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# Combining GIS and Expert Opinion to Model Landscapes for a Smallholder Forest Extension Program in Leyte, the Philippines

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**ABSTRACT**

A Geographic Information System (GIS) was used to model datasets of Leyte Island, the Philippines, to identify land which was suitable for a forest extension program on the island. The datasets were modelled to provide maps of the distance of land from cities and towns, land which was a suitable elevation and slope for smallholder forestry and land of various soil types. An expert group was used to assign numeric site suitabilities to the soil types and maps of site suitability were used to assist the selection of municipalities for the provision of extension assistance to smallholders. Modelling of the datasets was facilitated by recent developments of the ArcGIS® suite of computer programs and derivation of elevation and slope was assisted by the availability of digital elevation models (DEM) produced by the Shuttle Radar Topography (SRTM) mission. The usefulness of GIS software as a decision support tool for small-scale forestry extension programs is discussed.

Keywords: digital elevation model, Shuttle Radar Topography Mission

## INTRODUCTION

Where organizations with a focus on forestry or agricultural extension operate over large land areas, they need to provide advice which is sensitive to farmers' costs and returns. *Site suitability* is often the criterion which is used to determine whether a project operates in an area or not. From a farmer's point of view, the question is whether a particular species will grow at an economic rate on a specific site (Bristow *et al.,* 2005). In researchers' minds, site suitability is often a loosely defined qualitative concept which encompasses the full range of their experience about the appropriateness of land to grow crops. In this context, suitability could alternatively be described by soil fertility or distance to markets. Where site suitability cannot be defined, a surrogate index based on soil fertility maps and associated landuse planning maps is a useful starting point.

Maps of soil types are sometimes available which assign an index of fertility to the soils of an area and this allows the relative suitability of any land unit to be assessed. Land-use planning maps are also useful because they indicate land for which there may be planning restrictions or other priorities for development. Together with other datasets, both types of information assist the assessment of the suitability of land for crops in specific locations and these assessments are facilitated by the ability of modern GIS software to overlay map layers and undertake spatial modelling.

A GIS can be defined as a database which represents the world in geographic terms (ESRI, 2001a). The procedures described in this article were prompted by recent developments of the ArcGIS® software suite by the Environmental Systems Research Institute (ESRI). Modern desktop computers are now sufficiently powerful to permit the presentation of maps with ArcMap™ and to undertake spatial modelling with the Spatial Analyst™ and 3D Analyst™ extensions. With this software, modelling 'the systematic organisation of existing information for assembling the (often subjective) knowledge of experts' (Harrison 2002, p.75) can be undertaken by mathematical manipulation of data held in attribute tables which are linked to a visual display.

As part of one of the activities of an Australian Centre for International Agricultural Research (ACIAR) project *ASEM/2003/05 - Improving Financial Returns to Smallholder Tree Farmers in the Philippines*, spatial modelling was used to assess the suitability of land for project activities, including forestry extension to smallholders. The modelling process used GIS-compatible data sets provided from the Philippine Bureau of Agricultural Research through the Farm and Resource Management Institute (FARMI) at Leyte State University. FARMI also provided a map of the soil types found in Leyte.

Following sections of this paper describe the use of ArcGIS® software to model datasets so that they could be used to support project planning. The paper also describes how an expert group was used to derive generalized site suitabilities from the soils map and how these suitabilities were used to justify the selection of municipalities for extension activities.

## METHODS AND RESULTS, PROCESS AND REPRESENTATIONAL MODELLING

The aim of the modelling process was to provide a list of municipalities on Leyte Island in which the proportion of land in each municipality suitable for growing *Gmelina arborea* (gmelina) was indicated. This species was chosen because it is commonly grown on the island in small woodlots and is preferred by many sawmillers. 'Site suitability' was therefore defined in terms of land planning decisions, limits to the elevation above sea level above which gmelina does not grow well and the distance of woodlots from potential markets.

An arbitrary limit of 40 km was set as the maximum distance to potential markets. The underpinning rationale was that while trees are often milled with a chainsaw and used on-farm, there is a potential market for timber in the towns and cities of the island. Therefore, the distance from any of the four biggest cities and towns in Leyte, namely the cities of Tacloban, Maasin City, Ormoc and the town of Baybay, was used as one index of suitability.

An elevation limit of 300 m above sea level (masl) was also chosen because field observations had shown that gmelina does not grow well at higher elevations. Finally, land with a slope of more than 18° is classified as 'timberland' in the Philippines and is subject to special controls. Therefore, timberland was considered as unsuitable for growing gmelina.

The ArcGIS® Spatial Analyst™ extension was chosen to model these distance, elevation and slope characteristics because it can create representational or process models of a landscape. Representational models are the simpler of the two model types and describe the landscape as a series of data layers, the result often being a coloured map with points, lines and polygons denoting points of interest[1]. One of the advantages of these maps is that they can be informative while being easy to read and understand.

Process models attempt to describe the interaction of the objects that are modelled in representational models. The software can combine information from two or more layers to create new datasets of increasing complexity. As with representational models, simple models are often the most meaningful (ESRI, 2001b).

### Process Modelling of the Distance of Farmland to the Cities of Tacloban, Maasin City, Ormoc and the Town of Baybay

Electronic files of the outline of Leyte Island were rasterised using the Spatial Analyst™ extension of ArcMap™ to convert the vector files[2] of the outline of the

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[1] A common example of a representational model is a road map.

[2] Vector files consist of points, lines or polygons cf. raster files which are composed of cells.

island to raster (cell-based) format. An example of the rasterising process is presented in Figures 1a, 1b and 1c. The Spatial Analyst extension converts polygons of landcover into pixels or cells of any desired size. In this process, the software creates a cell wherever the centre of the cell is covered by the original polygon. Some of the definition of the original shape of the polygon is lost. However, while the mapping of the polygons is approximate, a coarse resolution reduces the size of datasets. A negative consequence of rasterising polygon datasets is that the coverage of the polygon by pixels is only approximate and therefore the accuracy of area calculations is reduced. For this scenario, polygon shapefiles were rasterised to a 500 m pixel size (0.0044949 decimal degrees).

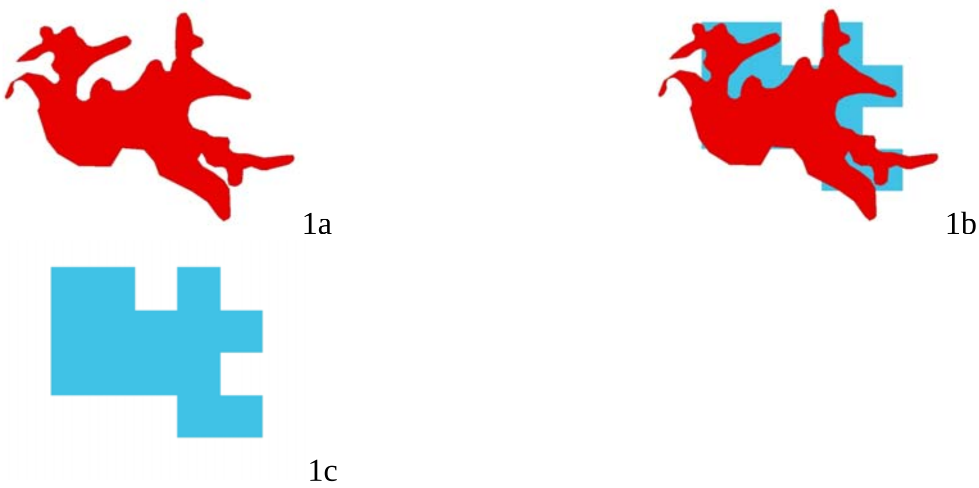



Figure 1. Polygon depicting an area of steep land (1a), a newly created raster with the original polygon laid on top (1b) and cells comprising the raster (1c)

Using ArcMap™, a map was made of the outline of Leyte Island and rasterised with a cell size of 500 m. The position of the towns and cities were overlaid onto this map and Spatial Analyst™ was used to calculate the straight-line distance from the cities in 5 km bands (Figure 2). Land outside a 40 km radius from one of the towns or cites - i.e. land in the north and south-east of the island - was therefore considered to be unsuitable for growing gmelina.

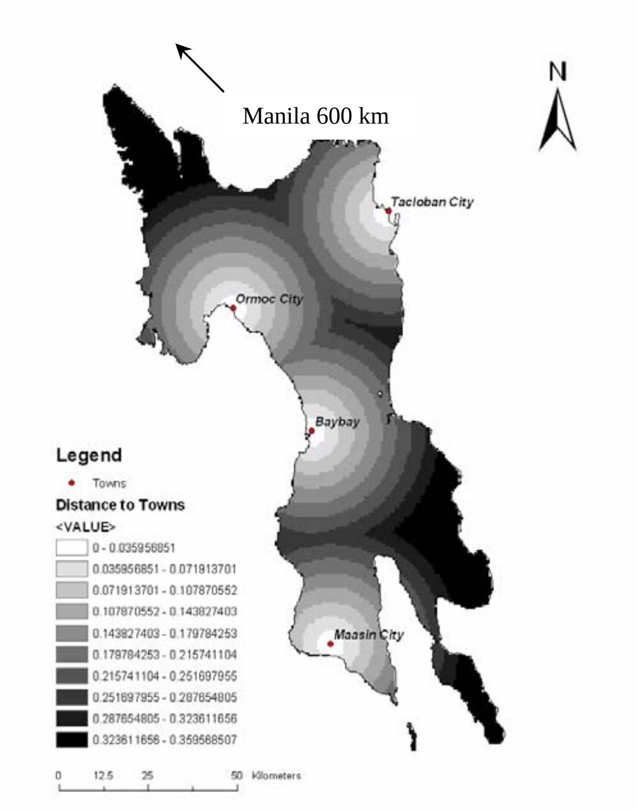



Figure 2. Straight-line distance from each of the main four towns and cities on Leyte Island in 5 km bands up to a maximum radius[3] of 50 km

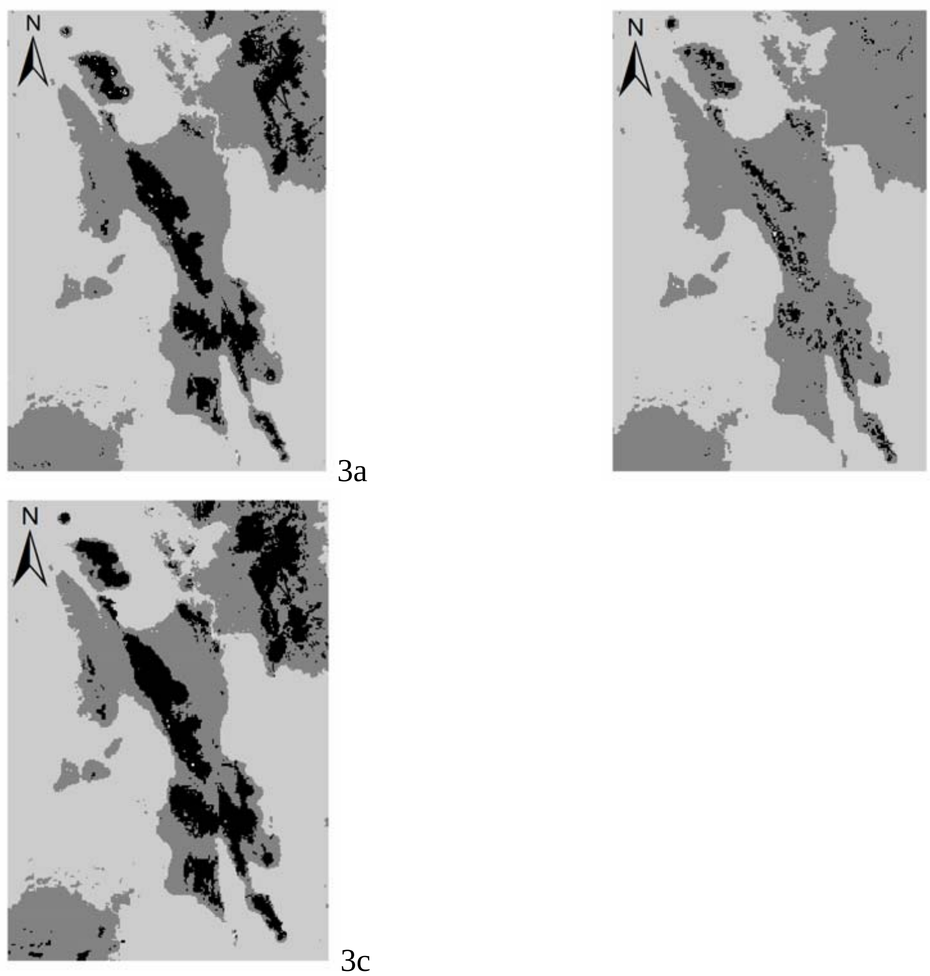
**Process Modelling of Land which is Higher than 300 masl and Steeper than 18°**

An old map of timberland could have been used to define areas over 18° slope but it was too broad in coverage and in any case population pressure has pushed many settlers from the lowlands into the steeper areas so much of the original timberland is now intensively cultivated. Therefore, to determine which parts of the island are higher than 300 masl or steeper than 18°, a DEM[4] of Leyte Island and the surrounding region was obtained from the United States Department of Geological Survey (USGS) as 3-arc-second (approximately 93 m) SRTM terrain elevation data. Using the 3D

[3] Land further than 40 km from a major town or city is coloured black. In the legend, this is shown as land 0.251697955 to 0.359568507 decimal degrees from a major town or city.

[4] A digital elevation model is a file of a geographic area, often in point or cell format, where elevations above sea level are stored for each point or cell location.

Analyst™ extension of ArcMap™, the DEM was reclassified to show areas of the island which are both more than 300 masl (Figure 3a) and steeper than 18° (Figure 3b). Unsuitable land is defined as land with either of these attributes and is coloured black in Figure 3c.




3a 3b 3c

Figure 3. Parts of Leyte Island and the surrounding region which are more than 300 masl elevation (Figure 3a), steeper than 18° (Figure 3b) or both (Figure 3c)[a]

[a] Land defined as unsuitable for forestry plantations is shown in black.

**Land which is Unsuitable because of Land-use Planning Decisions**

Maps of land designated as national park and land which is used for rice production were amalgamated. A map of this land is illustrated in Figure 4. In practice, rice is actually grown on much more land than is indicated on this map. However, the main rice production area south of Tacloban and the sugar production area north of Ormoc are shown as rice land and these areas are therefore classified as being unsuitable for growing gmelina.

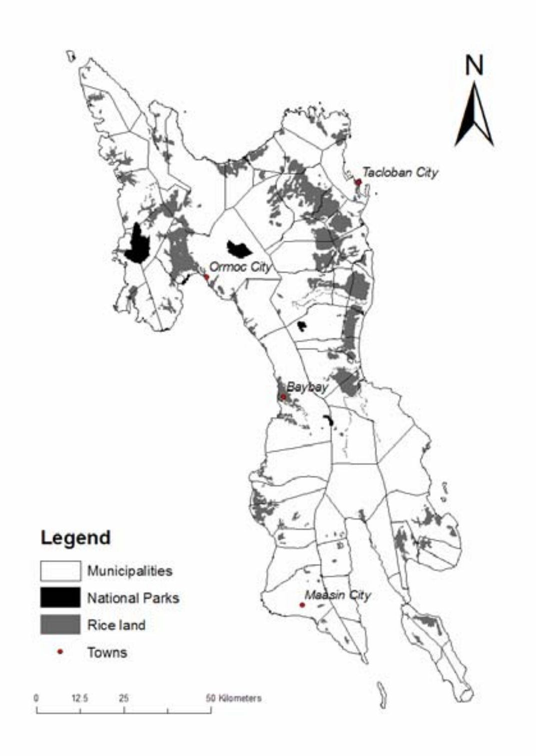



Figure 4. Map of national parks and land designated as ‘rice land’ and therefore classified as unsuitable for small-scale forestry

**Representational Modelling Using the Soils Map**

A map which describes the soils of Leyte Island using the United States Department of Agriculture (USDA) classification was obtained from FARMI. The soils map describes the soil types found on the island (as reported in Table 1 and Figure 5a). While the USDA description of soil types is useful to soil scientists, a general description of soil fertility which can be related to the growth of timber plantations is more useful to field researchers. Accordingly, an expert group consisting of a forester (Mr Jack Baynes, The University of Queensland), an agricultural engineer

(Dr Pastor P. Garcia, LSU) and a soil scientist (Dr Faustino Villamayor, also of LSU) was used to assign subjective site suitabilities to the soil types.

The term normally used by foresters to describe the capacity of a site to grow trees is *site quality* (SQ) and it has been used by foresters (e.g. Toumey and Korstian, 1937; Kramer and Kozlowski, 1960; Hocker, 1979) as a holistic assessment of a site's climate, soil, physiography and biota. In some forest management systems, the site quality number (e.g. site quality 1 for sites most suitable for growing trees and site quality 7 for sites not suitable for growing trees) is used in a similar way as *site index*[5] to describe the volume growth of plantations (Lewis *et al.*, 1976) and is often closely related to soil type. SQ or site index can change abruptly with variation in soil depth, drainage and topography. In this situation, because a large number of soils types are described on the map, the soil types have been aggregated into four site suitability classes according to their suitability for growing gmelina (Figure 5a and 5b).

[5] For forests in Queensland, Australia, site index is defined as the average height of the tallest 50 trees per hectare at age 25. The height measurement is of no interest except as an indication of the growth rate of the stand.

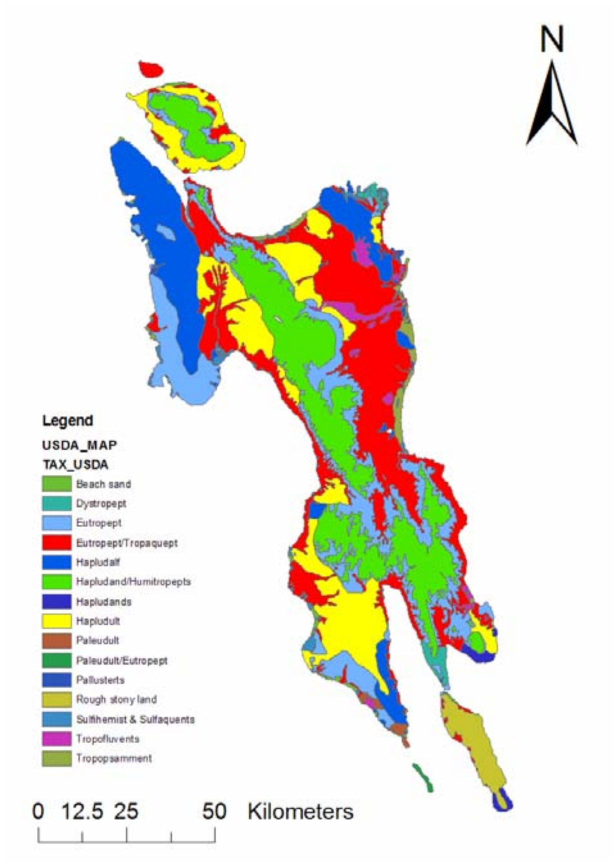

N
Legend
USDA_MAP
TAX_USDA
Beach sand
Dystropept
Eutropept
Eutropept/Tropaquept
Hapludalf
Hapludand/Humitropepts
Hapludands
Hapludult
Paleudult
Paleudult/Eutropept
Pallusterts
Rough stony land
Sulfihemist & Sulfaquents
Tropofluvents
Tropopsamment
0 12.5 25 50 Kilometers

Figure 5a

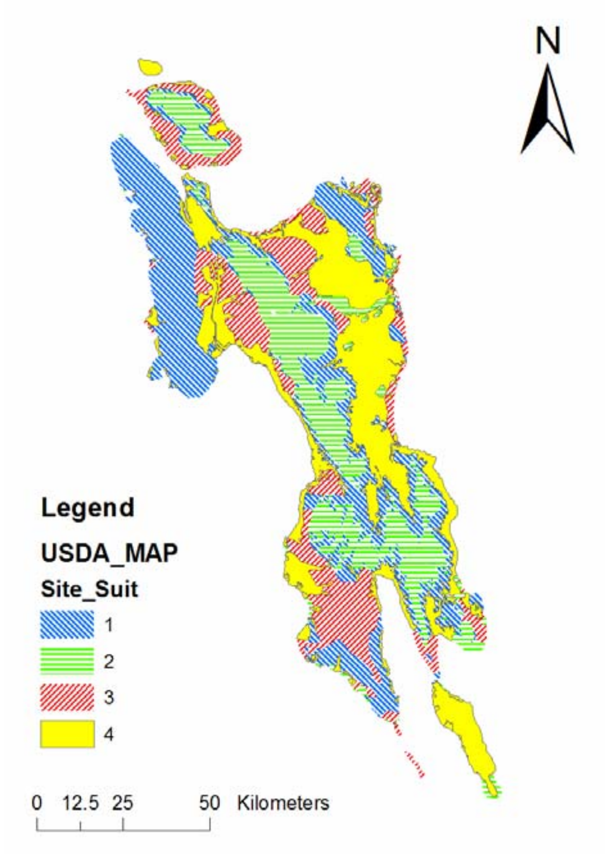



Figure 5b

Figure 5. Classification of soil types (5a) and their amalgamation into generic site suitability classes (5b)

After consultation between members of the expert group, subjective site suitabilities and descriptions were assigned to the soil types (Table 1), suitability 1 being assigned to the most fertile soils and suitability 4 being assigned to the poorest soils Figure 5b). The classification reflected the group's assessment of soil suitability for growing trees only, not fruit trees or agriculture. For example, the eutropept and tropaquept soil association was classified as suitability 4 even though this soil type is suitable for growing rice. Tropaquept soils have a water table close to the soil surface and this limits the volume of soil available for tree roots to grow. Even on slightly better drained soils, the confinement of roots to the upper soil horizons makes trees unable to withstand strong winds. The eutropept and tropaquept soil association was therefore classified as the same site suitability (suitability 4) as ‘rough stony land’ which is often found on steep land with shallow soil cover over rock. The two soil types are strikingly different, but in terms of tree growth they are both soils which are least preferred for the promotion of small-scale forestry.

Table 1. Soil type, description and subjectively ascribed site suitability for soils in Leyte[6]

| USDA great group and miscellaneous land type | Descriptive comments | Site suitability |
|---|---|---|
| Beach sand | Beach sand. | 2 |
| Dystropept | These soils have low fertility and a low base saturation. | 3 |
| Eutropept | Eutropepts are poorly to moderately developed soils in upland areas with a moderate to high fertility. The base saturation is 50% or more for all horizons. | 1 |
| Eutropept/ tropaquept | This soil association consists of poorly to moderately developed fertile soils in alluvial areas used for lowland rice production The water table is high for most of the time and the soil is often saturated unless artificially drained. | 4 |
| Hapludalf | Hapluālfs are well developed soils in upland areas with clayey subsoil, high base saturation and are generally fertile. Clay is often accumulated in the subsoil. | 1 |
| Hapludand/ humitropepts | Hapludands are young volcanic soils in the central highlands; generally fertile but unstable. Humitropepts are found in the mountains. They are poorly developed unstable soils of various parent materials but often with some organic matter. | 2 |
| Hapludands | These soils have good structure but are deficient in phosphorus. They are developed from volcanic ash and there is minimal horizon depth, especially on steep slopes. | 2 |
| Hapludult | Hapludalts are mature, highly weathered soils in stable upland areas, being reddish, acidic and clayey with a low to very low fertility. | 2 |
| Paleudult | Paleudults are old and infertile with a low level of weatherable minerals. | 2 |

[6] Source: Asio (2005)

Table 1. (Cont.)

| USDA great group and miscellaneous land type | Descriptive Comments | Site suitability |
|---|---|---|
| Paleudult/ eutropept | This association is old and infertile with low exchangeable ions in the clay and a low level of weatherable minerals. | 3 |
| Pallusterts | Pallusterts are characterized by a low chroma with some mottles of high chroma. Moisture may be limited and the soils have a high rate of shrink and swell. | 4 |
| Rough stony land | Rough stony land is often steep and the soil is often shallow. | 4 |
| Sulfihemist and sulfaquents | This soil association is acidic peat soils and undeveloped mangrove soils. They are ecologically fragile, waterlogged and often inundated by tides. | 4 |
| Tropofluvents | Tropofluvents are coarse textured, undeveloped soils along big rivers. They are well-drained with moderate to low fertility. They are also very young with no 'B' horizon and susceptible to flooding. | 2 |
| Tropopsamment | This soil type is a very sandy, undeveloped soil from marine deposits in coastal margins. It has low fertility with little water holding capacity. | 3 |

**Using the Process and Representational Models to Select Municipalities for an Extension Program**

The process and representational models were used as a decision-support tool to select municipalities which had the greatest proportion of suitable land. The areas of suitable and unsuitable land were calculated for each of the 61 municipalities in Leyte Island by using the Spatial Analyst™ extension of ArcMap™ to subtract areas designated as steeper than 18°, above 300 masl in elevation, national park or rice land from the area of each municipality. Appendix A provides a breakdown of the gross area, net suitable area, land classified as unsuitable because it is used for rice production, land which is either steeper than 18° or above 300 masl, or is a protected area.

Following the initial selection of municipalities for project activities, the soil site suitability map was used to justify further changes to the selected municipalities for extension and other project activities. One of these changes occurred when the mayor of Dulag made a personal representation for extension work to be carried out in his municipality. Both Dulag and the adjacent municipality of Julita (which had been originally selected) have extensive areas of rice fields (Figure 6), with a minor proportion of elevated land occurring in the northern part of both municipalities. The main soil type is the eutropept and tropaquept soil association which is classified as soil suitability 4. However, Dulag has a considerable proportion of land with of site suitability 1 (hapludalf) and site suitability 3 (tropopsamment) (Figure 6). Hence, the higher proportion of the more suitable soil types of Dulag municipality justified changing extension activities to that municipality. Since both municipalities are a similar distance from major towns or cities (30–40 km), distance to markets was not a deciding factor.

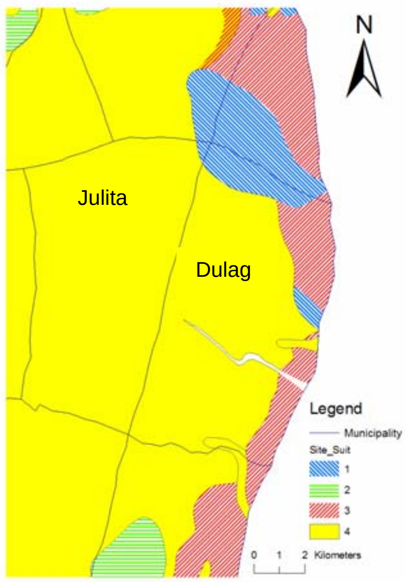



Figure 6. Soil suitability types of Julita and Dulag municipalities

## DISCUSSION AND CONCLUSION

For this work only five variables – distance to cities or towns, elevation, slope, fertility and land-use – were used to define the suitability of land for growing gmelina. Technically, it would have been a simple matter to include other variables or to use the software to combine the datasets and arrive at hypothetically ideal locations. However, ESRI advises care in combining datasets where the units of measurement are different (ESRI, 2001b). For elevation and slope, land was classified as either suitable or not suitable. The proximity of land to cities or towns was considered as being closer or further than 40 km from markets and the suitability of the soil types was assigned using a subjective numeric scale. Therefore, in this investigation, it was decided not to combine these datasets into an overall index of site suitability.

One of the three members of the expert group also commented that 'rough stony land' which was classified as site suitability 4 is still capable of growing trees, although at a lesser growth rate than more fertile soils. Also, because it is not suitable for annual crops, rough stony land may be the only land on which some farmers are willing to grow trees. These comments suggest that if the site suitabilities derived from the soils map are to be considered for purposes other than those described here, then they should be accompanied by an explanation of the criteria which have been used to assign the soils into each suitability.

As is common in GIS projects, variation in the provenance of the data sets caused problems. Bureau of Agricultural Research datasets have been gathered from many sources and use different datums and projections. Attempts to join or overlay them sometimes resulted in misalignment of shapefile boundaries. The software was not capable of fixing some of the projection problems and there was no alternative but to accept that some datasets should not be overlaid onto others. However, the ability of the Spatial Analyst™ extension to rasterise shapefiles and to save all the steps of the modelling procedure was invaluable because it allowed the models to be revised. The software has been specifically designed to model spatial datasets and both the instruction book and the on-line help are comprehensive.

Like any GIS project, the usefulness of the final result is dependent on the quality of the information in the datasets. In this case project workers were fortunate that two high quality datasets (the soils map and SRTM digital elevation data) were available. The maps produced as a result of this research indicate that GIS modelling is likely to play an increasing role as part of project decision-support systems, particularly as GIS software becomes more user-friendly. ACIAR staff were also fortunate that an expert group was available to provide qualitative advice concerning soil fertility which was not available from any other source.

**ACKNOWLEDGMENT**

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**Appendix 1.** Area ($km^2$) of municipalities in Leyte Island showing gross area of each municipality and net area suitable for planting gmelina.

| Municipality | Gross area | Net suitable area | Unsuitable land | Steeper than 18° and above 300 m asl | Protected areas |
|---|---|---|---|---|---|
| Abuyog | 273 | 112 | 31 | 130 | |
| Alangalang | 160 | 78 | 72 | 10 | |
| Albuera | 169 | 54 | 14 | 101 | |
| Babatngon | 148 | 92 | 17 | 39 | |
| Barugo | 77 | 64 | 13 | | |
| Bato | 58 | 52 | 6 | | |
| Baybay | 402 | 158 | 36 | 206 | 2 |
| Burauen | 194 | 99 | 22 | 73 | |
| Calubian | 116 | 112 | 4 | | |
| Capoocan | 371 | 241 | 53 | 77 | |
| Carigara | 88 | 39 | 21 | 28 | |
| Dagami | 145 | 66 | 32 | 47 | |
| Dulag | 74 | 29 | 45 | | |
| Hilongos | 161 | 106 | 30 | 25 | |
| Hindang | 103 | 50 | 8 | 45 | |
| Inopacan | 198 | 47 | 9 | 142 | |
| Isabel | 65 | 59 | 6 | | |
| Jaro | 203 | 132 | 22 | 49 | |
| Javier | 153 | 54 | 23 | 76 | |
| Julita | 55 | 42 | 13 | | |
| Lapaz | 138 | 85 | 1 | 52 | |
| Leyte | 146 | 125 | 11 | 10 | |
| Macarthur | 67 | 35 | 20 | 12 | |
| Mahaplag | 186 | 96 | 3 | 87 | |
| Matag-ob | 124 | 31 | 23 | 28 | 42 |
| Matalom | 114 | 103 | | 11 | |
| Mayorga | 45 | 14 | 31 | | |
| Merida | 134 | 106 | 12 | 16 | |
| Ormoc City | 496 | 224 | 93 | 156 | 23 |
| Palo | 77 | 44 | 33 | | |

Appendix 1 (cont.)

| Municipality | Gross area | Net suitable area | Unsuitable land | Steeper than 18° and above 300 masl | Protected areas |
|---|---|---|---|---|---|
| Palompon | 100 | 80 | 8 | 12 | |
| Pastrana | 76 | 49 | 21 | 6 | |
| San Isidro | 101 | 91 | 10 | | |
| San Miguel E | 108 | 69 | 22 | 17 | |
| San Miguel W | 131 | 114 | 17 | | |
| Santa Fe | 55 | 16 | 35 | 4 | |
| Tabontabon | 22 | 14 | 8 | | |
| Tacloban City | 112 | 48 | 11 | 53 | |
| Tanauan | 70 | 46 | 24 | | |
| Tolosa | 22 | 17 | 5 | | |
| Tunga | 17 | 13 | 4 | | |
| Villaba | 158 | 127 | 25 | 4 | 2 |
| Anahawan | 54 | 32 | 9 | 13 | |
| Bontoc | 91 | 79 | 2 | 10 | |
| Hinunangan | 190 | 43 | 23 | 96 | 28 |
| Libagon | 117 | 31 | | 73 | 13 |
| Liloan N | 21 | 19 | | 2 | |
| Liloan S | 65 | 4 | 16 | 45 | |
| Limasawa | 7 | 7 | | | |
| Maasin City | 203 | 171 | 2 | 30 | |
| Macrohon | 65 | 46 | 7 | 12 | |
| Malitbog | 86 | 60 | 1 | 25 | |
| Padre Burgos | 42 | 27 | | 15 | |
| Pintuyan | 48 | 34 | | 14 | |
| Saint Bernard | 78 | 20 | 20 | 35 | 3 |
| San Francisco | 61 | 40 | 5 | 16 | |
| San Juan | 32 | 28 | 1 | 3 | |
| San Ricardo | 40 | 15 | | 25 | |
| Silago | 203 | 73 | 1 | 129 | |
| Sogod | 222 | 95 | 5 | 122 | |
| Tomas Oppus | 89 | 63 | 1 | 25 | |
| Total | 7426 | 4120 | 987 | 2206 | 113 |