IDENTIFICATION OF POTENTIAL SITES FOR HOOP PINE PLANTATIONS IN THE ATHERTON TABLELANDS, NORTH QUEENSLAND, USING GIS AND EXPERT KNOWLEDGE

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Abstract: This study modeled the suitability of sites to establish hoop pine plantations in the Atherton Tablelands, North Queensland (NQ). The study was conducted to provide information regarding potential sites resulted from a broad level site assessment. Potential sites for hoop pine were identified using GIS which the criteria were derived from literature search and expert opinion which then were used to construct suitability criteria. Mean annual rainfall and soil types were used to assess the ecological suitability for hoop pine growth. These suitability criteria were then combined with availability criteria for determining possible expansions of hoop pine plantations on private lands, which comprise the land size, land status, land cover, land use and slope limit. The model was then validated using hoop pine site index records as a surrogate for hoop pine potential growth. From the results, the region was found to be edaphically and climatically suitable encompassing around 35,567 ha of land was identified as highly suitable and 4,680 ha as moderately suitable. It was also revealed that suitability classes derived from spatial modeling can only produce indicative locations of lands suitable for supporting hoop pine growth. While datasets came from various scales and precision, the results of the study have limited applicability for planning at individual farm but are useful to gain initial consideration at the regional level to target areas for plantation expansion.

Keywords: Hoop pine, land suitability, land-availability, GIS-based modeling

The economic share of plantation forestry to the Australia's economy is significant and expected to increase substantially over the coming years, which has stimulated the national desire to enhance forestry activities for boosting timber production one of which is the policy for tripling the plantation estates from a little over of one million to more than three million hectares by the year 2020 (Plantation 2020, 2003). In the light of land allocation for such expansion, the National Forestry Policy has clearly stated that any plantation expansion should not be in the areas of native forest and its development should be integrated into environmentally sustainable land uses (AFFRA, 2003).

For sustainable expansion, there are many aspects to be taken into account. Developing a plantation will mean involving a huge cost for operational activities, while it will also indicate significant social impacts in terms of jobs cre-

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ation and regional development, not to forget a number of reported negative impacts, ranging from thedecline in rural development (Spencer and Jellinek, 1995) and environmental problems resulting from inappropriate silvicultural practices (Sheperd, 1986). Nambiar (2002) states that sustainable forestry development can be considered in relation to the extent of alignment of several critical variables, namely environmental suitability of the sites, environmental values, and socio-economic benefits. Site assessment is regarded as one form of land evaluation for forestry in which FAO (1984) notes the goal as the basis for decision about land use planning. Yet, in the technical context, it is a demanding task due to its requirements of extensive data, multidisciplinary approach, significant time allocation, and off course inevitably high cost. This will lead to the need of a rapid, affordable but reliable assessment that can be used a tentative guideline in an initial study for plantation expansion.

Despite the extensive grow of hoop pine, little research had been made concerning on suitability studies for plantation establishment in Australia. The only tentative suitability assessment was the one done by the Queensland RFA employing several socio-economic considerations and a study from Anndale et. al (2003), taking rainfall and geologic features as variables. None studies were validated. This study was carried out to model potential sites for growing hoop pine under a Geographic Information System (GIS) environment. The GIS has widely been used for land resource assessment as it is capable of handling data in various formats and of performing a spatial representation derived from using modeling (Burrough, 1990).

METHODS

As fundamental consideration, the potential sites for hoop pine must be areas that are biophysically suitable for growing hoop pine and potentially available within socio-economic context of Australian forestry. The biophysical suitability was approached from land-based evaluation framework by developing suitability matrix. The key point of land suitability analysis is that land is taken to mean the assemblage of all environmental variables, which are considered to influence the desired land use (Davidson, 1992). It is worth noting that term "suitability" in many cases is interchangeable with "capability. Yet, capability reflects the overall land quality for general purposes, while suitability indicates a site-species matching process, targeting to a particular species, and preferably, is determined by relating the classes with economic or productivity goals. Thus, the suitability classes reflect the degree of sustainability of a particular site, which for this purpose; an initial assumption should be given prior to analysis considering the management scale defined (FAO, 1984). For this regard, the Mean Annual Increment (MAI)- an index used for showing the average of growth rate of a tree - of a 20 m3/year as the threshold assigned as potential from commercial point of view.

This criterion was then used to define the suitability of the selected ecological and variables as figured in Table 1. Soil types, and mean annual rainfall (MAR) were chosen as two proxies for determining land suitability as in several studies they showed significant influence to the growth of hoop pine (Annandale et al, 2003; Holzworth, 1980; Booth, 1985).

Table 1. Suitability classes in terms of potential growth of trees*

Suitability classes	Rainfall class (mm/year)
Highly suitable(H)	> 1300
Moderately suitable(M)	1000 - 1300
Marginally suitable(L)	750 - 1000
Unsuitable (U)	< 750

*) *Adopted from Queensland RFA (1998)*

While land suitability represents the biophysic potentials, the land availability refers to the operating criteria to assign whether or not a piece of land can be possibly turned into a plantation by considering current technical, legal, economic, and conservation issues. In this research, several important features had been selected as summarized in the following table.

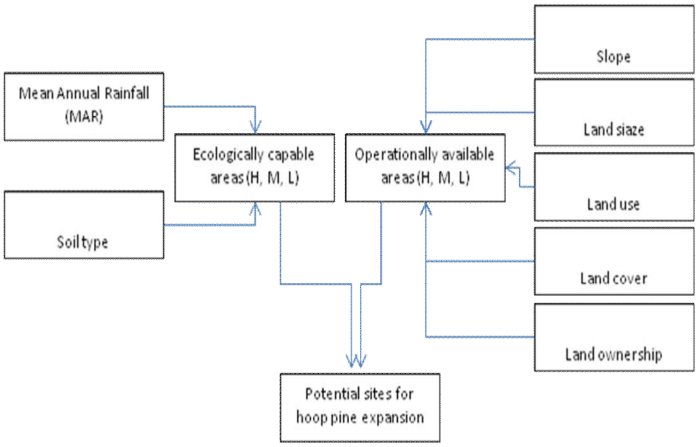
Table 2. Land availability criteria for hoop pine expansion & their rationale

Variable	Criteria	Rationale
Slope	• A slope of 25 percent as the upper limit	• Slope represents the sensitivity to soil erosion and the degree of ease of management prescriptions (DNR, 1999)
Land cover	• A maximum limit of 12% land cover	• Plantation must be established on cleared land (Kuhnell et al, 1998)
Land tenure	• Private land status	• Such plantation expansion must not be made on state land (Queensland RFA, 1998)
Land size	• A minimum of 10 ha land size	• 10 ha represents minimum economic profitability for plantation business (Queensland RFA, 1998)
Current Land Use	• Areas which are not as native plant ecosystems	• Conservation purposes (DNR, 1999)

For this study, the slope data was taken from a 250-m resolution DEM derived from Australian Geo-Science, while status of land ownership and land size were obtained from Digital Cadastral Database provided by NRMW as vector based datasets. The land cover density was classified from Foliage Projective Cover – Statewide Land and Tree Study (SLATS). While regional native ecosystems and current land uses were extracted from Environmental Protection Agency (EPA) and Australian Bureau of Rural Systems.

All bio-physic indicators and availability criteria were then taken together, used as the defining criteria for potential sites for hoop pine, which in brief, was depicted as in Figure 1.

Figure 1. General framework for modeling potential sites for hoop pine



Following the framework, suitability map was first constructed from digital raster datasets of a 1-km gridded MAR and soil type variables using GIS. The MAR was re-classified into rainfall suitability classes for plantations developed by the Queensland RFA (1998) as the following table.

Table 3. Mean Annual Rainfall Suitability Classes for plantation

Suitability classes	Potential growth of MAI (m3/ha/year)
Highly suitable(H)	> 20
Moderately suitable(M)	15 - 29
Marginally suitable(L)	10 - 14
Insuitable/ undesired (U)	< 10

To provide a surrogate for soil characteristics, digital soil map resulted from soil survey conducted by Malcom et al (1999) was classified based on its suitability in relation to potential growth based on its major soil attributes. An expert knowledge was applied due to unavailability of soil information and time constraints. A group of soil scientists from Department of Primary Industries was asked to assign and relate the soil characteristics in a particular unit to its potential growth of hoop pine.

In this study, the soil unit of analysis was Soil Profile Classes (SPC), which was a finer unit than land unit. A land unit was considered as incapable of representing soil variation and might less accurately represent the influence of soil attributes to hoop pine growth (Ryan, P.A et al, 2003). An SPC itself, though varies by size, is a soil classification unit containing major pedological and edaphological attributes such as solum depth, texture, structure, permeability, acidity-salinity level, stoniness and major minerals and mapped according to Australia's soil classification system.

Regarding with soil properties, Laffan (1997) stated that water supply is affected by clay content, soil permeability, soil depth and texture, and these attributes are more influential to plant growth than soil fertility as the fertility is possibly modified through fertilization. A decision matrix of suitability classes was developed to denote the overall land suitability, which in practice was carried out by GIS overlaying techniques. In this study, soil and rainfall was regarded as equally important for hoop pine growth. Accordingly, the more limiting criterion was used as the final status. In the final stage, the newly derived suitability map was then masked by availability criteria mentioned in table 2.

Table 4. Decision matrix of land suitability derived from soil and rainfall suitability classes

		MAR suitability classes			
		H	M	L	U
Soil Suitability classes	H	H	M	L	U
	M	M	M	L	U
	L	L	L	L	U
	U	U	U	U	U

Fornier et al (2000) highlighted the importance of developing a robust process to ensure scientifically defensible modeling and suggested that in such modeling, there should be a model validation process.

Table 5. Summary of Site Indices of Hoop Pine Growth Plots

No	Plot Number	State Forest	SI-25 (m)	Volume (m3/ha)	Planting year	Age (year)	MAI (m3/ha/yr)
1	1	185 (Danbulla)	28.6	1104.4	1947	43.56	25.35
2	2	191 (Wongabel)	32.1	1082.5	1937	48.0	22.55
3	3		27.5	1032.5	1931	53.89	19.16
4	4		30.4	1267.1	1942	48.44	26.34
5	5		29.9	1283.5	1939	55.56	23.10
6	8	0194 (Barron)	29.8	1247.7	1937	48.89	26.05
7	9	0310 (Gadgarra)	21.4	1070.3	1936	48.89	21.89
8	10		21.9	1586.0	1935	64.56	24.61
9	11		24.0	1052.8	1931	62.84	16.86
10	12		27.5	1231.4	1933	51.89	23.73
11	13		26.7	1082.9	1939	52.56	20.60

Growth plots have frequently been used as tools for validation in site index modeling. Yet, the use of growth plot in land suitability assessment using suitability ratings has never been used. In this study, growth plots were used to identify whether or not the assigned classes of suitability corresponded to the performance of trees in the growth plots. Growth plots as defined by DNRM Queensland (2001) are the permanent plots on which each tree has a recognized location and the plots were built on a variety of environmental conditions and potentials at young ages. Growth plots were established to represent the planting area and they provided information of forest productivity as indicators of site qualities. The MAI of each growth plot were then categorized based on the rank related to optimum productivity as classified in the table 1. The suitability rank obtained was then used to validate the suitability obtained from the modeling.

Result and Discussion Estimated Land Availability and Suitability

Operating criteria applied as the masks for determining operationally possible land to be converted into plantations were all put together in GIS. Based on the criteria, it is estimated that there is approximately 41,000 hectare of land which is permissible for plantation conversion. Steep land (>25°) was found invariably in the sites covered by natural vegetation. Hence, steep areas were automatically removed from the consideration of available land. From these available lands, the acreage of soil and rainfall suitability was obtained as presented in following table (table 6).

Table 6. Suitability classes based on soil type & rainfall attributes in the Atherton

Variable	Estimated areas based on suitability (hectare)				Total
	H	M	L	U	
Soil type	35,567	4,680	1,022	406	41,675
MAR	40,924	751	0	0	41,675
Overall suitability*	35,045	5,202	1,022	406	41,675

*) taken based on decision matrix on suitability

It is found that the area of Atherton Tableland exhibits an excellent condition in the light of rainfall (MAR). Almost 98% of the areas were classified as highly capable, showing excellent condition for water supply, left the only 2% categorized as moderately capable. Mean annual rainfall (MAR) is the only an approximate surrogate for the sufficiency of the water provision to plants. Despite its simplification, in the absence of alternative data relating to water availability, the classification used here appears to be adequate.

Based on major attributes attached to each soil type, the suitability levels vary more than the rainfall. Major SPCs in this area are Krasnozem, Prairie, Eucrozem, and Xanthozem. In the region, despite most of its soil types is classified as highly capable, accounting for around 35,567 hectare or 85% from the total, there are also areas found to be moderately and marginally suitable.

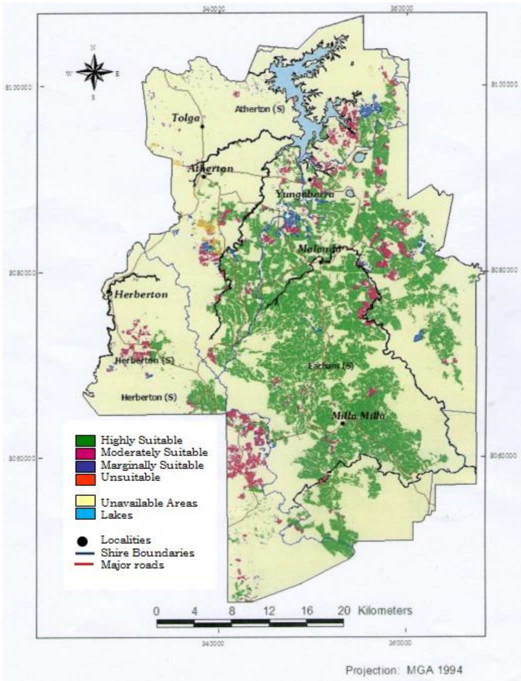


Figure 2. Areas for Hoop Pine Plantations by Suitability in the Atherton Tablelands

Modeling Validation and Issues

Models are considered a simplified representation of the real world and expressed in a wide range of forms such as mathematical equations, maps, conceptual diagrams, classification system, etc. Likewise in land suitability studies, modeling provides a means of collecting, processing, and estimating site performance in either qualitative or quantitative terms.

A model could be regarded as reliable if the predicted attributes indicates the same performance as or similar to the measured attributes. A number of hoop pine growth plots in the study area were used as the reference in comparing the predicted suitability of the site. Table 5 contains the productivity measures of hoop pine in the Atherton nine of which has the MAI measured as "high MAI" and coincided with areas modeled as "highly suitable". Yet, two other plots, categorized as "medium MAI" were on areas predicted as "highly suitable". Yet, for areas classified as moderately or marginally suitable could not be validated.

It is interesting to note the mismatch between the plots' MAI as the growth measurement and the areas' suitability estimation. There are at least two points can be outlined. First, the "medium MAI plots" are very similar to "high MAI plots" in terms of soil types, relief, and rainfall. One likely explanation of the MAI disparity is the individual plot history may show the occurrence of pest attacks or diseases. Second, the plots were on a 50 m x 50 m resolution as their size, while the area suitability was modeled from datasets with different resolution and precisions. For example, the original rainfall raster dataset was capture at a 5 km grid, and when re-sized onto a finer resolution, the newly gridded raster could not represent such variability.Similarly, despite its intensity in sampling, the mapping unit (expressed as SPC) of soil types could not reveal the variability within the unit.

It is worth noting that spatial variability of soil input data could influence the reliability of the results of empirical and physical models of soil and landscape processes (Burrough, 1993). Soil surveys have traditionally overlooked the spatial variability within map units for a variety of reasons including scale limitations. Further, soil mapping typically classifies soils into discrete entities using map units based on air photo interpretation and gathered information on soils in relation to landform, geology, vegetation and land use (Djikerman, 1974). Likewise, soils in the study area had been mapped according to primary soil types in which small differences had been refined into discrete units.

Taking together soil and rainfall to determine overall land suitability was meant to indicate interaction between soil and rainfall to site quality, which in this research, both variables were weighted equally, assuming an equal effect on plant growth. This is perhaps rather simplistic as the nature of soil-climate-plant interaction is actually complex.

Suitability Ratings and Implication

For this investigation, it is worth noting that combining datasets of suitable land or available land from various data formats was intended to calculate the minimum land area potentially available on the Atherton for hoop pine plantation expansion. The delineation for very small areas, however, was not possible. The preconception of farmers about which part of their farms they may be willing to allocate for plantation in moderate to high rainfall areas might change the possibility. Likewise, the expert group indicates that to some extent, the lower range of fertility in the soils classified as "moderately suitable" could be compensated by silvicultural management. For example, several SPCs in the area were classified by the experts as M-H or L-M. This is meant to address the effect of manipulation applied to the site. Put more simply, assuming that intensive silvicultural practices would be applied, an increasing suitability could be expected; however, the increase would be considered maximum up to the lower limit of higher classes (Ryan, P.A, 2003).

ESRI (2001) noted that care should be taken when calculating and interpreting indices derived from qualitative and quantitative attributes. In this regard, a continuous distribution of long-term mean annual rainfall was reclassified into a categorical distribution of four broad rainfall classes. Reclassification to a different criterion may have resulted in a completely differing set of statistics. Similarly, reclassification of the soil profile classes into broad categorical suitability classes may result in a loss of variation of their original attributes.

Concluding Remarks

For the purpose of regional planning, a broad level assessment showed that around 35,567 hectares of land is suitable and potentially available for growing hoop pine in the Atherton. In this region, economic problems for tropical agriculture are likely to drive fertile areas close to ports available for timber plantation (Underwood, 2006). While there are also many factors to be taken into account, if plantation is to be boosted, the GIS-based rapid modeling has shown that a considerable piece of land is available to grow hoop pine with a similar rate to FPQ plantations.

Identifying potential sites for hoop pine plantation expansion involves developing a model taking into account assorted elements considered as influential to the plantation establishment, which in many cases entails diverse approaches as it varies by scale, objectives and technicalities. The role of GIS was proven able to make the data handling in such a great ease, despite high concerns must be placed in interpreting the estimation resulting from generalization and simplification. Expert knowledge itself could serve as a potential information extraction in the absence of extensive literature and time-cost consuming survey, provided the selection of the target expert is assumed relevant to the research object.

In spite of the reported significance of rainfall and soil types to hoop pine, predicting land suitability to grow hoop pine solely on these variables appears to be simplistic. Inclusion of more variables of growth factors such as temperature, radiation, altitude, presented on a finer resolution, is expected to increase the reliability of the model.

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