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Population structure and dynamics of the endemic species *Phlomis aurea* Decne in different habitats in southern Sinai Peninsula, Egypt

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ABSTRACT

Phlomis aurea Decne is a rare and endangered species inhabiting high altitudes at southern Sinai Peninsula, Egypt. The present study investigated the population structure of *P. aurea*, in terms of size distribution, height, diameter, density, frequency and cover at its favourable habitats, and attempted to assess the effect of different habitats, which reflect the elevation gradients, on sizes distribution and density of occurrences of the study species. Sixty five stands (each of 25 × 25 m) were sampled to represent most variations among *P. aurea* populations in four main habitats (basins, mountain slopes, gorges and wadi beds). *P. aurea* in basins had the highest plant frequency, cover, plant diameter and height, size index, leaf length and width, leaves, branches, flowers, inflorescences and inflorescence length, while slope population had the lowest. Population in gorges and wadi beds had the highest height to diameter ratio, while in basin and slope had the lowest. Plants in gorges had the highest density, followed by those in basins, wadi beds and slopes. The size structures in the gorges and basins approximated the normal distribution; while that of the slope population approximated the positively skewed distribution. The plant cover was positively correlated with silt, clay, Ca, altitude, $CaCO_3$, fine sand and HCO_3; while it was negatively correlated with soil pH and Mg. In addition, plant cover response along soil salinity (EC) gradient approximated normal distribution. This study may help in planning for conserving this endemic species and we recommend, as a priority, to increase the area of the protected areas at mid- to high altitude in the Southern Sinai to grant further protection in zones with the highest density of endemics.

1. Introduction

Protection of species and biodiversity within natural reserves and protectorates was intuitively a remedy to attain recovery of endangered species and to reduce extinction risk (Deguise and Kerr, 2006; Wood and Gross, 2008). Scenarios for recovery, where threats to survival are removed in a manner that ensures long-term survival in nature, were mostly species-specific and single species management proved to be as important as multi-species and ecosystem management plans for valuable conservation strategies (Abbit and Scott, 2001). Species extinction often follows extended periods of population

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Table 1
Available Meteorological data of Saint Katherine Station in Southern Sinai, Egypt, after Moustafa and Abd El-Wahab (2013). Maximum and minimum values are underlined.

Month	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mean Min. Temp. °C	1.4	1.4	4.6	9.0	12.5	16.3	17.5	16.2	13.6	11.5	6.8	4.3
Mean Max. Temp. °C	14.3	15.1	17.7	24.4	28.3	30.8	31.8	28.7	27.7	26.1	20	16.3
Relative humidity %	49.8	43.3	39.4	28.6	24.9	27.2	28.8	30.1	28.1	31.9	34.2	42.7
Evap. mm/day	5.7	7.2	9.3	12.6	15.2	17.7	16.2	13.7	11.7	10.4	7.2	6.1
Rainfall mm	5.9	1.9	6	0.5	0.4	0.0	0.0	0.1	0.0	0.7	0.9	2.7

decline (Lande et al., 2003). Understanding the natural history of rare plants is then crucial for population management and conservation (Adams et al., 2005; Lehtilä et al., 2006; Massey and Whitson, 1980). Survival and reproduction patterns are a prerequisite in order to predict future growth or decline of populations and to help in the selection of appropriate management strategies for species conservation (Donovan and Welden, 2001).

Distribution and abundance of a plant species within a particular climatic zone is determined by environmental factors, especially soil conditions, interactions with other species; and dispersal. Survivorship and fecundity appear to be primarily determined by the size and the developmental stage, rather than age of individuals within a plant population (Silvertown, 1981; Werner and Caswell, 1977; Galal, 2011). Thus the status of a plant population will be reflected by its density and size structure. Size differences may be caused directly or through differences in growth rates due to age differences, genetic variation, heterogeneity of resources, herbivory, and competition (Weiner, 1985).

Southern Sinai includes Saint Katherine Protectorate (SKP) which is one of the Egypt's largest protected areas that includes the country's highest mountains which look like an ecological island surrounded by desert. It is one of the most floristically diverse spots in the Egypt, where 44% of Egypt's endemic plant species occur. In southern Sinai, the flora and vegetation of the mountains differ from the other areas due to the wide range of habitats and landscapes with varying microclimatic conditions, water regime, altitudes and topography (Perevolotsky et al., 1989; Hatab, 2009; Omar, 2014). The landscape ranges from rugged mountains, which include Katherine (2642 m asl), Egypt's highest peak, whose slopes are incised by wadi rivers. Wadi rivers generally slope to the east, towards the Gulf of Aqaba, or to the west towards the Gulf of Suez (Alqamy, 2002).

Genus *Phlomis* (Lamiaceae) comprises some 100 species in the world (Mediterranean region to central Asia and China). In Egypt, two *Phlomis* species occur, *Phlomis aurea* Decne and *Phlomis floccosa* D. Don (Täckholm, 1974; Boulos, 2002). *P. aurea* Decne (its Vernacular name is Awarwar) is a wild golden-woolly perennial species; it is a rare and endangered endemic species at southern Sinai Peninsula, especially in Gebel Mousa and Saint Katharine mountains (El-Hadidi and Hosni, 2000). It is restricted to the high altitudes in southern Sinai (Boulos, 2008). The local inhabitants use the dry individuals for fuel, while they cannot use the green individuals directly because it has hairs that attack the skin and eyes and cause itching and allergies (Shaltout et al., 2004). There are increasing threats facing its populations, as it is subjected to severe overcutting and uprooting (for fuel), as well as disturbance through unmanaged human activities and increased drought (Shaltout et al., 2004; Moustafa and Abd El-Wahab, 2013).

The previous studies did not focus on the variation of *P. aurea* populations in relation to various habitat types and the elevation gradient (Moustafa and Kamel, 1995; Ayyad et al., 2000; Abd El-Wahab, 2006; Khedr, 2007). The present study investigated the population structure of *P. aurea*, in terms of size distribution, height, diameter, density, frequency and cover at its favourable habitats, and attempted to assess the effect of different habitats, which reflect the elevation gradients, on sizes distribution and density of occurrences of the study species.

2. Methods

2.1. Study area

Saint Katherine Protectorate was declared as a national protectorate in 1996, under the support of the Egyptian Environmental Affairs Agency (EEAA). It extends over 4350 km^2 of South Sinai, making it the fourth largest protectorate in Egypt, between 33°55′ to 34° 30′E, and 28° 30′ to 28° 35′N with an elevation range of 1300–2600 m asl (Moustafa and Klopatek, 1995). The geologic structures of SKP lead to the differentiation of many habitats; each has its peculiar environmental conditions, unique landscape and flora that is rich in medicinal, rare and endemic plants (Khedr, 2007). Six landforms, reflecting 6 habitat types, are identified: basins that occur as depressions between the peaks of high mountains, mountain slopes, gorges originated from joints or faults, wadi beds, terraces and caves (Fig. 1).

South Sinai is characterized by a wide range of variation in air temperature. The lowest monthly mean minimum temperature ranges between 1.4 °C and 15.8 °C, while the highest monthly mean maximum temperature varies between 30.8 and 35.8 °C. St. Katherine is the coolest area in Sinai and Egypt as a whole due to its high elevation (1500–2641 m asl). The relative humidity in St. Katherine area ranges between 24.9% in May and 49.8% in January. Evaporation is greater during summer than winter, with maximum of 17.7 mm in St. Katherine in June, and minimum of 5.7 mm in January (Table 1). Precipitation may occur as snow on the high peaks of mountains, and winter snow lasting two to four weeks has been observed on the northern slopes of Mountain Katherine. Precipitation, which falls as rain in the valleys of South Sinai, may

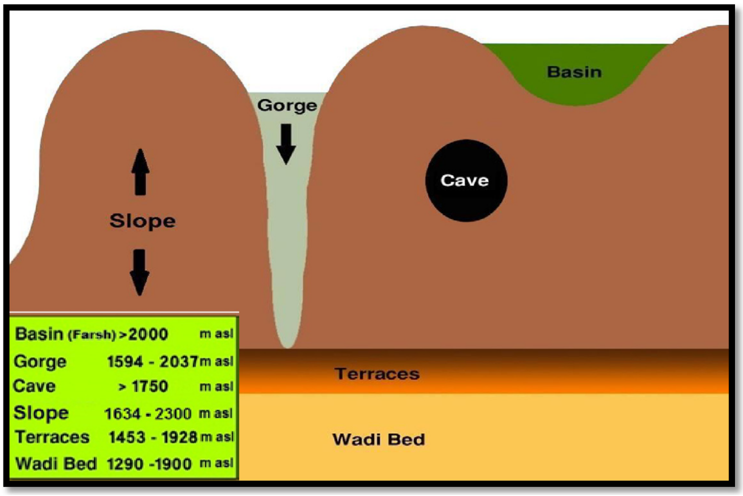

Fig. 1. Schematic illustration for the habitat types in Saint Katherine Protectorate.

occur as hail on the high peaks. Water derived from melting snow or hail is likely to infiltrate the desert soil. The spatial variability was prominent in that one locality may have amount of rainfall that resulted in floods, and at the same time there is no rainfall in another locality distance few kilometres. Rainfall data recorded from two different stations at St. Katherine demonstrates this variability. The first station (1550 m asl), the mean annual rainfall ranged between 72.6 and 119 mm for year 1993 and 1994 respectively, while the other station (1350 m asl) recorded 47.2, and 48.1 mm for those years respectively (Moustafa and Abd El-Wahab, 2013).

2.2. Data collection

Sixty five stands (25 m $\times$ 25 m) were selected at southern Sinai in different types of habitats (11 in mountain slopes, 22 in gorges, 5 in basins and 27 in wadi beds), which reflect the elevation gradients of 1290–2300 m above sea level (basins: $>$ 2000 m asl, mountain slope: 1634–2300 m asl, gorges: 1594–2037 m asl, and wadi beds: 1290–1900 m asl) associated with *Phlomis aurea*, monthly during spring 2009/2010. At each sampling stand; five quadrats (5 $\times$ 5 m each) were laid down to cover *P. aurea* populations (a total of 325 quadrates). In each quadrat, the number of individuals was counted and the height (H) and mean crown diameter (D) (based on 2–4 diameter measurements/ind.) were measured. Density, frequency and cover percentage were estimated using quadrat and line intercept methods (Mueller-Dombois and Ellenberg, 1974). The size index of each individual was calculated as the average of its height and diameter [(H + D)/2]. The size estimations were then used to classify population into twenty size classes (each of 10 cm-interval). The absolute and relative frequency of individuals and mean height, diameter and height to diameter ratio per individual in each size class were then determined (Shaltout and Ayyad, 1988). In addition, leaf traits (leaf length and width; leaf number per branch, branch number per plant and internode length) and reproductive traits (flower number per inflorescence, inflorescence number per individual and inflorescence length) were measured. Three soil samples were collected from each stand as profiles of 0–30 cm, soils in some mountainous sites were very shallow; therefore the maximum depth of soil samples, there, ranged from 15 to 25 cm. Most of the soil samples were collected from under canopy of the study plant species in the plot. Soil texture was determined by using sieves method (Piper, 1950), while Ca CO_3 was determined using titration against 1.0 N HCl (Allen et al., 1976) and oxidizable organic carbon (as indication of the total organic matter) according to Walkley and Black method (Black, 1965). Soil water extracts of 1:5 were prepared for the determination of EC, soil reaction, chlorides, calcium, magnesium, bicarbonates and sulphates (Allen et al., 1986).

2.3. Data analysis

The soil and morphological differences between habitats were statistically treated using one-way ANOVA, and the response curves were drawn to assess the relationships between the spatial variations in the estimated soil variables and the cover percentage of *P. aurea* individuals (SPSS, 2006).

3. Results

3.1. Soil characteristics

Most of soil characters had no significant variations, except pH, Ca, Mg, HCO_3 and SO_4^- ($P < 0.001$ to $P < 0.05$) (Table 2). Soils of basins had the highest fine sand (21.5%), pH (8.9) and Ca (2 mg 100 g^{-1}), but the lowest of clay (8.3%), $CaCO_3$ (8.1%),

Table 2
Mean and standard deviation (SD) of the soil characteristics of the 4 habitats supporting the 65 stands of *Phlomis aurea* populations in Saint Katherine Protectorate. Maximum and minimum values of each variable are underlined. *F* values are indicated.

Soil character		Habitats				Mean ± SD	*F*
		Basin	Slope	Gorge	Wadi bed		
Coarse sand	%	46.0 ± 7.4	44.9 ± 10.8	46.7 ± 8.6	46.6 ± 8.7	45.6 ± 1.2	0.335
Fine sand		21.5 ± 5.2	17.2 ± 4.5	19.1 ± 9.2	19.5 ± 5.4	19.7 ± 1.7	1.199
Silt		8.3 ± 3.4	8.5 ± 4.7	7.3 ± 2.9	7.6 ± 3.9	8.7 ± 1.9	1.738
Clay		8.3 ± 3.9	11.5 ± 7.9	9.6 ± 4.9	8.9 ± 4.8	9.0 ± 1.7	1.699
pH		8.9 ± 0.1	8.8 ± 0.2	8.8 ± 0.2	8.8 ± 0.2	8.7 ± 0.2	4.063**
EC	μS cm^{-1}	110.5 ± 13.2	107.7 ± 32.2	134.4 ± 111.7	146.6 ± 178.7	132.8 ± 24.3	0.647
Org. matter	%	7.8 ± 4.2	6.9 ± 3.9	7.7 ± 4.0	7.9 ± 4.0	6.8 ± 1.7	0.759
$CaCO_3$		8.1 ± 3.1	9.6 ± 4.5	8.9 ± 4.9	8.9 ± 3.2	8.3 ± 1.4	0.759
Ca^{++}	mg 100 g^{-1}	2.0 ± 2.0	1.1 ± 1.5	1.7 ± 2.7	1.0 ± 1.3	1.7 ± 1.3	7.770***
Mg^{++}		2.1 ± 0.8	2.9 ± 3.7	2.8 ± 2.1	3.1 ± 4.2	3.5 ± 3.7	5.030**
HCO_3^-		2.0 ± 1.9	2.6 ± 1.1	2.5 ± 1.3	2.5 ± 1.6	2.3 ± 0.7	2.500*
Cl^-		1.4 ± 0.7	1.5 ± 0.7	1.5 ± 1.1	1.8 ± 3.4	1.7 ± 0.6	0.948
SO_4^-		3.2 ± 2.4	4.4 ± 11.7	4.3 ± 7.4	4.5 ± 11.7	6.0 ± 8.8	2.917*

* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

Table 3
Mean ± standard deviation (SD) of species density, frequency, cover, altitude and morphological characters of *Phlomis aurea* population in Saint Katherine Protectorate in relation to habitat types. The values between brackets are the evaluated number of individuals. Maximum and minimum values of each variable are underlined.

Characters	Unit	Basin (50)	Slope (183)	Gorge (291)	Wadi bed (296)	Mean (822)	*F*
Density	ind. 1000 m$^{2-1}$	86.5 ± 52.7	71.3 ± 33.9	100.6 ± 50.4	75.9 ± 46.6	70.9 ± 30.6	
Frequency	%	100.0 ± 7.7	100.0 ± 0.0	100.0 ± 0.0	98.5±7.7	82.8±35.2	
Cover		8.3 ± 3.57	5.2 ± 1.99	7.4 ± 5.50	5.8 ± 2.16	5.53 ± 2.8	
Individual dimensions							
Plant diameter	↑	100.3 ± 47.5	65.8 ± 38.6	86.5 ± 49.5	88.6 ± 41.7	83.5 ± 45.5	10.4**
Plant height	cm ind^{-1}	93.7 ± 33.6	61.8 ± 32.2	83.2 ± 37.4	89.5 ± 34.1	81.3 ± 36.5	20.1**
Size index	↓	97.0 ± 37.7	63.8 ± 33.3	84.8 ± 40.8	89.1 ± 35.8	82.4 ± 38.7	15.9**
Height to diameter ratio		1.0 ± 0.4	1.0 ± 0.4	1.1 ± 0.4	1.1 ± 0.4	1.1 ± 0.4	1.2
Leaf traits							
Leaf length	cm leaf^{-1}	9.9 ± 11.6	6.5 ± 2.3	7.0 ± 2.1	6.7 ± 1.6	6.9 ± 3.5	10.9**
Leaf width		3.9 ± 1.7	3.0 ± 1.6	3.1 ± 1.3	2.9 ± 1.5	3.1 ± 1.5	7.1**
Leaf no. per branch	No. branch^{-1}	34.7 ± 16.5	22.4 ± 12.7	23.1 ± 15.0	24.6 ± 12.0	24.3 ± 13.9	9.4**
Branch no. per plant	No. ind^{-1}	21.4 ± 16.9	13.8 ± 10.5	14.4 ± 12.9	17.3 ± 11.7	15.7 ± 12.4	6.2**
Internode length	cm int^{1}	3.3 ± 1.2	3.3 ± 1.7	4.0 ± 1.6	4.2 ± 1.5	3.9 ± 1.6	11.1**
Reproductive organs							
Flower no. per infl.	No. infl^{-1}	15.9 ± 12.4	9.8 ± 11.0	13.6 ± 12.0	15.2 ± 11.2	13.5 ± 11.7	7.0**
Infl.. no.per ind.	No. ind^{-1}	8.5 ± 9.4	4.1 ± 6.0	4.7 ± 8.2	6.2 ± 7.1	11.5 ± 16.3	5.7**
Infl.. length	cm infl^{-1}	10.4 ± 8.4	5.8 ± 6.9	8.7 ± 8.5	9.3 ± 7.4	8.4 ± 7.9	7.1**

* $P < 0.01$.
** $P < 0.001$.

Mg (2.1 mg 100 g^{-1}), HCO_3 (2 mg 100 g^{-1}), Cl (1.4 mg 100 g^{-1}) and SO_4 (3.2 mg 100 g^{-1}). In addition, the mountain slopes had the highest of silt (8.5%), clay (11.5%), $CaCO_3$ (9.6%) and HCO_3 (2.6 mg 100 g^{-1}), and the lowest of coarse sand (44,9%), fine sand (17.2%), EC (107.7 μS cm^{-1}) and organic matter (6.9%); while gorges had the highest of coarse sand (46.7%) and lowest of silt (7.3%); and wadi beds had the highest of EC (146.6 μS cm^{-1}), organic matter (7.9%), Mg (3.1 mg 100 g^{-1}), Cl (1.8 mg 100 g^{-1}) and SO_4 (4.5 mg 100 g^{-1}), and the lowest of Ca (1 mg 100 g^{-1}).

3.2. Population variation

The basin population had the highest plant frequency (100%); cover (8.3%); crown diameter (100.3 cm); plant height (93.7 cm); size index (97 cm); leaf length (9.9 cm) and width (3.9 cm); number of leaves (34.7 branch^{-1}); branches (21.4 ind^{-1}); flowers (15.9 infl^{-1}); inflorescences (8.5 ind^{-1}); and inflorescence length (10.4 cm), but had the lowest of internode length (3.3 cm). In addition, mountain slope population had the lowest plant density (71.3 ind./1000 m^2); cover (5.2%); plant diameter (65.8 cm) and height (61.8 cm); size index (63.8 cm); leaf length (6.5 cm); leaves (22.4 branch^{-1}); branches (13.8 ind^{-1}); flowers (9.8 infl^{-1}); inflorescences (4.1 ind^{-1}); and inflorescence length (5.8 cm) (Table 3).

Table 4
Mean and standard deviation (SD) of elevation variation in morphological characteristics of *Phlomis aurea* populations in Saint Katherine Protectorate. Maximum and minimum values of each variable are underlined.

Characters	Unit	Elevation class (m asl)							
		1350-	1450-	1550-	1650-	1750-	1850-	1950-	2050-
Plant diameter	↑	82.6	93.8	105.2	66.9	76.2	82.1	96.4	89.9
Plant height	cm ind^{-1}	79.3	76.9	92.4	64.4	77.4	80	93.1	88.5
Size index	↓	81	85.4	98.8	65.6	76.8	81.1	94.8	89.2
Height to diameter ratio		1	0.9	1	1.1	1.1	1.1	1.1	1.1
Leaf traits									
Leaf length	cm leaf^{-1}	7.6	6.8	8.8	6.2	6.6	6.5	6.9	7.8
Leaf width		3.9	2.9	3.6	3.9	2.9	2.7	3	3.2
Leaf no. per branch	No. branch^{-1}	25.7	27.4	33.1	25.4	23.2	20.4	22.8	28.3
Branch no. per plant	No. ind^{-1}	12.3	9.6	22.4	13.6	15.1	15.4	16.2	16.9
Internode length	cm int^{1}	4.2	3.2	3.4	3.5	3.9	4.4	3.9	4.1
Reproductive organs									
Flower no. per infl.	No. infl^{-1}	11.8	14.5	15.8	11.7	12.8	13.1	14.6	14.9
Infl. no. per ind.	No. ind^{-1}	3.1	3.9	10.0	3.6	5.2	4.7	5.1	5.5
Infl. length	cm infl^{-1}	5.6	11.1	10.5	8.2	8	7	9.3	9.6

Population in gorges and wadi beds had highest height to diameter ratio (1.1), except population in basin and slope had the lowest (1.0); wadi bed population had the highest internode length (4.2 cm), and the lowest of frequency (98.5%) and leaf width (2.9 cm), while the gorge population had the highest density (100.6 ind./1000 m^2), followed by basin (86.5 ind./1000 m^2).

Regarding the variations due to elevation (Table 4), individuals from class 1 (1350–1450 m asl) had the highest leaf width (3.9 cm), but the lowest number of inflorescences (3.1infl. ind^{-1}) and inflorescence length (5.6 cm), while class 2 (1450–1550 m asl) had the highest inflorescence length (11.1 cm), but the lowest number of branches (9.6 branches ind^{-1}) and internodes length (3.2 cm). In addition, individuals of class 3 (1550–1650 m asl) had the highest crown diameter (105.2 cm); size index (98.8 cm); leaf length (8.8 cm); and number of leaves (32.1 leaves branch^{-1}), branches (22.4 ind^{-1}), flowers (15.8 infl^{-1}), and inflorescences (10 ind^{-1}), while those of class 4 (1650–1750) had the lowest crown diameter, height and size index (66.9, 64.4 and 65.6 cm), leaf length (6.2 cm) and flowers (11.7 infl^{-1}).

Population from classes ($\geq$1650 m asl) had the highest height to diameter ratio (1.1), but those of class 2 (1450–1550) had the lowest (0.9). In addition, population in class 6 (1850–1950 m asl) had the highest internodes length (4.4 cm), and the lowest leaf width (2.7 cm) and number of leaves (20.4 leaves branch^{-1}) and population in class 7 (1950–2050 m asl) had the highest plant height (93.1 cm).

3.3. Size-class frequency distribution

For the whole population of *P. aurea*, the size-class frequency distribution reflected, more or less, normal distribution (Fig. 2, Table 5). Regarding the habitat types, the size frequency distribution of the population in mountain slopes was positively skewed, while that of wadi beds tended to be negatively skewed (Fig. 2). On the other hand, its frequency distribution along the elevation gradient, for the whole population and its habitats, had negative skewed or J-shape towards the relative preponderance of the plant population at higher elevations (Fig. 3). Frequency of individuals varied from 2.7% at the first two elevation classes (1350–1550 m asl) to 41.8% at the fifth elevation class (1750–1850 m asl).

3.4. Species response curves

The species response curves of the plant cover of *P. aurea* versus the environmental characters indicated that some relations approximated the positive linear or curve linear shape (silt, clay, Ca^{++}, altitude, $CaCO_3$, fine sand and HCO_3^-), while others seemed to be negative (pH and Mg^{++}). In addition, plant cover response along soil salinity (EC) gradient approximated the normal distribution (Fig. 4).

4. Discussion

The threatened species in Sinai according to the IUCN Red List Categories were 51 species: 13 endangered, 14 vulnerable, 20 rare and 4 indeterminate. IUCN listed taxa should receive high priority in any conservation program (El-Hadidi and Hosni, 2000). *Phlomis aurea* was a rare and endangered endemic species inhabiting high altitudes at southern Sinai Peninsula, Egypt (Boulos, 2002; El-Hadidi and Hosni, 2000), and can adapt many environmental factors that lead to its distribution in this

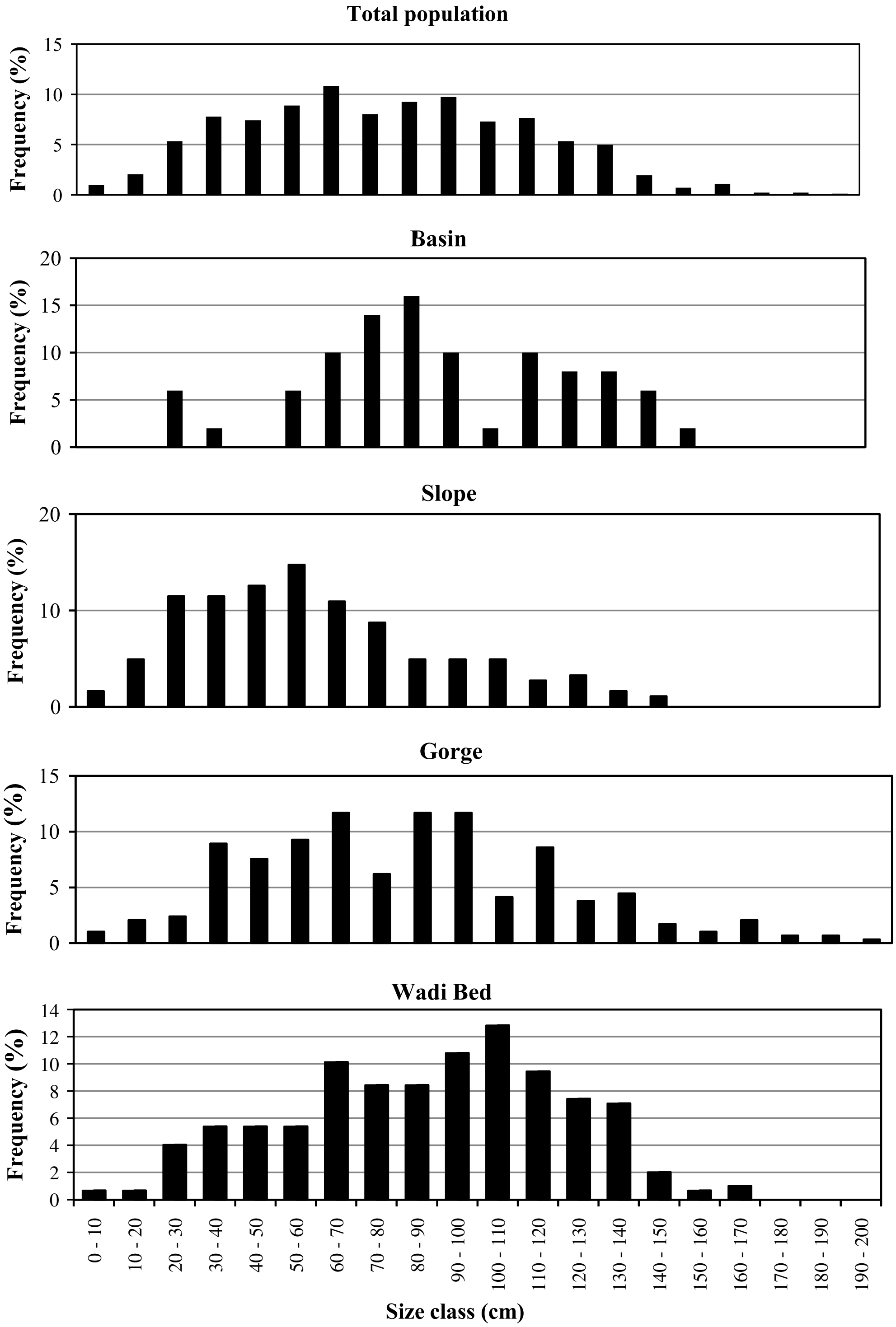

Fig. 2. Size-class frequency distribution of *Phlomis aurea* in the different habitats in Saint Katherine Protectorate.

region (Abd El-Wahab et al., 2004). Many shrubs and trees of the arid regions are of structural and economic importance (Crisp and Lange, 1976). They play an important role in soil protection and stabilization against movement by wind or water, provide a source of forage for animals and fuel for local inhabitants (Thalen, 1979). *P. aurea* was threatened by two major factors; over cutting and uprooting, the pressure of livestock on *P. aurea* increases as a result of the increase in Bedouin populations (Shaltout et al., 2004).

Table 5
Mean and standard deviation (SD) of the size characteristics of *Phlomis aurea* in the 20 size classes in Saint Katherine Protectorate. Maximum and minimum values of each variable are underlined.

Height class (m)	Ind. No ind^{-1}	Freq %	Height m ind^{-1}	Width m ind^{-1}	Size index m ind^{-1}	Height/diameter m ind^{-1}
0–10	8	1.0	<u>7.5</u> ± 2.8	<u>22.1</u> ± 37.0	<u>14.8</u> ± 19.1	<u>0.8</u> ± 0.4
10–20	17	2.1	17.5 ± 2.6	39.1 ± 47.2	28.3 ± 23.5	0.9 ± 0.5
20–30	44	5.4	26.5 ± 3.1	31.2 ± 16.4	28.8 ± 8.6	1.0 ± 0.4
30–40	64	7.8	36.5 ± 3.1	41.5 ± 15.5	39.0 ± 8.4	1.0 ± 0.4
40–50	61	7.4	47.0 ± 3.0	51.0 ± 19.0	49.0 ± 10.1	1.1 ± 0.4
50–60	73	8.9	56.7 ± 3.1	59.3 ± 24.0	58.0 ± 12.4	1.1 ± 0.4
60–70	<u>89</u>	<u>10.8</u>	66.7 ± 3.0	67.8 ± 25.2	67.2 ± 13.0	1.1 ± 0.4
70–80	66	8.0	77.1 ± 2.7	74.5 ± 27.3	75.8 ± 13.9	<u>1.2</u> ± 0.5
80–90	76	9.2	86.4 ± 3.1	82.4 ± 21.5	84.4 ± 11.2	1.1 ± 0.3
90–100	80	9.7	96.7 ± 2.8	96.8 ± 28.1	96.8 ± 14.3	1.1 ± 0.4
100–110	60	7.3	106.3 ± 2.8	106.7 ± 36.9	106.5 ± 18.9	1.1 ± 0.4
110–120	63	7.7	117.2 ± 2.7	122.1 ± 35.1	119.6 ± 18.0	1.0 ± 0.3
120–130	44	5.4	127.0 ± 2.9	127.9 ± 32.6	127.5 ± 16.2	1.1 ± 0.3
130–140	41	5.0	136.5 ± 3.2	141.3 ± 35.1	138.9 ± 17.7	1.1 ± 0.4
140–150	16	1.9	147.6 ± 2.6	161.5 ± 68.0	154.5 ± 34.3	1.1 ± 0.4
150–160	6	0.7	155.5 ± 3.7	160.7 ± 21.3	158.1 ± 11.2	1.0 ± 0.1
160–170	9	1.1	167.7 ± 2.5	153.7 ± 32.3	160.7 ± 16.1	1.1 ± 0.3
170–180	2	0.2	173.0 ± 1.4	193.0 ± 21.2	183.0 ± 9.9	0.9 ± 0.1
180–190	2	0.2	186.5 ± 4.9	173.5 ± 6.4	180.0 ± 0.7	1.1 ± 0.1
190–200	<u>1</u>	<u>0.1</u>	<u>195.0</u> ± 0.0	<u>200.0</u> ± 0.0	<u>197.5</u> ± 0.0	1.0 ± 0.0
Total (20)	822	100	81.3 ± 36.5	83.5 ± 45.5	82.4 ± 38.7	1.1 ± 0.4

Studies of Ayyad et al. (2000), Shaltout et al. (2004), Abd El-Wahab (2006) and Khedr (2007) recorded *P. aurea* in six habitats in SKP (basins, slopes, gorges, wadi beds, terraces and caves). The present study indicated that its presence was more important in the first four habitats, and its presence in the terraces and caves was occasional. In general, the species that occupies a wide range of habitats is more variable in morphology than that of a narrow range of habitats (Baker, 1974; Sultan, 2001; Richards et al., 2005). This means that the species of greater morphological variations would be more adaptive to wide environment gradients than that with small morphological variations (Pang and Jiang, 1995).

According to the theory of intra-specific competition, the increase of density often leads to decrease in the available resources for the individual, and thus decrease in its size and mass (Mithen et al., 1984). Contrary, the present study indicated that the population of *Phlomis aurea* in the basin had the second highest density (after the gorges) associated with the highest cover and size index; this may be attributed to sufficient moisture and nutrients compared with the other habitats, as it was a catchment area; received an additional amount of water and nutrients from the adjacent elevated areas (Shaltout and Ayyad, 1988). In addition, plant height decreased with increasing density as result of intra-specific competition, which significantly can affect plant height and total mass of certain species, both independently and interactively (Lentz, 1998). In contrast, *P. aurea* population in the slope had the lowest density associated with the lowest cover and size index; this may be due to the prominent rocky nature of the slopes that often leads to reduce the moisture availability as result of low retaining capability, as well as loss of water and organic matter due to run-off effect.

The height-to-diameter ratio gives an idea about the growth habit of the plant; variations in this ratio are largely a result of spacing (Wonn and O'Hara, 2001). Under hyper-arid conditions, this ratio is less than unity for many species (i.e. the plants tend to expanded horizontally rather than vertically), which may be a strategy of the desert plants to provide safe sights for their self regeneration, as the horizontal expansion usually provides shade that leads to decrease in the severe heating effect and increase in the soil moisture (Shaltout and Mady, 1993). In the present study, this ratio is slightly exceeded the unity, which means that the individuals tend to expand vertically rather than horizontally and this may be attributed to the high density and consequently high intra-specific competition of this plant (Galal, 2011).

Size differences in the plant population may be caused directly or through differences in growth rates due to age differences, genetic variation, heterogeneity of resources and competition (Weiner, 1985), and because fecundity was generally correlated with individual plant size; this variation can result in a few large plants of one generation contributing disproportionately to the next, with a consequent reduction in effective population size (El-Bana et al., 2010; Gottlieb, 1977; Sultangaziev et al., 2010). In this study, the size structure of *P. aurea* population in the gorges and basins approximates the normal distribution, i.e. population had a comparable proportion of young and mature individuals. On the other hand, the size structure of the slope population approximated the positively skewed distribution; this may represent the rapidly growing populations with high reproductive capacity (Shaltout and Ayyad, 1988), but may indicate high juvenile mortality as well (Harper, 1977; Tesfaye et al., 2010). The size structure of the wadi beds population approximated the negatively skewed distribution, which indicated the dominance of mature individuals over the juvenile ones. This distribution characterized the declining populations; because the population has a large proportion of big individuals than small ones (limited regeneration capacity) (Weiner and Solbrig, 1984).

The elevation patterns of endemism in the tropics generally show increasing endemism with elevation, peaking at mid- to high elevations and declining above the timberline (Gentry, 1986; Balslev, 1988; Major, 1988; Ibisch et al., 1996; Sklenar

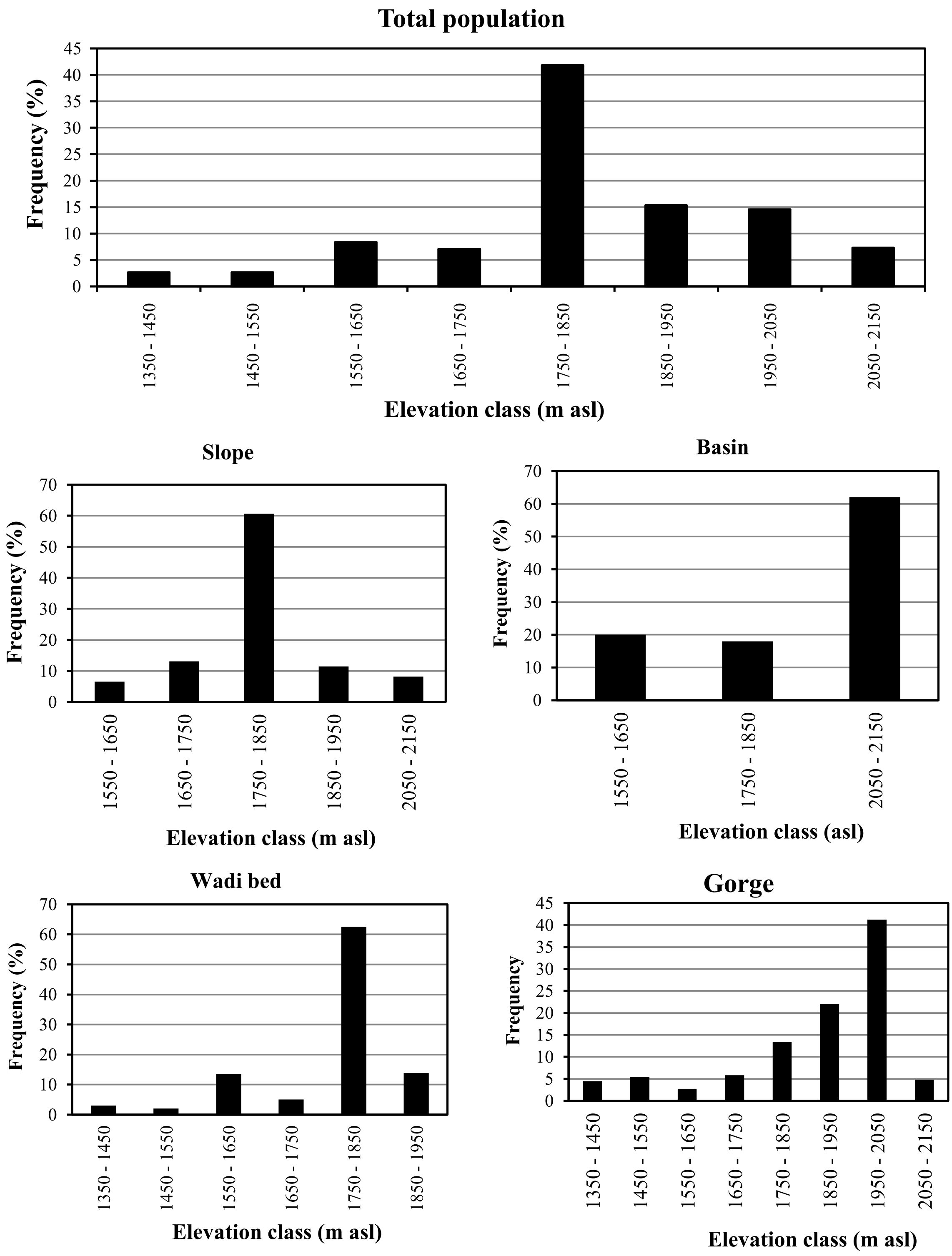

Fig. 3. Frequency distribution of *Phlomis aurea* individuals in relation to the elevation classes in the different habitats in Saint Katherine Protectorate.

and Jørgensen, 1999; Kessler, 2000, 2001a,b, 2002a,b; Kessler et al., 2001). The distribution of plant species along elevation gradients was governed by a series of interacting biological, environmental and historical factors (Colwell and Lees, 2000). Further, elevation gradients create varied climates, along with resultant soil differentiation; both can promote diversification of plants (Brown, 2001). Frequency distribution of *P. aurea* individuals along the elevation gradient reflected a positive

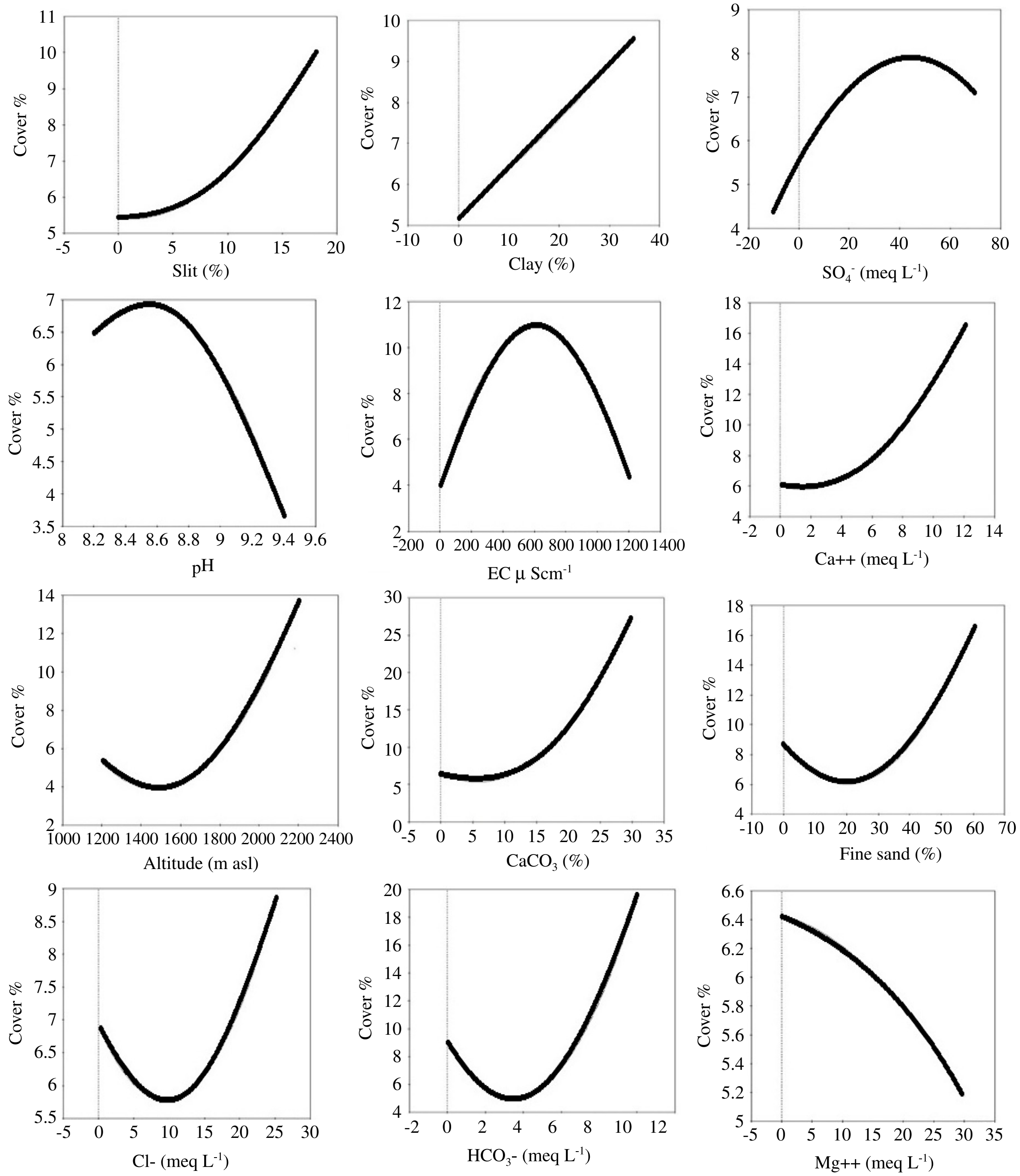

Fig. 4. Response curves of *Phlomis aurea* cover against the prevailing environmental gradients in Saint Katherine Protectorate.

skewed shape towards the relative preponderance of the mature individuals at high elevation levels (1750–1850). This indicated that the low elevations were not suitable for the growth of it, probably due to the stress of aridity and high temperature at low elevations. These results are comparable with those of Shaltout and Mady (1993) in their study on the size distribution of *Lycium shawii* in Central Saudi Arabia, Al-Sodany (2003) in his study on the size structure of *Phlomis floccosa* in the Western Mediterranean Coast of Egypt and Galal (2011) in his study on the size structure of some woody perennials along elevation gradient in Wadi Gimal, Red Sea coast of Egypt.

Abd El-Wahab (2006) reported that altitude, soil pH, EC, silt, clay, water holding capacity and organic matter were the most important factors that influencing the availability of soil nutrients and controlling the coverage and structure of vegetation. Studies of Migahid et al. (1958); Ramadan (1988); Abd El-Wahab (1995); Zaghloul (1997); Moustafa (1990);

Moustafa et al. (2001); Moustafa and Abd El-Wahab (2013), founded that vegetation variables and plant cover were positively correlated with altitude. The present study indicated that the cover of *P. aurea* was, more or less, positively correlated with silt, clay, Ca^{++}, altitude, $CaCO_3$, fine sand and HCO_3^-. On the other hand, it was negatively proportional to pH and Mg^{++}. In addition, plant cover response along soil salinity (EC) gradient approximated the bell shape (i.e. normal distribution), which means that *P. aurea* population preferred the medium salinity sites in southern Sinai, while its performance at low and high salinity was weak.

5. Conclusion

This study may help in planning for conserving this endemic species and we recommend, as a priority, to increase the area of the protected areas at mid- to high altitude in the Southern Sinai to grant further protection in zones with the highest density of endemics.

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References

Abbit, R.J.F., Scott, J.M., 2001. Examining differences between recovered and declining endangered species. Conserv. Biol. 15, 1274–1284.

Abd El-Wahab, R.H., 1995. Reproduction ecology of wild trees and shrubs in Southern Sinai, Egypt (M. Sc. Thesis), Bot. Depart., Fac. Sci., Suez Canal Univ, Ismailia, Egy, p. 119.

Abd El-Wahab, R.H., 2006. Landforms, vegetation, and soil quality in South Sinai, Egypt. Egypt. Soc. Environ. Sci. 1 (2), 127–138.

Abd El-Wahab, R.H., Zaghloul, M.S., Moustafa, A.A., 2004. Conservation of medicinal plants in St. Catherine protectorate, South Sinai. I. Evaluation of ecological status and human impact. In: Proc. of 1st Inter. Conf. on Strat. of Egyp. Herb., pp. 231-251.

Adams, V.M., Marsh, D.M., Knox, J.S., 2005. Importance of the seed bank for population viability and population monitoring in a threatened wetland herb. Biol. Conserv. 124, 425–436.

Allen, S.E., Grimshaw, H.M., Parkinson, J.A., Quarmby, C., Roberts, J.D., 1976. In: Chapman, S.B. (Ed.), Chemical Analysis of Ecological Materials. Blackwell Sci. Publ, Oxford.

Allen, S.E., Grimshaw, H.M., Parkinson, J.A., Quarmby, C., Roberts, J.D., 1986. In: Moore, P.D., Chapman, S.B. (Eds.), Methods in Plant Ecology, second ed. Blackwell Scientific Publications, Oxford, pp. 411–466.

Alqamy, H.M., 2002. Developing and assessing a population monitoring program for dorcas gazelle (*Gazella dorcas*) using distance sampling in southern sinai, Egypt (M. Sc. Thesis), School of Biology, Division of Environmental & Evolutionary Biology, University of St. Andrews, Scotland, UK.

Al-Sodany, Y.M., 2003. Size structure and dynamics of the common shrubs in Omayed Biosphere Reserve in the western Mediterranean coast of Egypt. Ecol. Mediterr. 29, 39–48.

Ayyad, M.A., Fakhry, A.M., Moustafa, A.A., 2000. Plant biodiversity in the Saint Catherine area of the Sinai Peninsula, Egypt. Biodivers. Conserv. 9, 265–281.

Baker, H.G., 1974. The evolution of weeds. Annu. Rev. Ecol. Syst. 5, 1–24.

Balslev, H., 1988. Distribution patterns of Ecuadorean plant species. Taxon 37, 567–577.

Black, C.A., 1965. Methods of soil analysis. Am. Soc. Agron. 2, 771–1572.

Boulos, L., 2002. Flora of Egypt, Vol. 3. Al-Hadara Publishing, Cairo, Egypt.

Boulos, L., 2008. Flora and vegetation of the deserts of Egypt. Flora Mediterr. 18, 341–359.

Brown, J., 2001. Mammals on mountainsides: elevational patterns of diversity. Glob. Ecol. Biogeogr. 10, 101–109.

Colwell, R.K., Lees, D.C., 2000. The mid-domain effect: geometric constraints on the geography of species richness. Trends Ecol. Evol. 15, 70–76.

Crisp, M.D., Lange, R.T., 1976. Age structure, distribution and survival under grazing of the arid-zone shrub Acacia burkitii. Oikos 27, 86–92.

Deguise, I.E., Kerr, J.T., 2006. Protected areas and prospects for endangered species conservation in Canada. Conserv. Biol. 20, 48–55.

Donovan, T.M., Welden, C., 2001. Spreadsheet Exercises in Ecology and Evolution. Sinauer Associates, Inc., Sunderland, MA, USA, p. 556.

El-Bana, M., Shaltout, K., Khalafallah, A., Mosallam, H., 2010. Ecological status of the Mediterranean *Juniperus phoenicea* L. relicts in the desert mountains of North Sinai, Egypt. Flora 205, 171–178.

El-Hadidi, M.N., Hosni, H.A., 2000. Conservation and threats. In: El-Hadidi, M.N. (Ed.), Flora Aegyptiaca Volume I, Part 1. Palm Press, Cairo, p. 151.

Galal, T.M., 2011. Size structure and dynamics of some woody perennials along elevation gradient in Wadi Gimal, Red Sea coast of Egypt. Flora 206, 638–645.

Gentry, A.H., 1986. Endemism in tropical versus temperate communities. In: Soulé, M.E. (Ed.), Conservation Biology: The Science of Scarcity and Diversity. Sinauer Associates, Sunderland, Massachusetts, pp. 153–181.

Gottlieb, L.D., 1977. Genotypic similarity of large and small individuals in a natural population of the annual plant *Stephanomeria exigua* ssp. *coronaria* (Compositae). J. Ecol. 65, 127–134.

Harper, J.L., 1977. Population Biology of Plants. Academic Press, London, UK.

Hatab, E.E., 2009. Ecological studies on the *Acacia* species and ecosystem restoration in the Saint Katherine Protectorate, South Sinai, Egypt (Ph.D., Thesis), Fac. Sci., Al-Azhar Univ., Cairo, Egypt.

Ibisch, P.L., Boegner, A., Nieder, J., Barthlott, W., 1996. How diverse are neotropical epiphytes? An analysis based on the 'Catalogue of the Flowering Plants and Gymnosperms of Peru'. Ecotropica 2, 13–28.

Kessler, M., 2000. Elevational gradients in species richness and endemism of selected plant groups in the central Bolivian Andes. Plant Ecol. 149, 181–193.

Kessler, M., 2001a. Patterns of diversity and range size of selected plant groups along an elevational transect in the Bolivian Andes. Biodivers. Conserv. 10, 1897–1921.

Kessler, M., 2001b. Maximum plant-community endemism at intermediate intensities of anthropogenic disturbance in Bolivian montane forests. Conserv. Biol. 15, 634–641.

Kessler, M., 2002a. Environmental patterns and ecological correlates of range size among bromeliad communities of Andean forests in Bolivia. Bot. Rev. 68, 100–127.

Kessler, M., 2002b. The elevational gradient of Andean plant endemism: varying influences of taxonspecific traits and topography at different taxonomic levels. J. Biogeogr. 29, 1159–1165.

Kessler, M., Herzog, S.K., Fjeldsa, J., Bach, K., 2001. Species richness and endemism of plant and bird communities along two gradients of elevation, humidity and land use in the Bolivian Andes. Divers. Distrib. 7, 61–77.

Khedr, A., 2007. Assessment, classification, and analysis of microhabitats supporting globally significant plant species. Conservation and Sustainable Use of Medicinal Plants in Arid and Semi-arid Eco-systems Project. Saint Katherine Protectorate, Egypt, Final Report: EEAA, GEF & UNDP, Cairo, Egypt.

Lande, R., Engen, S., Sæther, B.-E., 2003. *Stochastic* Population Dynamics in Ecology and Conservation. In: Oxford Sseries in Ecology and Evolution, Oxford Univ. Press, Oxford, UK, p. 222.
Lehtilä, K., Syrjänen, K., Leimu, R., Begoña, M.G., Ehrlen, J., 2006. Habitat change and demography of *Primula veris*: Identification of management targets. Conserv. Biol. 20, 833–843.
Lentz, K.A., 1998. Ecology of Endangered Northeastern Bulrush, *Scirpus ancistrochaetus* Schuyler (Ph.D. Dissertation), Pennsylvania State Univ., Univ. Park, Pennsylvania.
Major, J., 1988. Endemism: a botanical perspective. In: Myers, A.A., Giller, P.S. (Eds.), Analytical Biogeography, An Integrated Approach to the Study of Animal and Plant Distributions. Chapman & Hall, London.
Massey, J.R., Whitson, P.D., 1980. Species biology, the key to plant preservation. Rhodora 82, 97–103.
Migahid, A.M., El-Shafei, M.A., AbdelRahman, A.A., Hammouda, M.A., 1958. Ecological observations in western and southern Sinai. Bull. Soc. Geogr. Egypte 32, 165–205.
Mithen, R., Harper, J.L., Weiner, J., 1984. Growth and mortality of individual plants as a function of available area. Oecologia 62, 57–60.
Moustafa, A.A., 1990. Environmental gradients and species distribution on Sinai Mountains (Ph.D. Thesis), Fac. Sci., Suez Canal Univ., Ismailia, p. 115.
Moustafa, A.A., Abd El-Wahab, R.H., 2013. Soil Fertility in South Sinai, Egypt. Lap Lambert Academic Publishing, p. 165.
Moustafa, A.A., Kamel, W.M., 1995. Ecological notes on the floristic composition and endemic species of saint Catherine Mountains, South Sinai, Egypt. Qatar Univ. Sci. J. 15 (2), 339–352.
Moustafa, A.A., Klopatek, J.M., 1995. Vegetation and landforms of the Saint Katherine area, Southern Sinai, Egypt. J. Arid Environ. 30, 385–395.
Moustafa, A.A., Zaghloul, M.S., Abdel-Wahab, R.H., Shaker, M., 2001. Evaluation of plant diversity and endemism in Saint Catherine Protectorate, South Sinai, Egypt. Egypt. J. Bot. 41, 123–141.
Mueller-Dombois, D., Ellenberg, H., 1974. Aims and Methods of Vegetation Ecology. Wiley, New York, USA.
Omar, K.A., 2014. Ecological and climatic attribute analysis for Egyptian *Hypericum sinaicum*. Am. J. Life Sci. 2 (6), 369–381.
Pang, G.C., Jiang, D.M., 1995. Population genetic diversity and data analysis. Sci. Silvae Sin. 31 (6), 543–550.
Perevolotsky, A., Perevolotsky, A., Noy-Meir, I., 1989. Environmental adaptation and economic change in a pastoral mountain society: the case of the jabaliyah Bedouin of the Mt. Sinai region. Mt. Res. Dev. 9 (2), 153–164.
Piper, C.S., 1950. Soil and Plant Analysis. Univ. of Adelaide Press, Adelaide, Australia.
Ramadan, A.A., 1988. Ecological studies in Wadi Feiran, Its Tributaries and The Adjacent Mountains (Ph.D. Thesis), Fac. of Sci., Suez Canal Univ., Ismailia.
Richards, C.L., Pennings, S.C., Donovan, L.A., 2005. Habitat range and phenotypic variation in salt marsh plants. Plant Ecol. 176, 263–273.
Shaltout, K.H., Ayyad, M.A., 1988. Structure and standing crop of Egyptian *Thymelaea hirsuta* populations. Vegetatio 74, 137–142.
Shaltout, K.H., Heneidy, S.Z., Al-Sodany, Y.M., Marie, A.M., Eid, E.M., Hatim, M.Z., El-Gharaib, A.E., 2004. Floristic Survey of the Mountainous Southern Sinai. Conservation and Sustainable Use of Medicinal Plants in Arid and Semi-arid Eco-systems Project. Saint Katherine Protectorate, Egypt, Final Report, EEAA, GEF & UNDP, Cairo, Egypt.
Shaltout, K.H., Mady, M.A., 1993. Current situation of the raudha's woody plant populations in the central Saudi Arabia. Feddes Repert. 104, 503–509.
Silvertown, J.W., 1981. Introduction to Plant Population Ecology. Longman, London.
Sklenar, P., Jørgensen, P.M., 1999. Distribution patterns of paramo plants in Ecuador. J. Biogeogr. 26, 681–691.
SPSS, 2006. SPSS Base 15.0 User's Guide. SPSS Inc., Chicago, USA.
Sultan, S.E., 2001. Phenotypic plasticity for fitness components in *Polygonum* species of contrasting ecological breadth. Ecology 82, 328–343.
Sultangaziev, O., Schueler, S., Geburek, T., 2010. Morphometric traits and sexual dimorphisms do not strongly differentiate populations of Zeravshan juniper (*Juniperus seravschanica* Kom.) in Kyrgyzstan. Flora 205, 532–539.
Täckholm, V., 1974. Students' Flora of Egypt. Cairo University. Cooperative Printing Company, Beirut, Lebanon.
Tesfaye, G., Teketay, D., Fetene, M., Beck, E., 2010. Regeneration of seven indigenous tree species in a dry Afromontane forest, southern Ethiopia. Flora 205, 135–143.
Thalen, D.C.P., 1979. Ecology and Utilization of Desert Shrub Rangelands in Iraq. Junk Publ., The Hague.
Weiner, J., 1985. Size hierarchies in experimental populations of annual plants. Ecology 66, 743–752.
Weiner, J., Solbrig, O.T., 1984. The meaning and measurement of size hierarchies in plant populations. Oecologia 61, 334–336.
Werner, P.A., Caswell, H., 1977. Population growth rates and age vs. stage distribution models for teasel (*Dipsacus sylvestris* Huds.). Ecology 58, 1103–1111.
Wonn, H.T., O'Hara, K.L., 2001. Height: diameter ratios and stability relationships for four northern rocky mountain tree species. West. J. Appl. For. 16 (2), 87–94.
Wood, C.C., Gross, M.R., 2008. Elemental conservation units: Communicating extinction risk without dictating targets for protection. Conserv. Biol. 22, 36–47.
Zaghloul, M.S., 1997. Ecological studies on some endemic plant species in South Sinai, Egypt (M. Sc. Thesis), Bot. Depart., Fac. Sci., Suez Canal Univ, p. 279.