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Predicting the potential geographic distribution of Nepeta septemcrenata Benth. and Phlomis aurea Decne in St. Katherine protectorate, South Sinai, Egypt, by using the maxent technique

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***Abstract*---**The threatened and endangered species distribution data are frequently clustered, and modeling their suitable habitat distribution by commonly utilized modeling methods is difficult. Therefore, this work aimed to assess the potential geographic distribution of *Nepeta septemcrenata* and *Phlomis aurea* in the St. Katherine protectorate using a new maxent approach. In addition to identifying the principal environmental parameters, which highly affect the potential geographic distribution of *Nepeta septemcrenata* and *Phlomis aurea* in the St. Katherine protectorate. The findings presented that the assessment distribution of *Nepeta septemcrenata* and *Phlomis aurea* is concentrated in the high-mountain region in SKP. While the driest quarter's precipitation, the coldest quarter's precipitation, the warmest quarter's mean temperature, the coldest

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quarter's mean temperature, and elevation all had a role in *Nepeta septemcrenata* distribution. The coldest quarter's mean temperature, the driest quarter's mean temperature, precipitation seasonality, the warmest quarter's mean temperature, all had a role in the distribution of *P. aurea*. Additionally, the highly suitable ecological conditions for *Nepeta septemcrenata* cover about 200.5 km^2 from the total protectorate area, while the highly suitable ecological conditions for *Phlomis aurea* cover only 104.1 km^2. This work may help in conservation planning for these threatened and endemic species.

***Keywords*---**distribution, maxent, species distribution modeling, endemic species, Sinai.

Introduction

Plant diversity is essential to healthy ecosystems because it provides the processes and conditions that sustain life and are vital to all humans' livelihoods and well-being (1)., Floral diversity and vegetation structure are key conservation measures for arid ecosystems threatened by aridity and human impact (2). The conservation management necessitates knowledge of the distribution of plant biodiversity (3). In Egypt, there is an increasing concern with biodiversity conservation and its elements. Many studies focused on vegetation, including endangered species (4-7). Sinai's floristic significance stems from its unique location at the crossroads of Asia and Africa. Its vegetation is influenced by continents and dominated by four major families: Compositae (Asteraceae), Leguminosae, Labiatae, and Zygophyllaceae (8). The Sinai Peninsula has four main phytogeographical distribution patterns: Irano–Turanian (steppe vegetation), Saharo–Arabian (desert vegetation), the Mediterranean, and Sudanian, with a total flora of about 900 species (9).

One of the spots that riches with flora diversity in the Middle East is the St. Katherine protectorate (SKP). Recently, about 1261 species are reported in Sinai (10). Fayed and Shaltout (11) were recorded about 472 plant species from SKP. The Sinai Peninsula is home to about 36 endemic plant species, most of which (89.3%) are found in the Sinai massif (12-14), identified about 26 endemic plant species in the SKP, accounting for 42.6 percent of Egypt's endemic plant species. These endemic species are primarily found in four mountains: St. Katherine Mountain, Serbal Mountain, Sinai Mountain, and Umm Shaumer Mountain (7, 14). Because of its geomorphological formations and climatic altitudinal variations, SKP has a distinct flora (9). More than 115 plants identified in the SKP have therapeutic effects and are utilized in traditional remedies and therapies (15, 16).

Nepeta septemcrenata Benth. (Family: Lamiaceae) is grazed, near-endemic, and vulnerable (17, 18). The plant grew in stony wadis and is located in North-West Saudi Arabia and Sinai (19). *Nepeta septemcrenata* is utilized in traditional medicine as eyewash, antipyretic, gargle, and cardiotonic (20). Additionally, it is used as a laxative to treat dysentery, teeth troubles, and liver and kidney diseases (21, 22). *Phlomis aurea* Decne. (Family: Lamiaceae) is endemic to Sinai (23), and it grew in stony wadis (19). It is endangered and rare, especially in Mount St. Katharine and Mount Sinai (24, 25). *Phlomis aurea* is utilized in folk medicine for curing sore throat (14). The *Phlomis* extracts showed anti-inflammatory, cytotoxic, cytostatic, anti-microbial, immunosuppressant, and anti-diabetic activities (26). The loss of many plant species has been documented globally and in Egypt because of habitat destruction and severe environmental alterations (7).

The distribution models of species are generally crucial in assessing species distributions in various ecological, biological, and biogeographical applications (27). The Model investigations are critical in biological studies; their assessing abilities shed light on many problems, like increasing the distribution of protected species or the possible expansion of invasive species (28, 29). The MaxEnt technique could be utilized to evaluate the potential distribution of a target species. It can achieve high accurate results with only available appearance data. MaxEnt specifically analyzes location data to determine the target species' potential distribution depending on environmental variables (30). In Egypt, several reports were carried out by species distribution models to evaluate the potential geographic distribution of many species (23, 31, 32) (33-36). It is not easy to offer a full picture of the plant's condition and the parameters influencing it. However, it was assessed that two-thirds of the world's plant species would become extinct during the twenty-first century (37). Therefore, this work aimed to assess the potential geographic distribution of Phlomis aurea and *Nepeta septemcrenata* in SKP, South Sinai, Egypt, by the maxent technique. Moreover, this work aimed to recognize the principal environmental parameters which greatly affect the potential geographic distribution of Phlomis aurea and *Nepeta septemcrenata* in the SKP.

Methods and Materials

Study region

Several localities were selected to monitor and sample plant species in the high mountainous regions of SKP (Figures 1 & 2, Table 1&2).

Study plants

Nepeta septemcrenata **Benth. (Family: Lamiaceae)**

The plant is an appressed-tomentose perennial (30-60 cm); the Stems are many, hairy, branched, erect, and woody at the base; Leaves are small ovate-deltoid. The calyx is tubular and straight; Corolla is blue and bilabiate (19, 38).

Phlomis aurea **Decne. (Family: Lamiaceae).**

The plant is golden- woolly perennial (30-60 cm) with a woody base; stems are erect and branched; Leaves are ovate-lanceolate to elliptic and sessile or subsessile; Flowers are verticillasters (19).

Samples identification

According to recent studies (19, 38), plant samples were identified.

Assessing and mapping distributions of plant species

Location data for *Phlomis aurea* and *Nepeta septemcrenata* were reported by GPS (Garmin XL 12). The assessment of the potential geographic distribution of *Phlomis aurea* and *Nepeta septemcrenata* was built by the MaxEnt technique with environmental assessor layers for the study region, like temperature, moisture, altitude (39).

Environmental predictors of the model

As raster grids, the model made use of a variety of data sets. Climate data and topographical variables were used to categorize environmental assessors. The WorldClim data set (40, 41). contained 19 bioclimatic variables in addition to altitude (Table 3) that were more biologically significant in determining a species' eco-physiological tolerance (42). The potential habitat suitability in the map was classified into four categories: highly suitable distribution (70%-100%) (43), moderately suitable distribution (35%-70%), poorly suitable distribution (5%-35%), and unsuitable distribution (0-5%),

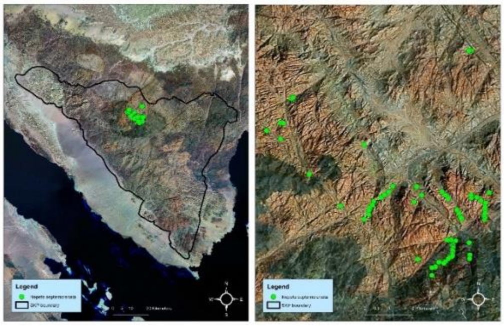

Fig 1. Location map shows the sampling regions of *Nepeta septemcrenata* in SKP in a high mountainous region

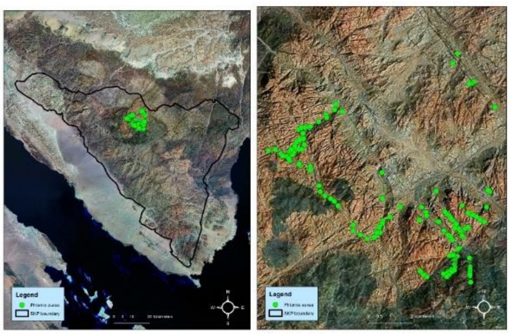

Fig 2. Location map showing the sampling sites of *Phlomis aurea* in SKP in a high mountainous region

Table 1
The Nepeta septemcrenata recorded sites in the high mountainous region of SKP

No.	Location	Coordinates	
		latitude	longitude
1	Shag Logar	28.60213	33.97053
2	Abo Gefa	28.54940	33.93977
3	Abo Tweata	28.56921	33.89969
4	Ain shenar	28.52286	33.96028
5	Ain Tofaha	28.55155	33.94130
6	Elgabel El-Ahmer	28.53185	33.96304
7	El-Maean	28.57521	33.89961
8	Farsh Elia	28.54374	33.97557
9	Farsh El-losa	28.54834	33.97040
10	Farsh Mesella	28.52109	33.95589
11	Gabel Kathrine trail	28.52155	33.95715
12	Kanest El-Homar	28.54720	33.97049
13	Monestary Stairs	28.54540	33.97584
14	Mount Sinai	28.54260	33.97562
15	Sarfet Gabal Abas	28.55601	33.91028
16	Selebat	28.54589	33.93424
17	Shag El-Gragnea	28.53056	33.96966
18	Shag Logar	28.60204	33.96952
19	Shag Mousa	28.53129	33.96461
20	Shag Tebook	28.54101	33.93239
21	Shag Telah	28.58424	33.90371
22	Wadi El-Arbaein	28.55143	33.94993
23	Wadi Faraa	28.53938	33.96703
24	Wadi Sherage	28.54821	33.96089
25	Wadi Tlaa	28.56701	33.93070
26	Zwatein	28.54419	33.92194

Table 2
The recorded locations of *Phlomis aurea* in the high mountainous region of SKP

No.	Location	Coordinates	
		latitude	longitude
1	Abo Gefa	28.54737	33.93693
2	Abo Tweata	28.56847	33.90021
3	Abo Zatona	28.59252	33.98017
4	Ain shenar	28.52286	33.96028
5	Ain Tofaha	28.55155	33.94130
6	Elgabel El-Ahmer	28.53185	33.96304
7	El-Maean	28.57521	33.89885
8	El-Zag	28.54163	33.92190
9	Enshail El-sofela	28.61051	33.96282
10	Farsh Elia	28.54622	33.97408
11	Farsh El-losa	28.54834	33.97040
12	Farsh Mesella	28.52279	33.95220
13	Farsh Shoeab	28.55208	33.96662

14	Gabel Kathrine trail	28.53088	33.96402
15	Kanest El-Homar	28.54325	33.96920
16	Kharazt El-Shag	28.58411	33.90203
17	Monestary Stairs	28.55146	33.97666
18	Sarfet Gabal Abas	28.55201	33.91566
19	Selebat	28.54589	33.93424
20	Shag El-Gragnea	28.53056	33.96966
21	Shag Logar	28.60291	33.97144
22	Shag Mousa	28.52560	33.96344
23	Shag Tebook	28.54092	33.93158
24	Shag Telah	28.59375	33.91478
25	Wadi El-Arbaein	28.55143	33.94993
26	Wadi El-Deer	28.55776	33.97799
27	Wadi Faraa	28.53938	33.96703
28	Wadi Sakr	28.57416	33.89746
29	Wadi Sherage	28.54821	33.96089
30	Wadi Teanea	28.55787	33.90838
31	Wadi Telah	28.59069	33.91726
32	Wadi Tlaa	28.55496	33.93384
33	Zwatein	28.53885	33.93051

Table 3
The WorldClim climatic predictors

	Climatic predictors
Bio1	Annual Mean Temperature.
Bio2	Mean Diurnal Range (Mean of monthly (max temp - min temp).
Bio3	Isothermality (P2/P7) (* 100).
Bio4	Temperature Seasonality (standard deviation *100).
Bio5	Warmest Month's Max Temperature.
Bio6	Coldest Month's Min Temperature.
Bio7	Temperature Annual Range (P5-P6).
Bio8	Wettest Quarter's Mean Temperature.
Bio9	Driest Quarter's Mean Temperature.
Bio10	Warmest Quarter's Mean Temperature.
Bio11	Coldest Quarter's Mean Temperature.
Bio12	Annual Precipitation.
Bio13	Wettest Month's Precipitation.
Bio14	Driest Month's Precipitation.
Bio15	Precipitation Seasonality (Coefficient of Variation).
Bio16	Wettest Quarter's Precipitation.
Bio17	Driest Quarter's Precipitation.
Bio18	Warmest Quarter's Precipitation.
Bio19	Coldest Quarter's Precipitation.

Statistical validation of the model

To determine the model's evaluation performance, a random presence data split into 75% of the points was used for assessment and 25% for model testing.The area under the curve (AUC) is utilized to indicate the model's accuracy (30). The

AUC ranges between 0 and 1, The AUC of 0.5 suggests a random, but an AUC of 1 reveals a perfect model (30). The present work utilized the classification system of AUC reported by (44). The AUC categories are listed as: (0.9 –1.0) indicates outstanding discrimination; (0.8-0.9) indicates excellent discrimination; (0.7-0.8) indicates acceptable discrimination; (0.6-0.7) indicates bad discrimination; (0.5-0.6) indicates no discrimination. The jackknife test of the MaxEnt model was utilized to calculate the variables contributing to the development of the model (30).

Results

Spatial assessment model of *N. septemcrenata*.
The assessed distribution range of *Nepeta septemcrenata* in SKP

The MaxEnt model for *Nepeta septemcrenata* is presented in (Figure. 3). The assessed distribution habitat of *Nepeta septemcrenata* covered several areas in the high mountainous region of SKP. A total of 19 presence data were used to train the model and six were used to test it.The AUC (Figure 4) for the training points was 0. 962, and for the test points was 0.959, with a standard deviation of 0.010. The AUC above 0.9 is demonstrating that *N. septemcrenata* exhibited exceptional discrimination. Between training points, the minimal training presence was 6.451. The fractional assessed area was 0.131 at this threshold, while the omission rate for test points was 0.000. The maxent model correctly categorizes the test points far more often than the random model (p0.001). The suitable assessed distribution of *Nepeta septemcrenata* is shown in (Figure. 5). Out of 4747 km^2 of the total area, 3860.7 km^2 (0-5%) was unsuitable for *N. septemcrenata;* the remaining area was categorized into 459.2 km^2 with poorly suitable habitat (5%-35%), 226.6 km^2 with moderately suitable habitat (35%-70%) and only 200.5 km^2 with the highly suitable ecological conditions (70%-100%).

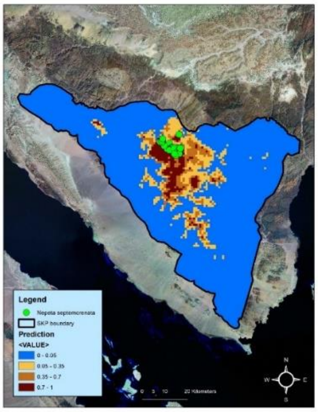

Fig. 3. The predicted Nepeta septemcrenata distribution range per the MaxEnt model

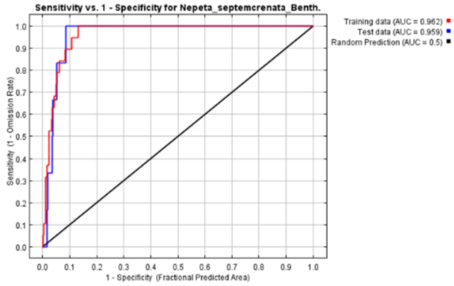

Fig 4. Training data (AUC = 0.962) and test data (AUC = 0.959) compared to random prediction (AUC = 0.5) in the ROC curve for the MaxEnt model representation for *N. septemcrenata*

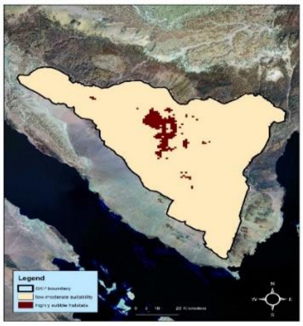

Fig 5. The predicted areas with the highly suitable distribution of *N. septemcrenata*

Effects of climatic variables in the MaxEnt model representation for *Nepeta septemcrenata*

The findings of the climatic variables' contribution in MaxEnt modeling of *Nepeta septemcrenata* are showed in (Table. 4). The climatic variable that exhibited the highest mean contributions was the coldest quarter's precipitation (Bio 19), the coldest quarter's mean temperature (Bio 11), the driest quarter's precipitation (Bio 17), the warmest quarter's mean temperature of (Bio 10), the coldest month's minimum temperature (Bio 6), mean diurnal range (Bio 2), elevation, driest month's precipitation (Bio 14), and the driest quarter's mean temperature (Bio 9) given high gains (>2) to the model when individually utilized, demonstrating that these variables contain more basic information than others.

Table 4
Estimation for an average contribution of the climatic variables utilized in *N. septemcrenata's* MaxEnt modeling

Variable	Percent contribution
Bio 19	20.2
Bio11	19.6
Bio 17	14.7
Bio 10	14.5
Bio 6	8

Bio 2	6.2
Elevation	5.7
Bio14	3.2
Bio 9	3
Bio 7	2
Bio 12	1.5
Bio 03	0.7
Bio 18	0.3
Bio 15	0.2
Bio 8	0

Spatial prediction model of *P. aurea*
The predicted distribution range of *Phlomis aurea* in SKP.

The *Phlomis aurea* MaxEnt model is presented in (Figure. 6). The predicted *Phlomis aurea* distribution habitat of scattered, covered areas in the high mountainous region of SKP. A total of 31 presence data were used to train the model and 10 were used to test it. The AUC (Figure. 7) for the training points was 0. 973, and for the test points was 0.952, with a standard deviation of 0.016. The AUC exceeded 0.9, showing outstanding discrimination for *P. aurea*. The minimum training presence among training points was 6.809. The omission rate for test points was 0.200, and the fractional predicted area was 0.111 at this threshold. The suitable predicted distribution of *Phlomis aurea* is shown in (Figure. 8). Out of 4747 km^2 of the total area, 4003.1 km^2 (0-5%) was unsuitable for *P. aurea;* The other region was divided into 442.4 km^2 with poorly suitable habitat (5%-35%), 197.5 km^2 with moderately suitable habitat (35%-70%) and only 104.1km^2 with the highly suitable ecological conditions (70%-100%).

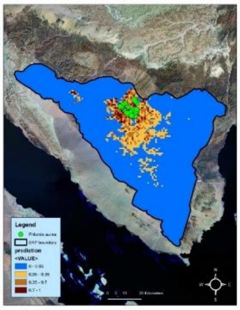

Fig 6. The predicted *Phlomis aurea* distribution range as per the MaxEnt model

Fig 7. Training data (AUC = 0.973) and test data (AUC = 0.952) compared to random prediction (AUC = 0.5) in the ROC curve for the MaxEnt model representation for *P. aurea*

Fig 8. The predicted areas with the highly suitable distribution of *P. aurea*

The effects of climatic variables in the MaxEnt model representation for *P. aurea*

The results of the climatic variables' contribution in MaxEnt modeling of *Phlomis aurea* are shown in (Table. 5). The climatic variable which displayed the highest mean contributions was the mean temperature of the driest quarter (Bio 9), the coldest quarter's mean temperature (Bio 11), the warmest quarter's mean temperature (Bio 10), the coldest month's minimum temperature (Bio 6), precipitation seasonality (Bio 15), annual mean temperature (Bio 1), precipitation of warmest quarter (Bio 18), elevation, the warmest month's max temperature (Bio 5), diurnal average range (Bio 2), When used singly, the wettest quarter's mean temperature (Bio 8) provided large gains (>2) to the model, demonstrating that some variables contain more basic information than others.

Table 5
Estimates for an average contribution of the climatic variables utilized in MaxEnt modeling of *P. aurea*

Variable	Percent contribution
Bio 9	26.6
Bio11	22.3
Bio 10	9.4
Bio 6	7.4
Bio 15	7.1
Bio 1	6.3
Bio 18	4.5
Elevation	4.1
Bio 5	3.8
Bio 2	2.3
Bio 8	2.2
Bio 17	1.1
Bio 16	0.9
Bio 7	0.8
Bio 4	0.7
Bio 3	0.5

Discussion

Under the current climatic condition, the study findings indicated that the most suitable habitats of *Nepeta septemcrenata and Phlomis aurea* is concentrated in the high mountainous region of SKP. These outcomes agree with the known distribution recorded in the literature (7, 12, 14, 17-19, 22, 25), and suggest that current distribution's climate optimal is found at high altitudes sites. The habitat distribution model of Nepeta septemcrenata and Phlomis aurea in SKP can be conducted utilising just few numbers of occurrence records combined with climatic assessor layers for the study region within the MaxEnt framework, according to this research. Therefore, the recent study fits with the fact that the Maxent approach works better for extremely tiny presence recorded species (31, 36, 45). The results of MaxEnt modeling under current conditions implied that the *Nepeta septemcrenata* distribution range was more affected by the coldest quarter's mean temperature, the coldest quarter's precipitation, the warmest quarter's mean temperature, and the driest quarter's precipitation, besides elevation.

Additionally, *the Phlomis aurea* distribution range was more affected by the coldest quarter's mean temperature, the driest quarter's mean temperature, precipitation seasonality, the coldest month's minimum temperature, the warmest quarter's mean temperature, and elevation. This is consistent with the factors that affective to the appropriate habitats with several endangered plant species in high-altitude areas; *Fritillaria cirrhosa* (46), *Artemisia* spp. (47), and *Rosa arabica* (33), The most important determinants in plant species distribution were climate conditions and altitude. Additionally, the significance of climatic parameters and altitude in the medicinal plants' spatial distribution was confirmed in Egypt (48), in addition for distribution of Nepeta septemcrenata and Hypericum sinaicum in the Protectorate of St. Katherine (49, 50). Rainfall and elevation greatly impact the endemic taxa distribution in the St. Katherine Protectorate (7).

Furthermore, the highly suitable ecological conditions for *Nepeta septemcrenata* cover approximately 200.5 km^2 of the total protectorate area, whereas *P. aurea's* highly suitable ecological conditions cover only 104.1 km^2. This might be attributed to the severe effect of human activities on *Phlomis aurea,* like over-cutting, overgrazing, and uprooting (for medicinal uses and fuel) (14). Additionally, the most effective environmental variables for explaining *Phlomis aurea* distribution were calcium, altitude, organic matter, bicarbonate, and fine gravels (25).

Conclusion

The Maxent method appears to be an effective technique in predicting suitable habitats for endangered and threatened species with small occurrence records and can be a vital tool for monitoring and conserving biodiversity. The potential habitat distribution maps for *Nepeta septemcrenata* and *Phlomis aurea* can be utilized to discover new populations, identify high-priority survey localities, and plan land-use management around its existing populations, and setting of priorities to restore its original habitat for more efficient conservation.

Recommendations

Depending on the assessment results and analysis, we must shed light on the suitable regions of *Nepeta septemcrenata* and *Phlomis aurea* in SKP, which should be the essential regions for conservation. We need to decline the extinction risk in the wild for the In-situ and Ex-situ conservation measures for *Nepeta septemcrenata* and *Phlomis aurea*. Increased policy activities and public awareness must complement these activities to reduce the effects of human activity.

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