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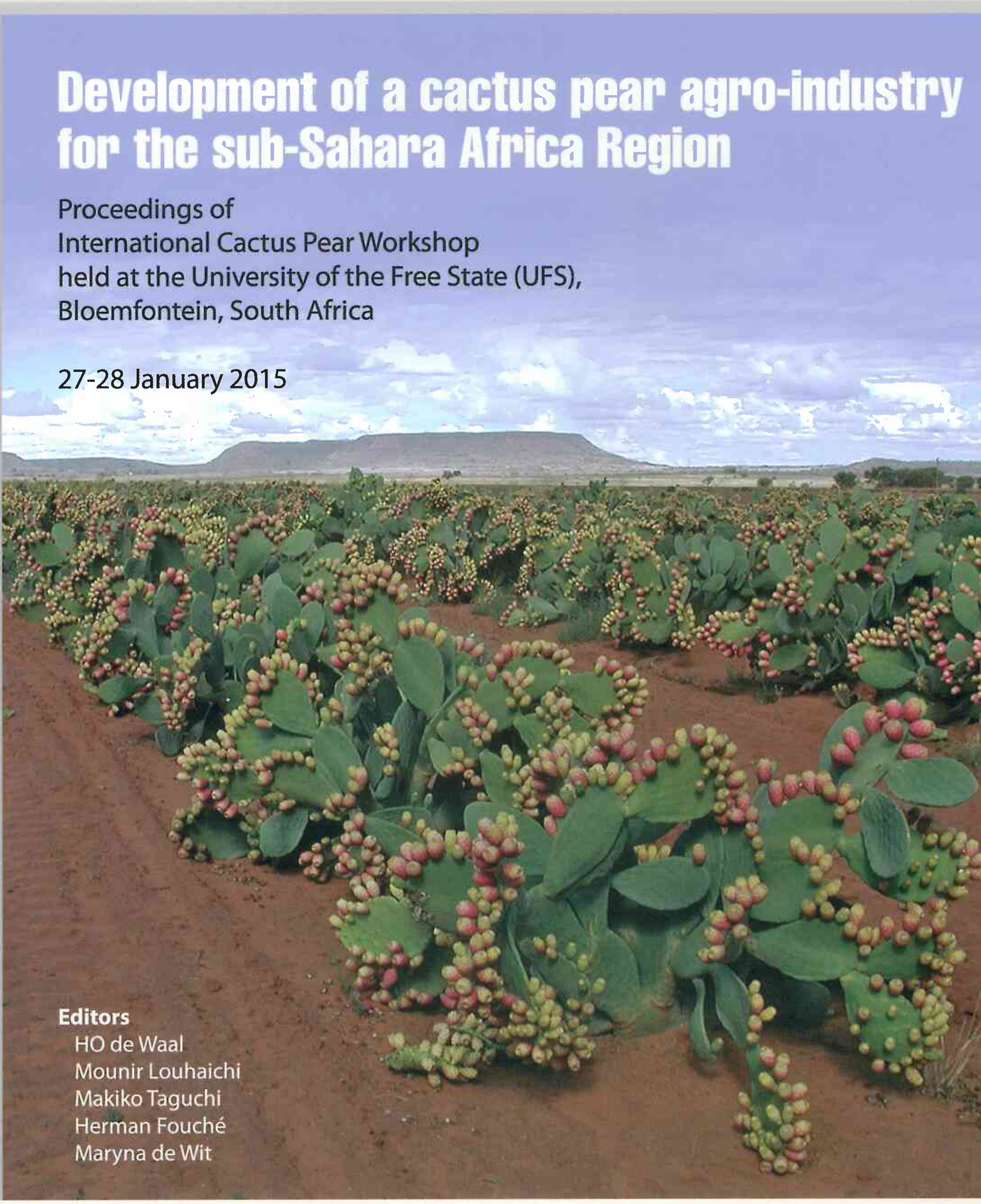

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Applications of geo-informatics in cactus pear R&D: Case study of habitat suitability mapping of *Opuntia ficus-indica* (L.) Mill.

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Abstract

Cactus pear (*Opuntia ficus-indica* (L.) Mill.) has been suggested as a sustainable crop for the dry regions of the world because it is used for a variety of products including: green fodder and fodder reserves for livestock, fruit and pads for direct human consumption, and high value organic oils in marginal agricultural regions. Cactus is being considered for introduction into new regions for these qualities. Because importation, site testing, and evaluation can take years, it is important to predict which locations are most suitable for the cultivation this species. We developed a niche habitat model that employs a weighted sums multi-criteria decision analysis approach to predict areas most likely for suitability. The model utilizes climatic, elevation, and other variables in a raster format along with the positions of known plantations of cactus to define the environmental or niche tolerance of the plant. The niche tolerance is then applied to environmental variables for the area of interest to determine which sites most closely resemble the conditions under which cactus thrives. The result is a theoretical habitat suitability index for the new area or region. For our model, we chose a scale of 30 arc seconds or approximately 1 square km and our area of interest was the eastern Mediterranean region. Suitability maps were produced using data from WorldClim climate layers and the GTOPO30 elevation models.

INTRODUCTION

Cactus pear (*Opuntia ficus-indica* (L.) Mill.) has been planted for forage reserves and human consumption in arid and semi-arid regions for centuries for its ability to grow in harsh conditions characterized with high temperature, lack of water and poor soil. Cactus pear has a high water use efficiency because it has a waxy cuticle that reduces evaporation from photosynthetic surfaces, lacks true leaves, and succulent stems (pads) that can store water. It also employs Crassulacean Acid Metabolism (CAM) to reduce water loss. Estimates of water use efficiency vary from 1 kg dry matter (DM) produced per 250 kg of water (De Kock, 1980) to 1 kg DM per 300 kg of water (Le Houérou and El Barghati, 1982). Cactus has been used extensively as a fodder crop for livestock because of its capacity to produce biomass, (Nefzaoui *et al.*, 2013). Cactus is limited in its distribution by freezing temperatures but tolerates high temperatures well. Areas in the semi-arid climatic zone with a mean annual rainfall between 400–600 mm are optimal for cactus, although it may grow in areas with as little as 200 mm year^{-1}, if soils are deep and permeable (Nobel, 2009). Our objective was to design a computer program in the R language that would use existing climatic and topographic databases to predict and map cactus suitability for the eastern Mediterranean region. We chose a weighted sum model (WSM) in a multi-criteria decision analysis (MCDA) approach to predict areas most likely for successful cactus plantations.

MATERIALS AND METHODS

Multi-criteria decision analysis allows managers to formalize a decision-making process so that the key factors upon which decisions are made are explicitly stated and applied (Greene *et al.*, 2011).

We constructed an application within a Geographic Information System (GIS) context that used existing locations of successful cactus *(O. ficus-indica)* plantations, coupled with climatic and topographic databases to define ecological niches of this species (Louhaichi *et al.*, 2015). The computer program was constructed in R (R Core Team 2014) in the Kinetic Resource Environmental Spatial Systems (KRESS) Habitat Suitability Analysis Module (HSAM) that allows the user to import locations where cactus plantations have been deemed successful. The program extracts climatic and topographic parameters for known cactus sites and constructs frequency histograms that display the frequency of occurrence versus the value range of the data set. This data is standardized so that each parameter extracted occupies a range from 0 to 255 (1 bit). This allows for meaningful inferences between parameters with different native ranges, for example temperature and precipitation. Locations were coded in simple comma separated values (CSV) in a text file with the longitude, latitude, elevation, plant genus, species, variety/accession, year the plantation was established (if known), estimated annual yield of pads, fruits, oil, soil classification, soil depth, plant vigour, observer, organization, email, and phone number. The latitude and longitude was then used to extract information by location from other world-wide databases that contain climatic and topographic information. Climate data was from the WorldClim Database (Hijmans *et al.*, 2005) and the topographic database used was the GTOPO30 elevation dataset (USGS 2015). Both these databases are at approximately the same scale (30 arc seconds or 1 km^2). Other variables could be added if they are in either ASCII Raster or Band Interleaved by Line (BIL) format.

We constructed a computer program in R (R Core Team 2014) the Kinetic Resource Environmental Spatial Systems (KRESS) Habitat Suitability Analysis Module (HSAM) that allows the user to import locations where cactus plantations have been deemed successful. The program extracts climatic and topographic parameters for known cactus sites and constructs frequency histograms that display the frequency of occurrence versus the value range of the data set. This data is standardized so that each parameter extracted occupies a range from 0 to 255 (1 bit). This allows for meaningful inferences between parameters with different native ranges, for example temperature and precipitation.

Cactus pear *(O. ficus-indica)* is more frequently limited by cold than by high temperatures; the maximal thermal of *O. ficus-indica* is near or exceeds 50°C (Le Houérou, 2002). The absolute minimum temperature cacti can tolerate depends on the difference between absolute and relative maximum daytime and minimum night time temperatures (Nobel *et al.*, 2002). In arid and semi-arid zones, the minimum mean annual rainfall of *O. ficus-indica* is 250 mm (Inglese and Scalenghe, 2009). Elevations above 800 m are one of the main limiting factors of cactus pear (Erre *et al.*, 2009).

In the program the user selects which parameters are important for the model based upon professional experience or literature review. The next step is to assign weights to each parameter. Important lifecycle parameters to the specific species such as minimum temperatures below freezing are weighted heavily (4.00) as contrasted with maximum temperatures which are weighted lightly (0.50). Less important, but still relevant, parameters such as mean temperatures are rated neutrally (1.00). This is used to generate tolerances for the plant in question. For this cactus example, we are using: minimum temperature, maximum temperature, mean temperature, precipitation, and elevation (Nobel, 2002).

An area of interest (AOI) is designated for analysis, and then imported into the R program KRESS HSAM. If a portion of the area of interest includes bodies of water, a true/false mask coded as 0s and 1s (0s being cells to exclude) can be applied to exclude those areas from consideration. The program then uses the tolerances and the weighted model built in the previous steps to generate a suitability value for each cell (30 arc second) in the area of interest (target area). The output from this process is a colour coded suitability map that predicts the sites that are most suitable for cactus to thrive in green, the least suitable sites in red and masked areas in black.

RESULTS AND DISCUSSION

Information from ground surveys in Tunisia and a database from the Polistes Foundation (Pickering, 2014) were used to identify locations where cactus plantations exist. In addition, a ground survey for cactus was conducted in Jordan. In the Jordan survey, roadways were driven and areas on both sides were visually searched for cactus. Local residents in villages were also interviewed in an attempt to locate plantations off roadways. Sites with cactus pear plantations were positioned with Global Position System (GPS) (Table 1). GPS locations were recorded along with the characteristics of the sites. Information from the three data sets was incorporated into an inclusive database. We then used the KRESS HSAM program to extract climatic and topographic parameters from those sites with cactus pear. The location of cactus plantations was entered into the program as a simple text (CSV) file where the position of each known stand of cactus was identified in the first two columns; longitude and latitude).

Table 1. A portion of the cactus pear database from Jordan.

Longitude	Latitude	Elevation (m)	Name	Observer	Institution
35.73029445° E	32.31199387° N	634	Ajloun 2	M. Louhaichi	ICARDA Jordan
35.76379720° E	32.73796881° N	233	Akraba	M. Louhaichi	ICARDA Jordan
35.79672792° E	32.47325498° N	783	Al Mazar	M. Louhaichi	ICARDA Jordan
35.74137225° E	32.32435486° N	732	Ajloun	M. Louhaichi	ICARDA Jordan
35.73029445° E	32.31199387° N	634	Ajloun 2	M. Louhaichi	ICARDA Jordan
35.76379720° E	32.73796881° N	233	Akraba	M. Louhaichi	ICARDA Jordan
35.79672792° E	32.47325498° N	783	Al Mazar	M. Louhaichi	ICARDA Jordan
35.74137225° E	32.32435486° N	732	Ajloun	M. Louhaichi	ICARDA Jordan
35.75749186° E	32.48097356° N	642	Inbah	M. Louhaichi	ICARDA Jordan
35.78267681° E	32.43290313° N	870	Erhaba	M. Louhaichi	ICARDA Jordan
35.87479017° E	32.21722786° N	228	Jarash Valley	M. Louhaichi	ICARDA Jordan
35.79401107° E	32.68635863° N	355	Kufer Soom	M. Louhaichi	ICARDA Jordan
35.77569089° E	31.63178790° N	711	Madaba	M. Louhaichi	ICARDA Jordan
36.35091148° E	32.29984434° N	651	Mafraq	M. Louhaichi	ICARDA Jordan
35.69093021° E	32.65395683° N	339	Malka	M. Louhaichi	ICARDA Jordan
35.77604414° E	31.84752106° N	726	Naour	M. Louhaichi	ICARDA Jordan

The KRESS HSAM program then was used to predict areas in the eastern Mediterranean region that are suitable for cactus plantations. Output from this analysis includes: number of rows and columns, x lower left, y lower left, cell size, minimum value, maximum value, mean value, standard deviation, cell count, and cell sum. Also produced are graphical representations of the parameters including a frequency histogram (Figure 1) and a choropleth map (Figure 2), where higher values are plotted as green, and lower values as red.

Larger datasets provide a larger measure of precision, and thus better approximate the suitability index generated by KRESS HSM. It is also important to include all controlling variables. For example, we know that cactus does not thrive in salty soils. Cactus pear is not tolerant of dissolved salts in its rooting zone. The growth, increase in dry weight, of cactus was 60% of the control when plants were grown in a salinity environment of 50 mol m^{-3} NaCl and about 20% at 150 mol m^{-3} NaCl (Nerd *et al.*, 1991).

The model can be made less robust with complete soil data. This model was based on a limited data set of known cactus plantations and did not include soils data. We are in the process of obtaining more locations of robust plantations and more complete soils information to create a more accurate model. As cactus is introduced into new areas, the model can

Fig. 1. Worldwide locations of cactus pear (*Opuntia ficus-indica* (L.) Mill.) used for determining climatic and topographic tolerances and the species environmental niche.

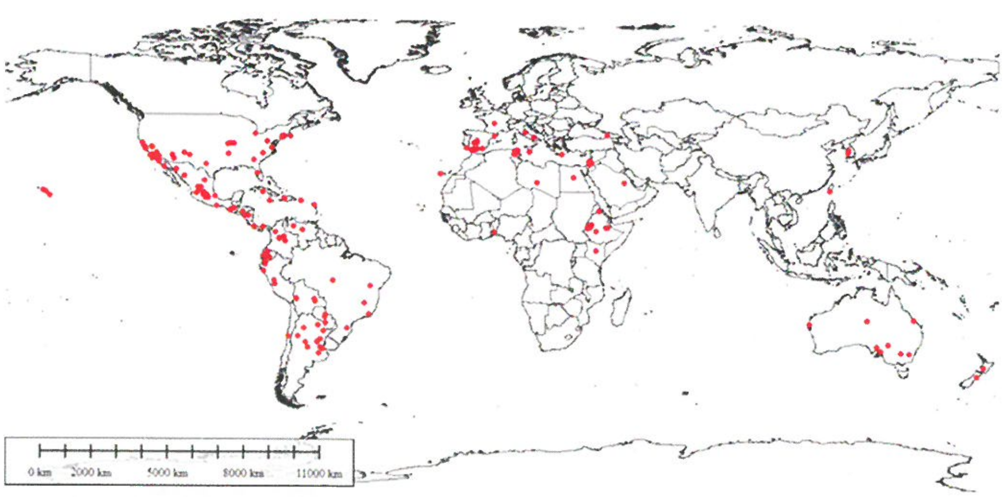
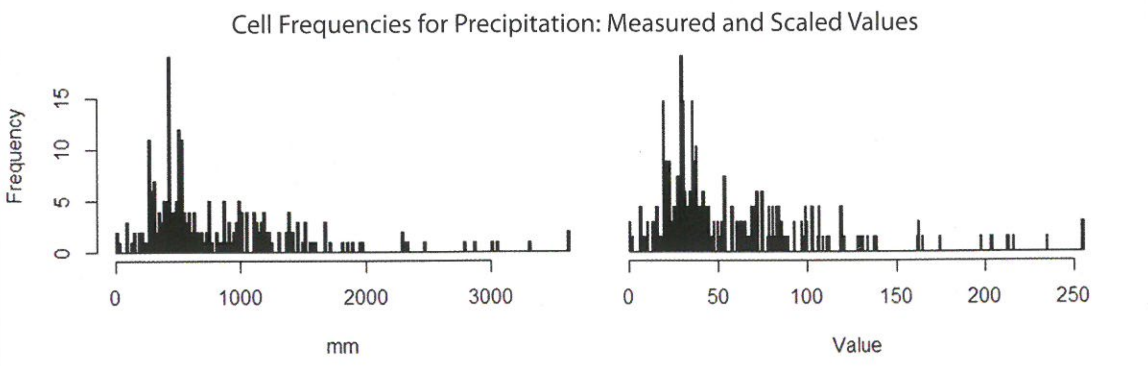


Fig. 2. Histogram of precipitation for cactus pear (*Opuntia ficus-indica* (L.) Mill.) extracted from the combined worldwide and regional database. Precipitation in mm is given on the left and scaled values (0 to 255) on the right.



be verified and modified to conform to results on the ground. We suggest that our approach can indicate sites with higher probabilities of success for cactus plantations and provide insight on the environmental tolerance of this species.

CONCLUSIONS

The niche models constructed and the land suitability maps generated identify locations where cactus pear should grow in the eastern Mediterranean region. Plantings in theoretically suitable areas will be prioritized based on the WSM score for locations with the highest values planted first. Planted sites will be evaluated for success or failure through time to determine if this simple and direct modelling approach has value in a broader context. Simultaneously, we will continue to log sites where cactus grows and expand baseline information so models can be refined as more information becomes available.

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References

Anderson, E.F., 2001. The cactus family. Timber Press, Portland, Oregon, USA.

De Kock, G.C., 1980. Drought resistant fodder shrub crops in South Africa. P. 399-408. In: H.N. Le Houerou (ed.), Browse in Africa, the current state of knowledge. International Livestock Centre for Africa. Addis Ababa, Ethiopia.

Greene, R., Devillers, R., Luther, J.E. and Eddy, B., 2011. An approach to GIS-based multiple criteria decision analysis that integrates exploration and evaluation phases: case study in a forest-dominated landscape. Forest. Ecol. Manag. 260:2102-2114.

Griffith, M.P., 2004. The origins of an important cactus crop, *Opuntia ficus-indica* (Cactaceae): new molecular evidence. Am. J. Bot. 91:1915-1921.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones P.G. and Jarvis, A., 2005. Very high resolution interpolated climate surfaces for global land areas. Int. J. Climatol. 25:1965-1978.

Le Houérou, H.N., 1994. Drought-tolerant and water-efficient fodder shrubs (DTFS), their role as a "drought-insurance" in the agricultural development of arid and semi-arid zones in Southern Africa. Report to the Water Research Commission No. KV 65/94 WRC, Pretoria, South Africa.

Le Houérou, H.N. and El Barghati, M.S., 1982. Shrub evaluation in the Bengazi plains. Technical Paper No. 45, FAO and Agricultural Research Center, Tripoli, Libya.

Louhaichi, M., Park, A.G., Mata-Gonzalez, R. Mohawesh, Y.M. and Johnson, D.E., 2015. A Preliminary Model of *Opuntia ficus-indica* (L.) Mill. Suitability for Jordan. Acta Hort. 1067:267-273.

Nefzaoui, A., Louhaichi, M. and Ben Salem, H., 2013. Cactus as a tool to mitigate drought and to combat desertification. J. Arid Land Studies 24(1):121-124.

Nerd, A., Karadi, A. and Mizrahi, Y., 1991. Salt tolerance of prickly pear cactus (*Opuntia ficus-indica*). Plant and Soil 137:201-207.

Nobel, P.S., 2009. Desert Wisdom, Agaves and Cacti, CO2, Water, Climate Change. Universe, New York, Bloomington.

Nobel, P.S., de la Barrera, E., Beilman, D.W., Doherty, J.H. and Zutta, B.R., 2002. Temperature limitations for cultivation of edible cacti in California. Madroño 49:228-236.

Pickering, J., 2014. *Opuntia ficus-indica* database. Discover Life. Polistes Foundation, Inc. http://www.discoverlife.org/mp/20m?kind=Opuntia+ficus-indica

R Core Team, 2014. An Introduction to R. http://www.r-project.org/USGS. 2015. http://eros.usgs.gov/

Wang, J., Jing, Y., Zhang, C. and Zhao, J., 2009. Review on multi-criteria decision analysis aid in sustainable energy decision-making. Renew. Sust. Energ. Rev. 13:2263-2278.