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Maxent modeling of the habitat distribution of the critically endangered *Pterocarpus indicus* Willd. forma *indicus* Inmindanao, Philippines

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Abstract

A current and projected suitable habitat distribution models for *Pterocarpus indicus* Willd. forma *indicus* were generated using Maximum Entropy Modeling algorithm (MaxEnt). The Receiver Operating Characteristic (ROC) - Area Under Curve (AUC) of the training and test data were 0.854 and 0.920 respectively. It was highly above the random prediction AUC of 0.5; therefore the model performance was good, reasonable and valid. The predicted suitable habitat distribution of Smooth Narra was heavily influenced by climatic variables. The variable with largest contribution was Mean Temperature of Warmest Quarter (MTWQ) with 31.2%. It was followed by Soil with 20.3%. Annual Precipitation (AP) and Precipitation of Driest Quarter (PDQ) belonged to 3rd and 5th in contribution rank with 12.8% and 8.8% respectively. This study also found out that the spatial pattern of distribution of suitable habitats is clustered. The study also predicted changes with suitable area coverage in terms of land class, protected areas and administrative boundaries would likely occur as climatic conditions change.

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Introduction

The Philippines is one of the countries harboring luxuriant biodiversity. Situated in the tropical region, the country is home of more than 12,000 flora and fauna, excluding fungi (IUCN Red list, 2011). Plants alone have a total of 9, 253 species of which 6, 091 are endemic (IUCN Red list, 2011). One of the important plant species in the country is its national tree, Smooth Narra. It is one of the two forms under the species *Pterocarpus indicus*. It is a large deciduous tree declared as the national tree of the Philippines, so as the other form called Prickly Narra. Being considered as the provincial tree of Chonburi and Phuket in Thailand (Thomson, 2006), the species is truly symbolic in other places outside of the Philippines. Moreover, Smooth Narra has been categorized as critically endangered in its natural Habitat.

Habitats of trees including that of Smooth Narra have been negatively altered due to decades of human-mediated modification and other natural causes. Habitat loss can be further worsened as climate change starts to affect ecosystems. 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 (Khanum *et al.,* 2013). As reported by Khanum *et al.* (2013), the Intergovernmental Panel on Climate Change (IPCC) estimated a 0.2 °C increase in temperature for each future decade (IPCC, 2007). This increase in temperature would have detrimental consequences on 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).

SDM tools are used to predict a species' past, current and future geographic distributions (Hof *et al*., 2012). SDMs have also been intensively used in projecting climate change driven range shifts and extinction risks for many species.

In recent years, multiple modeling programs have been developed and utilized to predict the impacts of climate change on species geographic distribution, even for areas that suffer from incomplete and biased samplings, or for areas where no collections have been made (Araujo & Guisan, 2006; Elith *et al*., 2006; Trisurat *et al*., 2011; Garcia *et al*., 2013). A popular modeling tool called MaxEnt is typically utilized in many SDM studies. MaxEnt is a statistical model, and to apply it to species distribution successfully, we must relate it to the other modeling components (Phillips *et al*., 2004) such as the ecological component and the mode of data collection. MaxEnt has been found robust to changes in sample size, and still have good predictive performance at low sample sizes making it the ideal model for the prediction of distributions of rare species (Hernandez *et al*., 2006; Wisz *et al*., 2008; Garcia *et al*., 2013).

This study is focused on predicting the habitat distribution of *Pterocarpus indicus* Willd. forma *indicus,* commonly known as Smooth Narra in Mindanao, Philippines. Being a symbolic tree with a critical conservation status, a study concerning its geographical distribution is needed in the light of a bigger environmental concern, climate change. The potential effect of climate change is accounted in this study by factoring-in climate projections. This study was undertaken in the perspective that SDMs can aid in the conservation of Smooth Narra. Modeling species distribution can provide useful means of commissioning future surveys in predicted species distribution area, consequently prioritizing conservation needs (Guisan and Thuiller, 2005; Khanum *et al*., 2013). It will be of great utility in conservation planning and land use management around the existing populations of the species.

The results of this research can help in setting priority areas where the species can be effectively restored, maintained and protected. Large, intact suitable habitats predicted in this study can be treated as top priority sites for the conservation of Smooth Narra.

The objectives of the present study are to: (i) Generate a current and future habitat distribution map of critically endangered *Pterocarpus indicus* Willd. forma *indicus* through MaxEnt. (ii) Analyze the habitat distribution pattern of the species as influenced by environmental factors. (iii) Assess the status of predicted suitable habitat of the species in relation to protected areas to gain information on potential species conservation strategies.

Materials and methods

Study area

The study was conducted in Mindanao Island, Philippines (Figure 1).

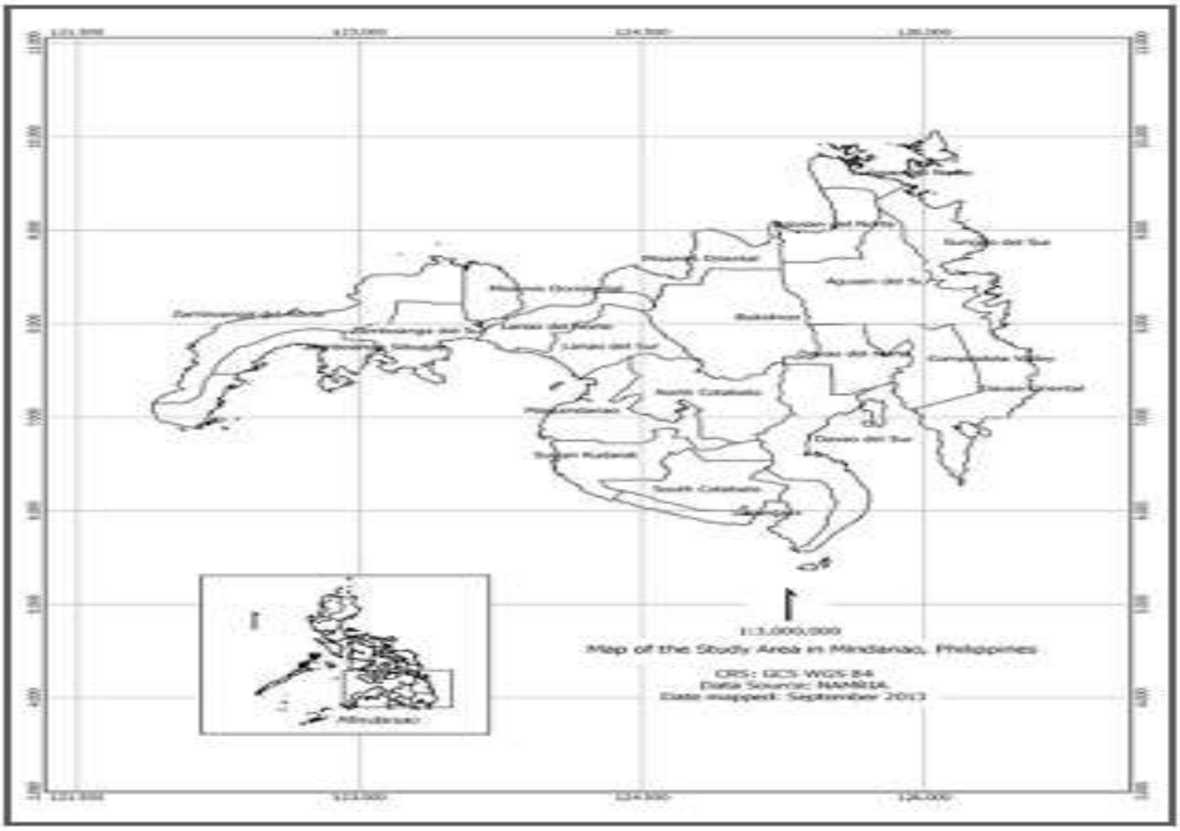

Fig. 1. Location map of the Study site.

Mindanao is the southernmost and second largest island in the Philippines. It encompasses the mainland region and the Sulu archipelago. The Island consists of six (6) regions that are further subdivided into 26 provinces.

Due to constraints on lack of complete environmental data in some areas, the actual study site covered only the mainland Mindanao and the Siargao and Samal islands. A great portion of eastern Mindanao is under Type IIclimate (No dry season). Parts of northern Mindanao are under type III while most of central, eastern, and southern Mindanao is under Type IV whereinrainfall is more or less evenly distributed throughout the year (www.fao.org/docrep). Based on Worldclim data, the annual mean temperature of the island ranges from about 12 to 28 °C. During warm quarters, mean temperatures rise by approximately 1°C. Warmer temperature is usually experienced from February to May during the dry season. Annual rainfall average falls between 1000 to 5000 mm. During the rainy season, the island receives a huge amount of rain as a result of frequent occurrence of thunderstorms and tropical cyclones. In drier quarters, rainfall averages decline significantly and recorded at between 130-730 mm. The mainland region is composed of 9 soil orders (www.worldmap.harvard.edu).

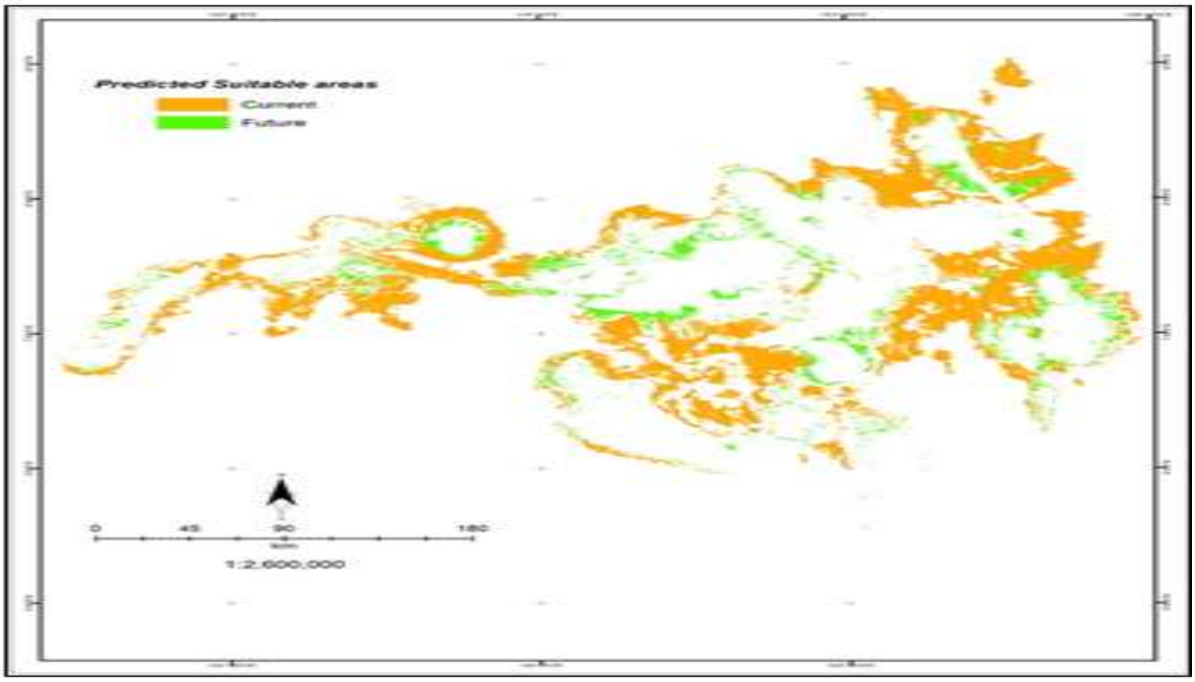

Fig. 2. Current and future Predicted Suitable Habitat of Smooth Narra.

Local data do not contain complete soil information at the soil type level. Extensive areas along the forested sections of the island are still classified as undifferentiated while some areas have no data.

Software and Data Acquisition

The MaxEnt software was downloaded from the Internet via the link; www.cs.princeton.edu/~schapire/MaxEnt

The current version which is 3.3.3k is freely accessible for download in the website as zip file. Quantum GIS was obtained from (www.qgis.org).

Majority of the SOPs were acquired from the Department of Environment and Natural Resources (DENR) and a significant number from www. gbif.org (ex. Garcia *et al.*, 2013, Tererai & Wood, 2014). There were roughly around 150 initial SOPs, but the number was reduced to 102 because some were too close spatially. The spatial resolution of all environmental layers was 0.0009 x 0.0009 degrees, which was roughly equivalent to 100 x 100 meters. The geographic coordinates were all in decimal degrees (dd) format hence referenced under World Geodetic System of 1984 (WGS 84). The predictors include climatic (precipitation and temperature) and biophysical variables (soil, slope and aspect).

Climate datasets were downloaded from the WorldClim database available at approximately 1 km^2 spatial resolution (Hijmans *et al.*, 2005). Future climate data were obtained in the Climate Change in the Philippines handbook published by PAGASA. In the publication, the projected changes in precipitation and temperature, including seasonal variations were presented at the provincial level. From the 2050 projections, a projected climate raster data were generated.

Data on soil order was acquired from the Digital Soil Map of the World (DSMW) (www.worldmap.harvard.edu). There were locally generated soil data but it contain areas that have undifferentiated and unclassified soils. Categorization is imperative to be able to utilize soil as an input in Max Ent. Table 2 shows the different soil orders and their corresponding categories. Slope and aspect variables were generated from the ASTER-GDEM and resampled to a 100x100 meter spatial resolution.

Aspect has to do with slope orientation and has some implications on exposure to solar radiation. While slope, has an implication on water and nutrient retention of soils.

Model Building and evaluation

In Quantum GIS (QGIS), SOPs were displayed to visualize its distribution across the entire study area. A total of 67 SOP's were used to build the habitat distribution model. About 27 SOPs independent of the composition of the training set were utilized for testing. The two sets of data are differed in the sense that, the training data were used to run and create the model, while the test data was utilized to test the accuracy of the model. The said test data set was randomly extracted from complete list of SOP's from the main list encoded in Microsoft excel. The performance of the model was gauged using the Receiver Operating Characteristic (ROC) Area Under Curve (AUC) method. The AUC measured the model performance with values ranging from 0 to 1. AUC is a widely used procedure for comparing species distribution models' performance (Philips *et al.*, 2004).

Results and discussion

Habitat distribution model

MaxEnt modeling revealed profound differences between current and future predicted suitable areas (Figure 2). Suitable areas have been predicted to occur throughout the lowland areas of Mindanao. Based on the threshold, suitable habitats were predicted to occur in a geographic space consisting of cumulative area of 2.46 and 0.65 million hectares for current and future prediction out of the 9.52 million hectare study area, respectively.

Table 1. List of environmental variables used in assessing the habitat distribution of Pterocarpus indicus Willd. forma indicus

Code	Description	Data type	Source
AMT	Annual mean temperature	Raster/Continuous	Worldclim/PAGASA
MTWQ	Mean temperature of the warmest quarter	Raster/Continuous	Worldclim/PAGASA
AP	Annual precipitation	Raster/Continuous	Worldclim/PAGASA
PDQ	Precipitation of the driest quarter	Raster/Continuous	Worldclim/ PAGASA
Slope	Slope	Raster/Continuous	USGS
Aspect	Aspect	Raster/Continuous	USGS
Soils	Soil order	Raster/Categorical	www.worldmap.harvard.edu

The current predicted suitable habitat therefore comprised 25.84 % while the future predicted suitable habitats accounted for 6.83 % of the extent of the study site.

The range of suitability for both predictions was similar, 0 to 0.98 to be specific. The value of the latter is very close to the maximum probability value of 1.0. Hence, areas with probability values that fall within or close to it carry the most suited conditions for Smooth Narra.

As predicted, a huge fraction of the current predicted suitable habitat would become unsuitable in the future.

The future geographic distribution would shrink under predicted levels of climate warming. Areas of high altitude where changes in climate would likely favor the species were predicted to become suitable.

Less elevated sections of the study area are generally warmer and drier. Following the predicted rise in temperature and fall of precipitation levels, those areas would become even more unsuitable. There are three probable scenarios relating to how plants will survive under climate change. Some will get extinct, some will migrate and some will be able to adapt.

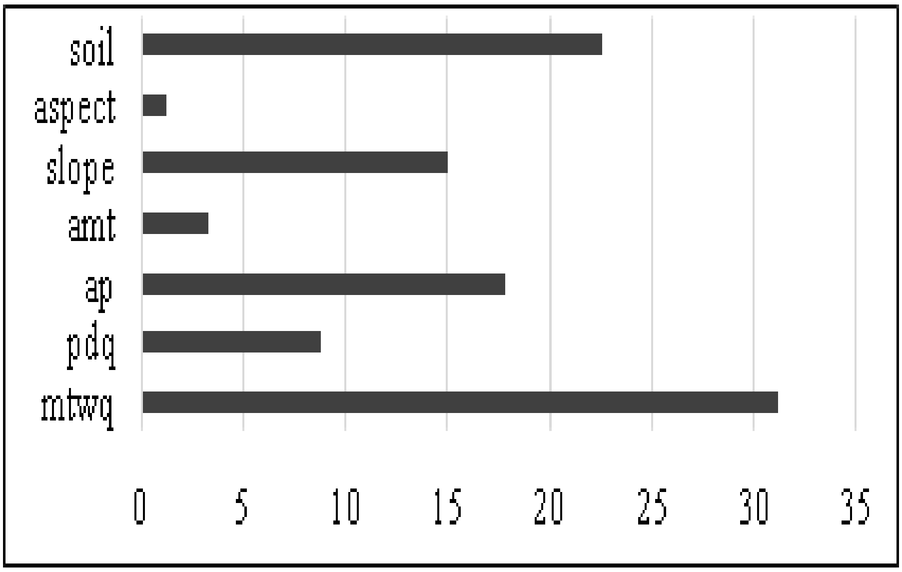

Fig. 3. Percent contribution of each environmental variable.

Figure 3 shows the estimated values of relative contributions of environmental variables to the MaxEnt model.

Overall, climatic variables fell to 1st, 3rd, 5th, and 6th in terms of percent contribution ranking. Among the variables, MTWQ (Mean Temperature of Warmest Quarter) had the greatest percent contribution of 31.2%. Other precipitation related variables; AP (Annual Precipitation) (12.8%) and PDQ (Precipitation of Driest Quarter) (8.8%) belonged to 3rd and 5th in contribution rank respectively. Soil (20.3%) was only second to MTWQ. As observed, most of the sample pixels were located within areas that have soil orders' Arenosol, Nitosol and Vertisol. Strong predictions were made along areas whose soil groups belong to one of the three mentioned. These were verified using the response curve created by the MaxEnt using only soil as variable.

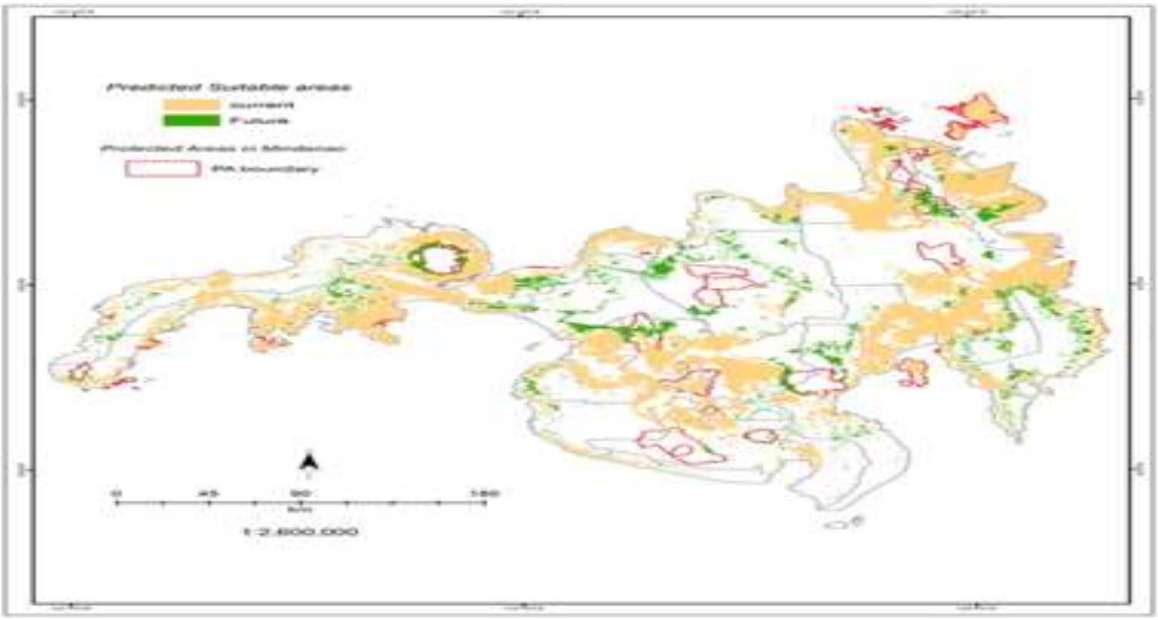

Fig. 4. Predicted suitable areas in relation to protected areas.

Aspect and slope have percent contribution values of 1.2% & 15%, respectively. When grouped together, climatic variables constitute 61.1 %, 16.2% for topographic variables and 22.6% for soil. Spatial variation in slope and aspect is a key determinant of vegetation pattern, species distribution and ecosystem processes in many environments. The slope and aspect of a vegetated surface strongly affects the amount of solar radiation intercepted by that surface (Bennie *et al.*, 2008). It is noteworthy to account that solar radiation propels photosynthesis and thus heavily afffects vegetational productivity. Being correlated with solar radiation, slope and aspect can greatly affect ecologically critical factors such as surface temperatures, evaporative demand and soil moisture content.

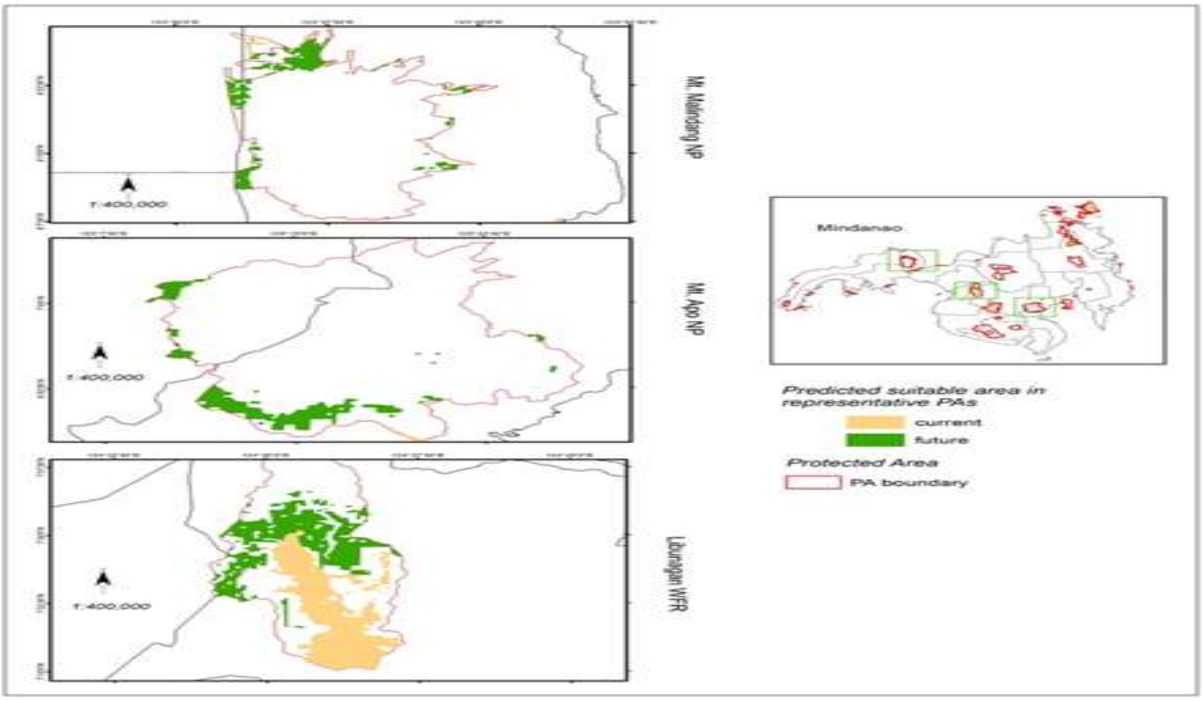

Fig. 5. Current and future Predicted suitable habitats within selected protected areas.

It also determines the exposure of vegetation to photosynthetically active and ultraviolet wavelengths. Sternberg and Shoshany (2001) highlighted that aspect had significant effects on the composition, structure and density of their studied plant communities. Plants in areas exposed to optimal solar radiation are more likely to have higher productivity rate than those in less exposed areas.

Many literatures support the idea that climate is the main factor regulating species distribution. Parallel findings have been reported from other studies in some parts of the world. Apart from climatic changes, other parameters such as soil and topography are likewise important. If the problem on rising temperature levels and declining amounts on rainfall will subsist, the distribution of Smooth Narra can be negatively affected. Various institutions working in the line of environmental protection should put more work on climate change mitigation and adaptation projects. Many programs in place nowadays, ranging from protected area management, reforestation projects, watershed management activities; pollution control projects are of great contribution to climate change mitigation. However, more effort should be exerted as everybody can tell that much still needs to be done to achieve real results. Stricter implementation of forestry laws must be made to preserve the remaining natural forests of the country. These forests serve as the most effective carbon sinks to offset carbon emission. The government should likewise fund more Industrial Tree plantation projects, as these would not only provide the people with livelihood but counter climate change as well.

The cooperation of the people is imperative but most lack the knowledge and appreciation of the importance of conservation. There is a need find and implement effective awareness campaign strategies to educate more people regarding environmental conservation and climate change mitigation.

Suitable Habitats in relation to Protected areas

The predicted suitable areas for Smooth Narra were analyzed in relation to the location and extent of protected areas (PA's). The prime reason for this was to determine areas within PA's that have the appropriate environmental conditions for growth and survival of the species. Figure 3 shows the locations of PA's and suitable areas throughout the entire extent of the study area.

Protected areas are public areas under land use restrictions and are set aside for protecting native ecosystems (Soares-Filho, 2009). These areas are considered as the stronghold for all living organisms where the great diversity of life is protected from human exploitation. Historically, protected areas were established and managed in response to ecological (e.g., protect wildlife populations) and social (e.g., promote tourism and recreation opportunities) values, and are now an important part of a Jurisdiction's commitment to combat ecosystem degradation, including biodiversity loss (Lemieux *et al.*, 2011). In Mindanao, extensive natural forests were declared as Protected areas such as Mt. Apo, Mt. Kitanglad, Mt. Malindang and Mt. Matutum. These areas cover immense forests protected from human exploitation.

Figure 5 shows the current and future predicted suitable PSH within selected protected areas. There seem to be no significantly large areas covered within PA's.

Close examination somehow produces a clearer picture and offers more detained information. The predicted suitable areas covered within the extent of PA's are presented in Figure 4. Apparently, in terms of land area for the predicted current distribution, Siargao attained the largest with 14,017 hectares. It was followed by Libunagan Watershed Forest Reserve (WFR) and Samal Island. However, it has been found out that, the coverage of certain PAs in relation to predicted suitable habitats will change. For instance, Misamis Occidental WFR and Siargao will be completely unsuitable as predicted. New areas within Pas would likely become suitable as climate changes. Typical example as shown in the table were Mt. Apo and Mt. Malindang. The bounds of protected areas can only extend according to spatial limits set by law. Protected areas cannot cover majority of suitable areas for a species. The aim might not be to cover every individual of species as long as representatives are in there. In the creation of most protected areas and in the identification of sites that achieve targets for habitat and species representation to date, a relatively constant climate has been assumed. Hence, planning and management of protected areas should consider climate change. Areas for future conservation efforts need to be assessed in relation to climate change. The current extent of protected areas has to be reviewed also to ensure that its intended purpose and results are attained and help mitigate negative climate change impacts.

Implications on conservation

Actual Smooth Narra trees might not be found in the suitable habitats predicted. Suitable habitats that have previously harbored the species have likely been altered and were devoid of any representative trees at present. These can be attributed to land use transformations and human exploitation. Much of the suitable habitat for these plants has already been converted into agriculture or urban. Hence, suitable habitats can be further diminished with the combined ill effects of land use and climate change. If the species is able to adapt to climatic changes and can manage to thrive in its current distribution even in the future. It can still be negatively affected, as land use change will continue to put pressure and contribute to loss of habitats. Species that are unable to adapt, would likely migrate in other areas where ecological conditions are ideal.

Remaining inhabitants are most probably be over-exploited. This scenario is not far from reality, since Smooth Narra is known to possess a high economic value with various uses.

Ex situ conservation through plantation establishment and urban forestry is important as the threats to the species subsist in areas where it thrives naturally. The present step taken by the government to reforest extensive marginal areas in the Philippines through the National Greening Program (NGP) will have its positive impacts in the future. In spite of the seemingly unsuccessful implementation of forest laws prohibiting exploitation of certain forest trees, it can still be considered as a strong option. New laws, amendments to existing ones, and proper implementation might be the key. However, history can tell how challenging implementation of forest laws were.

The present study demonstrated that habitat distribution modeling could be of great help in predicting the potential habitats of Smooth Narra. The suitable areas identified in the present study would not only help in rehabilitating habitats where the species had existed before but also in improving species population and consequently its conservation status. Therefore, the results will be quite useful for natural resource managers in management of this species and conserving overall biological diversity in the region.

Conclusion and Recommendations

MaxEnt has proven to be an effective tool to model the habitat distribution of Smooth Narra. With the proliferation of valuable environmental data and easy access SOPs from various organizations, the usefulness of MaxEnt will continue to be harnessed in aid of conservation. Likely many preceding related researches, this study found out that the performance of MaxEnt is statistically better than random and therefore acceptable. The results of this study indicate that the current habitat distribution of Smooth Narra facilitated by environmental conditions is vast. However its future distribution is predicted to shrink due to climate change.

The integrity of the MaxEnt model largely depended on the accuracy of the input data used. There were minor limitations with regards to data especially on soil. Hopefully, soil maps that contain richer information will be available in the future. Locally generated climate data is also difficult to utilize since readily available. Interpolated climate maps are not available. It is similarly challenging to acquire climate maps interpolated with respect to altitude.

There is still a gap of knowledge in the use of SDMs in conservation research. Further studies concerning distribution modeling should be conducted using accurate data from highly reliable sources. At any rate, the science behind MaxEnt is unquestionable and its outputs are very useful as an aid in conservation. Our results may have been affected by the lack of SOPs, though its number is comparably larger than in some related studies. The need for more SOPs was seen in the beginning. Using only naturally occurring Smooth Narra have hindered the utility of many primary gathered SOPs from planted trees. Nevertheless, we acknowledge the importance of taking advantage of the available SOPs from various sources. Future SDM efforts should be able to address these limitations.

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