Predicting the potential geographical distribution of *Nepeta septemcrenata* in Saint Katherine Protectorate, South Sinai, Egypt using Maxent

O. Khafaga[1], E.E. Hatab[2], K. Omar[3*]

[1] Botany Department, Faculty of Science (Girls branch), Al-Azhar University, Cairo, Egypt.
[2] Siwa Protectorate, the Nature Conservation Sector, Egyptian Environmental Affairs Agency, Egypt.
[3] Saint Katherine Protectorate, the Nature Conservation Sector, Egyptian Environmental Affairs Agency, Egypt.
*Kariem_npe@yahoo.com

Abstract: Accurate modeling of geographic distributions of species is crucial to various applications in ecology and conservation. Distribution data on threatened and endangered species are often sparse and clustered making it difficult to model their suitable habitat distribution using commonly used modeling approaches. We used a novel method called maximum entropy distribution modeling or Maxent for predicting potential suitable habitat for *Nepeta septemcrenata*, a threatened and endangered species in Saint Katherine Protectorate (SKP), South Sinai, Egypt, using small number of occurrence records. Our objectives were to: (1) predict suitable habitat distribution for threatened herb *Nepeta septemcrenata* using a small number of occurrence records to inform conservation planning in Saint Katherine Protectorate; and (2) identify the environmental factors associated with *N. septemcrenata* habitat distribution. Results showed that the environmental variable with highest gain when used in isolation is bio19 (Precipitation of Coldest Quarter). The approach presented here appears to be quite promising in predicting suitable habitat for threatened and endangered species with small sample records and can be an effective tool for biodiversity conservation planning, monitoring and management.

[O. Khafaga, E.E. Hatab, K. Omar. Predicting the potential geographical distribution of *Nepeta septemcrenata* in Saint Katherine Protectorate, South Sinai, Egypt using Maxent. Academia Arena. 2011;3(7):45-50] (ISSN 1553-992X). http://www.sciencepub.net.

Key words: Maxent; *Nepeta septemcrenata*; Saint Katherine Protectorate; prediction; biodiversity conservation; geographical distribution.

1. Introduction

Prediction and mapping of potential suitable habitat for threatened and endangered species is critical for monitoring and restoration of their declining native populations in their natural habitat, artificial introductions, or selecting conservation sites, and conservation and management of their native habitat (Gaston, 1996). But distribution data on threatened and endangered species are often sparse (Ferrier et al., 2002; Engler et al., 2004) and clustered making commonly used habitat modeling approaches difficult. Species distribution modeling tools are becoming increasingly popular in ecology and are being widely used in many ecological applications (Elith et al., 2006; Peterson et al., 2006). These models establish relationships between occurrences of species and biophysical and environmental conditions in the study area. Most species distribution modeling methods are sensitive to sample size (Wisz et al., 2008) and may not accurately predict habitat distribution patterns for threatened and endangered species.

The Saint Katherine region is situated in the southern part of Sinai and is a part of the upper Sinai massif. It is located between 33˚ 55' to 34˚ 30' East and 28° 30' to 28° 35' North. The Saint Katherine Protectorate (SKP) is one of Egypt’s largest protected areas and includes the country’s highest mountains. This arid, mountainous ecosystem supports a surprising biodiversity and a high proportion of plant endemics and rare plants. The flora of the mountains differs from the other areas, due to its unique geology, morphology and climatic aspects. The soil is formed mainly from mountains weathering, thus it is mainly granitic in origin. The soil layer is generally shallow were the bed rock is close to the surface. Annual rainfall is less than 50 mm. However, rainfall is not of annual character, rather 2 to 3 consecutive years without rainfall is common. Rain takes the form of sporadic flash floods or limited local showers, thus highly spatial heterogeneity in received moisture is also common (Hatab, 2009).

Our objectives were to: (1) predict suitable habitat distribution for threatened herb *Nepeta septemcrenata* using a small number of occurrence records to inform conservation planning in Saint Katherine Protectorate; and (2) identify the environmental factors associated with *N. septemcrenata* habitat distribution. We used species occurrence records, GIS (geographical information system) environmental layers (bioclimatic and topographic), and the maximum entropy distribution modeling approach (Phillips et al., 2006) to predict potential suitable habitat for *N. septemcrenata* .

2. Material and Methods

2.1. Target species and occurrence data

We recorded ninety one occurrence of *N. septemcrenata* (Lamiaceae) species in Saint Katherine Protectorate during the period between March to August 2009; these records represent the total known distribution of the species. *N. septemcrenata* is a threatened and endangered species, near endemic to Sinai and northwest Saudi Arabia (Boulos, 2002). Perennial herbs, appressed-tomentose 30-60 cm, woody at the base: stems many, erect, branched; leaves 1-2.5 x 1- 1.8 cm. ovate-deltoid, obtuse, crenate, the base cordate; petiole 2-8 mm: verticillasters remote, 3-8-flowered on a peduncle 3-6 mm (Boulos, 2002). Anti-viral and bactericidal activity from extract of aerial parts of *N. septemcrenata* was discovered (Soltan et al., 2008).

No specific habitat preference for *N. septemcrenata*, this species located into most of the micro-habitats, included Slope, Terraces, Gorge and Farsh, but showed much better growth in gorges habitats (Omar, 2010). Observation also found that there is no grazing on *N.septemcrenata*. Most of the *N.septemcrenata* populations are small and the plants occurred sporadically in space, as little groups or as individuals. In order to develop an efficient and effective conservation strategy using complementary in situ and ex situ techniques, we must have a clear understanding of *N. septemcrenata* geographical distribution.

2.2. Environmental variables

We considered twenty three environmental variables as potential predictors of the *N. septemcrenata* habitat distribution (Table 1). These variables were chosen based on their biological relevance to plant species distributions and other habitat modeling studies (For example, Kumar et al., 2006; Guisan et al., 2007a, b; Pearson et al., 2007; Murienne et al., 2009). Nineteen bioclimatic variables (Nix, 1986), biologically more meaningful to define eco-physiological tolerances of a species (Graham and Hijmans 2006; Murienne et al., 2009), were obtained from WorldClim dataset (Hijmans et al., 2005; http://www.worldclim.org/bioclim.htm). Altitude (Digital Elevation Model; DEM) data were also obtained from the WorldClim website; 1 km spatial data for model testing (Fielding and Bell, 1997).

However, this approach may not work with a small number of samples because the 'training' and 'test' datasets will be very small (Pearson et al., 2007). Therefore, we explicitly followed Pearson et al. (2007) and used a jackknife procedure, in which model performance is assessed based on its ability to predict the single locality that is excluded from the 'training' dataset (Pearson et al., 2007). Ninety one different predictions were thus made with one of the occurrence records excluded in each prediction and the final resolution. The DEM data were used to generate slope and aspect (both in degrees) using (ESRI) Environmental Systems Research Institute's ARC GIS version 9.2 and 'Suface Analysis' function. All environmental variables were resampled to 1 km spatial resolution. Maxent's predictions are 'cumulative values', representing, as a percentage, the probability value for the current analysis pixel and all other pixels with equal or lower probability values. The algorithm is implemented in a stand-alone, freely available application. In this study we considered each environmental variable (linear features) and its square (quadratic features). Because Maxent utilize pseudo-absence.

2.3. Modeling procedure

We used a novel modeling method called maximum entropy distribution or Maxent which has been found to perform best among many different modeling methods (Elith et al., 2006; Ortega-Huerta and Peterson, 2008), and may remain effective despite small sample sizes (Hernandez et al., 2006; Pearson et al., 2007; Papes and Gaubert, 2007; Wisz et al., 2008; Benito et al., 2009). Maxent is a maximum entropy based machine learning program that estimates the probability distribution for a species' occurrence based on environmental constraints (Phillips et al., 2006).

It requires only species presence data (not absence) and environmental variable (continuous or categorical) layers for the study area. We used the freely available Maxent software, version 3.1 (http://www.cs.princeton.edu/~schapire/maxent/), which generates an estimate of probability of presence of the species that varies from 0 to 1, where 0 being the lowest and 1 the highest probability. The 91 occurrence records and 10 environmental predictors were used in Maxent to model potential habitat distribution for *N.septemcrenata*. Testing or validation is required to assess the predictive performance of the model. Ideally an independent data set should be used for testing the model performance, however, in many cases this will not be available, a situation particular prevalent for threatened and endangered species. Therefore, the most commonly used approach is to partition the data randomly into 'training' and 'test' sets, thus creating quasi-independent potential habitat map was generated using all records (Figure 1). We used the *P* value program provided by Pearson et al. (2007) to test the significance of the model. The jackknife validation test required the use of a threshold to define 'suitable' and 'unsuitable' areas. We used two different thresholds, the 'lowest presence threshold' (LPT, equal to the lowest probability at the species presence locations), and a fixed threshold of 0.10; for more details see Pearson et al. (2007).

3. Results and Discussion

The Maxent model predicted potential suitable habitat for *N.septemcrenata* with high success rates (that is, low omission rates), 98% at LPT. Most suitable habitat for *N.septemcrenata* was predicted in the northern parts of the SKP in South Sinai (Figure 1), and its distribution is quite fragmented. The Maxent model's internal jackknife test of variable importance showed that 'Precipitation of Coldest Quarter (degree C)', and 'Precipitation of Wettest Quarter (degree C)' were the two most important predictors of *N.septemcrenata*'s habitat distribution (Figure 2; Table 1). These variables presented the higher gain (that is, contained most information) compared to other variables (Figure 2; Table 1). Using four arbitrarily defined probability classes, the high suitability class had an area of 49 km^2; medium-64.6 km^2; low- 150.4 km^2; and very low-4086 km^2 (Figure 1).

The distribution of highly and moderately suitable areas appears to follow the distribution of highly elevated areas in SKP (Map7 in Omar, 2010). The parts of the study area predicted in the 'very low' suitability class (probability < 0.10) can be interpreted as unsuitable for *N.septemcrenata* (Figure 1). We also calculated total extent of occurrence (EOO, as defined by IUCN, 2001) of *N.septemcrenata* based on the commonly used threshold of 0.4 (That is, the threshold above which the species is more likely to be present; Jimenez-Valverde and Lobo, 2007); it was estimated to be 926 km^2.

In this study we showed that the habitat distribution patterns for threatened and endangered plant species such as *N.septemcrenata* can be modeled using a small number of occurrence records and environmental variables using Maxent. This study provides the first predicted potential habitat distribution map for a plant species (*N.septemcrenata*) in SKP. Since Maxent is mapping the fundamental niche (different from occupied niche) of the species using bioclimatic variables the suitable habitat for *N.septemcrenata* may be over predicted in some areas (Pearson 2007; Murienne et al., 2009). The potential habitat distribution map for *N.septemcrenata* can help in planning land use management around its existing populations, discover new populations, identify top-priority survey sites, or set priorities to restore its natural habitat for more effective conservation. More research is needed to determine whether the existing protected areas adequately cover suitable habitat for *N.septemcrenata*. The methodology presented here could be used for quantifying habitat distribution patterns for other threatened and endangered plant and animal species in other areas and may aid field surveys and allocation of conservation and restoration efforts.

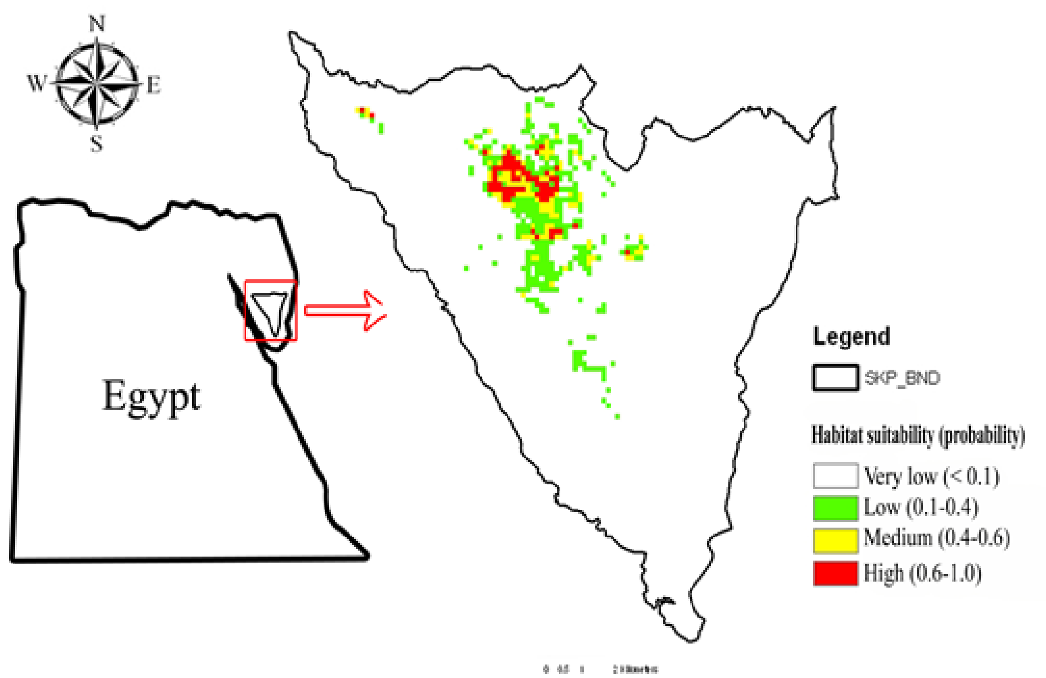

Figure 1. Predicted potential suitable habitat for *N.septemcrenata* species on Saint Katherine Protectorate, South Sinai, Egypt. Note: SKP_BND is the Saint Katherine Protectorate boundary.

Table 1. Selected environmental variables and their percent contribution in Maxent model for *N. septemcrenata* species in Saint Katherine Protectorate.

Environmental variable	Percent contribution	Source/Reference
Precipitation of Driest Quarter (Bio17, degree C)	37.6	WorldClim; Hijmans et al. 2005
Precipitation of Wettest Period (Bio13, degree C)	30.1	WorldClim; Hijmans et al. 2005
Habitat (degree)	10.4	Generated in GIS
Aspect (degree)	7.2	Generated in GIS
Mean Temperature of Warmest Quarter (Bio10, degree C)	4.5	WorldClim; Hijmans et al. 2005
Precipitation of Coldest Quarter (Bio19, degree C)	3.1	WorldClim; Hijmans et al. 2005
Precipitation of Wettest Quarter (Bio16, degree C)	2.6	WorldClim; Hijmans et al. 2005
Slope (degree)	2.0	Generated in GIS
Mean Diurnal Range (Bio2, degree C)	0.9	WorldClim; Hijmans et al. 2005
Mean Temperature of Driest Quarter (Bio9, degree C)	0.5	WorldClim; Hijmans et al. 2005
Mean Temperature of Coldest Quarter (Bio11, degree C)	0.5	WorldClim; Hijmans et al. 2005
Precipitation of Driest Period (Bio14, degree C)	0.2	WorldClim; Hijmans et al. 2005
Isothermality (Bio3, degree C)	0.2	WorldClim; Hijmans et al. 2005
Temperature Annual Range (Bio7, degree C)	0.2	WorldClim; Hijmans et al. 2005
Precipitation Seasonality (Bio15, degree C)	0.0	WorldClim; Hijmans et al. 2005

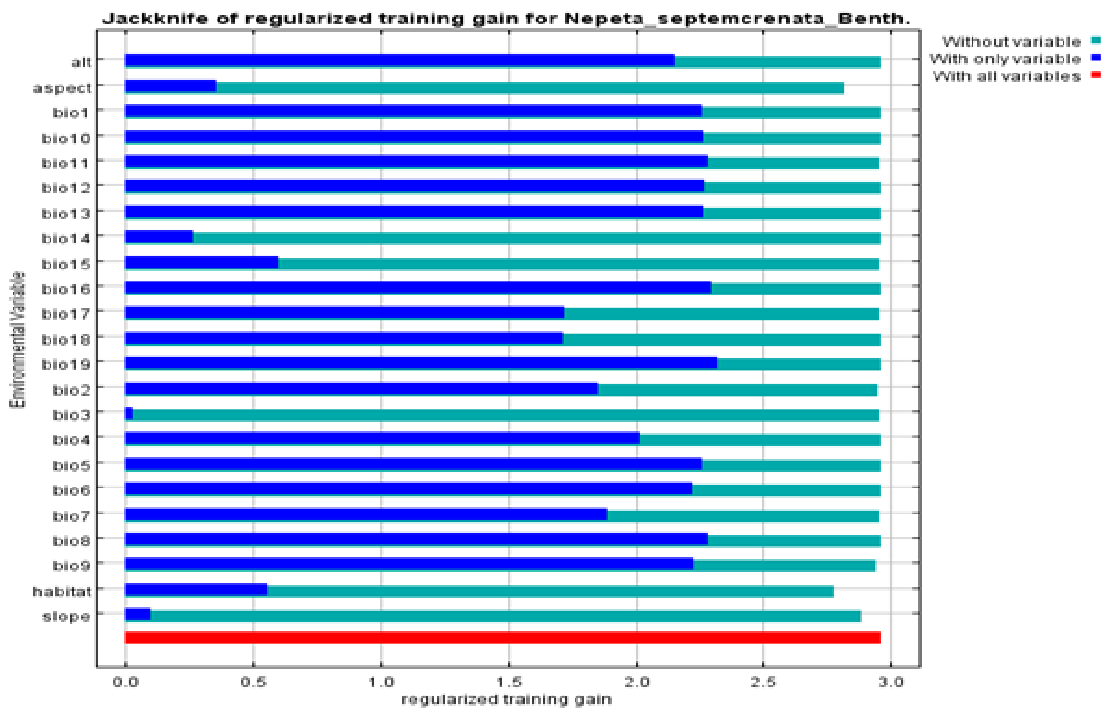

Figure 2. Results of jackknife evaluations of relative importance of predictor variables for *N.septemcrenata* Maxent model.

Note: ‘alt is elevation; Bio 1- Annual Mean Temperature; Bio 2-Mean Monthly Temperature Range; Bio 3 -Isothermality (2/7) (* 100); Bio 4 -Temperature Seasonality (STD * 100); Bio 5 -Max Temperature of Warmest Month; Bio 6-Min Temperature of Coldest Month; Bio7 -Temperature Annual Range; Bio 8 -Mean Temperature of Wettest Quarter; Bio 9 -Mean Temperature of Driest Quarter; Bio 10 - Mean Temperature of Warmest Quarter; Bio 11 -Mean Temperature of Coldest Quarter; Bio 12 -Annual Precipitation; Bio 13 -Precipitation of Wettest Month; Bio 14 -Precipitation of Driest Month; Bio 15 -Precipitation Seasonality (CV); Bio 16 -Precipitation of Wettest Quarter; Bio 17 -Precipitation of Driest Quarter Bio 18 -Precipitation of Warmest Quarter; Bio 19 -Precipitation of Coldest Quarter.

Acknowledgement:

I would like to express deepest grateful to **Mr. Mohammed Kotb,** General Manger of Saint Katherine protectorate for his support during research steps.

Corresponding Author:
Mr. Kariem Abd Elhay Omar
Environmental researcher
Saint Katherine Protectorate
The Nature Conservation Sector (NCS)
Egyptian Environmental Affairs Agency (EEAA) Egypt.
Tel: +002 019 6277308
+002 011 4903644
+002 069 347 00 32
E-mail: kariem_npe@yahoo.com

References

1. Benito, B.M., Martınez-Ortega, M.M., Munoz, L.M., Lorite, J., Penas, J., 2009. Assessing extinction-risk of endangered plants using species distribution models: a case study of habitat depletion caused by the spread of greenhouses. Biodiv. Conserv. doi: 10.1007/s10531-009-9604-8.
2. Boulos, L., 2002. Flora of Egypt, Vol. 3. Al hadara publishing, Cairo, Egypt, 373pp.
3. Elith, J., Graham, C.H., Anderson, R.P., Dudik, M., Ferrier, S., Guisan, A., Hijmans, R.J., Huettmann, F., Leathwick, J.R., Lehmann, A., Li, J., Lohmann, L.G., Loiselle, B.A., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., Overton, J.M., Peterson, A.T., Phillips, S.J., Richardson, K., Scachetti- Pereira, R., Schapire, R.E., Soberon, J., Williams, S., Wisz, M.S., Zimmermann, N.E. 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography 29: 129-151.
4. Engler, R., Guisan, A., Rechsteiner, L., 2004. An improved approach for predicting the distribution of rare and endangered species from occurrence and pseudo-absence data. J. Appl. Ecol. 41: 263-274.
5. Ferrier, S., Watson, G., Pearce, J., Drielsma, M., 2002 Extended statistical approaches to modeling spatial pattern in biodiversity: the north-east New South Wales experience. I. Species-level modeling. Biodiv. Conserv. 11: 2275–2307.
6. Fielding, A.H., Bell, J.F., 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environ. Conserv. 24: 38-49.
7. Gaston, K.J., 1996. Species richness: measure and measurement. Biodiversity: a biology of numbers and difference ed. K.J. Gaston, Blackwell Science, Oxford pp. 77–113.
8. Graham, C.H., Hijmans, R.J., 2006. A comparison of methods for mapping species ranges and species richness. Glob. Ecol. Biogeogr. 15: 578– 587.
9. Guisan, A., Graham, C.H., Elith, J., Huettmann, F., the NCEAS Species Distribution Modelling Group,. 2007a. Sensitivity of predictive species distribution models to change in grain size. Divers. Distrib. 13: 332- 340.
10. Guisan, A., Zimmermann, N.E., Elith, J., Graham, C.H., Phillips, S., Peterson, A.T., 2007b. What matters for predicting the occurrences of trees: techniques, data or species' characteristics? Ecol. Monogr. 77: 615- 630.
11. 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 227pp.
12. Hernandez, P.A., Graham, C.H., Master, L.L., Albert, D.L., 2006. The effect of sample size and species characteristics on performance of different species distribution modeling methods. Ecography 29: 773-785.
13. Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., Jarvis, A., 2005. Very high resolution interpolated climate surfaces for global land areas. Int. J. Climatol. 25: 1965-1978.
14. IUCN., 2001. IUCN Red List Categories and Criteria: Version 3.1. IUCN Species Survival Commission, IUCN, Gland and Cambridge.
15. Jimenez-Valverde, A., Lobo, J.M., 2007. Threshold criteria for conversion of probability of species presence to either-or presence-absence. Acta Oecologica-Int. J. Ecol. 31: 361-369.
16. Kumar, S., Stohlgren, T.J., Chong, G.W., 2006. Spatial heterogeneity influences native and nonnative plant species richness. Ecol. 87: 3186-3199.
17. Murienne, J., Guilbert, E., Grandcolas, P., 2009. Species' diversity in the New Caledonian endemic genera *Cephalidiosus* and *Nobarnus* Insecta: Heteroptera: Tingidae, an approach using phylogeny and species' distribution modelling. Bot. J. Linn. Soc. 97:177-184.
18. Nix, H.A., 1986. A biogeographic analysis of Australian Elapid snakes. In: Longmore R Editor, Australian Flora and Fauna Series 8: 4-15.
19. Omar, K., 2010: Eco-geographical study on *Nepeta septemcrenata* in Saint Katherine protectorate, South Sinai, Egypt. *M.Sc. Thesis*, Botany Dep., Facu. Of Sci. Al-Azhar Univ., Egypt. 200-390.
20. Ortega-Huerta, M.A., Peterson, A.T., 2008. Modeling ecological niches and predicting geographic distributions: a test of six presence-only methods. Revista Mexicana De Biodiversidad 79: 205-216.
21. Papes, M., Gaubert, P., 2007. Modelling ecological niches from low numbers of occurrences:

assessment of the conservation status of poorly known viverrids Mammalia, Carnivora across two continents. Divers. Distrib. 13: 890-902.
22. Pearson, R.G., 2007. Species' distribution modeling for conservation educators and practitioners. Synthesis. American Museum of Natural History. Available at http://ncep.amnh.org.
23. Pearson, R.G., Raxworthy C.J., Nakamura, M., Peterson, A.T., 2007. Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. J. Biogeo. 34: 102- 117.
24. Peterson, A.T., 2006. Uses and requirements of ecological niche models and related distributional models. Biodiv. Inform. 3: 59-72.
25. Phillips, S.J., Anderson, R.P., Schapire, R.E., 2006. Maximum entropy modeling of species geographic distributions. Ecol. Modell. 190: 231- 259.
26. Soltan, M.M., Zaki, A.K., 2008: Assessment of the anti-microbial and anti-viral properties of extracts from *Nepeta septemcrenata*. Planta Med 2008; 74: 1–338 Georg Thieme Verlag KG Stuttgart · New York. ISSN 0032-0943.
27. Wisz, M.S., Hijmans, R.J., Li, J., Peterson, A.T., Graham, C.H., Guisan, A., NCEAS Predicting Species Distributions Working Group., 2008. Effects of sample size on the performance of species distribution models. Divers. Distrib. 14: 763-773.

6/22/2011