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ORIGINAL RESEARCH PAPER

Modeling the effect of climate change to the potential invasion range of *Piper aduncum Linnaeus*

***J.C. Paquit*[1,]*, R.I.P. Rama*[2]**

[1]*Forest Biological Sciences, College of Forestry and Environmental Science, Central Mindanao University, Maramag, Bukidnon, Philippines*

[2]*Department of Environment and Natural Resources, Talakag, Bukidnon, Philippines*

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ABSTRACT: The potential effect of invasive plant species on biodiversity is one of most important subject of inquiry at present. In many parts of the world, the alarming spread of these plants has been documented. Knowing that climate exerts a dominant control over the distribution of plant species, predictions can therefore be made to determine which areas the species would likely spread under a climate change scenario and that is what this study aims to tackle. In the current study, a total of 211 species occurrence points were used to model the current and projected suitability of *Piper aduncum* in Bukidnon, Philippines using Maxent. Results revealed that the suitability of the species was determined primarily by climatic factors with Bio 18 (precipitation of the warmest quarter) as the strongest influencing variable with a mean percent contribution of 22.1%. The resulting model was highly accurate based on its mean test Area Under Curve that is equal to 0.917. Current prediction shows that suitable areas for *Piper* are concentrated along the southern portion of Bukidnon. Only 9% of the province is suitable for the species at present but is predicted to increase to 27% because of climate change. The central and southwestern parts of the province are the areas of high threat for invasion by *Piper.*

KEYWORDS: *Climate Change; Invasive species; Maxent; Species distribution modeling; Philippines.*

INTRODUCTION

Invasive plants can cause various changes in tropical ecosystems and pose threats to forest biodiversity. The threats and challenges of invasive alien plants are recognized in the context of sustainable forest management. For example, in any Forest Stewardship Council (FSC) certified concession, the forest management is required to maintain the ecological functions and the integrity of the forest by conserving biological diversity and its associated values (Padmanaba and Sheil, 2014). Plant invasion is recognized as an important component of the global biodiversity crisis that contains, amongst others, a loss of species, habitats, economic value, biodiversity, and health of invaded systems. This potential invasion is mainly driven by bioclimatic variables such as temperature, rainfall, soil and aspect. Temperature and precipitation are direct climatic variables. As the patterns of these variables are modified because of climate change, changes in species distribution, reproduction timings and length of growing season for plants will likewise occur (Thomson *et al.,* 2009). Climate change induced increases in temperature are projected to negatively affect ecosystems but other species might respond positively (Xu *et al.,* 2017). The productivity of an area is directly correlated with climate and several modeling tools and approaches are already in place that could be used to predict the effects of climate change using bioclimatic

*Corresponding Author Email: *jcpaquit@cmu.edu.ph*
Tel.: +929 696 0696 Fax: +63 (88) 356 1912

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parameters. Species distribution models (SDMs) have emerged from efforts to determine relationships between species and their environments (Guisan and Thuiller, 2005; Robertson *et al.,* 2004) and provide one of the best ways to overcome the sparseness of the species distribution data. SDMs which are also called ecological niche models (Elith and Leathwick, 2009) are used to predict climate change impacts, study biogeography, assist in reserve selection, improve species management and answer many conservation biology questions (Guisan and Zimmermann, 2000; Padalia *et al.,* 2014). These models establish relationships between occurrences of species and bioclimatic conditions in the study area (Khafaga *et al.,* 2011). Maxent (Maximum Entropy), a popular SDM tool could be used for this purpose. Maxent based on presence-only modeling and has been used successfully to predict the distributions of different floral and faunal species (Baldwin, 2009; Trisurat *et al.,* 2011; Weber, 2011). Maximum entropy models have become popular statistical models in biology, and can be useful tools for obtaining estimates of mutual information in biological systems (Macke *et al.,* 2011). According to Kumar and Stohlgren (2009) as cited by Garcia *et al.* (2013), maximum entropy principle provides a means to obtain least-biased statistical inference when insufficient information is available. Phillips and Dudik (2008) claimed that among other models, Maxent have often shown accurate prediction capabilities in simulations and evaluations with presence-only data, outperforming classical modeling approaches, such as domain, bioclim, and logistic regression (Padalia *et al.,* 2014). Since many have proven that Maxent performed best among SDM tools, it was seen that it is useful in predictive modeling of invasive species such as *Piper aduncum* L. Predictive modeling of invasive species geographic distributions based on the environmental conditions of sites of known occurrence constitutes an important technique in invasive-species management and other fields (Philips *et al.,* 2005). Accurate modeling and knowledge about the invasion range of alien species is crucial for understanding the ecology of invasive species and for conservation and management planning (Khafaga *et al.,* 2011; Padalia *et al.,* 2014). *Piper aduncum* L. is considered as an invasive alien species (IAS) and it is present in the province of Bukidnon. It is classified as a shrub with seeds easily dispersed by wind and birds (Bonaccorso *et al.,* 2002). The species is very common in Central America and is also thriving in Hawaii, Fiji, Vanuatu and Solomon Islands (Burger, 1972). Being considered as the food basket of Northern Mindanao, it is the largest contributor to the regional agricultural economy. The invasion of *Piper aduncum* L. is foreseen to alter natural ecosystems. If not mitigated, this invasive species can potentially pose negative impacts to the provinces' economy and environment. It is difficult to predict the potential invasion range of *Piper aduncum* L. without the use of proper tools and applications. It is therefore seen that Maxent and GIS can be of great utility for this purpose. This study sought to predict potential invasion range of Buyo-Buyo (*Piper aduncum* L.) within the province of Bukidnon. The result of this study may serve as baseline information for further and long- term study of the area. Records and statistics on the occurrence of *Piper aduncum* L. are very essential for monitoring purposes. By the use of Maxent together with the GIS applications, this research provide maps showing more accurate predictions of possible areas that could be invaded by *Piper aduncum* L. within the province of Bukidnon, such that, designated authorities such as Department of Agriculture and Department of Environment and Natural Resources can determine the areas potential for invasion or areas that were already affected by *Piper aduncum* L. invasion and can be provided with proper management strategies. This study has been carried out in Bukidnon province in the Philippines in 2017.

MATERIALS AND METHODS

Study area

Bukidnon is a landlocked province in Northern Mindanao and the only province that does not have a coast line (Fig. 1). It extends geographically from 7°20' – 8°40' N to 124°30' – 125°30' E, with land area of 910, 046 hectares (calculated in GIS) representing 2.76 % of the country's total land area. The Province is composed of 20 municipalities and 2 component cities. Although the Province has lofty mountains, the greater part is a gently rolling grassland plateau cut by deep and wide canyons of the Cagayan, Pulangui and Tagoloan rivers and their branches, and other rivers. Observations by Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) from 2006-2011 showed that Bukidnon has two prevailing type of climatic variations in the rainfall pattern existing between the northern and southern sections. The northern part falls under the third or intermediate A type. While the southern part, beginning from Malaybalay, falls under the fourth type of intermediate B type.

Data collection

Species Occurrence Points (SOPs)

The field survey was conducted from January 2017 to April 2017. The study made use of primary and secondary data. The primary data consisted of SOPs from GPS survey data obtained through opportunistic sampling across several municipalities in Bukidnon province. As shown in Fig. 2, a sampled location of the species has been recorded along a river and a road. SOPs are geographic coordinates that represent the location of *Piper aduncum* L. A single SOP datum could also represent an entire stand of the species of interest. The camera-based application called GeoCam was also employed to geotag the images taken from the field.

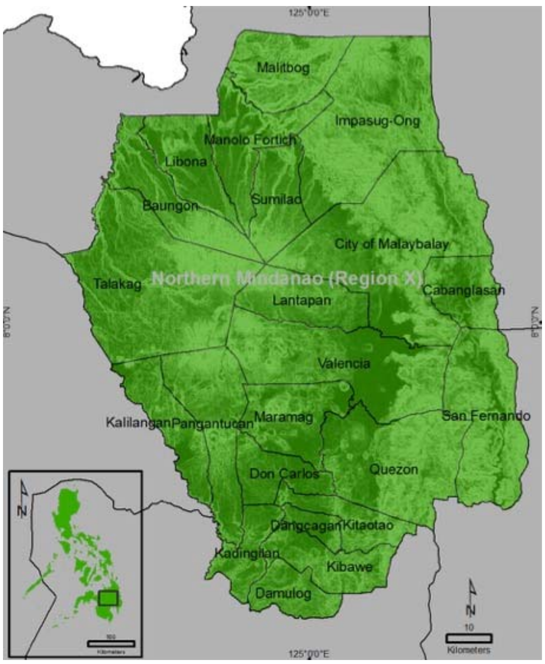

Fig. 1: Map of Bukidnon Province in Philippines

Environmental variables

Selecting relevant environmental datasets for modeling requires careful judgement as different formulation yield varying results (Peterson and Nakazawa, 2008). Hence, a comprehensive review of literature was done to finally come up with data for inclusion in the modeling. Topographic variables (e.g., slope and aspect) were processed from an ASTER DEM downloaded from the USGS website. Considering the altitudinal and climatic gradient in the study area and the perceived correlation between climate and elevation. It was decided not to include elevation as variable.

As seen in Fig. 3, three other environmental variables aside from bioclim data were used in the study. In the Philippines, an up-to-date soils map is still unavailable. To bridge the data gap, a conventional soils map was used. 19 bioclimatic variables sourced from WorldClim (Hijmans *et al.*, 2005) were initially considered. These variables, in raster (ASCII) format, are proven biologically important in regulating

Fig. 2: An image showing *Piper aduncum* L. in Quezon, Bukidnon

species distributions. Correlation analysis was applied to the variables to evaluate multi-colinearity (Table 1). For instance, there are four quarterly precipitation variables from which bio 17 and 19 are spatially correlated. Any of the two can be included in the final dataset and here we opted to keep bio 17. This resulted to the inclusion of only 14 non cross-correlated bioclimatic variables in the final model.

Data pre-processing

Most of the data processing was done in GIS. A .csv file was prepared containing all needed information regarding the SOPs. It was observed that the extent of available environmental variables was not coincident with the others. This is expected in raster data where the number of columns and rows usually do not match. For the soil data, which is in a shapefile form, clipping was done prior conversion to raster. The DEM was used to generate slope and aspect (both in degrees). All environmental variables were made uniform in terms of cell size and extent. All were resampled to 100, 100 meter spatial resolution (cell size) and set to have uniform extent. The coordinate reference system for all environmental variables was set to WGS 1984. All environmental raster layers were formatted to American Standard Code for Information Interchange (ASCII) format. ASCII is the common file format in modeling, and Maxent would not read raster file formats other than ASCII.

Model building and evaluation

Using the SOPs and all 17 variables, 10 replicate runs were made to obtain mean values from the models created. 75% of the occurrence points were set for training while 25% were for testing. All other fields were set to default. Maxent (Philips *et*

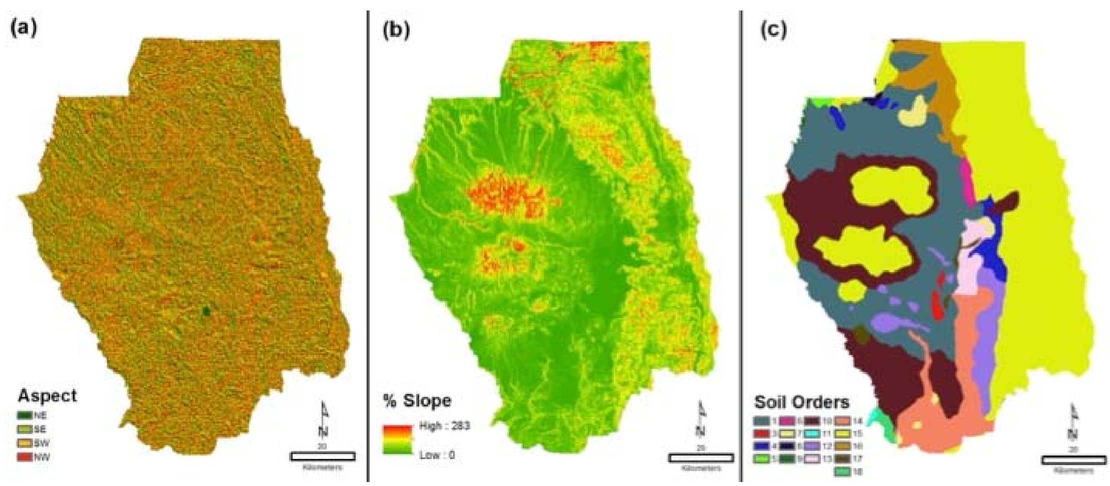

Fig. 3: Topographic and soil variables used in the study [aspect (a), slope (b), soil (c)]

Table 1: Summary of correlation analysis results using ENM tools

Group	Description	Subgroup Code	Correlation (+, 0, -)	Variables kept
1	Annual temperature	Bio1		Bio1
2	Quarterly temperature	Bio8, Bio9, Bio10, Bio 11	+ (all)	Bio9
3	Montly temperature	Bio5, Bio6	+	Bio5
4	Diurnal Range	Bio2		Bio2
5	Annual Precipitation	Bio12		Bio12
6	Quarterly precipitation	Bio16, Bio17, Bio18, Bio19	+ (17 and19)	Bio16, Bio17, Bio18
7	Monthly precipitation	Bio13, Bio14	0	Bio13, Bio14
8	Unique variables	Bio3, Bio4, Bio17, Bio15		Bio3, Bio4, Bio17, Bio15
Total		19		14

al., 2005) was used to model the climatic suitability of *Piper*. Maxent produces an output that can be interpreted as an estimate of relative probability of species distribution in space (Elith *et al.,* 2006). For model accuracy evaluation, the ROC-AUC that was produced as one of the Maxent outputs was used (Franklin, 2009). ROC-AUC is a threshold independent validation which has been tried and tested in many similar studies (Rebelo and Jones, 2010). The percent influence of each environmental variable on the distribution of the species was determined using jackknife test. The result of the test was automatically produced by Maxent. The summary of the modeling process is shown in Fig. 4.

Analysis of climate change impacts

Geographic distribution of plants is primarily regulated by climate (Davis & Shaw, 2001). Variations in species richness, composition and diversity across latitudinal and altitudinal gradients are clearly dictated by climate. To analyze climate change impacts, we used a future downscaled climate data (year 2050) from WorldClim for RCP 8.5. The 2050 data is the projected average for 2041-2060. RCP 8.5 was chosen, as it is the most extreme emission scenario. WorldClim provides statistically downscaled climate projections with a spatial resolution of 1km. To improve its resolution, a spatial interpolation procedure (IDW) was used to generate a 100 m resolution data set using previously converted elevation points from the original data. The resulting baseline and projected suitability maps were compared based on the extent of areas that are stable, gaining and losing suitability. The suitability information was then partitioned into two classes namely; suitable (AUC = 0.50 and above) and Unsuitable (AUC= 0.49 and below).

RESULTS AND DISCUSSION

Actual locations of Piper aduncum L.

A total of 211 species occurrence points were observed and recorded using handheld GNSS (GPS) receiver and GeoCam. *Piper spp.* has been observed along marginal areas, riparian zones, and along the roads. Marginal areas previously colonized by *Imperata spp.* are now inhabited by the species.

As depicted in Fig. 5, *Piper* is observed to be very abundant along the central and southern part of the province. It currently occupies a substantial proportion of marginal lands and continues to spread to other areas. At its current habitat, the species is useful as fuelwood. According to some sources, it is also used in making charcoal. Despite the relatively

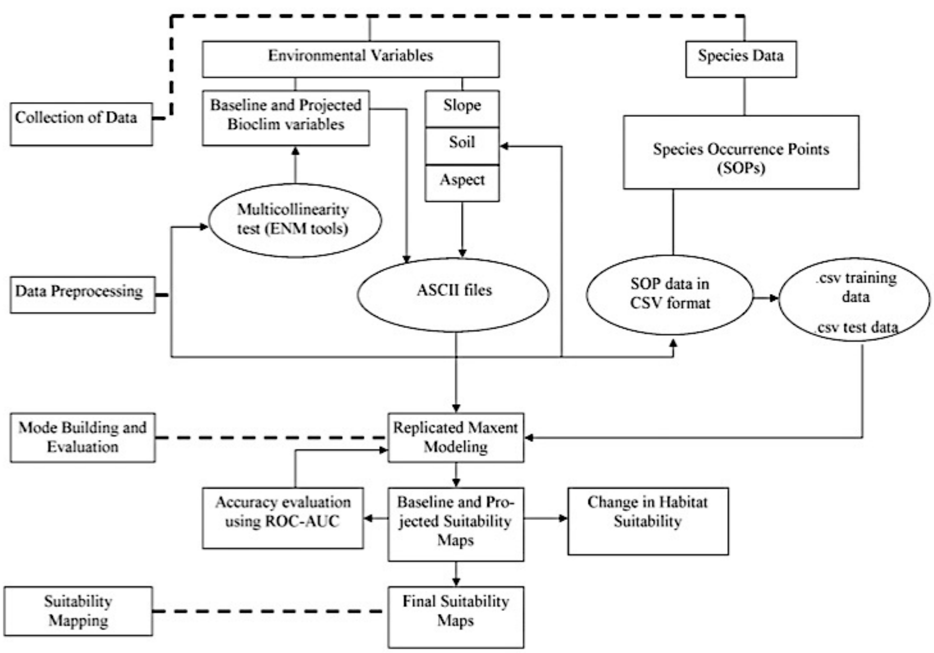

Fig. 4: Conceptual summary of modeling method

positive social perception for the species because of its ecological values such as enhancing soil fertility and controlling soil erosion (Hartemink, 2010), it poses a serious threat to local biodiversity. According to Siges *et al.* (2005), the shrub was able to dominate lowland areas of two Papua New Guinea provinces. Leps *et al.* (2002) suggested that the successful invasion of the species in the mentioned areas can be attributed to it's the wide native geographic range. As the species invades new areas, it is expected that a huge decline in biodiversity will happen. Biological invasion by alien species is known to pose significant losses in biodiversity and health of invaded systems (Padalia *et al.,* 2014). Table 2 shows the number of occurrence points observed and recorded per municipality. Among 22 municipalities, Valencia City had the most number with 72 occurrence points. Based on prior interviews, Valencia city and Quezon were prioritized for sampling because the species has been observed to thrive in the area.

Accordingly, *Piper aduncum* L. grows in areas that receive from about 1, 500 to over 4,000 mm of mean annual rainfall (Francis, 2003). The province is clearly within its precipitation range especially the Southern part. The southern part, beginning from Malaybalay, falls under the IV type or intermediate B type, which has rainfall that is more or less evenly distributed throughout the year (Calalang and Colinet, 2014).

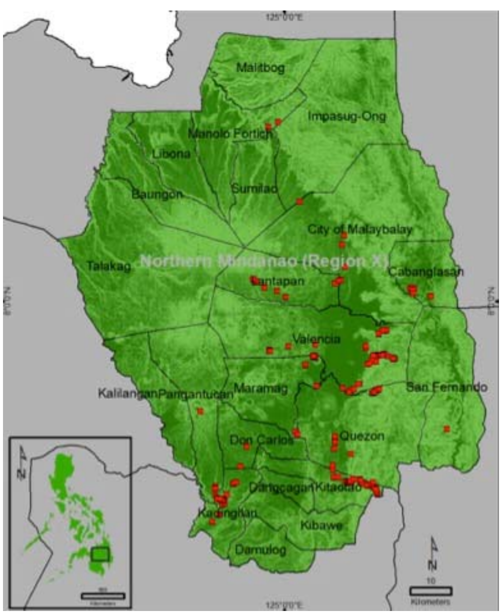

Fig. 5: Actual distribution of *Piper aduncum* L. in Bukidnon province

Current and projected suitability

Current prediction shows that suitable areas for Piper are concentrated along the southern portion of the province (Fig. 6). Suitable bioclimatic conditions for the species prevail in these areas. This finding conforms to the reported occurrence of the species at the south. Relative to its land area, Kitaotao (45.56%), Quezon (36.80%) and Kadingilan (33.11%) gained the greatest proportion of suitable areas. However, in terms of areal coverage, Quezon (23,558 ha) and Valencia city (14,958 ha) are at the top (Table 3).

A significant increase in suitable areas for *Piper* is predicted. As a result of climate change, the distribution of *Piper* is projected to change. Suitable habitats, as projected would increase by 291% percent. An additional 158, 879 ha of land is endangered of being invaded by the species as the range of its bioclimatic suitability widens (Table 3). Gains are mostly found along the central part and the southwestern part of the province.

Highly suitable areas are found in Maramag (69.24%) Kalilangan (51.35%) and Valencia (47.99%) (Table 4). With a gain in suitable areas of 61.35% based on model projections, a large area of Maramag is within the invasion range of *Piper*. Maramag is highly proximate to Quezon, which is also highly suitable for the species.

The areas of Kalilangan and Pangantucan are of higher concern. A portion of Mt. Kalatungan Range Natural Park is there and its biodiversity is in danger. Piper could potentially invade open areas along the buffer zone. Some portions of the buffer zone serve as ecotone where a number of species are found to thrive. Piper could seriously disrupt ecosystem functioning of the area by replacing native plants and grasses. This could lead to the displacement of some key species in the area.

Table 2: Location of species occurrence points

Location	Number	Percentage (%)
Valencia city	75	34
Kitaotao	35	16
Pangatucan	32	14
Quezon	23	10
Maramag	18	8
Kadingilan	13	6
Cabanglasan	7	3
Lantapan	7	3
Malaybalay city	6	3
Manolo Fortich	2	1
Don Carlos	2	1
San Fernando	1	0
Total	221	100

Model accuracy

AUC values indicated strong accuracy of the models, with most AUC values ≥ 0.90. Then mean value is 0.917 with a very small deviation. Only 3 replicates gained a lower AUC. By closely analyzing the AUC of the test data, one can infer that the Maxent model was highly accurate as far accuracy assessment using AUC is concerned. Uncertainties and limitations in the data used are recognized and interpretations of the AUC values depicted in Table 5 must be done with caution.

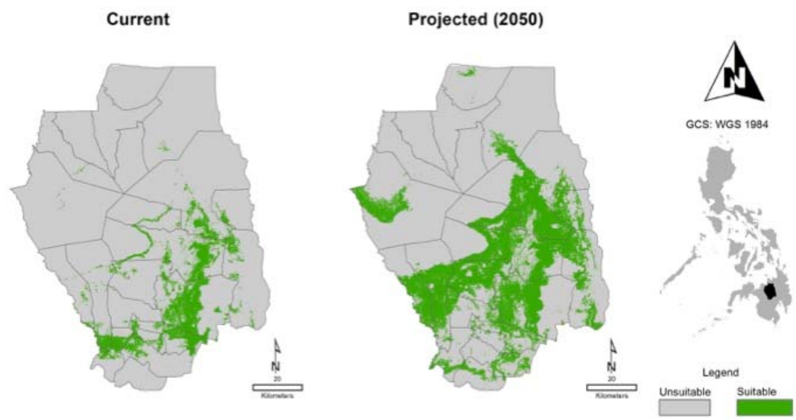

Fig. 6: Current of projected suitability map of *Piper spp.* in Bukidnon

Table 3. Changes in habitat suitability

Index	Description	Area (ha)		Change in % (Gain/loss)
		Current	Projected	
0-.49	Unsuitable	826,773	668, 074	- (19%)
0.50 - 1	Suitable	83,273	241,972	+ (291 %)
Total		910,046	910,046	100

Table 4: Areal and percentile distribution of suitability per municipality

Municipality	Current			Projected (2050)			
	Unsuitable (ha)	Suitable (ha)	Suitable (%)	Unsuitable (ha)	Suitable (ha)	Suitable (%)	Gain/loss in suitability (%)
Baungon	33,006	197	0.59	33139	64	0.19	- 0.40
Cabanglasan	21,086	1,190	5.34	13301	8975	40.29	34.95
Damulog	16,982	52	0.31	14170	2864	16.81	16.51
Dangcagan	5,142	2215	30.11	6437	920	12.51	-17.60
Don Carlos	20,146	237	1.16	13883	6500	31.89	30.73
Impasug-Ong	85,083	392	0.46	80400	5075	5.94	5.48
Kadingilan	11545	5715	33.11	13462	3798	22.00	-11.11
Kalilangan	25596	1206	4.50	13038	13764	51.35	46.85
Kibawe	21566	4112	16.01	19619	6059	23.60	7.58
Kitaotao	10281	8603	45.56	11424	7460	39.50	-6.05
Lantapan	27707	1394	4.79	19278	9823	33.75	28.96
Libona	28249	29	0.10	28272	6	0.02	-0.08
Malaybalay city	103876	7712	6.91	74021	37567	33.67	26.75
Malitbog	35766	0	0.00	34780	986	2.76	2.76
Manolo Fortich	35053	2	0.01	35050	5	0.01	0.01
Maramag	29827	2556	7.89	9960	22423	69.24	61.35
Pangantucan	38808	4442	10.27	23718	19532	45.16	34.89
Quezon	40466	23558	36.80	34808	29216	45.63	8.84
San Fernando	51323	4514	8.08	38385	17452	31.26	23.17
Sumilao	25952	0	0.00	25952	0	0.00	0.00
Talakag	101210	151	0.15	86651	14710	14.51	14.36
Valencia	57663	14958	20.60	37769	34852	47.99	27.39

Variable contributions

Percent variable contribution in Maxent depicts the importance of each variable to the model. Bio 18 (precipitation of the warmest quarter) gained the strongest contribution with a mean of 22.1% (Table 6). The said variable obtained consistent contributions across 10 replicate runs. Bio 13 (Precipitation of the wettest month) had 16.6%. Piper is a tropical plant species, which prefers optimal wet and warm climate to grow and survive. It is important to note that climate is a driver of species distribution as manifested by the variables that gained the strongest contribution. Many literatures support the idea that climate is the main factor regulating species distribution (Paquit *et al.,* 2017).

Table 5: Computed AUC values for training and test data

Replication	AUC	
	Training	Test
C1P1	0.949	0.932
C2P2	0.949	0.926
C3P3	0.953	0.930
C4P4	0.951	0.924
C5P5	0.961	0.887
C6P6	0.954	0.887
C7P7	0.954	0.898
C8P8	0.949	0.922
C9P9	0.952	0.934
C10P10	0.951	0.929
Mean	0.952	0.917
SD*	0.004	0.019

*Standard deviation

Slope and aspect were at 7th and 14th respectively. 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). Being correlated with solar radiation, slope and aspect can greatly affect ecologically critical factors such as surface temperatures, evaporative demand and soil moisture content (Paquit *et al.* 2017). Soil clearly have an influence, however, the scale of might have affected the contribution of this variables.

Implications on alien invasive species management

Piper spp. is a known IAS in the region, colonizing large tracts of marginal lands replacing *Imperata spp*. At present, it continues to spread to areas that are within its bioclimatic range. The identification of its current and future distribution would be very crucial for its management strategies (Davies *et al.,* 2009). It is alarming to see that its spread would even increase because of climate change. This could result to the degraded of habitat quality and loss of biodiversity. *Piper* could potentially alter the natural ecosystem of the area by displacing endemic species. Moreover, this predicted spread poses a challenge to the land use managers in the area. This is a challenge for both the Local Government Unit and the Environment Department, as this would impact local livelihood. There are various negative impacts of IAS that are

Table 6. Percent variable contribution to the Maxent model

Variable	C1P1	C2P2	C3P3	C4P4	C5P5	C6P6	C7P7	C8P8	C9P9	C10p10	Mean
Bio 18	20.8	24.9	24.3	22.3	21.8	22	25.1	18.5	18.1	23.8	22.1
Bio 13	15	17.4	18.6	17	17.6	12.4	20.1	14.5	17.2	15.9	16.6
Bio 15	11.1	11.5	8.1	17.7	5.5	15.1	9.7	15.3	7.1	9.2	11
Bio 17	9.4	6.2	15.9	7.1	10.3	7	20.1	4	10.3	17.6	10.8
Bio 5	12.4	13.1	8.8	7	1.6	10.2	5.5	10.9	13.8	7.4	9.1
Bio 14	9.6	10.8	9	9.4	7	5.7	2.7	13.2	11.2	5.7	8.4
Slope	7.2	6.4	5.4	6.9	8	5.7	7.7	8.2	7.4	7.1	7
Soils	5	0.4	1.8	2.1	2	4.8	0.5	5	3.9	1.4	2.7
Bio 12	2.5	1.7	2.5	1.7	2.6	2.3	2.4	3.4	2.5	2.7	2.4
Bio 9	2.6	1.9	1.1	4.1	0.8	4.4	1.7	1	0.9	2.3	2.1
Bio 1	0.2	0.8	0.5	0.8	15.7	1.3	0	0.6	0.9	0.3	2.1
Bio 4	1.4	1.3	1.6	1.5	2	3	2	1.7	3	0.5	1.8
Bio 16	0.9	1.3	1	0.3	1.2	3.4	0.6	1.5	1.1	2.8	1.4
Aspect	0.9	1.3	0.9	0.8	0.7	0.8	0.7	1.2	1	0.8	0.9
Bio 7	0.2	0.3	0.7	0.8	2.6	1.3	0.8	0.3	0.1	0.7	0.7
Bio 2	0.5	0.4	0.2	0.2	0.3	0.2	0	0.6	1.1	1.4	0.5
Bio 3	0.5	0.2	0.3	0.3	0.5	0.5	0.3	0.2	0.3	0.5	0.3

not seen directly. It is therefore high time for the local resource managers to undertake interventions to prevent the spread of the species.

CONCLUSION

The use of Species distribution modeling through Maxent has proven to be an effective way in assessing the potential impact of climate change to the spread of an invasive plant species. Bioclimatic variables are also very useful for this purpose. The use of other factors aside from climate must be studied first as scale in an important consideration (Pearson and Dawson, 2003). The suitable bioclimatic envelope of the species under study is predicted to widen because of climate change. Previously unsuitable area could become suitable for the species. Because of this, these areas could potentially be within the invasion range of *Piper* if the precipitation and temperature shifts will go as projected. This would have tremendous effects on local biodiversity and to local livelihood. This prompts effective action to stakeholders to proactively undertake actions to prevent this from happening.

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CONFLICT OF INTEREST

The authors and data providers did not encounter any conflict in the implementation of the study and publication of its results.

ABBREVIATIONS

ASCII	American Standard Code for Information Interchange
AUC	Area Under Curve
ASTER	Advanced Space-borne Thermal Emission and Reflection Radiometer
Bio	Bioclim
C,P	Current, Projected
DEM	Digital elevation model
DENR	Department of Environment and Natural Resources
ENM	Ecological niche models
EVs	Environmental Variables
GeoCam	Geotagging Camera
GIS	Geographic information system
GNSS	Global navigation satellite system
GPS	Global positioning system
ha	Hectare
IDW	Inverse distance weighted
SOPs	Species occurrence points
L.	Linnaeus
Maxent	Maximum entropy
NAMRIA	National mapping and resource information authority
PAGASA	Philippine Atmospheric, Geophysical and Astronomical Services Administration
RCP	Representative concentration pathway
ROC	Receiver operating characteristic
SD	Standard deviation
SDM	Species distribution modeling
USGS	United States Geological Survey

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AUTHOR (S) BIOSKETCHES

Paquit, J.C., M.Sc., Forest Biological Sciences, College of Forestry and Environmental Science, Central Mindanao University, Maramag, Bukidnon, Philippines. Email: *jcpaquit@cmu.edu.ph*

Rama, R.I.P., BSF., Department of Environment and Natural Resources, Talakag, Bukidnon, Philippines. Email: *rip_rama@hotmail.com*

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