Species-site Suitability Assessment of Native Species in Pantabangan-Carranglan Watershed Using Geographic Information System (GIS) and Analytic Hierarchy Process (AHP)

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Reforestation activities were employed in several locations of the Philippines due to deforestation. However, many of these efforts fail because of various reasons, one of which is the poor selection of species. This study aimed to improve chances of success of reforestation in one of the critical watersheds in the Philippines, the Pantabangan-Carranglan Watershed (PCW), through a Geographic Information System (GIS)-based species-site suitability assessment of selected native tree species. Thematic maps of soil properties, climate, topography, and biotic conditions were generated for the watershed. The silvical requirements of the selected native species were also established through a literature review. Thereafter, a species-site suitability analysis was done using a GIS platform with the importance of each site feature given different weights through an Analytic Hierarchy Process (AHP), an approach that hasn't been done in previous GIS-based species-site suitability assessment. Results showed that of the three species analyzed, "akle" [*Albizia acle* (Blanco) Merr.] was found to be the most suitable in the site, with 53% of the watershed falling under high suitability class, while "dita" [*Alstonia scholaris* (L) R. Br.] and "almaciga" [*Agathis philippinensis* (Warb.)] were both found to be suitable to the identified reforestation areas of PCW, signifying that they are able to potentially survive within the existing environmental conditions of the site. The generated spatial distribution maps of species-site suitability can serve as guides to the managers of the watershed in future reforestation activities.

Keywords: Analytic Hierarchy Process, Geographic Information System, silvics, species-site matching

INTRODUCTION

Watershed is an area of land that catches water from the atmosphere that falls to the ground through precipitation and is either taken up by the existing vegetation of the land, retained in the soil within its boundaries or percolates through the soil and is stored underground

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(Johnson and Bedell 2002). The water that is contained within the watershed sustains the urban, agricultural, and environmental needs of the community that lives within its boundaries – composing of humans, plants, and animals (Shukla 2004). Forest plays an essential role in maintaining the crucial functions of a watershed by actively influencing "the water cycle through the modification of soil properties and water flows, or the evapotranspiration of substantial amounts of water"

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(Hlásny *et al.* 2015). The severe loss of forest cover due to deforestation results in the occurrence of adverse hydrological events such as floods and droughts (Hlásny *et al.* 2015).

The PCW is one of the critical watersheds in the Philippines. It has various functions in the aspect of irrigation system and the production of electricity that sustains several households within its premises having "a total service area of 102,532 ha covering municipalities in the provinces of Nueva Ecija, Bulacan, and Pampanga" (Peras *et al.* 2008). However, the PCW suffered from extreme deforestation in the country, especially due to the persistence of timber harvesting from 1972–1981 (Peras *et al.* 2008).

In order to mitigate the effects of deforestation that damaged watersheds, projects aiming to restore forestlands of exhausted conditions were implemented in the different regions of the country throughout the years. Most of these projects encountered problems and constraints involving the use of exotic over indigenous species, inadequate site characterization, and poor species-site matching, which lead to substandard results (Carandang and Lasco 1998).

"The process of selecting the most appropriate species to be planted considering the prevailing conditions in the proposed planting area is very difficult because complete information on the site factors is lacking" (Carandang and Lasco 1998). To aid this process, a GIS approach can be done. GIS is a modern tool wherein information regarding specific features of land areas within the site like elevation, precipitation, and soil texture can be laid out and mapped. It has been applied in various studies like selecting suitable habitats for wildlife (Kliskey *et al*. 1999). Several initiatives have also been done with regard to its use in species-site matching. For instance, Galang (2010) identified 578 out of 4,244 ha of land that is highly suitable for planting "narra" (*Pterocarpus indicus* Willd.) in the Mt. Makiling Forest Reserve, Laguna using GIS. Likewise, Sarmiento and Casas (2015) also identified suitability of selected species in Mt. Mayapay Watershed, Butuan City using a GIS platform where they found out that majority of the area is moderately suitable for *Acacia mangium* (Willd.), *Spathodea campanulata* (Beauv.), and *Swietenia macrophylla* (King).

The use of GIS can also be enhanced through the application of the concept of AHP. AHP is a multi-criteria decision-making approach that derives ratio scales from paired comparisons of either quantitative data including price and height, or qualitative data including emotion and preference (Alonso and Lamata 2006). In the Philippines, several works have been done incorporating AHP with GIS for various purposes. Sandoval and Tiburan (2019) used AHP and GIS in the identification of groundwater recharge sites in Mt. Makiling Forest Reserve wherein they were able to find out that ~ 84% of the area is moderately suitable for artificial groundwater recharge. Similarly, Arizapa and co-authors (2015) used the same approach in locating landslide susceptible areas in Pagsanjan-Lumban watershed. Elsewhere, GIS and AHP have also been used in various studies like land-use suitability assessment (Akinci *et al.* 2013), selection of sites for solar photovoltaic power plant (Al Garni and Awasthi 2017), locating best sites for sanitary landfill (Kara and Doratli 2012), and identifying flood-prone areas (Liu *et al.* 2008). To date, however, no one has combined the use of AHP and GIS in the development of species-site suitability for any site in the Philippines.

This study determined the suitability of selected native tree species in the PCW, namely, "dita" [*Alstonia scholaris* (L) R. Br.], "akle" [*Albizia acle* (Blanco) Merr.], and "almaciga" [*Agathis philippinensis* (Warb.)], using GIS and AHP. Specifically, it aims to: 1) identify areas within PCW that need reforestation; 2) generate a weight for each site factor; 3) determine the most suitable species among the three; and 4) identify areas within the degraded sites of the watershed that are ideal for planting the selected species.

MATERIALS AND METHODS

Description of the Study Site
The PCW lies within 15°34'51.66" and 16°6'49.81" north latitude, and 120°59'58.15" and 121°23'8.57" east longitude (Figure 1). It is located in Central Luzon, comprising of several municipalities in the provinces of Nueva Ecija, Nueva Vizcaya, and Aurora. The watershed covers a total area of 133,242 ha. It is bounded on the north, northwest, and northeast by the Caraballo Mountain Ranges while the Sierra Madre Ranges bound the south, southeast, and southwest portions. The municipality of
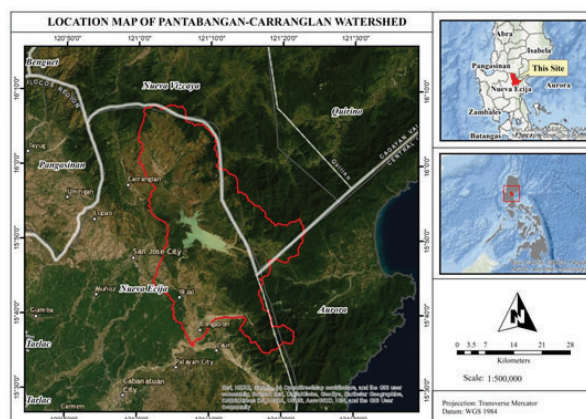

Figure 1. Location map of PCW.

Pantabangan is about 176 km away from Manila (Pulhin *et al.* 2006).

The watershed is composed of six soil textural types (Figure 2). Among them, clay loam is the most dominant which covers 77% of the entire site. Also, it has five soil series categories (Figure 3), with the Annam series covering the largest portion (82%). Soil series classification is an indication of the distinct soil pH composition of the land.
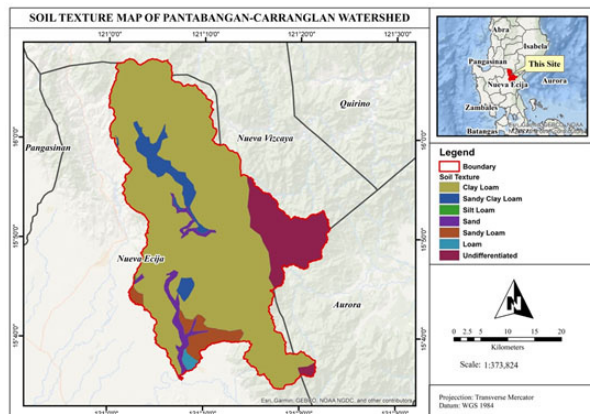

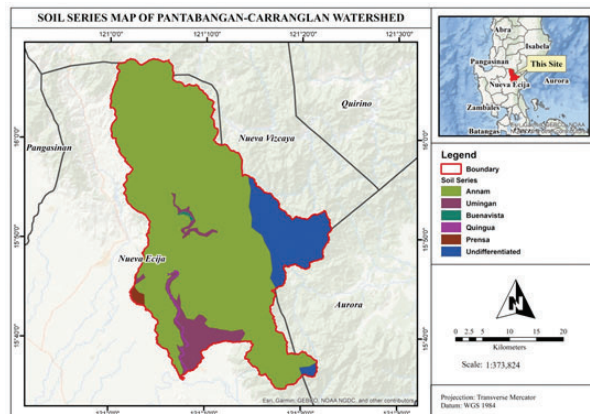**Figure 2.** Soil textural type map of PCW (source: DA-BSWM).

Figure 3. Soil series map of PCW (source: DA-BSWM).

PCW is characterized mainly by Climatic Type I with two pronounced seasons, having a dry season from Dec–Apr and wet season for the rest of the year. A minor part of the site is found to have Climatic Type II, with no dry season and very pronounced maximum rainfall from Nov–Jan (Pulhin *et al.* 2006). It has an annual precipitation of 1,892–2,926 mm (Figure 4) and an annual mean temperature of 17.4–26.9 ºC (Figure 5).

The elevation of the watershed ranges from 53–1,905 masl (Figure 6). The majority of the area lies within the range of 53–500 masl covering 63% of the watershed.
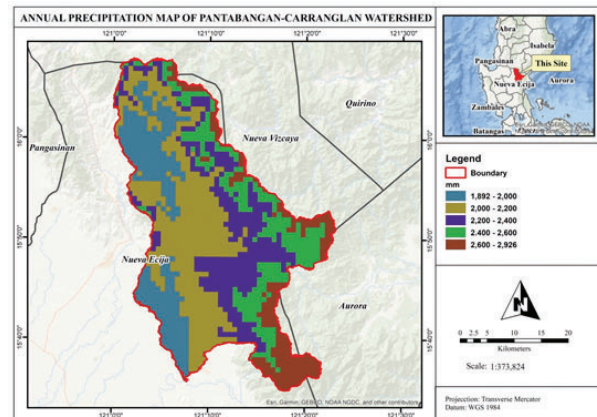

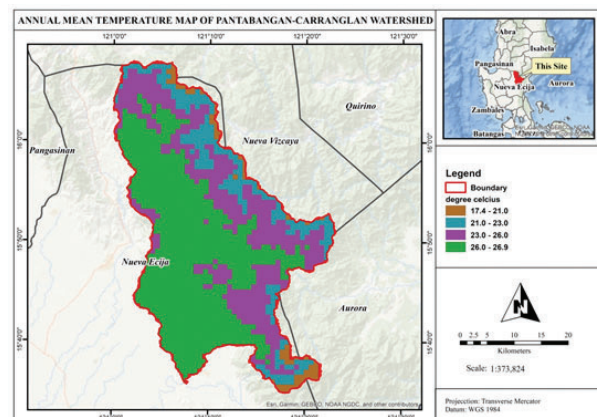**Figure 4.** Annual precipitation map of PCW (source: www. worldclim.org).

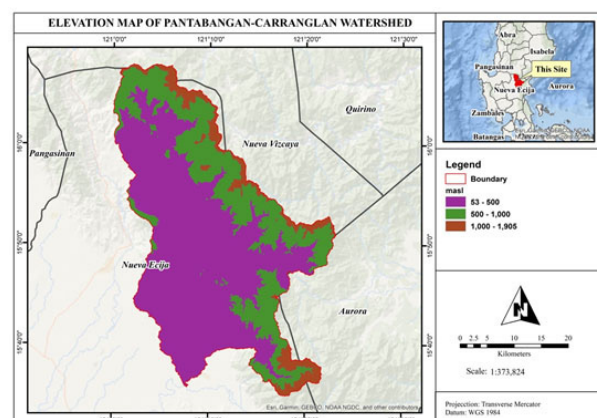**Figure 5.** Annual mean temperature map of PCW (source: www. worldclim.org).

Figure 6. Elevation map of PCW (source: www.earthexplorer. usgs.gov).

In order to identify the locations where reforestation is needed in the PCW, degraded areas within forestlands were determined by intersecting the land cover and land classification maps. All brushland and grassland

categories of the land cover map that intersects within the forestland category of land classification map were fundamentally considered as degraded areas, which pertain to locations in the watershed that are in need of reforestation and rehabilitation.

Selection and Description of the Tree Species

The three species of trees that were used in the study are "dita" [*Alstonia scholaris* (L) R. Br.], "akle" [*Albizia acle* (Blanco) Merr.], and "almaciga" [*Agathis philippinensis* (Warb.)]. These species were selected as they are naturally growing on-site prior to its degraded condition. They also represent various stages of vegetation succession: pioneer, seral or intermediate, and climax. The silvical requirements of these species are found in Table 1.

Thematic Map Generation of Site Variables

The primary tool used in the whole operation of the research was the ArcGIS 10.6, a GIS-based computer program developed by the Environmental Systems Research Institute (ESRI 2017). The general base maps that were obtained from various sources were manipulated using the ArcToolbox feature of the ArcGIS software in order to derive the different types of maps specific to the study site. The elevation map of the watershed was extracted from the digital elevation model of Central Luzon. The maps on annual mean temperature and annual precipitation were both extracted from world climatic data. Maps on land cover and soil texture were clipped or derived

from the National Mapping and Resource Information Authority (NAMRIA) land use map and Bureau of Soils and Water Management (BSWM) soils map. The BSWM map primarily contains data on the distribution of soil series in the watershed. Through cross-referencing with the Simplified Keys to Soil Series guidebook from the Philippine Rice Research Institute (PhilRice) (2014), the pH range of the established soil series was determined. Overall, thematic maps corresponding to the different site factors (soil texture, soil pH, precipitation, temperature, and elevation) were generated for the PCW (Table 2). All vector-format thematic maps were converted to raster for overlay analysis.

Species-site Matching

For the species-site matching, the following were used for ranking the suitability of selected native trees to the site factors based on their silvical requirements (Table 3).

Site Factor Weight Determination

The weights used for the overlay analysis were determined using the AHP. The AHP is a multi-criteria decision-making approach that derives ratio scales from paired comparisons of either quantitative data including price and height, or qualitative data including emotion and preference. It was introduced by Thomas L. Saaty, a distinguished University Professor at the University of Pittsburgh. It has gained popularity throughout the years due to its application in several decision-making

Table 1. Silvical requirements of the three selected species (ERDB 2013).

Site factor	"Dita"	"Akle"	"Almaciga"
Soil texture	Sandy	Sandy – clay loam	Clay loam – sandy loam
Soil pH	4.0–6.0	7.5–8.0	4.5–5.0
Annual precipitation (mm)	1,200–1,400 mm	All Philippine climatic types	> 200 mm
Annual mean temperature (°C)	12–32	0–35	3–20
Elevation (masl)	0–900	0–400	300–3,000

Table 2. Summary of data sources.

Data	Source	Description
Soil texture	Department of Agriculture – BSWM	Soil textural classes in shapefile format
Annual precipitation	www.worldclim.org	1 km resolution raster with annual precipitation (mm) values
Annual mean temperature	www.worldclim.org	1 km resolution raster with annual mean temperature (°C) values
Elevation	www.earthexplorer.usgs.gov	30 m resolution SRTM raster with elevation values
Land cover	NAMRIA	Land cover in the country for the year 2015 in shapefile format
Land classification	Department of Environment and Natural Resources	Land classification based on Presidential Decree 705 in shapefile format

Table 3. Reclassification of suitability values of the different site factors.

Value	Soil texture	Soil pH	Annual precipitation	Annual mean temperature	Elevation
1 (marginal)	Areas outside soil texture requirement of species and not belonging to similar soil textural group	Areas outside soil pH requirement of species; areas with < 4.5 and > 8.5 soil pH	Areas outside annual precipitation requirement of species	Areas outside annual mean temperature requirement of species	Areas above 1,000 masl lying outside elevation requirement of species
2 (moderate)	Areas outside soil texture requirement of species but belonging to similar soil textural group, or has a clay loam or sandy loam texture	Areas with exceeding but still comprising soil pH requirement of species, or within 6.0–7.0 pH level	Areas with an adjacent amount of annual precipitation to the requirement of species	Areas with an adjacent amount of annual mean temperature to the requirement of species	Areas above 1,000 masl lying within elevation requirement of species; areas under 1,000 masl lying outside elevation requirement of species
3 (high)	Areas within soil texture requirement of species	Areas within soil pH requirement of species	Areas within annual precipitation requirement of species	Areas within annual mean temperature requirement of species	Areas under 1,000 masl lying within elevation requirement of species

circumstances, and its usefulness in various fields (Alonso and Lamata 2006). The AHP takes into account a set of evaluation criteria and a set of alternative options among which the best decision is to be made. It develops weights for each evaluation criterion that corresponds to the decision maker's pairwise comparisons of the criteria. The weights that are developed reflect the degree of importance of the respective criterion relative to each other; the greater the value of the weight, the greater the importance of the corresponding criterion. For a fixed criterion, the AHP designates a score to each option that corresponds to the pairwise comparisons of the decision-maker on the options in relation to that criterion. The values of the scores imply the performance of the option based on the chosen criterion; the greater the value of the score, the greater the performance of the option. As a result, the AHP joins the criteria weights and the options scores in order to establish a general score for each option and corresponding ranking. The general score for a particular option is a weighted sum of the scores it acquired in relation to all the criteria (Saaty 1980).

For this study, five experts from the academe, government, research institution, and private sector were asked to answer a survey, which involves a paired comparison of site factors. The ranking is based on what the experts believe are the factors that play a more important influence on the growth and survival of the trees. The site factor variables that were considered are soil texture, soil pH, precipitation, temperature, and elevation. A score of nine (9) is given to a variable if the expert feels it is most significant compared to the other variable. A score of one (1) is given if they feel that it is least significant compared to the other variable. A median score of five (5) if the experts feel that both are of equal significance. Thereafter, the score of the five experts was averaged and eventually used in the determination of the site factor weight.

Species-site Suitability Assessment
The suitability analysis was based on the approach of the Food and Agriculture Organization (1976) for land evaluation. The final score of the suitability of each species is provided by the formula below:

$$S = \sum W_i X_i \qquad (1)$$

where S is the suitability index/final score, W_i weight of criterion i, and X_i score of class i.

A higher value indicates that the species is more suitable to the site factor. The final score/suitability index was converted to a suitability category of marginal, moderate, and high suitability. Finally, overlay maps that were obtained from integrating all site factor maps of the three selected species were developed to determine the overall suitability of each species to the site.

RESULTS AND DISCUSSION

PCW Reforestation Areas

The reforestation areas that were derived from the degraded areas in the forestland of PCW were determined to have a total land area of 28,845 ha, which equates to 22% of the entire area covered by the watershed (Figure 7). These areas are located mostly within the province of Nueva Ecija, particularly in the municipalities of Carranglan and Pantabangan.
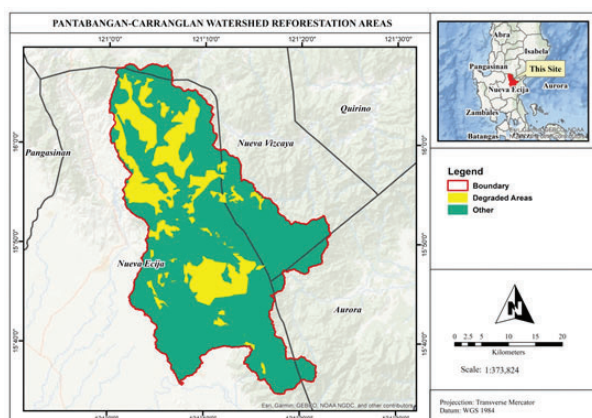

Figure 7. PCW reforestation areas

The identified sites for reforestation were observed to have dominant areas with environmental conditions that were conducive for planting trees and will most likely promote growth and development to the chosen reforestation species. The major land area is located at a low elevation that presumes higher temperature regimes, which are ideal for plants since they grow faster with the increase in temperature. The amount of precipitation annually is sufficient for tree growing: trees generally thrive along with soils composed of clay loam to sandy loam texture (Palijon 2018), which is abundant within the reforestation area, especially the clay loam soil texture. Furthermore, the majority of the site has a soil series of Annam, having a soil quality of good drainage and moderate permeability (PhilRice 2014), which is adequate for plants to survive. Although despite these notable features of the environment in the proposed sites for reforestation, the silvical

requirements of the selected species to be used remained valuable in indicating their suitability to the watershed.

Site Factor Weights

Among the site factors, precipitation was observed to have the highest importance with a weight of 25%, according to the overall result of the subjective ranking of site factors provided by the key respondents to the pairwise comparison survey questionnaires (Table 4). This particular climatic factor predominantly determines the availability of moisture in the soil that is necessary for the growth and development of plants. Apart from being a soil moisture determinant, precipitation also carries nutrient ions that can be consumed by vegetation through the nutrient cycle (Palijon 2018). Henceforth, the substantial functions of precipitation became the deciding factor of the respondents to affirm its top rank position with regards to its level of importance among the other environmental variables.

Soil texture and soil pH ranked second (23 %) and third (22 %), respectively. The small difference between the two indicates that these variables almost have the same degree of influence. Soil texture regulates the capabilities of the soil to contain moisture and nutrients, and the working capacities of the soil. Furthermore, it directly affects the drainage ability of the soil, which dictates the moisture conditions in the soil. On the other hand, soil pH influences the availability of nutrients in the soil depending on the level of acidity or alkalinity of the soil (Palijon 2018).

Elevation, having 19% weight, ranked fourth among the site factors. Unlike climatic and edaphic factors that have direct consequences to the environment where vegetation grows, physiographic factors such as elevation have indirect impacts to it, primarily through its impacts on the climatic and edaphic factors.

The temperature placed last among the site factors, with a weight of 11%. All the site factors that were included in the study were considered significant as they were the most prominently used environmental variables in similar analytic works that were presented in several works of literature such as that of Galang (2010). Having the least

Table 4. Summary of the pairwise comparison matrix and weights of each parameter based on the ranking provided by five experts.

Parameter	Elevation	Temp	Precipitation	Soil texture	Soil pH	Weight (%)	Rank
Elevation	–	1 5/9	7/9	7/9	1 1/4	19.27	4
Temperature	2/3	–	7/9	2/7	1/3	10.71	5
Precipitation	1 2/7	1 2/7	–	1 2/7	1 3/5	24.50	1
Soil texture	1 2/7	3 5/8	7/9	–	2/3	23.04	2
Soil pH	4/5	3	5/8	1 1/2	–	22.48	3

value of the assigned weight does not devoid the site factor of its significance. "Temperature has profound effects on the distribution and growth of woody plants" (Kozlowski *et al.* 1991). It affects the physiological processes of plants – including enzymatic activities catalyzing biochemical reactions, the solubility of carbon dioxide and oxygen in plant cells, transpiration, root absorption, and membrane permeability (Palijon 2018). These vital effects of temperature on vegetative properties remain valuable, although – compared to the previous site factors – it has the least influence on the survival of the trees to be planted in the site.

Suitability of Selected Species in PCW

"Dita" [*Alstonia scholaris* (L) R. Br.]. The majority of the areas in the PCW is highly suitable for "dita" in terms of its soil pH, temperature, and elevation; moderately suitable in soil texture; and marginally suitable in precipitation (Figure 8). Despite having three site factors that were highly suitable for the species, the result of the combination of all factors that were performed through overlay analysis showed a zero on high suitability areas. Instead of obtaining an outcome that would lean toward having a larger area with high suitability for "dita," this species has 99% moderate and 1% marginal suitability to PCW. This is most likely due to the higher weight values incorporated to the precipitation and soil texture site factors that "dita" was assessed to be marginally and
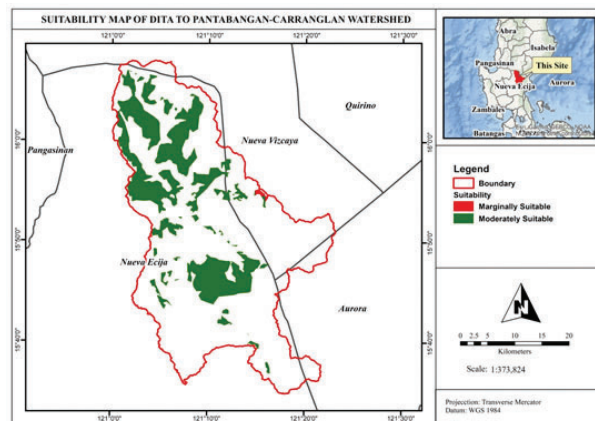

Figure 8. Suitability map of "dita" to reforestation areas in PCW.

moderately suitable with, respectively.

"Akle" [*Albizia acle* (Blanco) Merr.]

The "akle" tree displayed remarkable suitability to the site by being the most compatible among the selected species to its environmental factors, with a dominant area comprising of high suitability to soil texture, precipitation, temperature, and elevation (Figure 9). Soil pH is the only site factor that is marginally suitable for the species based
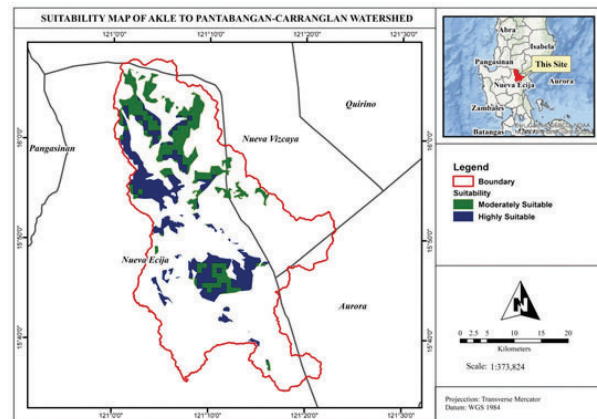

Figure 9. Suitability map of "akle" to reforestation areas in PCW.

on its silvical requirements. Thus, the overlaid map of the site factors revealed a 53% high, 47% moderate, and 0% marginal suitability to the interacting components of the environment in the watershed.

"Almaciga" [*Agathis philippinensis* (Warb.)]

"Almaciga" species, on the other hand, is highly suitable to the largest extent of PCW in terms of its soil texture, precipitation, and elevation, and marginally suitable to soil pH and temperature (Figure 10). It may not exhibit the same outstanding adaptability as the previous tree species, yet "almaciga" presented itself to be capable of surviving through the prevailing environmental conditions and
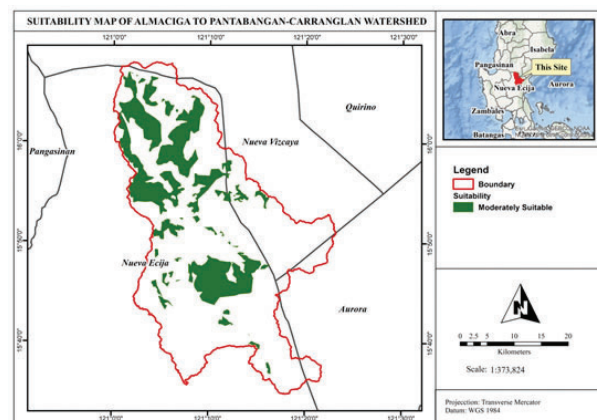

Figure 10. Suitability map of "almaciga" to reforestation areas in PCW.

qualifies for reforestation purposes in the site by having an overall 100% moderate suitability.

Among the three selected native species, "akle" was the most suitable, with the highest likelihood of survival in the degraded areas of forestland where planting of these species was proposed, given the prevailing environmental

Figure 11. Overall suitability distribution of the selected species.

conditions of these locations (Figure 11). Most of the site factors in the proposed site were ideal for "akle" to grow and develop, particularly its climatic features with both precipitation and temperature yielding high suitability for the species. Furthermore, even though the soil properties of the entire watershed – which is dominantly composed of acidic soils – do not match the alkaline soil pH requirement of "akle," the majority of the reforestation areas resulted to be highly suitable for the species in the overlay analysis. The consideration of other environmental components that matched the growth requirements of the tree species, especially the ones that were more important than the soil pH according to the AHP, which were the precipitation and soil texture, that exceedingly influenced the outcome of the overlaid components.

Species of the same genera of *Albizia* are generally characterized to have the ability to improve soil condition due to their nitrogen-fixing ability and profuse growth, as well as become a good soil cover and green manure crops. With this, they are capable to reforest idle and denuded hill lands or other sub-marginal areas. It also provides nitrogen, organic matter, and minerals to the upper soil layers through the natural shedding of leaves, pods, and small branches. Furthermore, its widespread surface-root systems enhance the soil by breaking up heavy soils and allowing channels for drainage and aeration (NRC 1979).

The result of this study is still limited by field validation. This process requires a long time as it will need actual field trials where the selected species will actually be planted and observe for a certain period of time (years) to ascertain their performance on the ground. However, the results of this study can still serve as a basis for any future reforestation activity in the area as the match between the site characteristics and the species' silvical requirements have been established. This also presents an argument for the need to conduct a species-trial study, even if it is lengthy and requires big funding, in order to strengthen the use of GIS-AHP approach in species-site suitability assessment. The above result also did not factor one of the most important site variables, the anthropogenic condition.

Survival and performance of these potential reforestation species in the PCW can be hampered by human activity, especially since the area is prone to summer grass burns. Slash-and-burn practice by locals could wipe out any successful reforestation that takes years to accomplish in a snap.

CONCLUSION AND RECOMMENDATION

The identified areas in the PCW that need reforestation intervention comprised 22% of the entire watershed. Of the various site factors, it was precipitation that was given the highest importance by a panel of experts. Incorporating this in the GIS-bases species-site suitability assessment, "akle" (*Albizia acle*) was determined to be the most suitable species among the three species analyzed, with 53% of the entire reforestation area exhibiting high suitability, and the remaining 47% indicating moderate suitability. Nevertheless, the other two species used in the suitability analysis were found to be suitable to the identified reforestation areas of PCW, signifying that they are able to potentially survive within the existing environmental conditions of the site. The result of this study should be validated in the ground since it was not done in this research due to time and budget constraints. Field trials can be performed for this purpose, the results of which can strengthen the use of GIS-AHP in species selection for reforestation in specific areas. Nevertheless, the results of this study can still serve as a basis for any future reforestation activity in the area as the match between the site characteristics and the species' silvical requirements have been established. Future research can deal with the incorporation of anthropogenic site factors in the analysis.

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