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Original article

Predicting impacts of climate change on medicinal asclepiads of Pakistan using Maxent modeling

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ABSTRACT

Maximum entropy (Maxent) modeling was used to predict the potential climatic niches of three medicinally important Asclepiad species: *Pentatropis spiralis*, *Tylophora hirsuta*, and *Vincetoxicum arnottianum*. All three species are members of the Asclepiad plant family, yet they differ in ecological requirements, biogeographic importance, and conservation value. Occurrence data were collected from herbarium specimens held in major herbaria of Pakistan and two years (2010 and 2011) of field surveys. The Maxent model performed better than random for the three species with an average test AUC value of 0.74 for *P. spiralis*, 0.84 for *V. arnottianum*, and 0.59 for *T. hirsuta*. Under the future climate change scenario, the Maxent model predicted habitat gains for *P. spiralis* in southern Punjab and Balochistan, and loss of habitat in south-eastern Sindh. *Vincetoxicum arnottianum* as well as *T. hirsuta* would gain habitat in upper Peaks of northern parts of Pakistan. *T. hirsuta* is predicted to lose most of the habitats in northern Punjab and in parches from lower peaks of Galliat, Zhob, Qalat etc. The predictive modeling approach presented here may be applied to other rare Asclepiad species, especially those under constant extinction threat.

1. Introduction

It is widely accepted that biodiversity is being lost at an unprecedented rate (Pimm et al., 1995). Climate change is a significant driver for biodiversity loss as it may affect species' natural distribution, cause temporal reproductive isolation, and increase pest and disease outbreak frequencies (Millennium Ecosystem Assessment, 2005). The Intergovernmental Panel on Climate Change (IPCC) estimates a 0.2 °C increase in temperature for each future decade (IPCC, 2007). This increase in temperature would have harmful consequences for ecosystems (Millennium Ecosystem Assessment, 2005). To mitigate the impacts of climate change on ecosystems, biodiversity conservation is a key objective that will require both quantifying biodiversity and monitoring its losses (Balmford and Bond, 2005). Modeling species distribution can provide a useful means of commissioning future surveys in predicted species distribution area, consequently prioritizing conservation needs (Guisan and Thuiller, 2005).

Subcontinents, especially India and Pakistan, are a secondary center of diversity for Asclepiads. Briefly stating, asclepiads form a group of perennial herbs, twining shrubs, lianas, stem succulents or rarely trees of dicotyledonous plants that contains over 3000 known species (Meve, 2002). The name originated from type genus Asclepias (milkweeds). Previously they belonged to the family Asclepiadaceae, but now classified as the subfamily Asclepiadoideae of the dogbane family Apocynaceae (Endress and Bruyns, 2000). Asclepiads are named for their milky juice. Pollination in this genus is accomplished in an unusual manner. Pollen is grouped into complex structures called pollinia. These species produce their seeds in follicles ((Nasir and Ali, 1982).

Pakistan has a unique assemblage of species that are under serious threat of extinction from habitat loss and rapidly developing climatic changes. Surprisingly, there have been no studies investigating the impact of climatic change on the distribution of Asclepiads. Preliminary studies report explorations in the Lal Suhanra Park in southern Punjab (Hameed et al., 2002), Harboi rangeland near Quetta, and Baluchistan (Durrani and Hussain, 2005). These include studies on phytosociology of grass-dominated communities of Karachi (Khan and Shaukat, 2005), and phytosociology and structure of Himalayan forests (Ahmed et al., 2006). Based on Asclepiads collected from the study areas and herbaria, the three most medicinally important species are *Pentatropis spiralis*, *Tylophora hirsuta*, and *Vincetoxicum arnottianum*.

Among these species, *P. spiralis* has antimicrobial and antifungal properties, and its tubers are edible. *T. hirsuta* has laxative, expectorant, diaphoretic and purgative properties. This plant is used for

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Abbreviations: P. spiralis, *Pentatropis spiralis*; T. hirsuta, *Tylophora hirsuta*; V. arnottianum, *Vincetoxicum arnottianum*; GB, Gilgit Baltistan; PMNH, Pakistan Museum of Natural History.

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the treatment of various disorders such as asthma and retention of urine (Srivpuri et al., 1972; Thiruvengadam et al., 1978; Udupa et al., 1991; Reddy et al., 2009, 2010). Other species of *Tylophora*, including *Tylophora indica* also known as *Tylophora asthmatica*, and *Tylophora vomitoria*, are used for traditional medicines and are mentioned in pharmacopoeia texts such as Bengal Pharmacopoeia and Chinese Materia Medica (Shiu-Ying, 1980). Similarly, *V. arnottianum* along with other species of this genus, are used for ailments like gastritis, malaria, cholera, asthma, skin diseases, ulcer and constipation (Jan et al., 2008). *Vincetoxicum arnottianum* is also used to treat external wounds and injuries in humans and animals (Zaidi and Crow, 2005). Phytochemically it contains floral volatile (Jurgens et al., 2009), alkaloids (Stockel et al., 1969) and other medicinal properties (Ertuğ, 2000).

This study used ecological niche modeling (ENM) to predict the distribution of the three medicinally important Asclepiads (*P. spiralis*, *T. hirsuta* and *V. arnottianum*) in Pakistan using combined occurrence data from field and historical (herbaria) specimens. Ecological niche modeling provides a strong predictive framework for locating additional field populations of a species (Menon et al., 2010), and for relocating threatened populations to suitable habitats. ENM merges known occurrence records for a species with environmental data to estimate species ecological requirements and potential geographic distribution patterns. This estimation helps to narrow down sets of possible occurrence sites for more targeted field surveys (Menon et al., 2010). Several authors have described using ENM to locate poorly known species (e.g., de-Siqueira et al., 2009; Buchmann et al., 2010; Sanchez et al., 2011). These species were chosen as a case study to represent taxa with contrasting ecological requirements, biogeographic importance and conservation value. This approach may also be applied to other taxa in the geographic region to assess and manage their respective conservation needs. We believe that ENM modeling is an important conservational tool for present and future distribution of species.

2. Materials and methods

2.1. Occurrence data collection

A total of 553 records for all three Asclepiad species were collected from major herbaria [Karachi University Herbarium (KAR), National Herbarium Program, National Agricultural Research Council (NARC), the Quaid-i-Azam University Herbarium (IBD) and Pakistan Museum of Natural History (PMNH)] in Pakistan. Encarta Atlas (2011) and Google Earth (2011) were used to geo-reference herbarium records. The locality of each specimen was transformed into geographic coordinates (WGS84 datum) using National Geographic Tylor software (2003). Based on herbarium records, fresh specimens were collected during field surveys in 2010 and 2011, from March to September, in the Potohar plateau that lies between 33°28′ and 33°48′N latitude, and 72°48′ and 73°22′E longitude.

The Potohar plateau covers Rawalpindi and its adjoining areas: Attock, Jhelum, Salt range, Murree, and Dungagali. The climate in this area varies from sub-temperate to temperate with arid conditions, and allows for a wide variety of trees and plants to flourish (Blood, 1996). Walking transects were used in field surveys in the mountainous terrain of the Margalla Hills, regions of the lower and outer Himalayas, and the Hazara and Kala Chitta Ranges. A Global Positioning System (GPS, Garmin 12) was used to determine the coordinates for all collections in the field. Appendix A shows number of occurrence records collected for three plant species from different regions of Pakistan. After maintaining one record per 1-km^2 cell; as Maxent automatically removed duplicates, we had 99 unique records for *P. spiralis*, 26 for *T. hirsuta*, and 36 for *V. arnottianum* (Detail of data are available from the first author on request).

2.2. Climatic data

Climatic data were downloaded from the WorldClim database, available at approximately 1 km^2 spatial resolution (Hijmans et al., 2005; http://www.worldclim.org/). The WorldClim data are derived from measurements of altitude, temperature and rainfall from weather stations across the globe (Period 1950–2000). We used 19 bioclimatic variables (Table 1) from the WorldClim dataset to assess current climatic conditions. These variables are frequently used in modeling species distributions (e.g., Kumar et al., 2009; Evangelista et al., 2011; Sanchez et al., 2011), and capture annual ranges, seasonality, and limiting factors such as monthly and quarterly temperature and precipitation extremes (Hijmans et al., 2005). Future climate scenario data for 2050 (A2a emission scenario) were obtained from Consultative Group on International Agricultural Research (CGIAR)'s Research Program on Climate Change, Agriculture and Food Security (CCAFS) climate data archive (http://ccafs-climate.org). These future climate projections are based on IPCC 4th assessment data and were calibrated and statistically downscaled using the data for 'current' conditions. To reduce the uncertainty in single global circulation model (GCM) predictions, we used data from three different global climate models. These models were: Canadian Center for Climate Modeling and Analysis (CCCMA), Hadley Coupled Model V3 (HadCM3), and Commonwealth Scientific and Industrial Research Organization (CSIRO). We ran separate models for each species using future climate data from these three GCMs. Future potential habitat predictions for each species were obtained by averaging results (ensemble approach; Araujo and New, 2007) from the CCCMA, HadCM3 and CSIRO future climate models.

2.3. Predictive modeling

We used the maximum entropy model (Maxent version 3.3.3; Phillips et al., 2006; http://www.cs.princeton.edu/~schapire/maxent/) because it performs better with small sample sizes

Table 1

Percent contributions of the bioclimatic variables in the Maxent models for the three target species; values shown are averages over 10 replicate runs. Variables without any values (indicated by -) were removed because of high cross-correlations.

	P. spiralis	*T. hirsuta*	*V. arnottianum*
Precipitation seasonality (CV) (Bio15)	27.2	–	–
Precipitation of driest quarter (Bio17)	21.6	–	–
Temperature seasonality (SD × 100) (Bio4)	21.2	18.8	5.3
Precipitation of wettest month (Bio13)	13.3	–	–
Mean temperature of wettest quarter (Bio8)	12.7	–	–
Mean diurnal range in temperature (Bio2)	4.0	–	–
Annual mean temperature (Bio1)	–	70.0	–
Precipitation of warmest quarter (Bio18)	–	9.0	–
Precipitation of driest month (Bio14)	–	2.2	–
Mean annual precipitation (Bio12)	–	–	72.3
Temperature annual range (Bio7)	–	–	13.9
Mean temperature of warmest quarter (Bio10)	–	–	8.5
Isothermality (Bio3)	–	–	–
Maximum temperature of warmest month (Bio5)	–	–	–
Minimum temperature of coldest month (Bio6)	–	–	–
Mean temperature of driest quarter (Bio9)	–	–	–
Mean temperature of coldest quarter (Bio11)	–	–	–
Precipitation of wettest quarter (Bio16)	–	–	–
Precipitation of coldest quarter (Bio19)	–	–	–