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Predicting the potential current distribution of the near-endemic *Centaurea glomerata* Vahl. in Egypt

Nourhan Ramadan*, Mohamed Abdelaal, Ghada A. El-Sherbeny and Ibrahim A. Mashaly

Botany Department, Faculty of Science, Mansoura University, Mansoura 35516, Egypt

**** Correspondence to:** Email: nourhanramadan@mans.edu.eg, Tel: 0103533852*

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Abstract Different threats to endemic vascular plants have been recognized in the Mediterranean region. For Egypt, the threats to endemic vascular plants along the northern Mediterranean coast include their limited population size, low genetic diversity, habitat specificity, extensive man-made impacts, and climate change. *Centaurea glomerata* Vahl.is an annual, herbaceous plant, near endemic endangered species, distributed along the Mediterranean coast regions of Egypt and Libya. Using 50 georefernced occurences and 19 bioclimatic factors in MaxEnt, the potential current distribution *of C. glomerata* in Egypt was predicted. The models demonstrated high prediction performance with high value of AUC (0.989± 0.001). The main predictors that exhibited the highest contributions were precipitation seasonality, precipitation of coldest quarter and mean diurnal range. The current anticipated locations match the *C. glomerata* where requirements precipitation seasonality range from 70 to 130, mean diurnal range from 7.4 to 17°C and precipitation of coldest quarter range from 20 to 90 mm. The outputs of the models revealed that the most suitable sites for the growth of *C. glomerata* along the western Mediterranean coast of Egypt are El-Agamy and Sidi Krir sites. The awareness and research activities as well as *in-situ* conservation must be raised to reduce threats of *C. glomerata* in the wild.

Keywords: Near-endemic taxa, environmental variables, conservation, Mediterranean coast.

1.Introduction

Biodiversity plays an essential role in ecosystem functioning Therefore, this may positively affect the provision of ecosystem services that benefit the community [1]. Despite the advantages of biodiversity, threats to species and ecosystems are rising alarmingly quickly. In addition to climate change, human mismanagement of biological resources is frequently exacerbated by reckless economic policies, pollution, and faulty institutions. [2]. Plant-environment interactions and their effects on plant development have been the subject of research for several decades. [3]. Species distribution is significantly influenced by environmental variables (such as temperature, water, soil, and surface humidity). Climate has an impact on population dynamics, distribution, abundance, and species fitness as well as structure and function of ecosystems [4]. Rare plant species have distinctive functional characteristics that greatly aid in crucial ecological activities including productivity, organic matter decomposition, bioerosion, and bioturbation. Their extinction might affect biogeochemical and dynamic ecosystem processes [5]. Endemism is the restriction of a taxon's native range to a specific geographical area or habitat [6]; with either political limits of a country (endemics), or eco- geographical limits of two or more countries without regard to their political boundaries (near- endemics), however, the taxa with a narrow distribution are called steno -endemics or steno- near endemics [6].

The first stage of establishing a conservation strategy for these taxa is to determine the current geographic range, population size, and the problems that put them at risk of extinction[7].

Wherefore it is essential to estimate and map out feasible habitat that would be suited for threatened and endangered species in order to monitor and restore their dwindling native populations in their natural habitats, introduce them artificially, or choosing conservation area [8]. There are many species distribution models (SDMs) readily available for predicting a species' probable distribution. Among SDMS, Maximum Entropy algorithm (MaxEnt) was selected.

Centaurea glomerata Vahl is an annual, herbaceous species of the Asteraceae family [9] (Fig 1a). It is a near endemic species in Egypt and Libya [10]. It is found in cultivated lands and roadsides [11]. *C. glomerata* acts as an antioxidant with large amounts of flavonoids and saponins [12]. Four novel sesquiterpene lactones and the lignan lactone were produced by the aerial sections of *C. glomerata*. [13]. Due to their outstanding medicinal value, One of the most frequently used plants in traditional medicine for the treatment of cancer and microbial infections is the *Centaurea* species. Additionally, research on *Centaurea* species has revealed that they possess anti-ulcerogenic, anti-hepatoprotective, anti-plasmodial, cytotoxic, anti-proteasomal, antioxidant, anti-bacterial, anti-fungal, and anti-diuretic properties. They also have diuretic, antimalarial, anti-inflammatory, anti-pyretic, analgesic, anti-platelet, and anti-inflammatory properties [14]–[16]. *C. glomerata* is one of North Egypt's rare and threatened plants [17], it was evaluated as endangered (EN) taxon by [9] and [18].

Hence, our goals in the current study were: (1) To estimate the probable current *C. glomerata* distribution along Egypt's Mediterranean coast, and (2) to determine the important environmental variables that closely connected with the area of distribution.

2. Materials and methods

2.1. Study area

The sampled sites are distributed along Egypt's Mediterranean coast, where *C. glomerata* grows. Using GPS (Global Positioning System, Garmin eTrex 30x model), geographic coordinates for each stand were recorded. The Mediterranean coast in Egypt covers approximately 970 km and is divided into three sectors: the Nile Delta coast, the North Eastern coast, and the North Western coast [19]. The north western coast, also known as the Mariut Coast, stretches for around 550 km from Sallum to Abu Qir, 180 km from Abu Qir to Port-Said, and 240 km from Port-Said to Rafah [19] **(Fig 1b)** . The Mediterranean coastal desert has a less arid climate than the rest of Egypt's southern regions. It belongs to sub desertic warm climate, according to the UNESCO/FAO bioclimatic map from 1963.

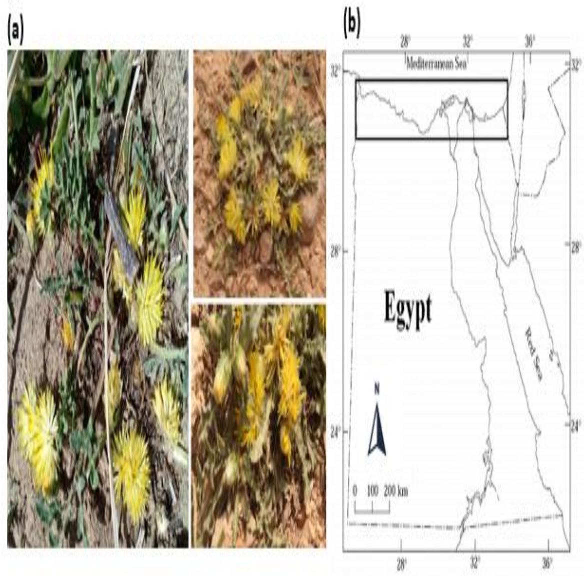

Fig 1: (a) Photos of *Centaurea glomerata* Vahl. and **(b)** Map of Egypt shows the study area.

2.2. Selection of variables and data sources

After reviewing the literature, fieldwork was conducted to collect the most recent information on the distribution of *C. glomerata* in the study's area [9], [10], [17], [20], [21]. The autocorrelation problems were resolved by removing redundant presences depending on the scale of the employed bioclimatic variables from each 1 × 1 km grid. [22]. Furthermore, records were screened in Arc GIS 10.8.1 for spatial autocorrelation to remove spatially correlated points [23]. Finally, 50 occurrence points of *C. glomerata* were used to generate SDMs.

Nineteen variables were used as predictors to model the potential niche of *C. glomerata*. 19 bioclimatic layers were obtained from World Clim database (https://www.worldclim.org/data/worldclim21.html) [24] at a spatial resolution of 30 arc-second (ca. 1× 1 km). Table 1 shows the environmental variables. In order to get rid of multicollinearity and choose the predictors that are most suitable and have the most contribution to the model. The chosen variables consist of annual mean temperature (Bio1), mean diurnal range (Bio2), isothermality (Bio3), temperature seasonality (Bio4), minimum temperature of coldest month (Bio6), mean temperature of warmest quarter (Bio10), mean temperature of coldest quarter (Bio11), precipitation seasonality (Bio15) and precipitation of coldest quarter (Bio19).

Table 1. Bioclimatic variables used for modelling the potential distribution of *C. glomerata* in the present study. Through the use of a multi-collinearity test, the variables in bold were chosen for modelling.

Variable	**Code and unit**
Annual mean temperature	Bio1 (°C)
Mean diurnal range (max. temp – min. temp)	Bio2 (°C)
Isothermality	Bio3
Temperature seasonality (SD ×100)	Bio4 (°C)
Maximum temperature of warmest month	Bio5 (°C)
Minimum temperature of coldest month	Bio6 (°C)
Temperature annual range (Bio5-Bio6)	Bio7 (°C)
Mean temperature of wettest quarter	Bio8 (°C)
Mean temperature of driest quarter	Bio9 (°C)
Mean temperature of warmest quarter	Bio10 (°C)
Mean temperature of coldest quarter	Bio11 (°C)
Annual precipitation	Bio12 (mm)
Precipitation of wettest month	Bio13 (mm)
Precipitation of driest month	Bio14 (mm)
Precipitation seasonality	Bio15
Precipitation of wettest quarter	Bio16 (mm)
Precipitation of driest quarter	Bio17 (mm)
Precipitation of warmest quarter	Bio18 (mm)
Precipitation of coldest quarter	Bio19 (mm)

2.3. MaxEnt model

All models in this study were run using the MaxEnt technique(version 3.4.4) [25] with the standard defaults. For habitat appropriateness, we used an average of probability maps with 10 replicates [26]. MaxEnt model is preferable, especially when a small number of entries are only present in the data points [27]. There were 80% of training data points and 20% of test data points, respectively. Using the % contribution of the Jackknife test, the relative significance of each environmental predictor for the models of *C. glomerata* was evaluated. [25], which index is best for use with tiny sample sizes [28]. The area under curve (AUC) is fundamental metric used in MaxEnt to evaluate a model's quality [29]. Due to its independence from threshold selections, the AUC score is the most common metric used to assess model performance. [30]. The model performs better the higher the AUC value (near to 1)[31]. The smallest difference between training and testing AUC data (AUC_{Diff}) was also taken into account, and the lower difference indicates that the model is less overfit ([32].

With values ranging from 0 (unsuitable) to 1 (optimal), the logistic output of the MaxEnt programme is a map that indexes the environmental appropriateness of *C. glomerata*. The data from MaxEnt were imported into Arc GIS 10.8.1 for additional analysis, and four categories of prospective habitats were formed: unsuitable (0.22), low potential (0.23- 0.37), moderate potential (0.38- 0.77), and high potential (0.78) [33].

3. Results

3.1. Potential current habitat appropriateness of *C. glomerata*

With values of AUC, our models demonstrated significant levels of predictive performance (training data, 0.989± 0.001; testing data, 0.987± 0.015) and AUC_{Diff} (0.014± 0.008). Table 2 displays the findings of the variables' contributions using the Jackknife test in the distribution modelling of *C. glomerata*. Environmental variables exhibiting the greatest average contributions were precipitation seasonality (Bio15), precipitation of coldest quarter (Bio19) and mean diurnal range (Bio2). Considering percent contribution, Bio2, Bio15 and Bio19 were the most significant environmental predictors that affect the probable distribution of *C. glomerata* (**Table2**). During our field surveys, *C. glomerata* was recorded in six localities along the Mediterranean coastal region: Agiba, Marsa Matrouh, Qalabshu, Rasheed-Alexandria Road, Rosetta and Burg El Arab.

Figure 2 displays the response curves for four significant variables to the habitat appropriateness of *C. glomerata*. According to probabilities of temperature variables , *C. glomerata*'s mean annual temperature range (Bio1) was 14.9–27.7°C and its mean diurnal temperature (Bio2) was 7.4–17°C. Additionally, the isothermality range (Bio3) ranged from 34.5 to 55., temperature seasonality (Bio4) ranged from 411.6°C to 718.5°C, whereas the minimum temperature for the coldest month (Bio6) ranged from 0.5 to 14.8°C, the mean temperatures for the warmest quarter (Bio10) varied from 21°C to 34.5°C and the coldest quarter (Bio11) varied from 7.7°C to 21°C. On the other hand, seasonality of precipitation (Bio15) ranged from 70 to 130, while that of the coldest quarter (Bio19) ranged from 20 to 90 mm. In fact, the conditions that are best for the presence of *C. glomerata* include a mean diurnal range of 7.4 to 17°C, seasonality of precipitation of 70 to 130, and precipitation of coldest quarter of 20 to 90 mm. In contrary, *C. glomerata* prefers habitats with an annual temperature below 27°C. Fig. 3 shows probable distribution map of *C. glomerata* along the Mediterranean coastal region, Egypt.

Table 2. Estimates of average contribution and permutation importance's of the bioclimatic variables used in modelling of *C. glomerata*

Variable	Percent contribution	Permutation importance
Bio01	1.6	21.4
Bio02	31.1	3.2
Bio03	3.5	9
Bio04	10.9	0.6
Bio06	0.1	0.3
Bio10	3.9	5.1
Bio11	0.1	7.1
Bio15	15	52.9
Bio19	33.9	0.3

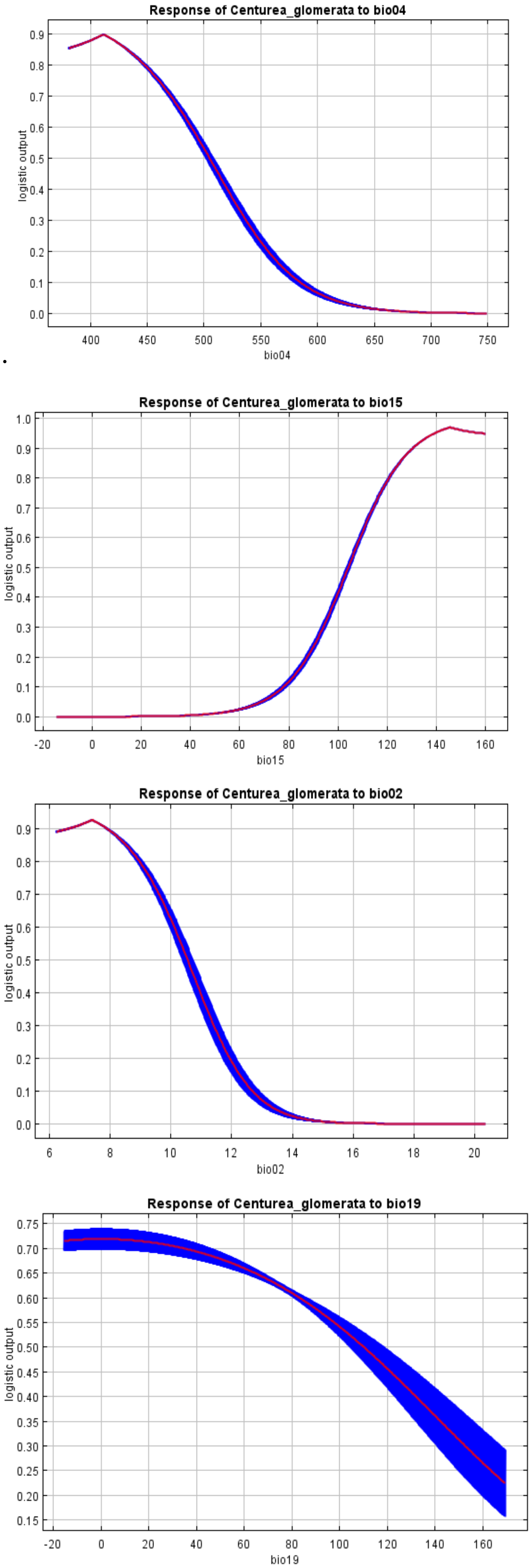

Fig 2. Response curves of the most important four bioclimatic predictors used in the potential distribution of *C. glomerata*.

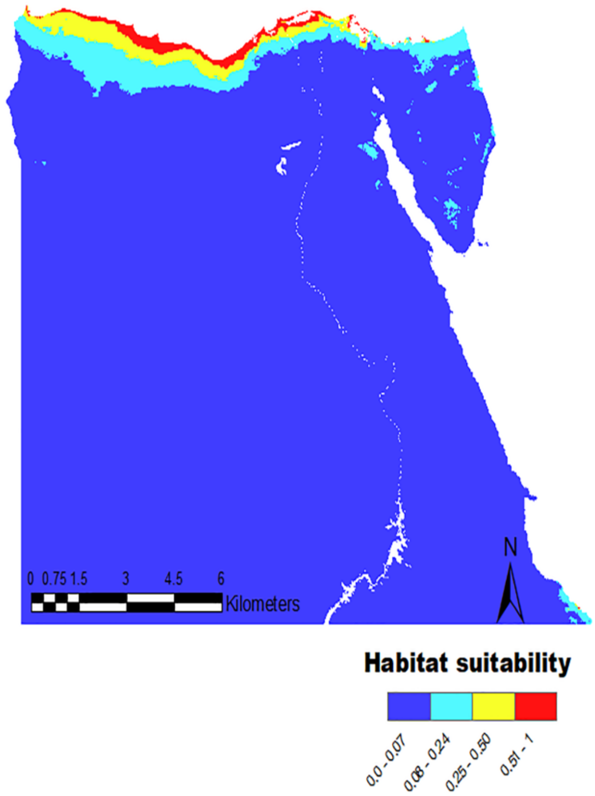

Fig.3. Map showing the probable appropriateness of the current distribution for *C. glomerata* in the Mediterranean region of Egypt. The four categories of habitat suitability are: unsuitable (0.0–0.07), low potential (0.08–0.24), moderate potential (0.25–0.50), and high potential (0.51–1)

4. Discussion

Our results indicated that the Mediterranean coast of Egypt where *C. glomerata* is most environmentally suitable regions under the current climatic conditions. The results of this study is consistent with both our field findings and the known distribution given in the literature [9], [10], [17], [21], [34], [35], [36]-[37] and indicates that the current distribution shows their climate optimum in locations with high precipitation. The results of the models showed the sites along the Mediterranean coast are suitable for the growth of *C. glomerata*, especially Agami and Sidi Kerir. However, additional studies are encouraged in these areas to look for new *C. glomerata* populations or to find out what reasons have prevented this species from colonising all eligible sites.

Precipitation plays a major role in the growth of plants and in species occurrence [38]-[39]. MaxEnt outputs under the current conditions showed that *C. glomerata* the distribution range was more influenced by the seasonality of the precipitation, the mean diurnal range and the precipitation of coldest the quarter. This result in agreement with the results for *Ephedra equisetina* obtained by [40]. The present study showed that precipitation was the most important predictor of *C. glomerata* habitat distribution. This agrees with the findings of [41] who suggested that Average annual precipitation and average cool season precipitation has a positive association with annual grass cover and the mean diurnal range has concurred with the view of [42] which *Thuja sutchuenensis* in southwestern China provided satisfactory results The model was mainly affected by precipitation during the warmest quarter (Bio18) , then mean diurnal range (Bio2). In Egypt in St. Catherine protected area as a suitable habitat *Anthrax chionanthrax* and *Anthrax melanista* were dominated by temperature, whereas on *Anthrax aethiops bezzii* was significantly associated with precipitation variables [43]. The two most significant predictors of the habitat distribution of *Nepeta septemcrenata* were precipitation of the coldest quarter and precipitation of the wettest quarter. [8]. Elevation, annual precipitation, and annual temperature were the main factors affecting *Rosa arabica* distribution [44]. In China The most important criteria for determining the distribution of *Paeonia delavayi* have been determined to be temperature seasonality and isothermality, while the most important factor for determining the distribution of *Paeonia rockii* was determined to be annual precipitation. [45]. In west Iran, the habitat of the endemic plant species *Nepeta crispa* was mostly determined by elevation, annual mean temperature, geology, and precipitation of the driest quarter [46].

5. Conclusion

This study suggests that the regional distribution of *C. glomerata* might encounter habitat range shifts due to the extinction of this species with Precipitation seasonality less than 70, precipitation of coldest quarter fewer than 20 mm and more than 90 mm and mean diurnal temperature less than 7.4°C and higher than 17°C. *Ex situ* and *in situ* conservation strategies for *C. glomerata* are essential to reduce the possibility of extinction in the wild.. More specifically, program of assisted migrations and reinforcements of the existing populations should be planned in the wild. To reduce the effects of human activity, these actions should be accompanied with increased public awareness campaigns and policy initiatives.

Additional field surveys along the Mediterranean coastal region of Egypt are recommended for searching new populations of *C. glomerata*.

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