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Determination of the distribution of *Calotropis gigantea* (L.) in Sri Lanka using MaxEnt modelling technique

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Abstract *Calotropis gigantea* is a drought-resistant, salt-tolerant, native plant in Sri Lanka with ayurvedic medicinal values. The plant is used for fiber, fodder and fuel, as well as a fertilizer. Despite its benefits, *C. gigantea* has become an emerging problem in countries where it has been introduced because of its invasiveness. Although *C. gigantea* is widely distributed in Sri Lanka, precise information on its distribution is lacking. Therefore, the present study was aimed at determining the distribution of *C. gigantea* in Sri Lanka. Field surveys were conducted in 120 sites covering all provinces in Sri Lanka from December 2014 to June 2015 to record the occurrence of *C. gigantea*. *C. gigantea* was distributed in all provinces except the Central province. It was more widespread along coastal regions, but its occurrence was low in the Western and Sabaragamuwa provinces. MaxEnt modelling predicted that the entire coast of Northern, North-Central and Eastern provinces contain the highest probability of *C. gigantea* distribution whereas the low probability was in North-Western, Western, Southern, Uva, Central, and Sabaragamuwa provinces. No occurrence probability was predicted in certain regions of Southern, Sabaragamuwa, Uva, and Central provinces of Sri Lanka. The study provides information on the current and potential distribution range of *C. gigantea* in Sri Lanka.

Keywords: *Calotropis gigantea*, MaxEnt modelling, plant distribution

1 Introduction

The spatial distribution of a species is the arrangement of that species across the earth's surface. No species in the world is adapted to live in all environmental conditions of the earth. Their spatial distribution is limited by biotic and abiotic factors (Pidwirny 2018). Climatic factors act as major limiting factors for the distribution of plants. The microclimate is the climatic condition that prevails in localized regions closer to the surface of the earth. It consists of environmental variables including temperature, moisture content, wind speed, and light (Naiman *et* *al*. 2005) and is closely bound with the habitat and influence on plants on a fine scale (Bramer *et al*. 2018). Climatic differences create significant changes in the vegetation and form climatic zonation (Azarkhavarani *et al*. 2015). The close relationship of climate and vegetation is used to define and analyze bio-climatic zones using different vegetation and climatic maps (Azarkhavarani *et al*. 2015). Later, the use of computerized data related to climate and vegetation has led to species distribution modelling techniques (Barbet-Massin *et al.* 2018). Primarily, species distribution models are developed to predict the distribution of species and secondarily to study the functional association of species with their living environment (Austin 2002).

Since 2006, the MaxEnt software package is widely used for modelling the species distribution covering more than 1000 publications. MaxEnt program uses presence-only data (species recorded locations) and data of environmental predictors as input data of the program (Merow *et al*. 2013). Modelling techniques have been applied to study the distribution range of *Calotropis procera*, an invasive plant in Australia. The driving factors for its distribution had not been identified and assuming "climatic conditions" as a driving factor on the plant distribution, MaxEnt modelling has been applied to identify the current and potential distribution of *C. procera*. According to the model prediction, the distribution of plants is best explained through climatic variables and human disturbances (Menge *et al.* 2016).

C. gigantea is native to India, China, Sri Lanka, and Malaysia (Dhileepan 2014) and is also distributed in Afghanistan, Algeria, Burkina Faso, Cameroon, Ghana, Guinea-Bissau, and Iran (Kumar *et al*. 2013). It is considered a medicinal plant having Ayurvedic value in its native range (Kumar and Kumar 2015). Different plant parts of *C. gigantea* are used to cure a wide range of diseases including bronchial asthma, cholera, convulsions, pneumonia, ringworm infection, smallpox infection, toothache, epilepsy, skin diseases, and epilepsy (Kumar and Kumar 2015). In addition, *C. gigantea* is used as fodder, fiber source, fuel and febrifuge (Kumar *et al.* 2013). However, in certain countries, the plant is considered as an invasive species. It is recorded as an exotic- invasive plant in Australia, the Virgin Islands of the United States, Mexico, and Brazil (Kumar *et al.* 2013). They prefer to grow on the abandoned over-cultivated areas, over-grazed grounds, roadsides and lagoon edges (Kumar *et al*. 2013).

C. gigantea is commonly found in Sri Lanka, but there are no published records on its distribution in Sri Lanka and the habitats they occupy. Therefore, the objectives of the present study are to collect occurrence data of *C. gigantea* in Sri Lanka, to identify habitats and habitat characteristics of *C. gigantea*, to prepare a map of its distribution concerning selected environmental variables by using MaxEnt modelling technique and to study the density of the plant in different regions of Sri Lanka.

2 Material and Methods

2.1 Collecting occurrence data of *C. gigantea*

A field survey on the distribution of *C. gigantea* was conducted from December 2014 to June 2015 covering 120 sampling sites representing nine provinces of Sri Lanka (Figure 1). Each field visit covered eight (8) sampling sites on average. Sampling was done only once for each site. The roadside sampling was done as *Calotropis* spp. tend to grow closer to road-edges and for easy accessibility of sampling (Sharma *et al.* 2010). Roadside sampling sites were selected randomly maintaining equal distances on the main road at 30-minute intervals while travelling on a vehicle with a speed of 50 Km per hour. If a new site with *C. gigantea* plants was not observed after 30 minutes, travelling continued until observing a site with *C. gigantea* plants. In every sampling site, *C. gigantea* distribution (GPS coordinates) occurrence data were recorded.

2.2 Mapping the distribution of *C. gigantea* in Sri Lanka

The bioclimatic variables were downloaded from the Worldclim Global climate data website (https://www.worldclim.org/). Bioclimatic variables used in the present study were derived from the monthly temperature and rainfall values. Biologically meaningful variables derived from the monthly temperature and rainfall (e.g., mean annual temperature, annual precipitation, annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g. temperature of the coldest and warmest month, and precipitation of the wet and dry quarters) are used to represent annual trends. The above data is in the form of layers in a grid format covering the global land area. They are in the latitude/longitude coordinate reference system. This data is available in ESRI grid (raster) format, Geo TIFF format and, Generic grid (Raster format). It is also available at 4 different spatial resolutions; from 30 seconds (0.93 x 0.93 = 0.86 km^2 at the equator) to 2.5, 5 and 10 minutes (18.6 x 18.6 = 344 km^2 at the equator). Environmental variables such as temperature and rainfall should be included in raster Arc/Info ASCII Grid format.

The maximum entropy model (MaxEnt) software and DIVA-GIS software were used. In Worldclim, the globe is divided into 60 squares which refer as tiles. Each tile consists of an enormous data package including climatic data of different regions of the World. The global climatic data is available in 1 km^2 spatial resolution approximately (Fick and Hijimans 2017). As original data of WorldClim is available in 30 seconds spatial resolution, it was selected for the study. For this study, bioclimatic data of WorldClim related to 28 tiles (India - Sri Lanka region) was downloaded from http://www.worldclim.org/tiles.php and in addition, the Generic grid (Raster) format was used. For the calculations of MaxEnt, two file types are needed. They are Comma Separated Values (.csv) and ESRI ASCII GIS (.asc) (Young *et al.* 2011). However, in Worldclim, the data is not in the .asc format and it does not support MaxEnt. DIVA-GIS software was used to convert downloaded bioclimatic data of WorldClim into .asc format and mapping of *C. gigantea* distribution of Sri Lanka was done (Figure 1).

2.3 Model suitability and validation

The suitability of the model was determined by the Area Under the Curve /AUC. It represents the ratio of sensitivity vs. specificity of *C. gigantea*. AUC makes a comparison between the performances of one model with another. In addition, AUC is useful to evaluate multiple models of MaxEnt. ACU contained a possible value range 0 to 1, and values above 0.5 represent the higher predictive power while values less than 0.5 represent lower model performance. In other words, if the value of AUC is closer to 1 means the mode is extremely appropriate for the predicted distribution while a value close to 0 means the model is not suitable (Young *et al.* 2011).

Model validation is necessary to assess the model's overall performance and application potential (Uden *et al.* 2015). Independent data or data which is not used for model training is required for the model validation (Uden *et al.* 2015). If the data set is sufficient, observations are taken as randomly or spatially subset into training and testing data sets. As there were sufficient observations (n=120) in this study, 20 per cent of data was set aside for testing the model (Uden *et al*. 2015).

2.4 Habitats of *C. gigantea* in Sri Lanka

The patterns of land use indicate the changes in the plant habitats. As a result, land-use patterns greatly influence plant distribution (Honnay *et al.* 1999). To study the land-use pattern, habitats of *C. gigantea* were recorded during the field study. Habitats were categorized as roadsides without disturbances, roadsides with wastelands, roadsides with abandoned lands, roadsides near to seashore, roadsides adjacent to a cemetery, roadsides closer to reservoirs and roadsides with continuous anthropogenic activities such as railway tracks, road construction sites and cattle grazing lands.

2.5 Plant density of *C. gigantea*

To calculate plant density, a randomly selected (3m ×3m) plant patch of *C. gigantea* in each site was observed. *C. gigantea* plants in randomly selected 9 m^2 areas were counted and recorded. The recorded values were ranked as High density (H), Moderate density (M) and, Low density (L). These ranks were given according to the number of plants that were present in 9 m^2 of selected *C. gigantea* patch (1 to 2 plants: low density, 3 to 4 plants: moderate density, more than 4 plants: high density). Percentage of *C. gigantea* plant density was calculated as,

$$\textit{C. gigantea}\text{ plant density }\% = \frac{\text{Number of sampling sites having the same density rank of the selected district}}{\text{Number of }\textit{C. gigantea}\text{ sampling sites per selected district}} \times 100\%$$

3 Results

3.1 Predicted distribution of *C. gigantea* in Sri Lanka

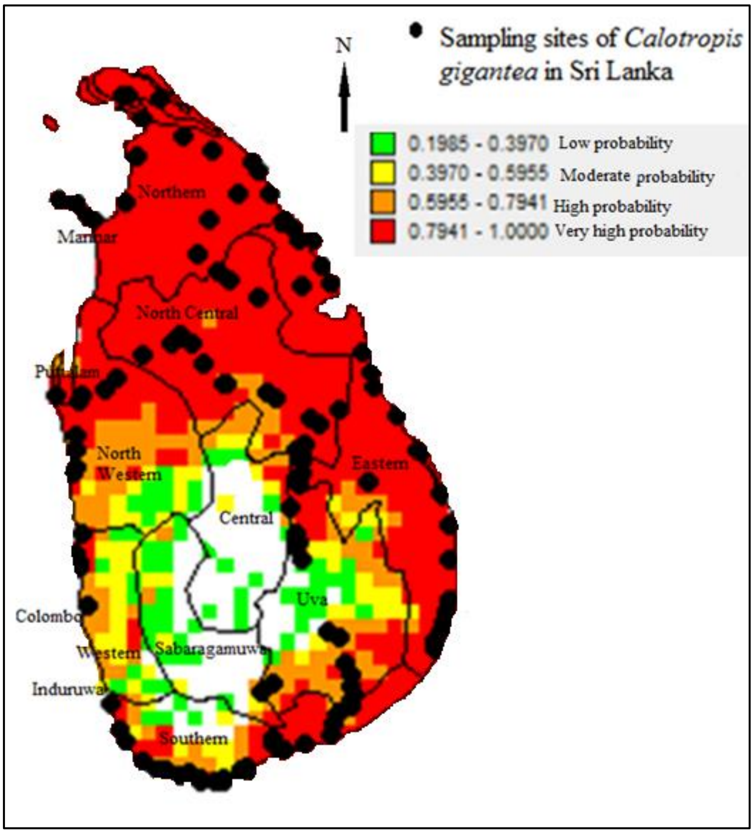

Fig 1. Sampling sites and predicted probability of *Calotropis gigantea* distribution in Sri Lanka using MaxEnt modelling

The probability of *C. gigantea* distribution according to the environmental variables of the MaxEnt modelling technique is shown in Figure 1. In Figure 1, warmer colours (red and orange) show the areas with a predicted high probability of *C. gigantea* distribution including the whole coastal belt of the country, Northern, North-Central, and Eastern provinces of Sri Lanka. In addition, a high probability of *C. gigantea* is predicted in certain regions of Southern and North-Western provinces. The low probability of *C. gigantea* distribution (yellow and green) is predicted in regions in North-Western, Western, Southern, Uva, Central and, Sabaragamuwa provinces of the country. According to the prediction of the model, there is no probability of occurrence of *C. gigantea* (white) in certain regions of Southern, Sabaragamuwa, Uva and, Central provinces of Sri Lanka.

3.2 Evaluation of quality of MaxEnt model

AUC is used to predict the accuracy of the model. It determines whether the probability of a present location is ranked higher than a random background location or not, and Reddy *et al*. (2015) described the ranking system in values of AUC as 0.50-0.60 (fail), 0.60-0.70 (poor), 0.70-0.80 (fair), 0.80-0.90 (good), and 0.90-1.0 (excellent).

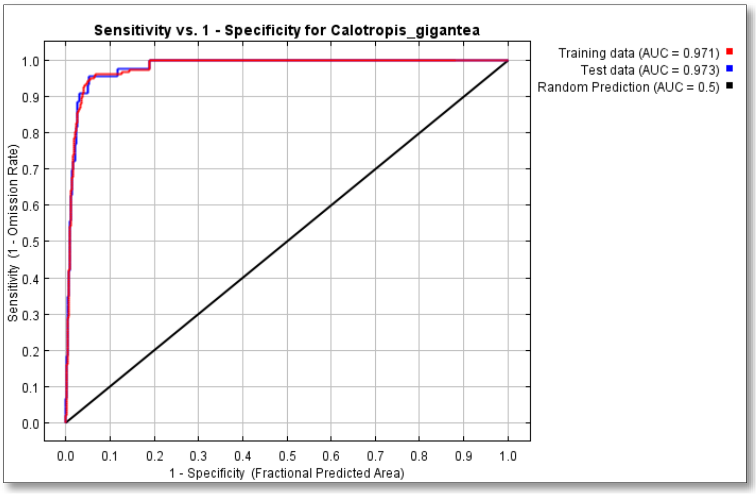

Fig 2. AUC curve of sensitivity versus specificity for *Calotropis gigantea*

In the present study, the AUC was obtained based on the potential climatic factors which affect the distribution of *C. gigantea* in Sri Lanka. The AUC values were 0.971 and 0.973, for training and test data, respectively (Figure 2). It indicates the constructed model to be appropriate with an 'excellent' predictive accuracy. Therefore, it is suitable to make predictions on the geographic distribution of *C. gigantea* in Sri Lanka. By entering '20' in the settings of 'random test percentage', the program randomly set aside 20% of the sample records for testing. The analysis utilizes a threshold to make a binary prediction with suitable conditions predicted above the threshold level (suitable) and below the threshold level (unsuitable). Figure 3 indicates the omission rate and predicted area as a function of the cumulative threshold. The calculation of the omission rate was done on the training records as well as the test records (80% and 20% of the presence records, respectively).

According to Reddy *et al.* (2015), the omission rate should be close to the predicted omission.

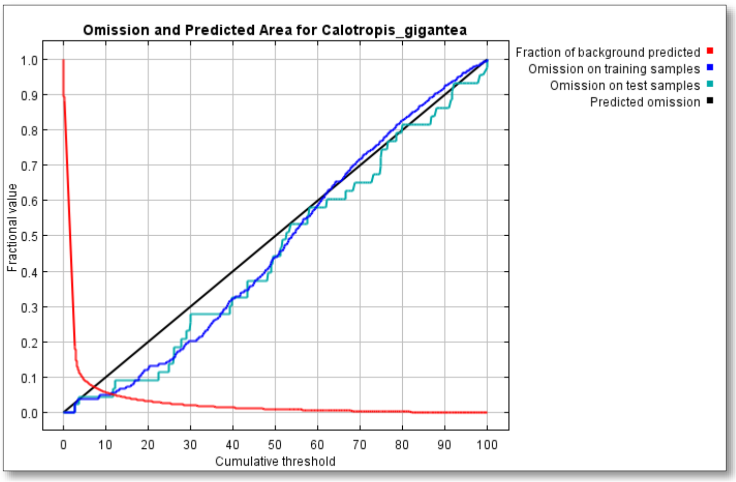

Fig 3. Graph of omission and predicted area for *Calotropis gigantea*

Figure 3 shows how testing and training omission and predicted area for *C. gigantea* vary with respect to the cumulative threshold. The omission on test samples has high compatibility with the predicted omission rate. In some situations, the test omission line lies well below the predicted omission line. On the other hand, in some situations, the test omission line lies well above the predicted omission line. Such conditions appear due to the dependency of test and training data, as they are derived from the same spatially auto-correlated presence data. This denotes that the MaxEnt model is significantly better than random in the binomial test of omission and predicted area curve.

3.3 Habitats of *C. gigantea* in Sri Lanka

The percentage occurrence of *C. gigantea* according to habitat category is given in Table 1. The majority (66.9%) of *C. gigantea* plants were located on either side of the roads with undisturbed soil. During the survey, 12.1 % of *C. gigantea* plant sites were recorded in dumped lands closer to roadsides while 7.3% of them were recorded at sea-shore closer to roadsides. In the dry zone, *C. gigantea* plants were recorded closer to reservoirs such as tanks, lakes and, estuaries. It was also recorded in cultivations such as paddy and coconut. Only 4% of *C. gigantea* habitats were associated with roads where continuous anthological activities prevail.

Table 1. Percentage of occurrence of *C. gigantea* in Sri Lanka according to habitat category.

Habitat category	% Occurrence of *C. gigantea* according to habitat
Roadsides without disturbances	66.9
Dumped lands near roadsides	12.1
Seashore near roadsides	7.3
Cultivations near roadsides	6
Reservoirs close roadsides	4.8
Roadsides with continuous anthropogenic activities	4.0
Abandoned lands close to roadsides	2.4
Cemetery at roadsides	2.4

3.4. Plant density of *C. gigantea*

The percentage of plant density according to the province is recorded in Table 2. *C. gigantea* plants are highly preferred to grow in low plant densities in Northern (73.68%) and Eastern (72.0%) provinces. A higher percentage of moderate plant density was recorded in Western (33.33%) and North-Western (31.25%) provinces. In the Uva province, *C. gigantea* plants tend to grow as high-density mass with a peak (50%) percentage. In contrast, Western and Northern provinces have no sites with high *C. gigantea* plant density. The plant was absent in Central province.

Table 2: Percentage *Calotropis gigantea* plant density with respect to provinces in Sri Lanka.

Province	Low plant density %	Moderate plant density %	High plant density %
Northern	73.68	26.32	0
Eastern	72.0	4.0	24.0
Western	66.67	33.33	0
North- Central	57.89	15.72	26.32
Southern	50.0	19.44	30.56
North- Western	37.5	31.25	31.25
Uva	30.0	20.0	50.0
Central	0	0	0
Sabaragamuwa	NE	NE	NE

NE- Not estimated due to less coverage area of Sabaragamuwa Province

4 Discussion

There are many records on roadside surveys on invasive species (Baard and Kraaij 2019). It may be due to two reasons; invasive species tend to grow on roadsides and easy accessibility for sampling. Roads act as corridors that facilitate the distribution of invasive species to introduced areas. The development of road networks and frequent road constructions further facilitate the range expansion of invasive species. Therefore, road edges are ideal habitats for invasive plants which facilitate their dispersal to different geographical regions (Sharma *et al.* 2010).

According to Sharma *et al.* (2010), anthropogenic activities on roads pave the way for the invasion of *Calotropis procera* into introduced areas. The study also describes that road usage, vehicle smoke, and vehicle gust further facilitate seed dispersal of *C. procera*, and that invasion from urban areas to rural regions is possible via road systems (Sharma *et al.* 2010). In the present study, *C. gigantea* is in a broad range of habitats including undisturbed roadsides, cemeteries, abandoned lands, dumped lands, seashore and, cultivations. Quazi *et al.* (2013) also mentions that *Calotropis* spp. tend to grow on sand dunes closer to estuaries as well as over-grazed grasslands. Kumar *et al.* (2013) also record that, it appears as a weed in over-grazed lands where there is no competition from grasses. However, if there is grass, *C. gigantea* may not act as a dominant plant in open areas which is well studied for *C. procera* in Australia. According to Menge *et al.* (2017), *C. procera* is a poor competitor with respect to the native grass (Mitchell grass) and fails to invade grasslands. It also prefers to grow in desert regions due to its xerophytic nature such as milky latex in leaves, highly branched root system and waxy, thick leaves (Kumar *et al.* 2013).

Low population densities limit the reproductive output of the plant. Pollinator limitation is a leading factor for low population densities of *Calotropi*s spp. (Menge *et al.* 2017). In the present study, low population densities are present in the Western, Eastern and, Northern provinces on a large scale where there is a smaller number of pollinators. Personal observations reveal that highly urbanized Western Province contains a low number of pollinators which may be the reason for low plant density. Eastern and Northern regions are under road construction after the civil war and as a result, *C. gigantea* populations have been cut down and cleared. It may lead to low population densities in Northern and Eastern regions.

As *Calotropis* spp. are salt and drought tolerant and resistant to low rainfall (300-400 mm) (Kumar *et al*. 2013), they are abundant in places with similar climatic conditions such as in coastal regions of Southern, Northern, Eastern and, North-Central provinces of Sri Lanka. The observations (Table 1) are compatible with MaxEnt output (Figure 1) indicating climatic conditions highly affecting the *C. gigantea* distribution. As an example, MaxEnt predicts a low probability of *C. gigantea* in the Western province which belongs to the wet zone of the country. A similar observation is recorded during field visits also. In contrast, a higher percentage occurrence of *C. gigantea* is recorded in the Eastern, North-Central, Northern and Southern provinces of Sri Lanka. The MaxEnt model also predicts the same result indicating climatic suitability for *C. gigantea* growth prevailing in these areas.

However, the model predicts a high probability of *C. gigantea* distribution in the coastal belt of Puttalam to Mannar which is not observed during field visits (Figure 1). The fragmentation of *C. gigantea* distribution from Puttalam to Mannar may be due to human activities that occurred during road construction projects after the civil war prevailed in these regions although there are ideal environmental conditions available for *C. gigantea* plants. Maxent model also predicted, a low probability of *C. gigantea* from Induruwa to Colombo, as it belongs to the wet zone of the country. On the other hand, field observations reveal that clearance of the *C. gigantea* coverage occurs due to high urbanization. The combined effect of lack of climatic suitability and urbanization may have led to the disappearance of *C. gigantea* from Induruwa to Colombo.

AUC values indicate that MaxEnt produced significantly accurate results. The sensitivity versus 1-specificity graph indicated that the MaxEnt model got an excellent predictive accuracy (mean AUC = 0.972) concerning the relationship between the distribution of *C. gigantea* and the selected environmental variables. The results show that the MaxEnt model can be used to study the climatic suitability for the distribution of *C. gigantea* in Sri Lanka. It acts as a tool to understand the potential distribution of *C. gigantea* in Sri Lanka.

Most of the observed results in Table 2 are compatible with the predicted distributions in Figure 1. Field observations revealed high plant occurrence in the Northern, North- Central and, Eastern provinces of the country which is compatible with the model prediction. Similarly, the model predicts a low probability of *C. gigantea* distribution in large land areas of Uva, North-Western, Western and Central provinces of Sri Lanka which is observed during field visits also (Table 2). In addition, the model predicts a low probability of *C. gigantea* distribution in Sabaragamuwa province where the percentage of occurrence is not evaluated due to lack of land coverage during field visits (Table 2). Therefore, the MaxEnt model facilitated the prediction of species distributions where there is a lack of occurrence data.

5 Conclusions

The present study provides a detailed map of *C. gigantea* as well as detailed information on *C. gigantea* plant distribution, plant density and, habitats of the plant in Sri Lanka. The knowledge of the distribution of *C. gigantea* is important as it has medicinal value. On the other hand, the association of environmental factors for its distribution is greatly important to control its invasiveness in the introduced range. The present study would be the first of its kind in Sri Lanka using MaxEnt to evaluate climatic suitability on *C. gigantea*. MaxEnt modelling predicted the distribution of the plant within the whole country concerning environmental variables. According to the MaxEnt, climatic factors highly influence on the distribution of *C. gigantea*. In addition, anthropological activities also play a considerable role in *C. gigantea* distribution. The study also provides occurrence data of *C. gigantea* in Sri Lanka which will be greatly important for further studies on its distribution in Sri Lanka as well as in the World.

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