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HABITAT SUITABILITY MODELLING OF SPIKED PEPPER (*Piper aduncum* L.) IN MINDANAO, PHILIPPINES

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ABSTRACT – Invasive alien species is the biggest threat to biodiversity next to habitat destruction. In Mindanao, *Piper aduncum* L. is considered as the most invasive alien plant species that affects forest ecosystem and agricultural areas. This study provides insights in identifying suitable areas for *Piper aduncum* in Mindanao using a novel modelling method known as Maxent. Two models were generated: Full Model which is based on the 25 environmental variables and Final Model which is based on the final set of variables maintained after a series of variable reduction method. The relative predictive performance of the two models were evaluated using Receiver Operating characteristic (ROC)-Area under curve (AUC). Result showed that the Final Model performed best with AUC score of 0.825 compared to the Full model (AUC=0.749). The predicted suitable habitat of *Piper aduncum* was heavily influenced by these top five predictors: Soil type, Mean Temp of Warmest Quarter, Mean Diurnal Range, Max Temp of Warmest Month and Precipitation of Seasonality. Overall, this study will contribute to natural resource managers especially in setting priority areas for current management of the species and predict its potential spread in the future.

Keywords: invasive species, Maxent, species distribution models

INTRODUCTION

The spread of invasive plant species has been described as one of the significant threats in the global biodiversity and ecosystem functioning. Invasive species has been posing several ecological impacts in almost all types of ecosystems, including disrupting the structure and function, and evolutionary processes of native communities (Vitousek *et al.*, 2011). Over the last few decades, invasion of non-invasive plants frequently spread through undertakings related to global economic trade and trans-boundary activities (Evangelista *et al.*, 2012).

Piper aduncum is an introduced shrubby tree species in the Philippines belonging to family Piperaceae. It is commonly known as spiked pepper (Fig 1). It is a shade-intolerant neotropical tree, a native of the West Indies and Central America from Mexico to the Northern Argentina. This invasive species has become a significant environmental concern by dominating regrowth vegetation over large areas, displacing native species, slowing forest recovery, and interfering with agriculture (Hartemink, 2010).

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In response to increasing invasions, species-environment matching models (or species distribution models or niche models) are becoming common tool for natural resource managers, agencies, and nongovernment organizations mostly in developed countries. 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. Environment matching models that does not require absence data is useful for invasive species models because it is difficult to determine if the point that is collected as an absence point is considered as unsuitable habitat. There is still possibility that it may be suitable but the species has not yet germinated in or migrated to that area (Guisan and Thuiller, 2005). The primary goal of the study is to provide useful information to assess the potential range of *P. aduncum* in Mindanao through habitat suitability model. This can be very useful to control their growth and protect our existing forest ecosystem.

Figure 1. Stand of *Piper aduncum* in open gaps of Mt. Matutum Protected Landscape area in South Cotabato, Philippines.

MATERIALS AND METHODS

Study Area

Mindanao is the southernmost and second largest island in the Philippines. The Island consists six regions that are subdivided into 26 provinces (Fig 2). The annual mean temperature of the island ranges from about 13 to 28 ˚C. Warmer temperature is usually experienced during the dry season, from February to May with the mean temperature of 28.3˚C. While the coolest months usually fall in the month of January with a mean temperature of 25.5˚C (Fig 3). Annual rainfall average falls between 1000 to 5000 mm (Fig 3). In drier quarters from April to May, the average rainfall decline significantly and recorded at between 130 – 730 mm (WorldClim, 2015). Some areas in this study do not have complete information with regards to one of the environmental parameters that were used in this study. Hence, the study only covered the mainland of Mindanao and few islands that have complete data information.

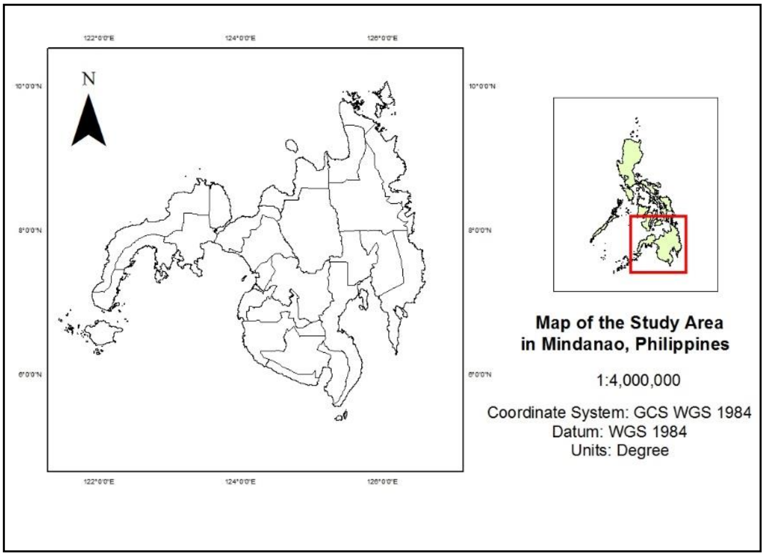

Figure 2. Location map of the study area.

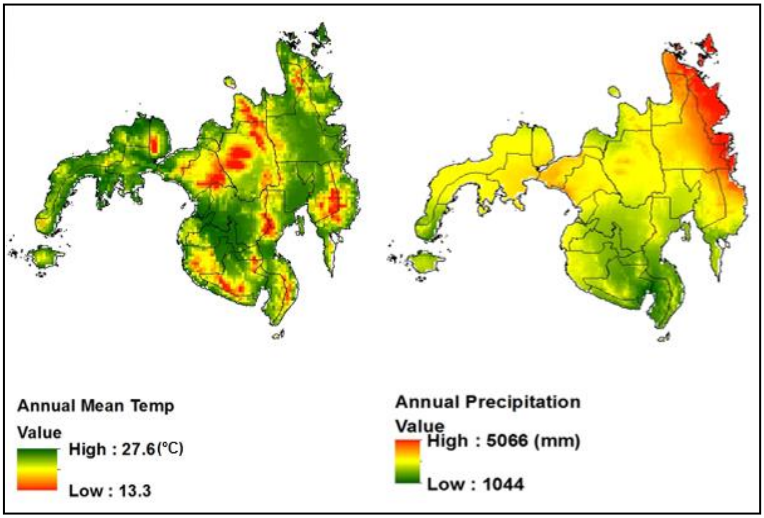

Figure 3. Annual mean temperature and annual precipitation map of Mindanao.

Occurrence Points

The occurrence points that were used in this study was only based from few actual points collected, technical reports and biodiversity surveys from various sources that mentioned the presence of *P. aduncum* in different areas in Mindanao. Overall, a total of 31 points were collected in this study. The geographic coordinates were all in decimal degrees (dd) format and were georeferenced under World Geodetic System of 1984 (WGS 84). Maxent can generate good models even with small sample size (as low as 5) (Pearson et al., 2007) as reported by Garcia et al. (2013).

Environmental Variables

Twenty-five environmental variables were considered as potential predictors of the distribution of *P. aduncum*. These include nineteen climatic variables that were created using combinations of minimum and maximum temperatures and precipitation and six biophysical variable (Aspect, Elevation, Land Cover, Population, Slope, and Soil type). The data for temperature and precipitation were collected from the WorldClim website (www.worldclim.org). These data are 50-year climatic normal and long-term averages from weather stations across the globe (Period 1950-2000). All the physical variables were downloaded from PhilGIS clearing house (www.philgis.org) and NAMRIA (NationalMapping Authority). Aspect, elevation and slope were derived through the analysis of the 30-meter Digital Elevation Model (DEM) data derived from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER-DEM) (http://asterweb.jpl.nasa.gov/). The land cover data for the year 2010 was in vector format (ESRI shapefile), then converted into raster format. On the other hand, the data for soil type classifications were obtained from Bureau of Soils and Water Management. Human population density data was based on NSO census data calculated for year 2015. All the data were projected and masked within the boundary of Mindanao and then resampled to 0.008 decimal degrees or roughly 850 meter resolution and then converted into American Standard Code II (ASCII) grid format (.asc) as required by Maxent using ArcGIS 10.2.2. The variables where then classified into two groups: bioclimatic and biophysical.

Maxent Modelling Procedure

A novel modelling method called Maximum Entropy Distribution or Maxent was used to conduct all modelling analyses. The freely available Maxent software, version 3.3.3k was downloaded from the website: http://www.cs.princeton.edu/~schapire/maxent/. This technique follows the principle of maximum entropy, where it interprets the given data while evading constraints from incomplete information about the target distribution (Phillips et al., 2004). Thus, distribution must go along with the environmental conditions where the species occur and so making any assumptions that are not supported by the data must be avoided (Phillips et al., 2006).

Pre-selected independent variables based on prior studies served as predictors while the occurrence records of *P. aduncum* was the dependent variable for the study. The data were then entered into the software. During modeling, occurrence records were further subdivided into two parts: 75% were used to generate species distribution models while the remaining 25% were kept as independent data for model validation (Garcia et al., 2013; Peters et al., 2013). There are two models that were created in this study: ‘Full Model’ and ‘Final Model’ using the procedure shown in Figure 4. These two models were generated to compare and determine how the models behave when fitted to different numbers of variables. A series of variable reduction was done to eliminate redundancy with the predictor variable in the model similar to the procedure used by Garcia et al. (2013) and Nicopior (2014) and partly based on the methods proposed by Kendal et al. (2013). All variables retained from Pre-final modelling stages 1 and 2 were used as inputs for the Final model, then were used for the final modeling procedure.

Logistic Probability Distribution

The study used the generated probability distribution in continuous raster in a logistic format. This format gives the probability values ranging from 0 to 1 for each pixel (Phillips et al., 2006). This is very useful in showing information on the different levels of species suitability. Pixels with high probability value indicates areas with better predicted conditions (Trisurat et al., 2011). Since there is no standard scale as to which threshold to select, this study utilized the categorization method applied by Galleti et al. (2013) to determine both the suitable and unsuitable areas for *P. aduncum*. A probability of occurrence with 0.25 and below represents unsuitable areas, while a 0.26 to 1.0 represents suitable areas.

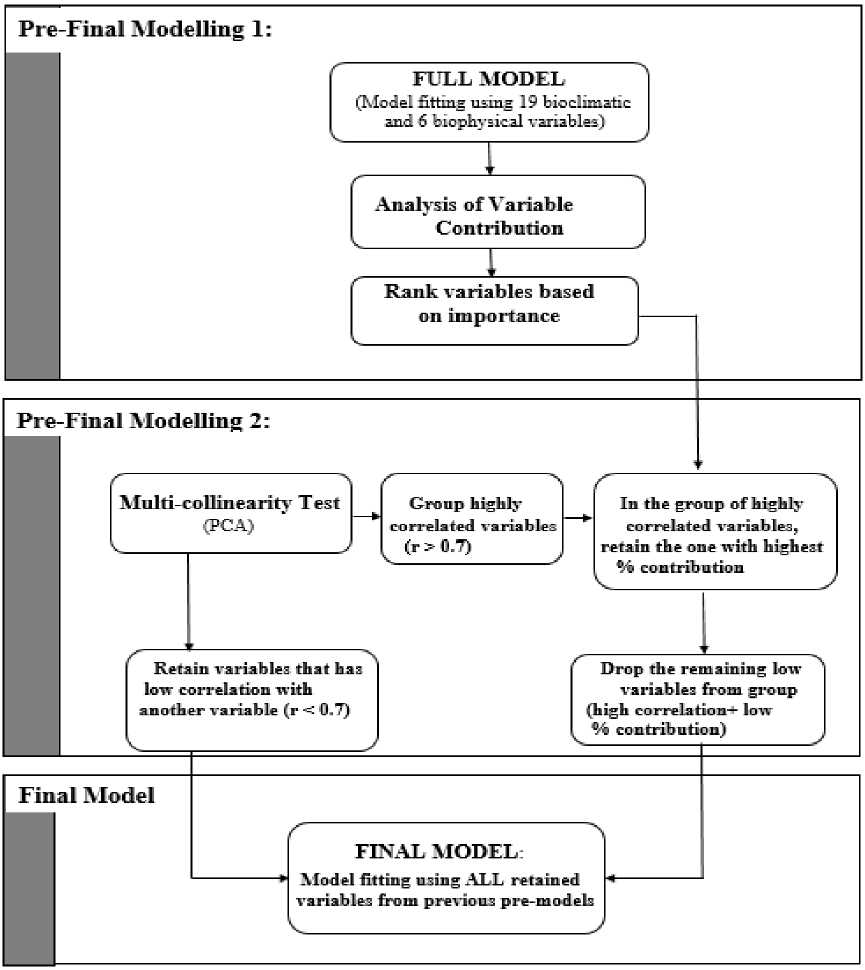

Figure 4. Methods of variable selection leading to the final model.

Model Evaluation and Validation of Model Performance

The validation of predictive performance of Maxent modelling was accomplished using Receiver Operating Characteristic (ROC) Analysis, which evaluates the performance of a model at all possible thresholds through the area under curve (AUC) (Fielding and Bell, 1997). AUC is a threshold-independent measure of model performance and varies from 0 to 1. This model performance validation technique primarily generates information whether the prediction made was better than just a random prediction. An AUC value of 0.50 indicates that model did not perform better than random whereas a value of 1.0 indicates perfect discrimination (Khanum et al., 2013). Swets (1988) interprets the AUC value range of 0.5-0.7 as low accuracy, 0.7-0.9 as useful result, and greater than 0.9 as high accuracy.

Assessment of the Status of Predicted Suitable Habitats

The model showing areas with high probability of habitat suitability of *P. aduncum* was visualized through GIS. A shapefile of administrative map was overlain with the model to determine which areas have covered the suitable habitats. Predicted provinces and protected areas were identified and the extent of coverage was examined through calculation of area into hectares. Assessment of the administrative and protected area coverage of suitable sites is important in identifying areas to protect and manage against the potential spread of *P. aduncum*.

RESULTS AND DISCUSSION

Habitat Suitability Maps of Two Models for Piper aduncum

The two models have almost the same pattern of predicted suitable areas for *P. aduncum.* The maps show that *P. aduncum* mostly occur in the southern part of Mindanao which means that the spread of this species is worse in this area (Fig 5). In measuring the area of the different predicted suitable areas, we only considered the probability values of 0.26 to 0.98 which is categorized as suitable as adapted to the method applied by Galleti et al., (2013). It is worthy to note that the areas are relative estimates only since the resolution that was used for the raster data inputs is 0.008 decimal degrees or approximately 890m per pixel. The predicted suitable habitats for the final model of *P. aduncum* had cumulative area of 1,205,180 hectares out of 8.9 million study area. On the other hand, the full model had 863,785 hectares (Fig 6).

Model Evaluation

All the AUC scores were greater than 0.5. According to the AUC classification by Swets (1988), this could mean that all the models that were generated has better performance than random. The Final Model had the best performance with an AUC score of 0.825 while the Full model perform fairly with 0.749 AUC score. This only means that models with fewer predictor variables often outperform those of models with complex counterparts (Mazzoni, 2016). Thus, the performance of the model is also related to the set of variables being used. Moreover, the result of the model may be affected with some drawbacks of Maxent as this modelling tool doesn’t provide any information on abundance or absence of the species of interest. Hence, it creates problem like: the species records no longer reflect stable relationships with environmental conditions since species distribution models follow the general assumption that distribution must go along with the environmental conditions where the species occur (Elith *et al*., 2010). However in this study, we consider deriving background data or pseudo-absent points in lieu of true absence data and we limit the background samples to areas we assumed were recorded for the presence location of the species. This can be useful for invasive species or range-shifting species as there are concerns about there are no assurances that a point that is collected as an absence point is legitimately unsuitable habitat because there are instances that the habitat may be suitable, but the species has not migrated yet or germinated to that location (Holcombe *et al.,* 2010). Given with the caveat above, this modelling technique are still well suited to generate maps of habitat suitability from current point distribution.

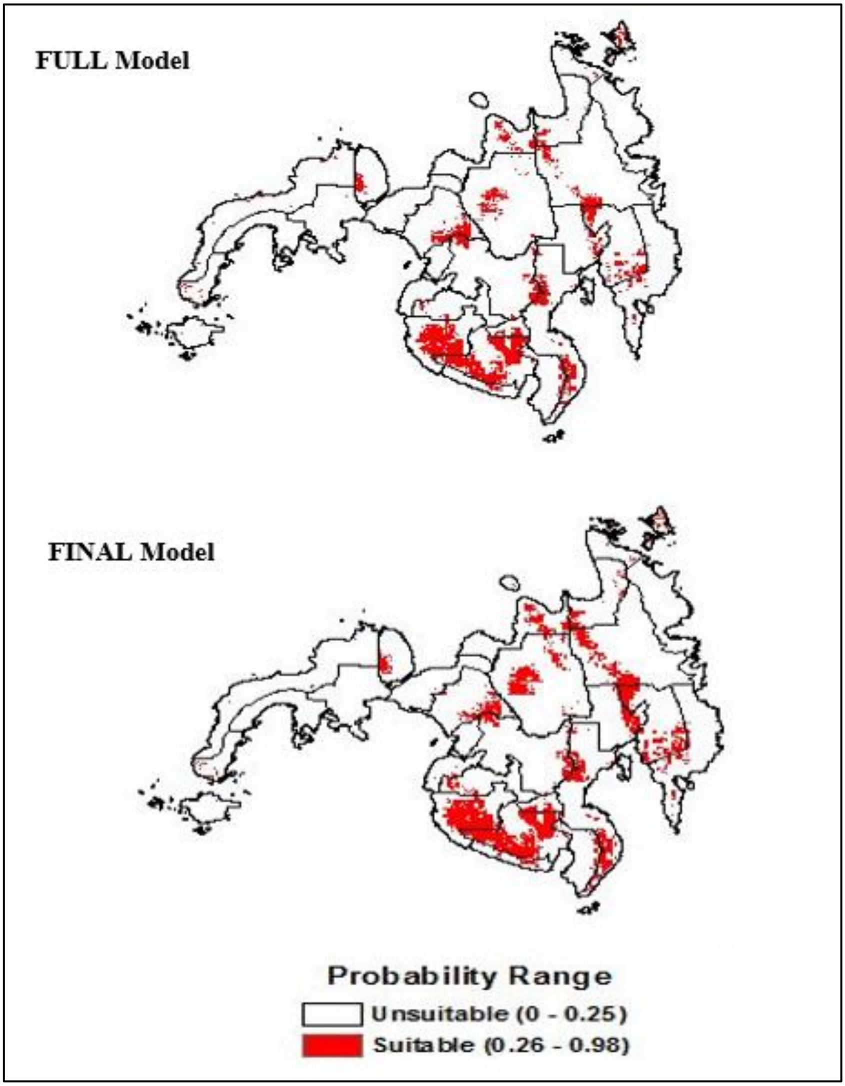

Figure 5. Probability Suitability Maps of the two models.

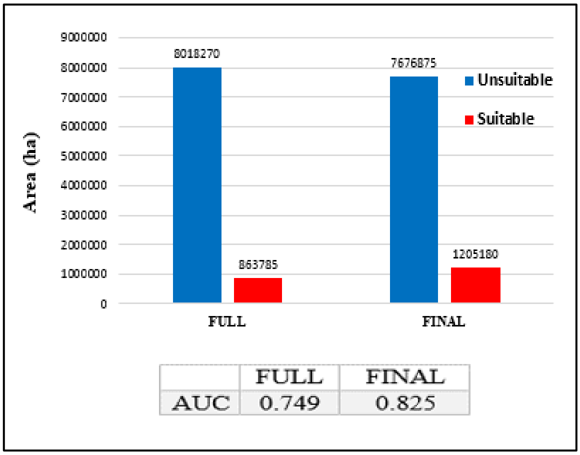

Figure 6. Area coverage of two models.

Variable Contribution

Overall, biophysical variables have combined percent contribution equal to approximately 44% with soil type being the highest (29.5%), followed by Land cover (6.3%), Population (5.2%) and then Aspect (2.6%) that had the lowest percent contribution. Climatic variables that represent temperature and precipitation have a highest total of combined percent contribution with relatively equal to 56%. Mean Temperature of Warmest Quarter (MTWaQ) and Mean Diurnal Range (MDR) ranked 2nd and 3rd respectively (Table 1).

Table 1. Relative importance of variables in the Final Model.

VARIABLE	PERCENT CONTRIBUTION
Soil Type	29.5
Mean Temp of Warmest Quarter (MTWaQ)	22.8
Mean Diurnal Range (MDR)	10.4
Max Temp of Warmest Month (MTWM)	9.6
Precip of Seasonality (PS)	7.8
Land Cover	6.3
Precip of Warmest Quarter (PWaQ)	5.7
Population	5.2
Aspect	2.6
TOTAL	**100**

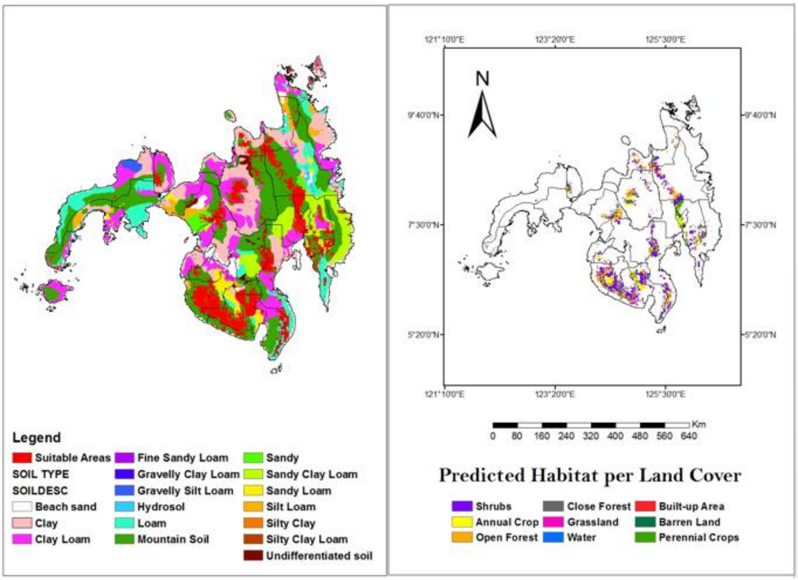

Figure 7. Suitable habitat of *Piper aduncum* per soil yype (left) and land cover (right).

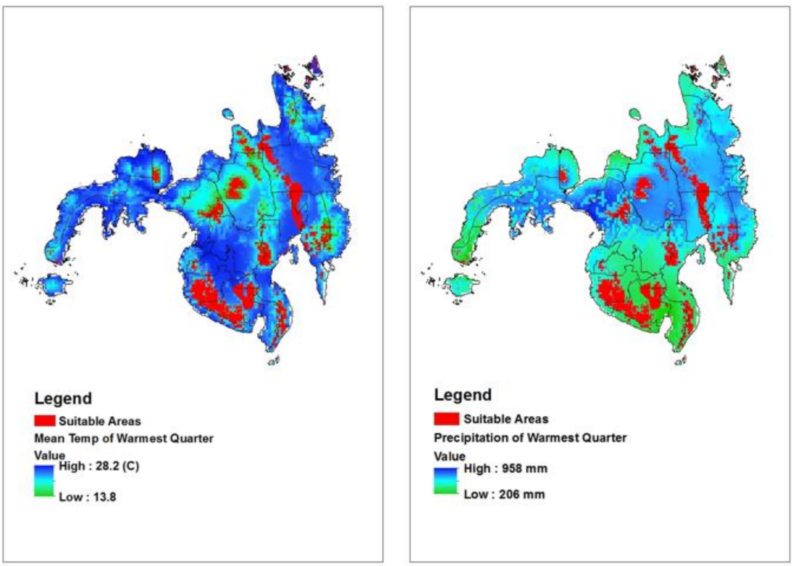

Figure 8. Suitable Habitat of *Piper aduncum* overlain in temperature (left) and precipitation map (right).

This could mean that soil type is the primary determining factor of occurrence of *P. aduncum*. Figure 7 shows that strong prediction were made along whose soil type belongs to Mountain Soil and Loam. *P. aduncum* has known to colonize in most soil types, especially in well-drained soils (Francis, 2003). As for the Land cover, the highest prediction for the presence of *P. aduncum* is in shrubs, perennial crops and annual crops. This trend could be sensible since *P. aduncum* most often occur in agricultural and disturbed areas.

Furthermore, temperature and precipitation could be a large factor for the presence of *Piper aduncum* in different areas in Mindanao. For Mean Temp of Warmest Qurater, as shown in Figure 6, strong predictions occur in mid to low temperatures. Furthermore, suitable areas were also observed from mid to low range of Precipitation of Warmest Quarter (Fig. 8).

Jackknife Test

The environmental variable with highest gain when used in isolation is soil type which therefore appears to have the most useful information by itself. This was followed by Mean Temp of Warmest Quarter (MTWaQ), Mean Diurnal Range (MDR), Maximum and Temp of Warmest Month (MTWM). Land cover and Precipitation of Seasonality (PS) almost have the same gain when they are used separately in isolation. On the other hand, Precipitation of Warmest Quarter (PWaQ), Population and Aspect were the lowest and may not be very useful for estimating the probability occurrence of the species. As far as Jackknife of test gain is concerned, when used in isolation, Soil Type was the most important in predicting where the species can survive. Meaning to say, when soil type is omitted then there will be less information available to determine habitat suitability. It should be noted that the jackknife results provide training and test gain and these two usually vary. Thus, these results are only applicable for the training data. Nevertheless, both test and training gain have shown that the most important variable is soil type (Fig 9). This is also consistent in terms of which variables have higher percent contribution.

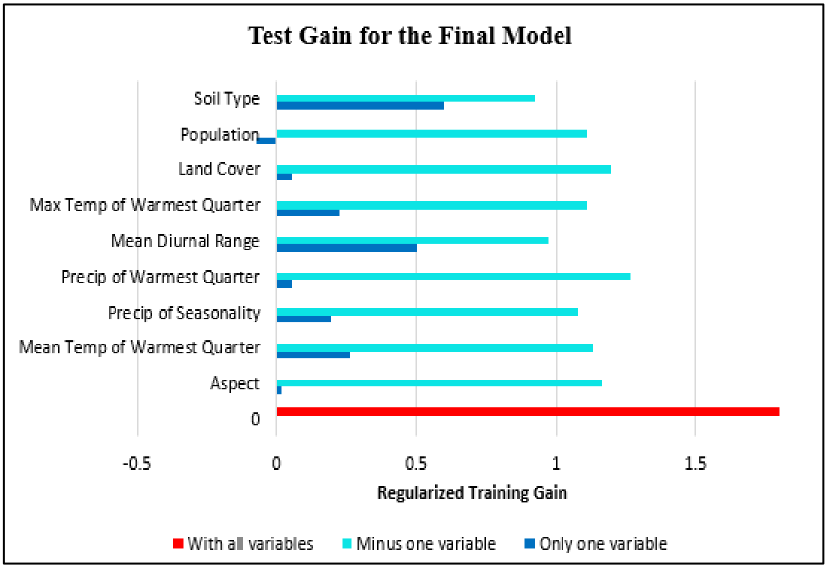

Figure 9. Jackknife Test gain using the Final Model.

Assessment of the Status of Predicted Suitable Habitats

Piper aduncum are expected to occur mostly within South Cotabato, Sultan Kudarat, North Cotabato, Davao del Sur, Compostella Valley, Surigao del Norte, Bukidnon, and Sarangani. However, the province of South Cotabato (229,947) obtained the largest suitable area for the final model. This is followed by the province of Sultan Kudarat (164,598) and Davao del Sur (116756) as the third in the rank. On the other hand, the least size of suitable habitat for *Piper aduncum* is in Surigao del Sur (238 ha). While other areas have very low probabilities, there are still chances that the species could occur and spread in those areas and should be taken into consideration especially with the changing of climate (Fig 10).

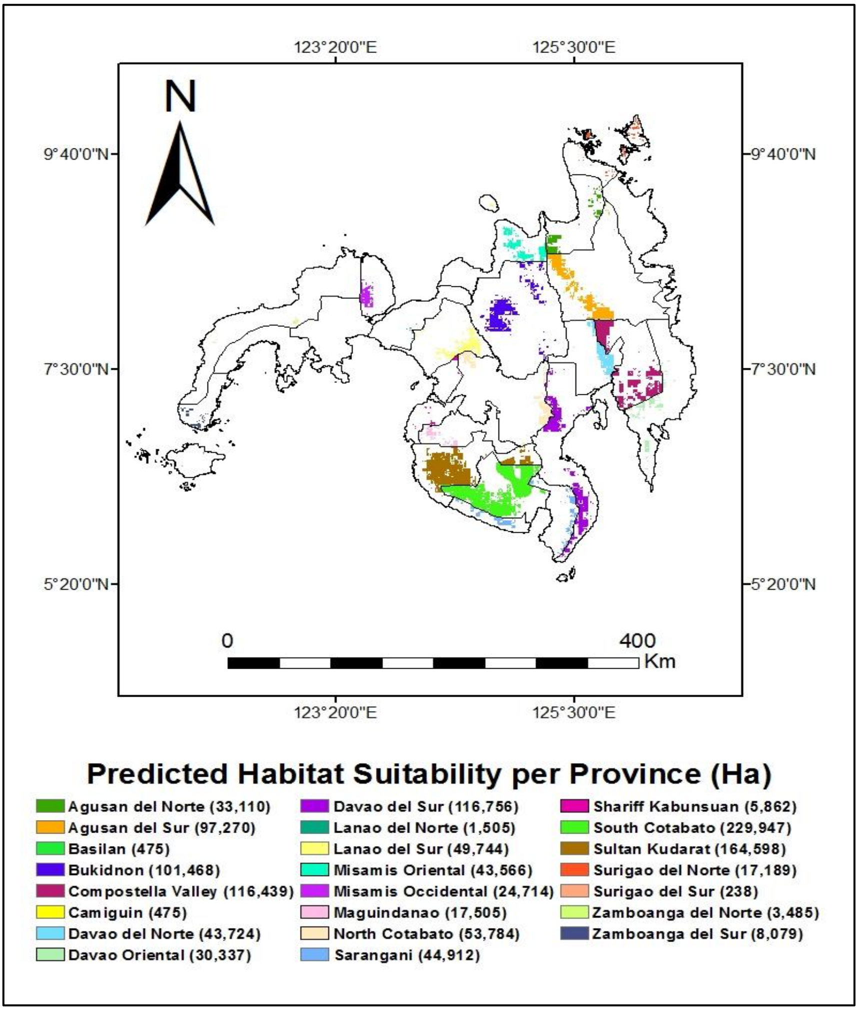

Figure 10. Habitat suitability of *Piper aduncum* per province.

Most of the predicted suitable areas of *Piper aduncum* in Mindanao were covered within the protected areas (Fig 11). This could mean that most of the protected areas have the appropriate environmental conditions for growth and survival of *Piper aduncum*. Thus, current management of the species should be highly prioritized in these areas.

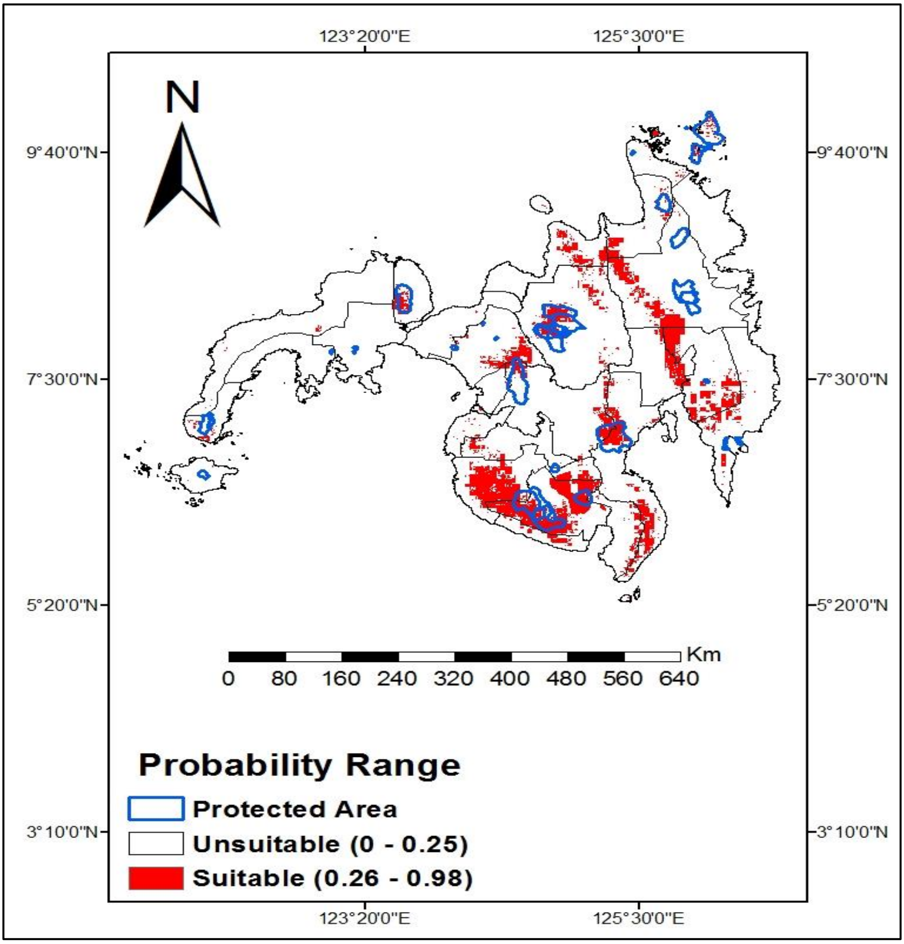

Figure 11. Locations of protected areas and suitable areas throughout Mindanao

CONCLUSION AND RECOMMENDATION

Piper aduncum is expected to occur mostly within South Cotabato, Sultan Kudarat, North Cotabato, Davao del Sur, Compostella Valley, Surigao del Norte, Bukidnon, and Sarangani. Most of the predicted suitable areas of *Piper aduncum* also fall within the boundaries of protected areas throughout Mindanao. Current management of the species should be prioritized in the areas that were identified in this study. However, these suitable areas may change through time especially considering climate change and other constraints like land use transformation and human exploitation that may possibly affect the spread of *Piper aduncum.* Thus, natural resource managers should put more efforts in implementing strategic plans to control the spread and understand how this species behave especially in a changing climate as it affects the production capacity of the forest ecosystem. Hopefully, the techniques being done in this study can be adapted in other areas in the country to control the onslaught of other invasive alien species that most likely pose economic or ecological harm to the natural environment.

Finally, this study recommends to gather more species occurrence data all throughout the study area. The result may be affected with the lack of occurrence points of *Piper aduncum*, though its number is still acceptable. However, if there is sufficient available resources like georeferenced database for plant invasive species then it would be more helpful to track these species. Nevertheless, we acknowledge the importance of using the available occurrence points using technical reports and biodiversity surveys from various sources. There were also limitations in the predictor layers as there are other variables were not utilized in this study, like wind-related data and dispersal methods of the plant to identify the nearest propagule pressure. Although the performance of the model that was generated is good (AUC= 0.825), considering these variables in the future studies might help improve the model performance. Exploring future climate scenario should also be done in modelling the habitat distribution of *Piper aduncum* to further understand how invasive species would likely behave especially with the pose of climate change. This can be a good way to allow land managers to assess where an invasion may move in the next couple of years. The cooperation of local communities is also imperative in managing this invasive species using techniques in appropriate biological control and weed management. Thus, agencies working in line of environmental protection should also consider implementing effective awareness campaign strategies to inform the locals on these management techniques. Furthermore, resource managers should be familiar on how to use Maxent modelling as this method provides cost-effective and efficient way to control small invasions early in the process (Holcombe *et al.* 2010, Moody *et al.* 1988).

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STATEMENT OF AUTHORSHIP

The first author initiated the concept, gathered the primary and secondary data, conducted the literature search, and undertook the writing up. The second author commented and added some inputs on the concept of the study and reviewed the final paper.

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