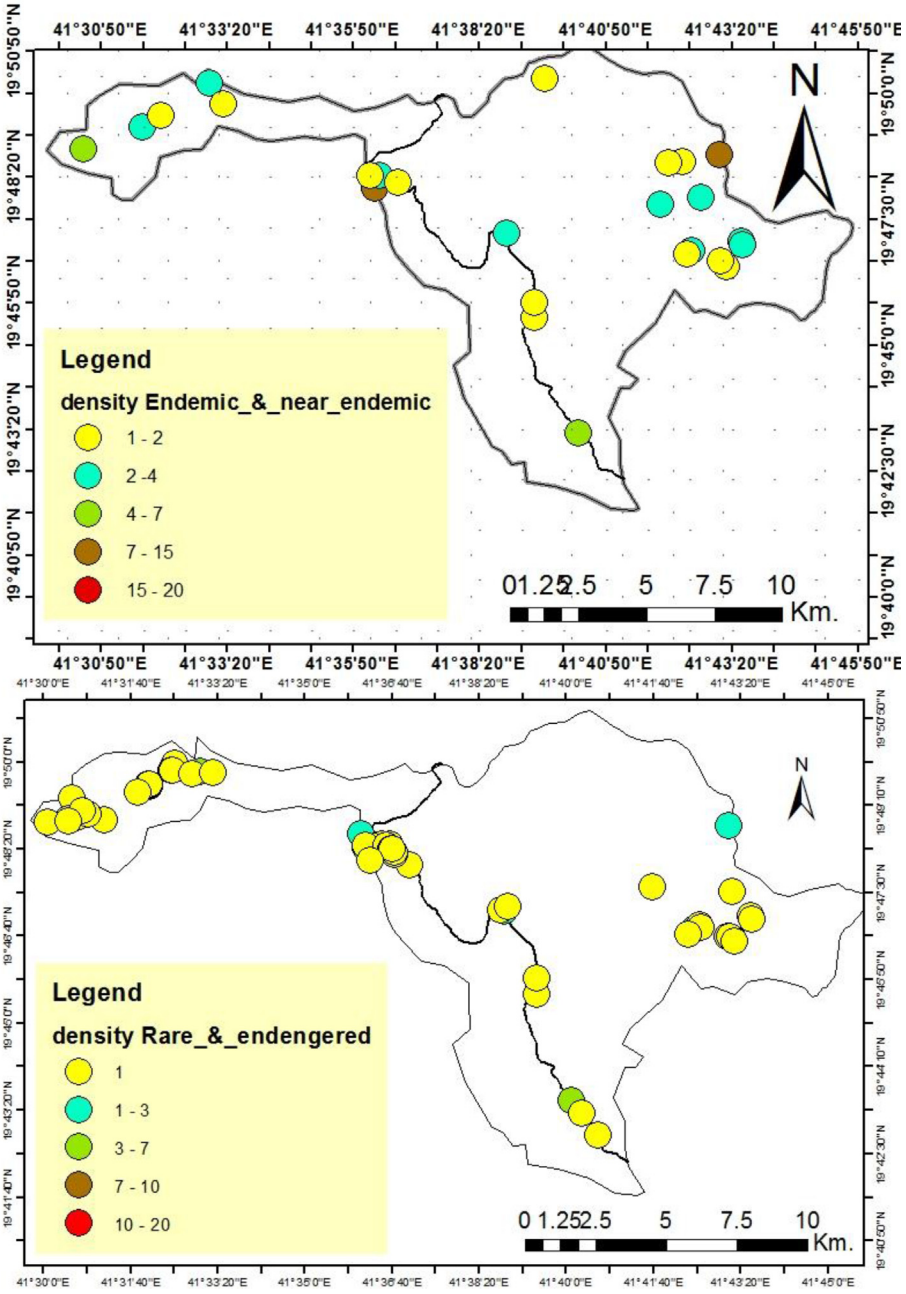

Fig. 4. The concentration of endemic, rare and endangered plant species.

of regional endemic plants was based on information from (Thulin 1993- Volume 1, 2, 3 and 4, Thulin 2008, Edwards et al. (2000); Hedberg and Edwards (1989) as well as Wood (1997).

3. Results

In total, 319 plant species belonging to 75 families and 228 genera were found in the surveyed area (Appendix1). Two species are endemic to Saudi Arabia, 14 are endemic to Arabian, 5 regional endemic only found in East Africa and Arabian Peninsula and 39 are rare and endangered, most of them were concentrated around Jabal Uthrub, Hawala, and at the top of Al Abna and Huzna descents (Fig. 4)

The family Asteraceae is represented by the highest number of species (35 species) followed by the Poaceae (27 species), Lamiaceae (19 species), Fabaceae (15 species), Acanthaceae (12 species), Apocynacaea (11 species), Euphorbiaceae and Mimosaceae (10 species) (Fig. 5). The previous prominent eight families together contribute 139 plant species (44% of the overall total species). Twenty-eight families (29% of the overall total) are represented by only a single species, with the most common ones being Barbeyaceae (*Barbeya oleoides*), Ericaceae (*Erica arborea*).

3.1. Plant population parameters

3.1.1. Frequency

About 82% of the total plant species were categorized in the lowest frequency class, whereas 11% of the plants were distributed in the second frequency class. With a frequency of 49%, *Juniperus procera* is the most frequent species followed by *Maytenus parviflora* (41%) and *Senegalia asak (=Acacia asak)* with frequency

(39%). Most abundant species with a frequency of more than 20% are shown in Fig. 6. Many species were very rare and endangered, with a frequency between 1 and 2%. The most important and rarest species were *Boscia angustifolia, Periplocha aphylla, Commiphora kua, Euphorbia cuneata, Kleinia odora, Psitacia falcata, Salvia merjamie, Teclea nobilis,* and *Jasminum fluminense* with a frequency 1% (Table 1).

3.1.2. Endemism

The study area contains a remarkable number of endemic plant species. These are estimated to be about 16% of the vascular flora of the study area, in which endemic (two species), near endemic (14 species) and regional endemic (34 species) (Table 2). Fig. 3 shows the distribution of endemism, rare and endangered plant species of the study area.

3.1.3. Plant density

The Majority of high-density plants were grasses. These grasses are confined mainly to high altitude areas namely *Hyparrhenia hirta* and *Themeda triandra*. Further annual species such as *Asphodelus fistulosus* and *Osteospermum vaillantii* were also recorded as high-density species; both species appear along road margins and disturbed sites in the summertime. Among trees, *Juniperus procera* was a high-density tree and forms woodland of varies vegetation and structure types (Fig. 7).

3.1.4. Plant diversity

The most diverse sample sites were: 371, 367, 420 and 423 (Table 3 & Fig. 8). These sample sites were located on the high-altitude areas facing mainly South and South West such as the top of Al Abna descent and on Jabal Uthrub (Hawala).

4. Discussion

There are 29 rare and endangered plant species in the study area, with a frequency of less than 2% (Table 1). Many plant species in the world are threatened with extinction due to climate change and intensive human activities (Chaudhary and Khan, 2010). A recent study estimates 46 rare and endangered plant species in Al Baha region (Al-Khulaidi et al. 2018b)., Species richness, endemism, or rarity are paramount criteria in selecting important plant areas (IPAs) for conservation strategies (Sánchez de Dios et al., 2017), single plant families can be worth to adding them as one criterion in selecting IPA. Two rare species with single plant families Barbeya oleoides and Erica arborea are found in the study area (Fig. 9).

The topographic factor in some areas, especially those facing the Red Sea, such as areas that located around Hawala, Jabal Uthrum (East) as well as at the top of Al Abna descent and around Huzna village (West), where there are waves of fog, helped to enrich these areas with plant diversity (Fig. 10). Generally, these areas are characterized by both a high density of vegetation and a high number of plant species (i.e. species richness). In terms of conservation, these areas have to be protected and managed properly so that their rich plant diversity resources are preserved.

Barbeya oleoides, is found only in 7 locations around Huzna and at the top of Al Abna descent, the most dominants were found between 1454 and 1768 masl, on drainage lines facing South West and North East. The plant is an endemic of the eastern Afromontane escarpment of the Ethiopian plateau, horn of Somalia, Eritrea, between 1200 and 2900 masl (Rendle 1916; Friis, 1983; Thulin 2008). Thus, it is forming part of the transition element between Afromontane and Somalia-Masai regions (Hall, 2008), and SW of Arabian Peninsula mountains, between 700 and 2135 masl (wood, 1997; Collenette, 1985). This species forms a vegetation type with *Olea europaea* and *Juniperus procera* on steep to moderate rocky slope and wadis between 1700 and 2065 masl. (Al-Aklabi et al., 2016). This species recorded also at about 1540 masl in Taif region that characterized by monthly temperature ranges from 13.7 °C to 30.9 °C and an annual rainfall of about 208 mm (Ragab, et al, 2005). This rare plant is considered as one of the medicinal plants of Saudi Arabia (Zakaria, 2010).

Furthermore, *Barbeya oleoides* has been evaluated by the International Union for Conservation of Nature IUCN as Least Concern and is considered a monotypic tree family that is represented by

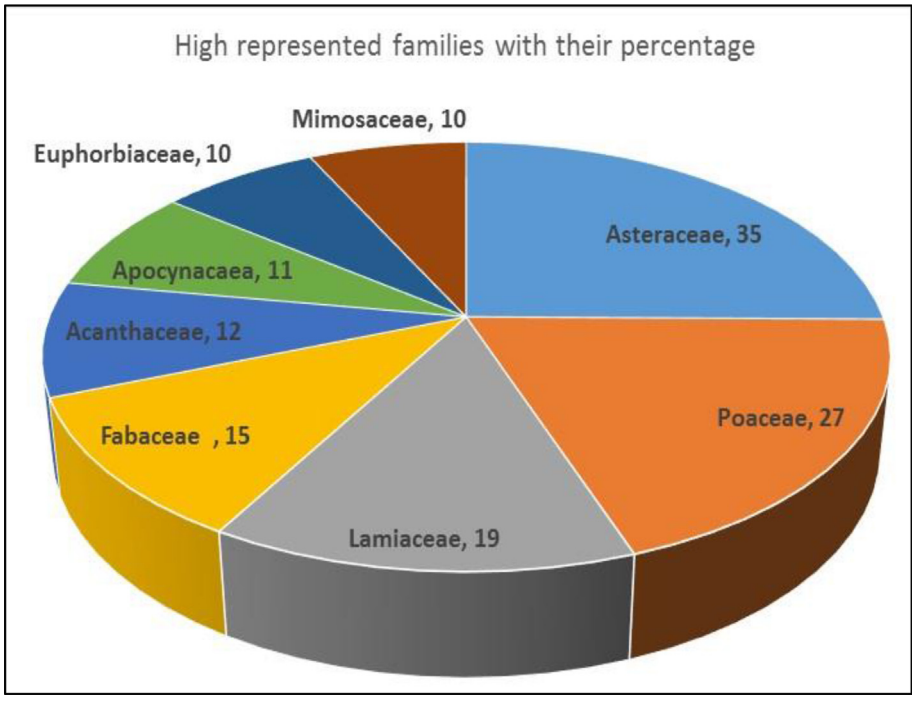

Fig. 5. High represented families with their percentage.

Plant name	freq.%
Juniperus procera	49
Maytenus parviflora	41
Senegalia asak	39
Hyparrhenia hirta	38
Aristida adscensionis	35
Dodonaea viscosa	35
Solanum incanum	32
Olea europaea	31
Vachellia origena	31
Eragrostis papposa	30
Pennisetum setaceum	29
Aerva javanica	28
Cenchrus ciliaris	27
Psiadia punctulata	27
Themeda triandra	27
Sageretia thea	25
Tripteris vaillantii	24
Micromeria imbricata	22
Ficus cordata	21
Jasminum grandiflorum	21
Blepharis edulis	20
Rhus retinorrhoea	20
Lavandula dentata	20

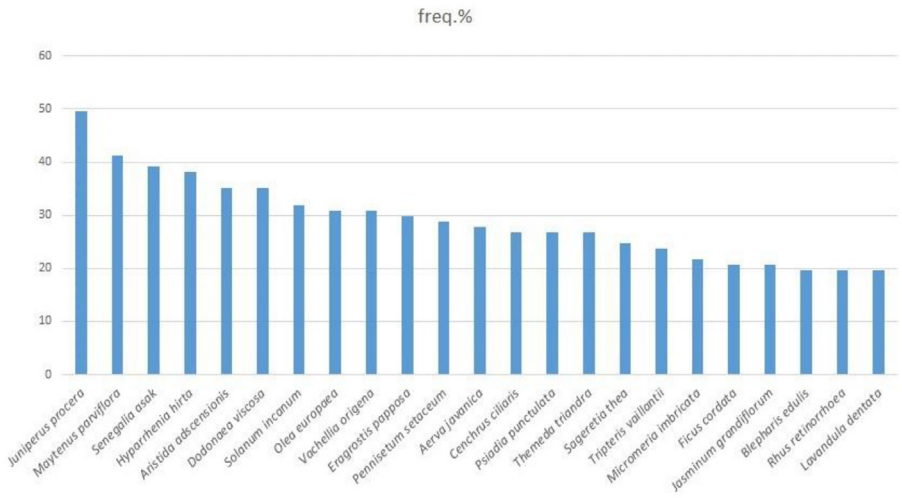

Fig. 6. Most abundant species with their percentage frequency.

Table 1
Rare and endangered plant species, with a frequency between 1 and than 2%.

Plant name	Freq.%	Plant name	Freq.%	Plant name	Freq.%
Acacia oerfota (=Vachellia oerfota)	2	Lycium shawii	2	Boscia angustifolia	1
Aloe castelorum	2	Monolluma quadrangula	2	Periplocha aphylla	1
Barleria acanthoides	2	Pentas lanceolata	2	Commiphora kua	1
Caralluma wissmani	2	Phoenix caespitosa	2	Euphorbia cuneata	1
Celtis africana	2	Pulicaria petiolaris	2	Kleinia odora	1
Cordia monoica	2	Rhamnus staddo	2	Psitacia falcata	1
Cynoglossum bottae	2	Silene yemensis	2	Salvia merjamie	1
Dobera glabra	2	Tamarix nilotica	2	Teclea nobilis	1
Euclea racemosa	2	Grewia velutina	1	Jasminum fluminense	1
Leucas alba	2	Barleria hochstetteri	1		

Table 2
Endemic, near endemic and regional endemic of the study area.

Plant name	Endemism	plant name	Endemism	plant name	Endemism
Aloe pseudorubroviolacea	*	Felicia abyssinica	***	Felicia dentata	***
Plectranthus asirensis	*	Acacia etbaica (=Vachellia etbaica)	***	Grewia velutina	***
Acacia johnwodii (=Vachellia johnwoodi)	**	Acacia hamulosa (=Senegalia hamulosa)	***	Kickxia pseudoscoparia	***
Aloe castelorum	**	Acacia origena (=Vachellia origena)	***	Kleinia odora	***
Barleria bispinosa	**	Anisotes trisulcus	***	Lavandula atriplicifolia	***
Centaurothamnus maximus	**	Barbeya oleoides	***	Lavandula pubescens	***
Crinum album	**	Buddleja polystachya	***	Minuartia filifolia	***
Cynoglossum bottae	**	Caralluma retrospiciens	***	Phoenix caespitosa	***
Gymnosporia parviflora	**	Carissa spinarum	***	Pistacia falcata	***
Leucas alba	**	Cometes abyssinica	***	Pulicaria schimperi	***
Monolluma quadrangula	**	Commiphora gileadensis	***	Searsia retinorrhoea	***
Nepeta deflersiana	**	Commiphora kataf	***	Rumex nervosus	***
Orbea wissmannii var. eremastrum	**	Commiphora kua	***	Seddera arabica	***
Phragmanthera austroarabica	**	Commiphora myrrha	***	Silene yemensis	***
Picris scabra	**	Cordia monoica	***	Solanum schimperianum	***
Teucrium yemense	**	Cyphostemma digitatum	***	Triumfetta flavescens	***
Acacia asak (=Senegalia asak)	***	Dorycnopsis abyssinica	***		

KEY Endemism.
* Endemic, ** near endemic, *** regional endemic found in Eritrea, Djibouti, Ethiopia, Sudan, Kenya, Tanzania.

a single genus and single species. Thus, this species is important taxonomically, and in terms of phytogeography and phylogenetic studies (Rana, and Ranade 2009; Sarwar and Araki, 2010). Some of the monotypic trees can be remnants of past forests and ancient heritage (Aronson et al. 2016), where many forest elements have destroyed and declined due to climate change and human activities.

The rare tree Erica arborea is only found in three locations over 2000 m east of the study area (Jabal Uthrub), on habitats of rock

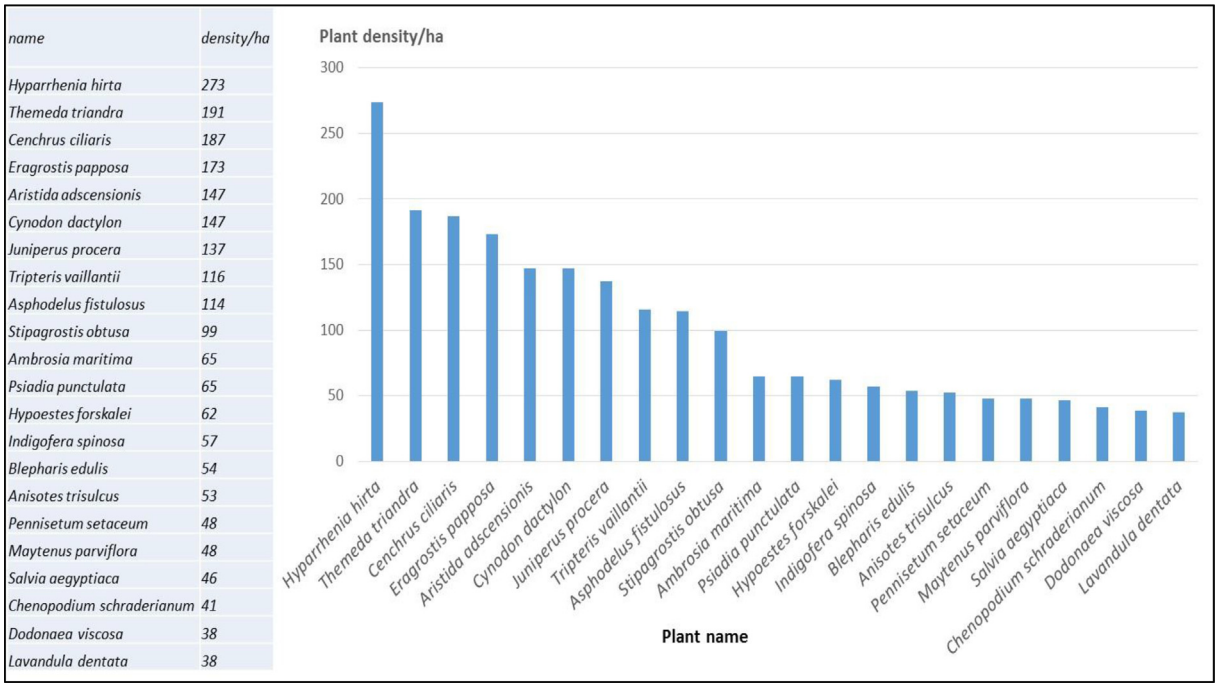

Fig. 7. Most density species with their density per hectare.

Table 3
The most diverse sample sites according to Shannon's and Simpson's methods.

Shannon's method Log base e				Simpson's method Log base e			
Index	Sample	Evenness	Num.Spec.	Index	Sample	Evenness	Num. Spec.
361	371	0.91	53	0.96	371	0.98	53
346	367	0.91	45	0.95	367	0.98	45
333	420	0.88	44	0.95	420	0.97	44
333	423	0.89	43	0.95	423	0.97	43

outcrops and with relatively deep soil terraces facing North West. Studies conducted in the region considered this species as one of the rare and endangered taxa (Al-Khulaidi, 2018a; Al-Khulaidi, et al., 2016). According to IUCN categories, the species is considered as Least Concern (Harvey-Brown and Barstow, 2017; Rivers, et al., 2019). The plant is native to the Mediterranean, Tropical African Mountains, and Arabian Peninsula (Harvey-Brown and Barstow, 2017). The plant forms a community on mountains with loam; moderate fine granular located between 2800 and approximately 3250 masl South-eastern Highlands of Ethiopia (Yimer, 2007). The plant forms a community in Mediterranean regions of Turkey, where the temperature ranges between 14 and 18 °C with high humidity in summers (Yildirim and Yilmaz, 2005), and ranges in altitudes from 660 to 820 masl, and slope gradient is between 14 and 55%. And in southwest Sardinia where the predominant soils are Leptosols, with average annual rainfall 1056–1072 mm, and average annual temperature in the area 13 °C (Vacca, 2017). Generally, the plant grows and forms communities in areas with high rains and low temperatures in the world, such as the Mediterranean and East Africa regions.

Teclea nobilis, Boscia angustifolia are remarkable species found only in East Africa, Saudi Arabia and Yemen (Thulin 2008). Both are very rare species with a single tree in the habitat (i.e., the study area), the first only seen at 1734 masl, on drainage line facing SW, while the latter is only seen in two locations, inaccessible rocky slope between altitudes 900 and 1650 masl. The two species generally are rare in Al Baha region (Al-Khulaidi et al., 2018a) (Fig. 11). The tree *Faidherbia albida* is only seen in one location, this rare tree is considered as one of the enigmatic old tree species of great cultural significance in the Middle East (Aronson et al. 2016).

Still few rare plant species need to be investigated in detail. These rare and remarkable plant species need taxonomic evaluation, documentation, and conservation, and also need special attention from the preservation and conservation points of view, the extinction of these species, would represent a big loss of plant diversity. The rarity of this plant may be due to the low rain and fog. However, these rare trees may have been introduced in the past, but have not spread, and have thus remained isolated (Rana, and Ranade 2009).

Declaration of Competing Interest

The authors declared that there is no conflict of interest.

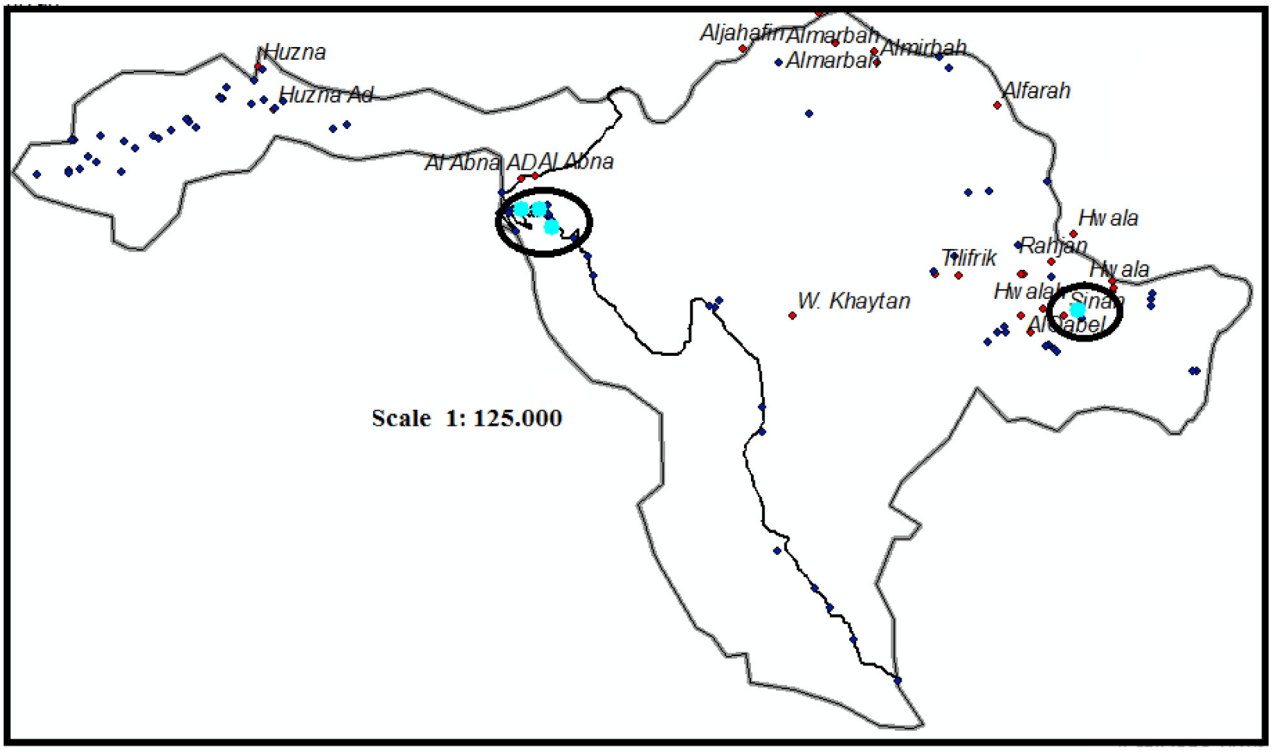

Fig. 8. The most diverse sample sites are around Hawala and at the top of Al Abna descent.

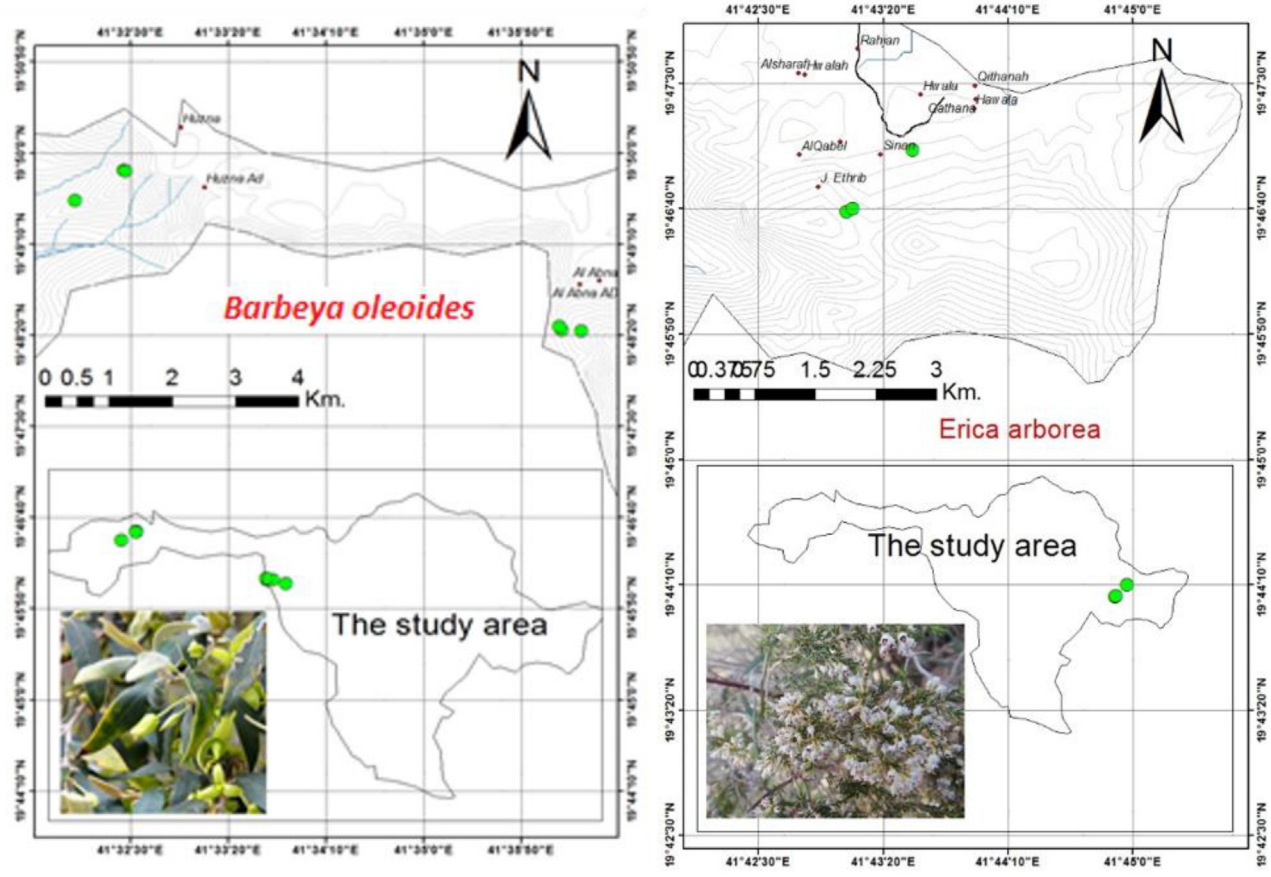

Fig. 9. Rare species representing a family with a single species. The latitude and altitude points and the scale are for enlarged map.

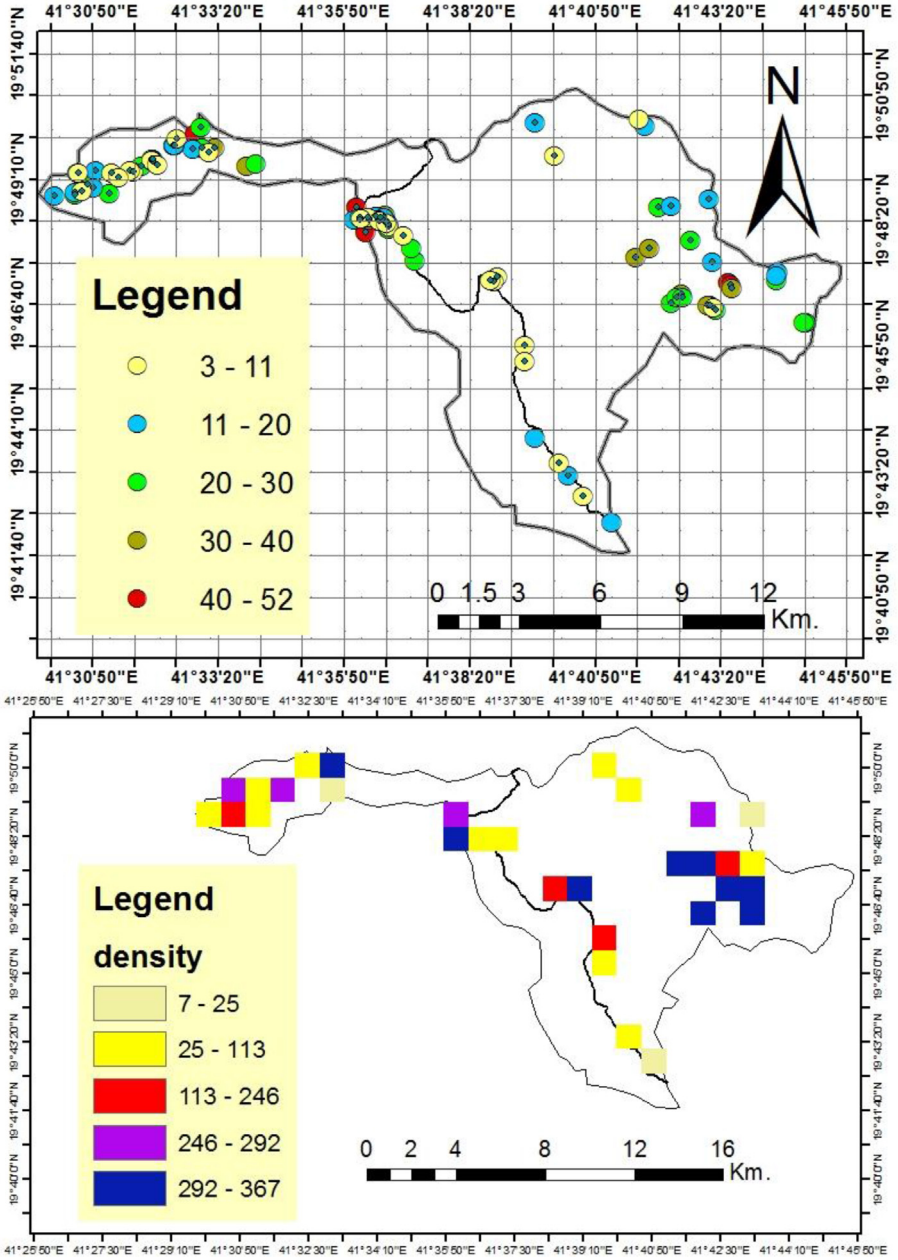

Fig. 10. Number of species (Richness) per sample site (20 by 20 m.) top and density of plant species per km^2. Below.

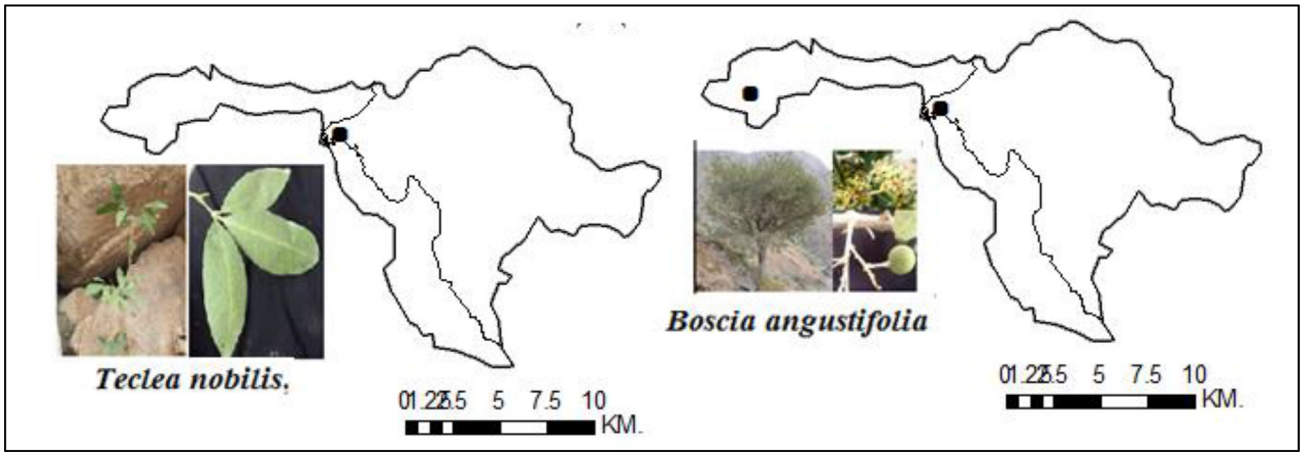

Fig. 11. The distribution of *Teclea nobilis*, *Boscia angustifolia.*

Appendix:. Surveyed plant species list with density and frequency for each species.

Plant name	Frequency %	density/ ha	Relative density	Relative frequency	plant name	Frequency %	density/ ha	Relative density	Relative frequency
Abutilon fruticosum	7.2	9.5	0.240	0.354	***Hibiscus micranthus***	2.1	0.5	0.013	0.101
Abutilon sp.	6.2	8.8	0.221	0.303	***Hibiscus vitifolius***	3.1	2.1	0.052	0.152
Acalypha fruticosa	9.3	9.8	0.247	0.455	***Huernia*** sp.	1.0	1.3	0.032	0.051
Achillea arabica (=Achillea biebersteinii)	7.2	36.1	0.910	0.354	***Hyparrhenia hirta***	38.1	273.5	6.895	1.870
Achyranthes aspera	10.3	24.7	0.624	0.505	***Hypoestes forskaolii***	11.3	61.9	1.560	0.556
Adenium obesum	18.6	10.6	0.266	0.910	***Ifloga spicata***	3.1	3.6	0.091	0.152
Aerva javanica	27.8	32.0	0.806	1.364	***Indigofera*** sp.	3.1	16.2	0.409	0.152
Aerva lanata	10.3	11.1	0.279	0.505	***Indigofera spiniflora***	2.1	1.0	0.026	0.101
Aizoon canariense	4.1	7.5	0.188	0.202	***Indigofera spinosa***	18.6	57.0	1.436	0.910
Aloe castellorum	2.1	4.9	0.123	0.101	***Jasminum fluminense***	1.0	0.5	0.013	0.051
Aloe pseudorubroviolacea	5.2	7.7	0.195	0.253	***Jasminum grandiflorum***	20.6	17.5	0.442	1.011
Alyssum desertorum	2.1	1.0	0.026	0.101	***Jatropha glauca***	2.1	2.8	0.071	0.101
Amaranthus sp.	1.0	0.8	0.019	0.051	***Jatropha pelargoniifolia***	5.2	2.6	0.065	0.253
Ambrosia maritima	2.1	64.9	1.638	0.101	***Juniperus procera***	49.5	137.1	3.457	2.426
Ammi majus	2.1	3.4	0.084	0.101	***Justicia flava***	5.2	4.6	0.117	0.253
Anarrhinum forskaohlii subsp. ***forskaohlii (=Anarrhinum orientale)***	1.0	4.1	0.104	0.051	***Justicia odora***	1.0	0.5	0.013	0.051
Anchusa ovata	1.0	0.3	0.006	0.051	***Kickxia pseudoscoparia***	6.2	2.3	0.058	0.303
Andropogon distachyos	12.4	35.1	0.884	0.606	***Kleinia odora***	1.0	0.3	0.006	0.051
Andropogon sp.	1.0	2.6	0.065	0.051	***Lactuca dissecta***	2.1	2.1	0.052	0.101
Anisotes trisulcus	17.5	52.6	1.326	0.859	***Lamarckia aurea***	2.1	18.0	0.455	0.101
Argemone ochroleuca	4.1	6.2	0.156	0.202	***Lantana*** sp.	3.1	1.5	0.039	0.152
Argyrolobium arabicum	6.2	4.4	0.110	0.303	***Launea*** sp.	4.1	1.5	0.039	0.202

Appendix (*continued*)

Plant name	Frequency %	density/ ha	Relative density	Relative frequency	plant name	Frequency %	density/ ha	Relative density	Relative frequency
Aristida adscensionis	35.1	147.2	3.711	1.718	***Lavandula atriplicifolia***	2.1	0.5	0.013	0.101
Arthraxon sp.	1.0	0.5	0.013	0.051	***Lavandula coronopifolia***	4.1	3.1	0.078	0.202
Asparagus africanus	1.0	0.5	0.013	0.051	***Lavandula dentata***	19.6	37.6	0.949	0.960
Asphodelus fistulosus	10.3	114.2	2.879	0.505	***Lavandula pubescens***	16.5	9.8	0.247	0.809
Astragalus pelecinus (=Biserrula pelecinus)	1.0	0.5	0.013	0.051	***Lavandula*** sp.	2.1	2.1	0.052	0.101
Atractylis cancellata	1.0	0.5	0.013	0.051	***Leucas alba***	2.1	6.4	0.162	0.101
Avena barbata	1.0	2.6	0.065	0.051	***Leucas glabrata***	6.2	5.9	0.149	0.303
Avena sp.	9.3	17.0	0.429	0.455	***Lindenbergia indica***	1.0	1.0	0.026	0.051
Barbeya oleoides	12.4	3.9	0.097	0.606	***Lolium multiflorum***	2.1	5.2	0.130	0.101
Barleria acanthoides	2.1	0.8	0.019	0.101	***Lotus*** sp.	1.0	0.5	0.013	0.051
Barleria bispinosa	7.2	7.7	0.195	0.354	***Lycium shawii***	2.1	0.8	0.019	0.101
Barleria hochstetteri	1.0	0.8	0.019	0.051	***Lysimachia arvensis*** subsp. ***arvensis (=Anagallis arvensis)***	8.2	30.9	0.780	0.404
Barleria sp.	3.1	1.5	0.039	0.152	***Maerua crassifolia***	5.2	1.3	0.032	0.253
Bidens biternata	1.0	0.8	0.019	0.051	***Malva parviflora***	1.0	0.5	0.013	0.051
Blepharis edulis	19.6	53.9	1.358	0.960	***Maytenus*** sp.	3.1	1.0	0.026	0.152
Boerhavia diffusa	2.1	0.8	0.019	0.101	***Medicago minima***	1.0	14.2	0.357	0.051
Boerhavia elegans	1.0	0.3	0.006	0.051	***Medicago polymorpha***	1.0	0.5	0.013	0.051
Boscia angustifolia (=Boscia integrifolia)	1.0	0.3	0.006	0.051	***Medicago*** sp.	1.0	0.5	0.013	0.051
Brachiaria sp.	1.0	1.3	0.032	0.051	***Melhania ovata***	2.1	0.8	0.019	0.101
Brassica rapa	1.0	1.8	0.045	0.051	***Melilotus indicus***	1.0	6.4	0.162	0.051
Brassica sp.	1.0	0.8	0.019	0.051	***Micromeria imbricata***	21.6	36.1	0.910	1.061
Brassica tournefortii (=Coincya tournefortii)	4.1	27.6	0.695	0.202	***Micromeria*** sp.	26.8	45.1	1.137	1.314
Bromus rigidus	1.0	3.1	0.078	0.051	***Minuartia filifolia***	8.2	4.6	0.117	0.404
Buddleja polystachya	3.1	0.8	0.019	0.152	***Misopates orontium***	1.0	0.5	0.013	0.051
Cadaba farinosa	3.1	1.3	0.032	0.152	***Monolluma quadrangula (=Ceropegia quadrangula)***	2.1	0.5	0.013	0.101
Cadaba glandulosa	3.1	1.0	0.026	0.152	***Nepeta deflersiana***	5.2	10.8	0.273	0.253
Calendula arvensis	1.0	6.4	0.162	0.051	***Nicotiana glauca***	14.4	10.8	0.273	0.707
Calotropis procera	11.3	5.4	0.136	0.556	***Notoceras bicorne***	1.0	9.0	0.227	0.051
Campanula edulis	1.0	0.5	0.013	0.051	***Nuxia oppositifolia***	5.2	3.9	0.097	0.253
Capparis cartilaginea	4.1	1.0	0.026	0.202	***Ochradenus baccatus***	1.0	0.3	0.006	0.051
Carduus pycnocephalus	1.0	0.5	0.013	0.051	***Ocimum filamentosum***	2.1	2.6	0.065	0.101

(*continued on next page*)

Appendix (*continued*)

Plant name	Frequency %	density/ ha	Relative density	Relative frequency	plant name	Frequency %	density/ ha	Relative density	Relative frequency
Carissa spinarum	9.3	7.2	0.182	0.455	***Ocimum forskoelei***	2.1	4.4	0.110	0.101
Caroxylon imbricatum (=Salsola imbricata)	2.1	4.6	0.117	0.101	***Olea europaea***	30.9	34.3	0.864	1.516
Caylusea hexagyna	1.0	0.8	0.019	0.051	***Onopordum heteracanthum***	3.1	1.3	0.032	0.152
Celtis africana	2.1	0.5	0.013	0.101	***Opuntia ficus-indica***	4.1	13.1	0.331	0.202
Cenchrus ciliaris	26.8	187.1	4.718	1.314	***Orbea wissmannii (=Caralluma wissmannii)***	2.1	1.0	0.026	0.101
Cenchrus setaceus (=Pennisetum setaceum)	28.9	47.7	1.202	1.415	***Osteospermum vaillantii (=Tripteris vaillantii)***	23.7	116.0	2.924	1.162
Cenchrus sp. ***(=Pennisetum*** sp.***)***	3.1	12.6	0.318	0.152	***Osyris quadripartita (=Osyris lanceolata)***	3.1	1.3	0.032	0.152
Centaurea pseudosinaica	2.1	2.1	0.052	0.101	***Otostegia fruticosa***	10.3	9.8	0.247	0.505
Centaurothamnus maximus	1.0	0.8	0.019	0.051	***Oxalis corniculata***	3.1	1.5	0.039	0.152
Cheilanthes pteridioides	3.1	9.5	0.240	0.152	***Panicum turgidum***	1.0	0.3	0.006	0.051
Chenopodium album	3.1	4.9	0.123	0.152	***Paronychia sinaica***	3.1	4.4	0.110	0.152
Chenopodium murale	1.0	0.3	0.006	0.051	***Pentas lanceolata***	2.1	1.5	0.039	0.101
Chrozophora oblongifolia	1.0	0.3	0.006	0.051	***Pentatropis nivalis***	3.1	11.0	0.278	0.152
Chrysopogon plumulosus	6.2	5.4	0.136	0.303	***Periploca aphylla***	19.6	11.1	0.279	0.960
Chrysopogon sp.	3.1	5.2	0.130	0.152	***Periploca somaliensis***	13.4	5.9	0.149	0.657
Cissus quadrangula	3.1	3.9	0.097	0.152	***Phagnalon stenolepis***	8.2	12.9	0.325	0.404
Cissus rotundifolia	13.4	20.6	0.520	0.657	***Phoenix caespitosa***	2.1	0.5	0.013	0.101
Citrullus colocynthis	1.0	1.3	0.032	0.051	***Phragmanthera austroarabica***	3.1	1.3	0.032	0.152
Clematis hirsuta	5.2	2.8	0.071	0.253	***Phyllanthus*** sp.	1.0	0.5	0.013	0.051
Cleome gynandra (=Gynandropsis gynandra)	1.0	0.5	0.013	0.051	***Picris scabra***	4.1	5.7	0.143	0.202
Cleome scaposa	1.0	0.5	0.013	0.051	***Pistacia falcata***	12.4	3.9	0.097	0.606
Cleome sp.	3.1	1.0	0.026	0.152	***Plantago afra***	1.0	6.4	0.162	0.051
Clutia lanceolata	12.4	6.2	0.156	0.606	***Plantago ovata***	3.1	22.4	0.565	0.152
Coccinia grandis	8.2	9.5	0.240	0.404	***Pluchea dioscoridis***	1.0	2.8	0.071	0.051
Cocculus pendulus	1.0	0.3	0.006	0.051	***Polycarpon tetraphyllum***	1.0	0.5	0.013	0.051
Coleus arabicus (=Plectranthus asirensis)	3.1	6.2	0.156	0.152	***Polygala abyssinica***	11.3	6.4	0.162	0.556
Combretum molle	14.4	17.8	0.448	0.707	***Portulaca oleracea***	1.0	0.3	0.006	0.051
Cometes abyssinica	2.1	0.8	0.019	0.101	***Portulaca quadrifida***	1.0	0.8	0.019	0.051

Appendix (*continued*)

Plant name	Frequency %	density/ ha	Relative density	Relative frequency	plant name	Frequency %	density/ ha	Relative density	Relative frequency
Commelina forskaolii	4.1	2.8	0.071	0.202	***Premna resinosa***	4.1	4.6	0.117	0.202
Commelina sp.	2.1	1.0	0.026	0.101	***Psiadia punctulata***	26.8	64.7	1.631	1.314
Commicarpus grandiflorus	4.1	2.6	0.065	0.202	***Psydrax schimperianus***	3.1	2.6	0.065	0.152
Commicarpus plumbagineus	7.2	3.4	0.084	0.354	***Pulicaria petiolaris***	3.1	1.3	0.032	0.152
Commicarpus sp.	3.1	1.0	0.026	0.152	***Pulicaria schimperi***	5.2	2.1	0.052	0.253
Commiphora gileadensis	3.1	0.8	0.019	0.152	***Pulicaria undulata***	11.3	19.3	0.487	0.556
Commiphora kataf	3.1	1.8	0.045	0.152	***Pupalia lappacea***	18.6	26.0	0.656	0.910
Commiphora kua	1.0	0.5	0.013	0.051	***Rhamnus staddo***	2.1	0.5	0.013	0.101
Commiphora myrrha	12.4	6.2	0.156	0.606	***Rhynchosia*** sp.	4.1	3.1	0.078	0.202
Conyza stricta	18.6	25.0	0.630	0.910	***Ricinus communis***	3.1	2.3	0.058	0.152
Coptosperma graveolens	4.1	2.1	0.052	0.202	***Ruellia patula***	2.1	1.5	0.039	0.101
Cordia monoica	2.1	0.5	0.013	0.101	***Rumex nepalensis (=Rumex steudelianus)***	1.0	0.8	0.019	0.051
Crassula schimperi	4.1	3.4	0.084	0.202	***Rumex nervosus***	11.3	7.0	0.175	0.556
Crepis sp.	3.1	12.1	0.305	0.152	***Rumex vesicarius***	10.3	17.3	0.435	0.505
Crinum album	3.1	1.0	0.026	0.152	***Ruta chalepensis***	3.1	1.0	0.026	0.152
Crotalaria sp.	17.5	18.8	0.474	0.859	***Saccharum spontaneum***	1.0	1.0	0.026	0.051
Cucumis sp	1.0	0.3	0.006	0.051	***Sageretia thea***	24.7	18.6	0.468	1.213
Cymbopogon sp.	1.0	0.8	0.019	0.051	***Salsola tragus***	9.3	11.3	0.286	0.455
Cynanchum viminale (=Sarcostemma viminale)	10.3	6.4	0.162	0.505	***Salvadora persica***	1.0	0.8	0.019	0.051
Cynodon dactylon	6.2	146.9	3.704	0.303	***Salvia aegyptiaca***	8.2	46.4	1.170	0.404
Cynoglossum bottae	2.1	1.8	0.045	0.101	***Salvia dianthera (=Meriandra bengladensis)***	1.0	1.3	0.032	0.051
Cynoglossum sp.	1.0	1.3	0.032	0.051	***Salvia merjamie***	1.0	0.3	0.006	0.051
Cyperus sp.	2.1	2.1	0.052	0.101	***Sansevieria forskaliana (=Dracaena forskaliana)***	1.0	1.5	0.039	0.051
Cyphostemma digitatum	7.2	11.1	0.279	0.354	***Scandix pecten-veneris***	1.0	2.6	0.065	0.051
Dactyloctenium aegyptium	1.0	1.3	0.032	0.051	***Searsia glutinosa (=Rhus abyssinica)***	2.1	0.8	0.019	0.101
Desmidorchis retrospiciens (=Caralluma retrospiciens)	9.3	3.6	0.091	0.455	***Searsia natalensis (=Rhus natalensis)***	1.0	0.5	0.013	0.051
Digitaria velutina	3.1	9.8	0.247	0.152	***Searsia retinorrhoea (=Rhus retinorrhoea)***	19.6	11.3	0.286	0.960
Dobera glabra	2.1	0.5	0.013	0.101	***Seddera arabica***	5.2	6.2	0.156	0.253
Dodonaea viscosa subsp. ***angustifolia***	35.1	38.4	0.968	1.718	***Seddera*** sp.	1.0	0.3	0.006	0.051
Dysphania ambrosioides (=Chenopodium ambrosioides)	1.0	1.0	0.026	0.051	***Senegalia asak (=Acacia asak)***	39.2	31.4	0.793	1.920

(*continued on next page*)

Appendix (*continued*)

Plant name	Frequency %	density/ ha	Relative density	Relative frequency	plant name	Frequency %	density/ ha	Relative density	Relative frequency
Dysphania schraderiana (=Chenopodium schraderianum)	13.4	41.0	1.033	0.657	***Senegalia hamulosa (=Acacia hamulosa)***	3.1	0.8	0.019	0.152
Ecbolium gymnostachyum	1.0	1.0	0.026	0.051	***Senna alexandrina***	1.0	0.3	0.006	0.051
Ecbolium viride	1.0	0.8	0.019	0.051	***Silene*** sp.	5.2	3.1	0.078	0.253
Echinops sp..	12.4	10.6	0.266	0.606	***Silene yemensis***	2.1	11.9	0.299	0.101
Echium rauwolfii	2.1	26.3	0.663	0.101	***Sisymbrium erysimoides***	1.0	7.7	0.195	0.051
Ehretia obtusifolia	3.1	0.8	0.019	0.152	***Sisymbrium irio***	1.0	0.8	0.019	0.051
Ephedra foliata	4.1	1.0	0.026	0.202	***Solanum incanum***	32.0	23.2	0.585	1.567
Eragrostis papposa	29.9	172.9	4.361	1.466	***Solanum schimperianum***	9.3	4.4	0.110	0.455
Erica arborea	3.1	2.8	0.071	0.152	***Solanum*** sp.	2.1	0.5	0.013	0.101
Erigeron bonariensis (=Conyza bonariensis)	1.0	0.3	0.006	0.051	***Solanum villosum***	6.2	4.6	0.117	0.303
Erodium cicutarium	6.2	9.3	0.234	0.303	***Sonchus oleraceus***	5.2	3.9	0.097	0.253
Erodium malacoides	5.2	10.8	0.273	0.253	***Spergularia bocconei***	1.0	1.3	0.032	0.051
Erodium moschatum	1.0	1.3	0.032	0.051	***Stipagrostis ciliata***	2.1	2.1	0.052	0.101
Erucastrum sp.	1.0	1.3	0.032	0.051	***Stipagrostis obtusa***	11.3	99.5	2.508	0.556
Euclea racemosa	2.1	2.1	0.052	0.101	***Suaeda aegyptiaca***	1.0	0.3	0.006	0.051
Euphorbia cuneata	1.0	0.3	0.006	0.051	***Talinum portulacifolium***	1.0	0.5	0.013	0.051
Euphorbia schimperiana	4.1	6.4	0.162	0.202	***Tamarix nilotica***	2.1	0.5	0.013	0.101
Euphorbia serpens	1.0	0.3	0.006	0.051	***Tetrapogon tenellus***	3.1	4.9	0.123	0.152
Euphorbia sp.	2.1	0.5	0.013	0.101	***Tetrapogon villosus***	4.1	5.4	0.136	0.202
Fagonia indica (=Zygophyllum indicum)	13.4	12.6	0.318	0.657	***Teucrium*** sp.	1.0	0.5	0.013	0.051
Faidherbia albida	3.1	5.7	0.143	0.152	***Teucrium yemense***	13.4	15.5	0.390	0.657
Farsetia longisiliqua	6.2	4.1	0.104	0.303	***Themeda triandra***	26.8	191.5	4.828	1.314
Felicia abyssinica	8.2	18.8	0.474	0.404	***Torilis arvensis***	2.1	1.8	0.045	0.101
Felicia dentata	5.2	3.9	0.097	0.253	***Torilis nodosa***	1.0	0.5	0.013	0.051
Ficus cordata subsp. ***salicifolia***	20.6	7.2	0.182	1.011	***Tribulus parvispinus***	1.0	1.8	0.045	0.051
Ficus ingens	15.5	5.4	0.136	0.758	***Trichodesma*** sp.	4.1	1.0	0.026	0.202
Ficus palmata	7.2	2.3	0.058	0.354	***Trifolium arvense***	5.2	10.1	0.253	0.253
Ficus sycomorus	11.3	5.4	0.136	0.556	***Trifolium campestre***	3.1	9.0	0.227	0.152
Flueggea virosa	8.2	5.2	0.130	0.404	***Triumfetta flavescens***	11.3	9.8	0.247	0.556
Forsskaolea tenacissima	9.3	7.0	0.175	0.455	***Triumfetta*** sp.	4.1	2.3	0.058	0.202
Fumaria abyssinica	3.1	1.8	0.045	0.152	***Umbilicus horizontalis***	2.1	2.6	0.065	0.101
Galium setaceum	1.0	0.5	0.013	0.051	***Urospermum picroides***	2.1	10.3	0.260	0.101
Galium sp.	2.1	1.0	0.026	0.101	***Urtica urens***	1.0	0.3	0.006	0.051

Appendix (*continued*)

Plant name	Frequency %	density/ ha	Relative density	Relative frequency	plant name	Frequency %	density/ ha	Relative density	Relative frequency
Geranium sp.	8.2	30.4	0.767	0.404	***Vachellia etbaica (=Acacia etbaica)***	5.2	2.3	0.058	0.253
Gladiolus dalenii	1.0	2.6	0.065	0.051	***Vachellia flava (=Acacia ehrenbergiana)***	18.6	22.2	0.559	0.910
Glinus lotoides	1.0	0.5	0.013	0.051	***Vachellia gerrardii (=Acacia gerrardii)***	5.2	3.9	0.097	0.253
Gomphocarpus fruticosus	11.3	6.7	0.169	0.556	***Vachellia johnwoodii (=Acacia johnwoodii)***	7.2	6.7	0.169	0.354
Grewia erythraea	5.2	1.3	0.032	0.253	***Vachellia oerfota (=Acacia oerfota)***	2.1	1.5	0.039	0.101
Grewia tembensis	9.3	6.2	0.156	0.455	***Vachellia origena (=Acacia origena)***	30.9	35.1	0.884	1.516
Grewia tenax	7.2	5.2	0.130	0.354	***Vachellia tortilis (=Acacia tortilis)***	9.3	7.0	0.175	0.455
Grewia trichocarpa	18.6	11.9	0.299	0.910	***Vepris nobilis (=Teclea nobilis)***	1.0	0.3	0.006	0.051
Grewia velutina	1.0	0.3	0.006	0.051	***Verbascum*** sp.	9.3	7.5	0.188	0.455
Grewia villosa	5.2	2.6	0.065	0.253	***Verbesina encelioides***	3.1	3.1	0.078	0.152
Gymnosporia parviflora (=Maytenus parviflora)	41.2	47.7	1.202	2.021	***Vermifrux abyssinica***	1.0	0.8	0.019	0.051
Helichrysum glumaceum	9.3	10.8	0.273	0.455	***Vernonia*** sp.	3.1	2.6	0.065	0.152
Helichrysum sp.	1.0	5.2	0.130	0.051	***Veronica opaca***	1.0	0.5	0.013	0.051
Heliotropium sp.	3.1	2.1	0.052	0.152	***Vicia sativa***	1.0	0.5	0.013	0.051
Hibiscus aponeurus	2.1	0.5	0.013	0.101	***Withania somnifera***	5.2	1.8	0.045	0.253
Hibiscus aponeurus	1.0	0.3	0.006	0.051	***Xanthium spinosum***	2.1	2.3	0.058	0.101
Hibiscus deflersii	9.3	7.7	0.195	0.455	***Ziziphus spina-christi***	11.3	4.4	0.110	0.556

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