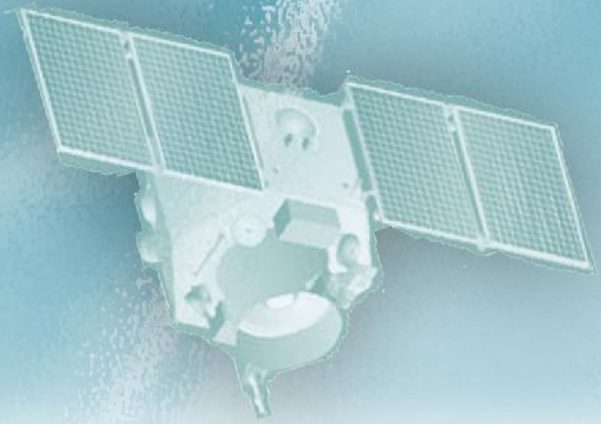

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HABITAT SUITABILITY ANALYSIS OF THE STARCH-RICH SAGO PALM USING SATELLITE-DERIVED DATA AND A SPECIES DISTRIBUTION MODEL

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ABSTRACT

We utilized satellite-derived datasets and a species distribution model in finding areas in Visayas and Mindanao, Philippines that are suitable to plant Sago palms. The locations of existing sago palm stands were detected through analysis of satellite images (ALOS AVNIR-2, ASTER VNIR, Envisat ASAR and WorldView-2) and conduct of field surveys. From a database of confirmed sago palm stand locations, samples were randomly taken for habitat characterization and suitability analysis. Biophysical and bioclimatic characteristics of the actual sago palm habitats were determined through GIS overlay analysis with the different biophysical and bioclimatic data layers that included elevation, slope, soil texture, and WordClim - a set of 19 global climate layers depicting temperature and precipitation. Basic statistical analysis was then conducted to explore the ranges of biophysical and bioclimatic values of the sago palm habitats in Visayas and Mindanao which could then assist in understanding the characteristics of these habitats. Habitat suitability analysis consisted of two steps: finding suitable areas based on biophysical characteristics, and finding suitable areas based on bioclimatic characteristics using a species distribution model called DOMAIN. The results of both steps are raster grids, with pixel resolution of 1 hectare. Each pixel is coded as 0 for "not suitable" and 1 for "suitable". The final suitability map is then obtained by multiplying the two raster grids. Further refinement to the map was done by identifying areas with optimal conditions set by the Food and Agriculture Organization. Results show a total of 1,003,142 hectares of suitable areas in all of Visayas and Mindanao of which 102,470 hectares are found to have optimal conditions for Sago palm to grow.

Keywords: Sago palm, habitat suitability analysis, WorldClim, DOMAIN, remote sensing, Philippines

INTRODUCTION

The sago palm (*Metroxylon Sagu Rottb.*), as shown in Figure 1, is a pinnate-leaved palm occurring in the hot humid tropics of South-East Asia and Oceania. The palm grows well in humid tropical lowlands, up to an altitude of 700 m, with temperature above 25°C, and in clayey soils with a high organic matter content yield (Flach, 1997). Its trunk contains starch and used as a staple food for humans in South-East Asia. Once planted, a regular succession of suckers is produced from the lowest part of the trunk, forming a cluster in various stages of development. Although the initial waiting period after planting is long (up to 10 years for the plant to be harvestable), Sago is the

Figure 1. Sago palm clusters in Agusan del Norte, Mindanao, Philippines.

highest starch producer at 25 tons per hectare per year (Bujang, 2008). It is now grown commercially in Malaysia, Indonesia and Papua New Guinea for production of sago starch and/or conversion to animal food or fuel ethanol (McClatchey et al., 2006). The largest sago palm plantation can be found in Sarawak, Malaysia wherein between 30,000 to 50,000 tons of sago starch have been exported annually, procuring incomes of between US$3.4 million to US$10.8 million (Bujang, 2008).

Aside from its economic benefits and as potential source of raw material for biofuel production, there are also environmental benefits in the propagation of Sago palms. Its large fibrous root system traps silt loads and removes pollutants, faecal contaminants, and heavy metals (Singhal et al., 2008). Sago forest also acts as an excellent carbon sink for carbon sequestration, thereby mitigating the greenhouse effect and global warming arising from the release of carbon dioxide into the atmosphere due to industrialization, and increase in the number of motorized vehicles (Stanton, 1991; Singhal et al., 2008). Throughout the years, interest in Sago palm has increased considerably because it is: economically acceptable; relatively sustainable; environmentally friendly; uniquely versatile; vigorous, and promotes socially stable agroforestry systems (Flach, 1997).

Because of the sago palm's significant and relatively balanced economic and environmental benefits, there has been keen interest by the Philippine government for its mass propagation in order to develop and sustain a large-scale sago starch industry that can supply raw materials for food and non-food uses, as well as for production of high value products such as ethanol and lactic acid. For this to be realized, finding areas that are suitable for sago palms to grow is a crucial step.

In this paper, we present the utilization of satellite-derived datasets and a species distribution model in finding areas in Visayas and Mindanao, Philippines that are suitable to plant Sago palms.

MATERIALS AND METHODS

The methods employed in this study consist of mapping actual locations of Sago palms in Visayas and Mindanao, conduct of biophysical and bioclimatic characterization using a subset of actual Sago palm locations, and suitability mapping using biophysical and bioclimatic data together with a species distribution model.

Sago palm mapping based on satellite-derived datasets and field surveys

We used a multi-source approach in mapping Sago palms in Visayas and Mindanao. This consisted of applying the Maximum Likelihood Classifier (MLC) to a stack of calibrated and co-registered ALOS AVNIR-2 images, NDVI, Envisat ASAR images, and an ASTER GDEM. This approach, which has been tested on multi-source datasets of Agusan del Norte in Mindanao, Philippines, has an overall classification accuracy of 95.82%, and Producer's and User's Accuracy for Sago palm of 96.26% and 91.37%, respectively (Santillan, 2013). ASTER VNIR images were also used in areas where ALOS AVNIR-2 images are not available. For areas where only optical images are available (ALOS AVNIR-2 and ASTER), the MLC was just applied to these datasets with incorporation of NDVI and ASTER GDEM. This latter approach has classification accuracy greater than 85%. All Sago palm locations mapped using these approaches were confirmed and refined by using 0.5-m resolution Worldview-2 images together with field surveys. A total of 1,250 hectares of Sago palms were mapped, of which 733 hectares have been confirmed.

Datasets used for Sago palm habitat characterization and suitability analysis

A sample set consisting of 1,767 unique locations were randomly selected from the map of confirmed Sago palms. From the total number of generated samples, 80% were selected for exploratory statistical and habitat suitability analysis while the remaining 20% were used for validating the habitat suitability maps. The number of samples generated for Visayas and Mindanao are summarized in Table 1 with their locations depicted in Figure 2.

Table1. Number of samples representing actual sago palm locations in Visayas and Mindanao used for exploratory statistical and habitat suitability analysis.

Locality	No. of Training Samples (80%)	No. of Validation Samples (20%)	Total Number of Samples
Visayas	404	103	507
Mindanao	1,008	252	1,260
Total	1,412	355	1,767

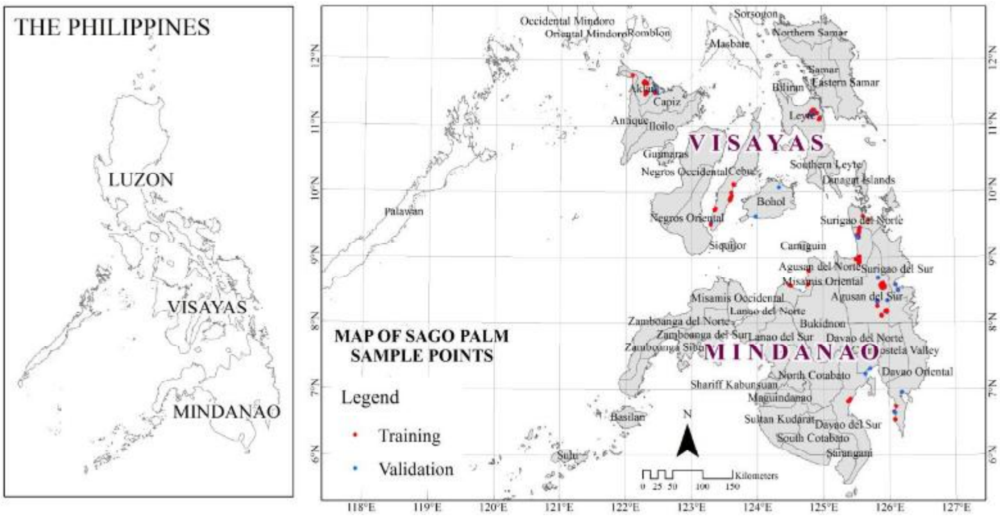

Figure 2. Map of the study area showing the location of actual Sago palm locations used for habitat characterization and suitability analysis.

Biophysical datasets used in the analyses include elevation from SRTM DEM (ELEV), slope computed from the SRTM DEM (SLOPE), and soil texture (SOIL) obtained from the Bureau of Soils and Water Management of the Philippines' Department of Agriculture.

For the bioclimatic characterization, we used WorldClim version 1.4, a dataset consisting of global climate surfaces interpolated using time series of temperature and rainfall data measured between 1950 – 2000 at different meteorological stations throughout the world with a 30 arc-second spatial resolution (approximately 1 km x 1 km). WorldClim has 19 global climate grids depicting temperature and precipitation (Table 2) that can be used for mapping and spatial modeling in a GIS or with other computer programs. This dataset is well documented in Hijmans et al. (2005), and has been used in a variety of plant species distribution and habitat suitability modeling studies (e.g., Maes et al., 2009).

Table 2. The 19 climate grids in WorldClim version 1.4.

Temperature Layers	Symbology	Precipitation Layers	Symbology
Annual mean temperature	BIO1	Annual precipitation	BIO12
Mean diurnal range	BIO2	Precipitation of wettest month	BIO13
Isothermality	BIO3	Precipitation of driest month	BIO14
Temperature seasonality	BIO4	Precipitation seasonality	BIO15
Max temperature of warmest month	BIO5	Precipitation of wettest quarter	BIO16
Min temperature of coldest month	BIO6	Precipitation of driest quarter	BIO17
Temperature annual range	BIO7	Precipitation of warmest quarter	BIO18
Mean temperature of wettest quarter	BIO8	Precipitation of coldest quarter	BIO19
Mean temperature of driest quarter	BIO9		
Mean temperature of warmest quarter	BIO10		
Mean temperature of coldest quarter	BIO11		

Biophysical and bioclimatic characterization of Sago palm habitats

Biophysical and bioclimatic characteristics of the actual sago palm habitats were conducted through overlay analysis of selected confirmed Sago palm locations with the biophysical and bioclimatic datasets. ArcGIS was used to extract the biophysical and bioclimatic values at each sampling location. Basic statistical analysis was then conducted to determine the frequency of sago training samples according to each data layer, as well as to get the minimum, mean and maximum values. The purpose of the statistical analysis is to explore the ranges of biophysical and bioclimatic values of the sago palm habitats in Visayas and Mindanao which could then assist in understanding the characteristics of these habitats.

Habitat suitability analysis

Habitat suitability analysis was conducted primarily to search for lands in Visayas and Mindanao where sago palms can grow based on biophysical and bioclimatic factors. A one hectare (100 m x 100 m) mapping unit was utilized upon the assumption that 1 ha corresponds to the unit of decision making for agricultural or forestry management. The suitability analysis consisted of two steps: (1) finding suitable areas based on biophysical characteristics; and (2) finding suitable areas based on bioclimatic characteristics. The results of both steps are raster grids, with pixel resolution of 1 hectare (100 x 100 m). Each pixel is coded as 0 and 1: 0 is "not suitable" and 1 is "suitable". The final suitability map is then obtained by multiplying the two raster grids.

Step 1 of the suitability analysis is dependent of the results of the exploratory statistical analysis. The ranges of elevation and slope values and the type of soil textures of the sago palm training samples are used to create the biophysical habitat suitability map ($SUIT_{BIOPHYSICAL}$). The following decision rule is implemented in each pixel of ELEV, SLOPE and SOIL raster grids:

$$SUIT_{BIOPHYSICAL} = \left\{ \begin{array}{l} 1 \quad \text{if} \quad \min_{ELEV} \leq ELEV_i \leq \max_{ELEV} \ \text{ AND} \\ \qquad\quad \min_{SLOPE} \leq SLOPE_i \leq \max_{SLOPE} \ \text{ AND} \\ \qquad\quad SOIL = \left(SOIL_1 \text{ OR } SOIL_2 \text{ OR } SOIL_3 \ldots \text{ OR } SOIL_n\right) \\ \qquad \text{else} \\ 0 \end{array} \right\} \qquad (1)$$

In the above equation, i is a 100x100m pixel in a layer stack of ELEV, SLOPE and SOIL. The variables $\min_{ELEV}$, $\max_{ELEV}$, $\min_{SLOPE}$ and $\max_{SLOPE}$ are the minimum and maximum values of elevation and slope in the sago sample locations or as obtained from the sago palm literature. $SOIL_1$, $SOIL_2$, $SOIL_3$, $SOIL_n$ are the soil textures in the sago sample locations. The basis for the above rule is simple: the fact that a sago palm stand has been found in a location within the elevation and slope ranges and with the soil texture as determined through overlay analysis is a good indication that sago palm can grown in other areas with the same biophysical characteristics.

The goal in Step 2 is to find those other areas that have similar bioclimatic conditions to those areas where Sago palm actually grows. Here, a species distribution model called DOMAIN was used. DOMAIN (Carpenter et al., 1993) derives a point-to-point similarity metric called the "Gower metric" to assign a classification value to a potential suitable site based on its proximity in environmental space to the most similar occurrence. The Gower metric, which is the sum of the standardized distance between two points for each predictor variable, is used to quantify the similarity between two sites. The standardization is achieved using the predictor variable range at the presence sites to equalize the contribution from each predictor variable. Similarity is then calculated by subtracting the distance from 1. The maximum similarity between a candidate point and the set of known occurrences is assigned to each grid cell within the study area; these similarity values are degrees of classification confidence.

The DOMAIN model was implemented in DIVA GIS version 7.5 to generate potential distribution grids for Sago palms. All the 19 bioclimatic variables were used inputs in these 2 models based upon the argument that inclusion of further variables (instead of a just a selection) provides for a more useful discrimination of potentially suitable habitat. Also, all the 19 variables are considered to be relevant and effectively represents correlates of physiological tolerance of sago palms, as described in McClatchey et al. (2006) and as listed in the Ecrocrop Datasheet for *Metroxylon sagu* (FAO, 2007). The output of the DOMAIN model was reclassified to values of zero or one for unsuitable or suitable using the similarity index cutoff of 0–0.95 and 0.95– 1.0, respectively as has been done in Vargas et al (2004). This means all the areas classified as "suitable" are 95% or more similarity with the bioclimatic characteristics of actual Sago palm habitats. The output suitability map is referred to as $SUIT_{BIOCLIMATIC\text{-}DOMAIN}$.

In order to generate the final habitat suitability map, the $SUIT_{BIOPHYSICAL}$ map (result of Step 1) was multiplied with $SUIT_{BIOCLIMATIC\text{-}DOMAIN}$ (result of Step 2). The final map was then subjected to accuracy assessment by overlaying the 355 validation samples. Further refinement in the suitability map was done by finding those suitable areas that have optimal conditions for Sago palm propagation. The criteria based on the FAO Ecocrop (FAO, 2007) suggest that a suitable area is considered to have optimal conditions if it satisfies all the following conditions:

- Annual Mean Temperature Range: 25 – 36 degrees Celsius
- Annual rainfall/precipitation: 3000 – 4,500 mm

- Soil type: soils with poor drainage (e.g., clay, silty clay, sandy clay) or soils which are saturated more than 50% of a year (e.g., hydrosol, peatlands)

RESULTS AND DISCUSSION

Biophysical characteristics of Sago palm habitats

Table 3 and Figure 3 show the elevation and slope characteristics of Sago palm habitats. It appears that the most of the sago palm habitats are located in lowly elevated and flat areas.

In terms of elevation characteristics, majority of all sago palm habitats are located within 0 to 50 meters from Mean Sea Level (MSL), while the rest are located in areas with elevation starting from 51 meters. However, there were no habitats that are located in areas with elevation greater than 437 meters. Based on the basic statistics of all samples, the elevation range is from 2 to 437 meters above MSL, with an average of 37 meters. On the average, Sago palm habitats in Visayas are located in higher elevations (average of 63 m) than those habitats in Mindanao (average of 26). In Visayas, sago palm habitats can be found in areas with elevation up to 437 m. On the other hand, habitats in Mindanao have maximum elevation of 97 m.

In terms of slope characteristics, most of the sago palm habitats are located in flat areas (0 to 3% slope). Although some habitats were found in areas with slopes greater than 3%, the number of habitats is low. In terms of locality, some sago palm habitats in Visayas exist in moderately steep areas while this is not true for Mindanao habitats. On the average, it can be observed that in both localities the slope characteristics are similar. The average slope for Visayas is 2% while the average slope for Mindanao is 4%. But looking into the range, habitats in Visayas is more widespread because they can exist in areas with slope up to 31%.

Table 3. Elevation and slope characteristics of Sago palm habitats of sago palm habitats based on a training dataset consisting of 1,412 sago palm locations in Visayas and Mindanao.

Dataset	Average Elevation and Range (m)	Average Slope and Range (%)
All Samples	37 (2 - 437)	2 (0 - 31%)
Visayas Only	63 (2 - 437)	4 (0 – 31)
Mindanao Only	26 (2 - 97)	2 (0 – 18)

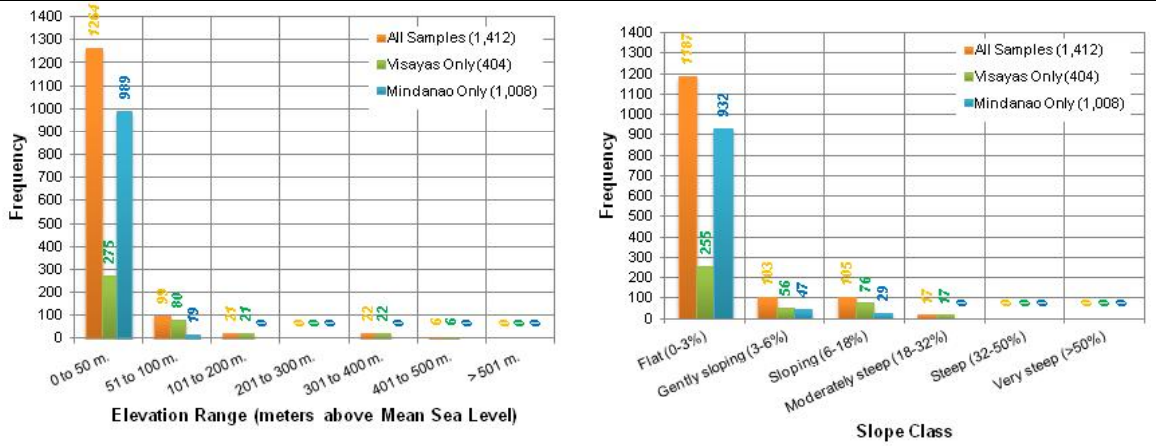

Figure 3. Graphs showing the elevation ranges and slope classes of Sago palm habitats based on a training dataset consisting of 1,412 actual Sago palm locations in Visayas and Mindanao.

Figure 4 show the soil textures of the sago palm habitats in Visayas and Mindanao. Based on these figures, it appears that the most of the sago palm habitats have clayey soils, followed by loam soils and hydrosol. Hydrosols are soils where a greater part of the profile is saturated for at least several months per year. Some habitats have combination of clay, loam, sand and silt soils. In terms of locality, sago palm habitats in Mindanao are more varied in soil textures compared to Visayas habitats. Mindanao habitats were found to have seven soil textures (clay, clay loam, hydrosol, loam, sandy loam, silt loam and silty clay loam). It is also worth noting that only Mindanao sago palm habitats have loam soil texture, which is also the major texture in this locality. In Visayas, the major soil texture is clay.

The differing topographic characteristics of sago palm habitats in Visayas and Mindanao can be explained by the nature of the sago palm stands. As verified during the field surveys, most of the sago palms in Mindanao can be found in the wild, especially in the Agusan Marsh. They are being harvested mostly by the Manobo tribes for food uses. These stands are limited to narrower range of elevation and slope. In contrast, most of the sago palm stands in Visayas were cultivated by farmers who utilize the leaves of the palm as roofing materials (shingles). As these palms are being planted, it could then be understood that in Visayas, they are found at a wider range of elevation and slope (i.e., even at highly elevated and slope areas). This confirms the report by McClatchey et al. (2006) that sago palms growing away from lowland areas are the result of human cultivation.

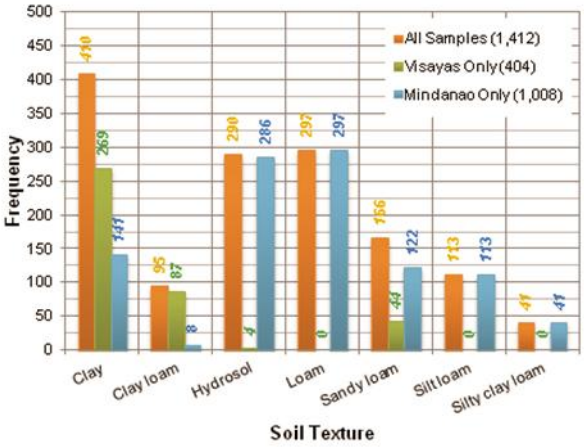

Figure 4. Sago palm clusters in Agusan del Norte, Mindanao, Philippines.

Bioclimatic characteristics of Sago palm habitats

Figure 5 depict the average values of WorldClim temperature and precipitation variables of Sago palm habitats in Visayas and Mindanao. The graph indicates the degree of hotness or coldness at the locations of the sago palm habitats.

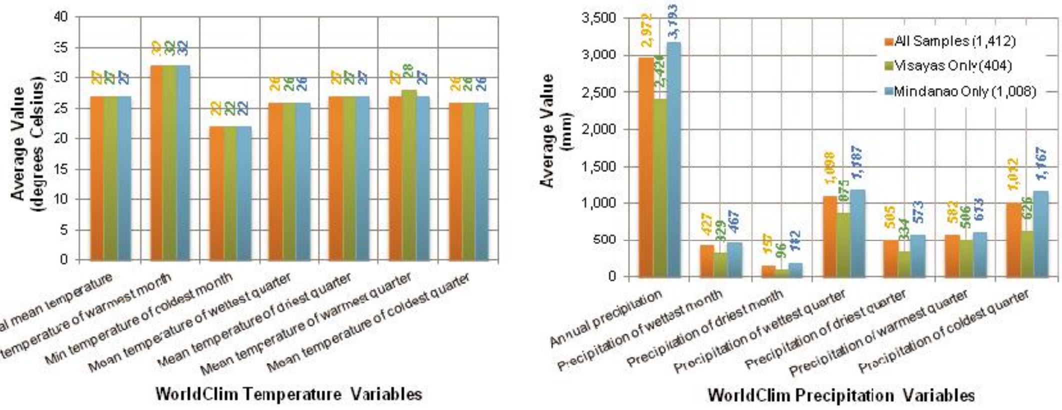

Figure 5. Average values of WordClim temperature and precipitation in actual Sago palm habitats in Visayas and Mindanao.

All Sago palm habitat locations in Visayas and Mindanao have the same average annual temperature of 27^{o}C. During the warmest month of the year, maximum temperature in these locations reaches 32^{o}C while in the coldest month, the temperature goes down to an average of 22^{o}C. In the wettest quarter of the year (when precipitation is maximum), the average temperature is 26^{o}C which is slightly lower than the average annual temperature. In the driest quarter (when precipitation is minimum), the average temperature is 27^{o}C which is the same as the average annual temperature. Both of these average temperature values are the same in both Visayas and Mindanao habitat locations. During the warmest quarter, the mean temperature in all sago habitat locations is 27^{o}C. This is the same temperature for Visayas sago habitat locations but for Mindanao, the mean temperature is higher and reaches 28^{o}C. This means that it is warmer in Visayas than in Mindanao during the warmest quarter of the year. On the other hand, the mean temperature during the coldest quarter is the same with the mean temperature during the wettest quarter (26^{o}C).

Figure 5 also indicates the average amounts of rain that falls over the sago palm habitat locations throughout the year (annual), during the wettest and driest month and quarter, as well as during the warmest and coldest month and quarter. The overlay analysis of sampling point locations with

WorldClim precipitation layers showed that all the sago palm habitat locations receive an average of 2,972 mm of rain in a yearly basis. In terms of locality, it appears that Mindanao habitat locations receive more rainfall (3,193 mm) than those habitats located in Visayas (2,420 mm). The same pattern (i.e., higher rainfall depth in Mindanao than in Visayas) is observed during the wettest and driest month and quarter, as well as during the warmest and coldest month and quarter. As rainfall amount is greater in Mindanao than in Visayas, it may suggest that the soils of sago palm habitat locations in Mindanao are high in moisture than those in Visayas.

Sago palm suitability map

The results of the exploratory statistical analysis of biophysical and bioclimatic characteristics of sago palm habitats in Visayas and Mindanao provided important information on deriving a very basic relationship to determine if the biophysical and bioclimatic characteristics of a certain locality are suitable for sago palm to grow.

Using the field data combined with information from published sago palm literature (McClatchey et al, 2006; FAO, 2007), the rule for biophysical suitability (see Equation 1) has been updated as follows by setting ELEV range to 1-700, SLOPE range to 0-31%, and setting all kinds of soil textures that are in actual Sago palm habitats (clay, clay loam, hydrosol, loam, sandy loam, silt loam or silty clay loam.

The final suitability map which is the product of the biophysical and bioclimatic suitability maps is shown in Figure 6. In this final map, the suitable areas with optimal conditions are already are shown. It has an accuracy of 93.52% (332 of the 355 validation points were correctly classified as suitable). This high accuracy may be due to the realistic nature at which this map was generated. It contains suitability patterns that are most consistent with the known ecology of the Sago palm. The map is also logical and appropriate for findings suitable areas because the map specifically informs the user that all areas indicated as "suitable" have greater similarities to the biophysical and bioclimatic characteristics of actual Sago palm habitats. The statistics of Sago palm suitable areas are shown in Table 4.

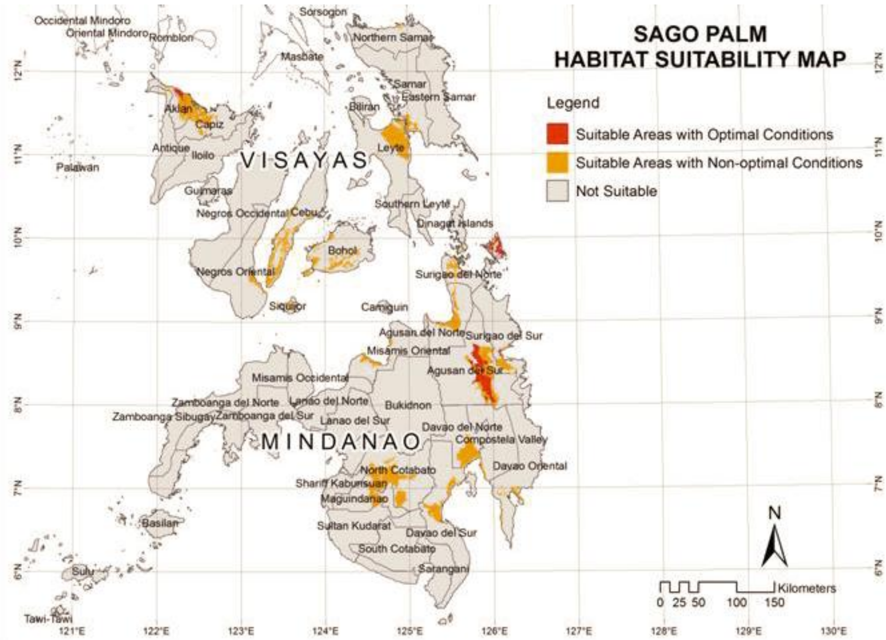

Figure 6. The final Sago palm suitability map.

Table 4. Statistics of Sago palm suitable areas in Visayas and Mindanao, Philippines

Locality	Suitable With Optimal Conditions (in hectares)	Suitable Non-Optimal Conditions (in hectares)	Total (in hectares)
Visayas	9,811	383,287	393,098
Mindanao	92,659	517,385	610,044
Total	102,470	900,672	1,003,142

CONCLUSION

In this study, we have conducted habitat suitability analysis of sago palms in Visayas and Mindanao. The suitability analysis was aided by (1) actual Sago palm location data derived from the analysis of satellite datasets and field surveys, and (2) exploratory statistical analysis that determined the biophysical and bioclimatic characteristics of known sago palm habitats. The suitability map shows a total of 1,003,142 hectares of suitable areas in all of Visayas and Mindanao of which 102,470 hectares are found to have optimal conditions for Sago palm to grow. While the study was able to identify specific locations of sago palm suitable areas, the locations identified as "suitable" should be interpreted as areas that have the biophysical and bioclimatic conditions suited for growing sago palm. Factors such as existing land-uses/land-cover in the suitable areas, and socioeconomic conditions are not yet accounted. These factors must be accounted in order to narrow down the suitable areas only to those locations where it is indeed possible to grow sago palms (e.g., you cannot grow sago palms in built-up areas). An example of this would be determining whether a "suitable" area in the map has other land-uses (e.g., forest, protected area, cropland, grassland, etc.), and determining whether these suitable areas have favorable conditions for sago palms to be propagated at plantation scale (i.e., nearness to water supply, roads, processing plants, etc.). All these are considered for future studies.

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