

REFORESTATION PLANNING BASED ON PLANT HARDINESS ZONES IN VITILEVU ISLAND, FIJI

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ABSTRACT:

Significant land use changes in Fiji Islands caused soil degradation, pollution and biodiversity losses. The planting of trees is an option of sustainable land use with long term ecological and economic advantages. Spatial models based on ecological requirements of tree species facilitates decision making, planning and risks management before planting. A land suitability analysis with Geographic Information System (GIS) was carried out to identify areas in *Vitilevu* island for the planting of eleven native and exotic tree species. Altitudes, rainfall and forest cover maps were used as discrimination factors in *boolean* operations. The species with higher ecological potential for plantation were *Syzygium decussatum* (22% of the total area), *Tectona grandis* (19% of the total area), and *Metroxylon vitiense* (18% of the total area). The model is robust but can be enhanced by adding thematic layers of other environmental factors.

1. INTRODUCTION

Over the last 20 years irrational logging of natural tropical forests worldwide shifted into sustainable management plans and plantations (Evans 1992) of varied composition, scale, complexity, and purpose. They are reported to halt deforestation, increase timber production, and improve soil and water quality and wildlife habitat (Nambiar 1999); in Fiji, the clearing of large areas for the planting of sugar-cane, coconuts and cotton resulted on soil losses of up to $90 \text{ t ha}^{-1} \text{ yr}^{-1}$ (Clarke and Morrison 1987), far above the permissible level for tropical regions of $13.5 \text{ t ha}^{-1} \text{ yr}^{-1}$ (Hudson 1971). The forested area in *Viti Levu* island covers almost 50% of its $10,389 \text{ km}^2$, 5–6% of which are planted (Leslie and Tuinivanua 2009) with similar proportions of planted hardwoods (4.9%) and softwoods (4.5%) and of natural mangrove forests (4.3%) (Figure 1).

Fiji had the most aggressive forest plantation establishment policy of any of the Pacific Islands in order to meet the local demand for timber and to maintain a sustainable export trade in timber products, reinforced with the new markets opened by the Kyoto Protocol (IPCC 2006). The Fiji Hardwood Corporation Ltd (FHCL) and the Fiji Pine Limited (FPL) carry out the planting of mainly Mahogany and Pine respectively at a combined rate of around $9,200 \text{ ha}^{-1} \text{ yr}^{-1}$ (Whiteman 2001).

Other aim of planting native trees is to support biodiversity conservation. Land-use changes, human-induced fragmentation, and invasive species are main threats to biodiversity conservation in small and remote islands (Martins 1993); confirmed since ancient times by palaeoecological records that reveal declines of forest taxa including palms, and a rapid invasion of introduced weed species (Prebble and Dowe 2008). In Easter Island flora decimation was almost complete after human colonization (Hunt and Lipo 2006); a natural rehabilitation is slow. More than 200 villages In Fiji established participatory conservation measures over 10800 km^2 of sea and land (Watling and Chape 1992) which may be still insufficient for the long term preservation of species with unknown genetic plasticity (CBD 2010); therefore the reserves will need to be or relocated.

Most of these environmental problems can be mitigated with a land evaluation, which is the procedure of predicting land performance over time according to particular types of use (Rossiter, 1996). It's a valuable guide for planners to identify alternative land uses.

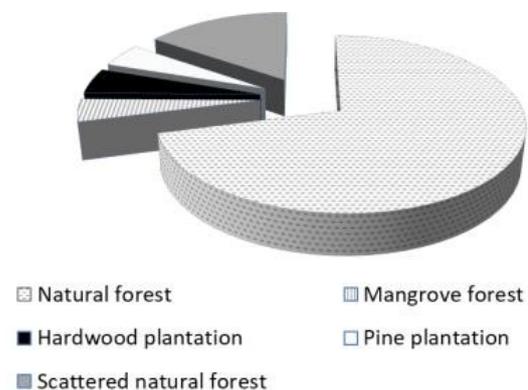


Figure 1. Forest cover distribution over land area in Fiji Islands (Hasni 1997).

2. PLANNING TREE PLANTATIONS WITH GIS

GIS forestry applications mainly focused on resource inventory (including monitoring and analysis) and modelling to support decision making (McKendry and Eastman 1991) specially on forest growth (Riano *et al.* 2004) and hydrological issues (Ticehurst *et al.* 2003); however the planning of reforestation projects at local, regional and national levels can be improved by (1) constructing geographical databases of land suitability for tree species, (2) assessing the land suitability, and (3) selecting possible land areas for new plantations. The areas in the database can be classified on the basis of discontinuities in climate, geology (Mackey *et al.* 2008), biota (Clifford and Stephenson 1975) or on their integration.

Land evaluations, traditionally based on soil surveys, predict land performance over time according to specific types of land use (Rossiter 1996). Carver (1991) applied a multiple-criterion evaluation (MCE) that identifies and map locations for the plantation of eucalyptus and pine trees according to variations on mean annual rainfall, rainfall regime, dry season length, mean maximum temperature of the hottest month, mean minimum temperature of the coldest month and mean annual temperature. The information that goes into the system determines suitability as incompatible (zero) or ideal (one) for each point of the area per vegetation type. The value of suitability depends on a set of physical and biological factors that favor or limit the growth of a tree species for decision-making (Felicisimo *et al.* 2002). The approach has been demonstrated at global and continental scales. In Finland, Kangas (1993) applied multi-criteria discrete methods to a reforestation plan by defining a three-level structure with three objectives: timber production, amenity, and impact on water. Nousiainen *et al.* (1998) added scenic values in a two-stage forest management application.

Plant hardiness is the ability of a plant to survive adverse growing climates such as drought, flooding, heat and cold. Tree species require specific growing environments to thrive; soil types, moisture levels and amount of sunlight are adjustable, but temperature and precipitation are hard to control (Gilmour 2019). In Fiji islands the changes on vegetation structure and composition respond to differences in temperature and rainfall (Walther *et al.* 2002). The rate of decrease of temperature is of 6.5 degrees C for each 1 km altitude change (Engineering ToolBox 2003). Choosing trees with hardiness levels appropriate to specific planting zones provides the best chance of landscaping success. In this paper I hypothesize that precipitation and altitude differences can determine potential areas for tree planting at large scale in *Vitilevu* island.

3. MATERIALS AND METHODS

Maps of forests, elevations and rainfall for *Vitilevu* Island were downloaded from the internet, their original file formats converted into TIFF and imported into Ilwis Open by geospatial data abstraction library. They were georeferenced by corner points used a 1451-meter grid cell size in the elevations map, a 1355-meter grid cell size in the rainfall map, and a 460-meter grid cell size in the forests cover map rainfall map with resulting root mean square errors (RMSE) of less than 0.6 in all cases. A vector map was digitized for each of the maps (figure 3), the corners of the maps were 17°02'26.10"S, 176°23'43.94"E top left and 18°44'41.40"S, 178°47'38.72"E bottom right. Contour maps (rainfall and elevation maps) were linearly interpolated, by rasterizing them and then calculating values for pixels that were not covered by segments. The forest cover raster map was converted into a binary map (0 and 1 values), then into a points format map to capture forested areas, and finally reconverted to raster format for further processing. The pixels of the resulting three raster maps were resampled to a common georeference of 966 m² pixel size by bicubic interpolation, which determines the XY-coordinate of each pixel in the output map and calculates an interpolated value for each pixel using the 16 surrounding pixels of the input map. The areas to be planted per specie (Table 1) were found by applying decision rules. In a boolean operation the IF statement performs different things depending on a certain condition in the logical expression. The general syntax is 'If a then b [else c]', where a is a boolean expression, and b and c are either a single or a compound statement. Figure 2 is a simplified example of a map calculation process to solve OutMap1 = IFF

((Landuse = "Coffee") AND (DEM >= 20), 50, 10). For example, areas to be planted with Pine are calculated: Pinus = IFF ((Alt' > 460) AND (Alt' < 760) AND (rainfall'

> 600) AND (rainfall' < 1000) AND (land cover' = 1), 1, 0); where land cover = 1 are areas without forests. In the case of the palm trees (*sago* and *balaka*) they need to be planted under cover so in their equations land cover = 1. The results were compiled on Table 2.

Landuse			DEM			OutMap1		
C	C	G	45	40	30	50	50	10
F	F	?	?	15	10	10	10	10
G	C	C	10	15	30	10	10	50

Figure 2. Example of map reclassification with conditional function (Ilwis 2016).

Table 1. Ranges of ecological requirements per specie (AFT 2016).

Specie	Altitude	Rainfall
	range (masl)	range (mm)
Pinus caribaea	460-760	>600
Tectona grandis	0-1300	1250-3750
Leucaena leucocephala	0-500	<2500
Sesbania grandiflora	1000-2500	0-800
Metroxylon vitiense	2000 - 2500	0-700
Balaka microcarpa	>4000	50 - 300
Intsia bijuga	0-600	2000-3000
Syzygium decussatum	0-2000	1500-6000
Agathis macrophylla	0-480	4000-5000
Swietenia macrophylla	0-500	1000-2000
Gliricidia sepium	650 - 3500	5 - 1500

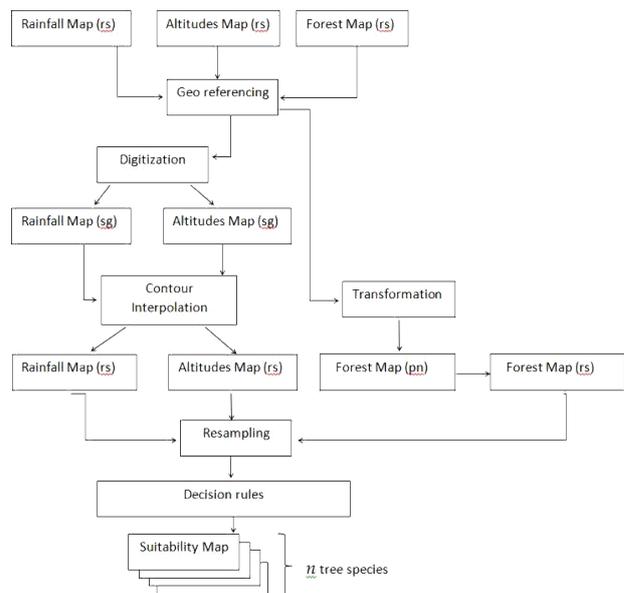


Figure 3. Method flowchart. Map formats are raster (rs), segment (sg) and points (pn).

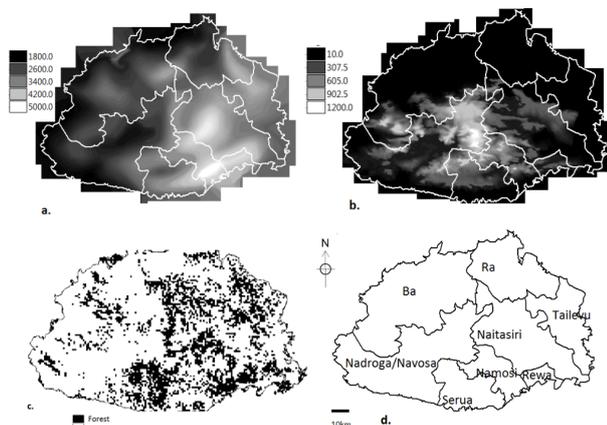


Figure 4. Rainfall (a), elevation (b), forest cover (c), and political (d) maps for *Vitilevu* Island.

Table 2. Resulting number of pixels and equivalent areas (ha) to be planted per specie.

Specie	Family	Common name	Status	Pixels number of optimum areas	Area (ha)	Percentage
<i>Pinus caribaea</i> Morelet	Pinaceae	Pine	Commercial	66668	118802.4	5.5
<i>Tectona grandis</i> L. f.	Lamiaceae	Teak	Commercial	225118	401160.3	18.7
<i>Leucaena leucocephala</i>	Leguminosae	Vaivai	Common	71234	126939.0	5.9
<i>Sesbania grandiflora</i> Pink	Fabaceae	Bean tree	Common	86636	154385.4	7.2
<i>Metroxylon vitense</i>	Palmae	Fiji sago palm	Threatened	215132	383365.2	17.8
<i>Balaka microcarpa</i>	Palmae	Balaka	Threatened	9548	17014.5	0.8
<i>Intsia bijuga</i> (Colebr.) Kuntze	Fabaceae	Vesi	Threatened, commercial	101404	180701.9	8.4
<i>Syzygium decussatum</i>	Myrtaceae	Yasiyayi	Commercial	266908	475630.1	22.1
<i>Agathis macrophylla</i>	Araucariaceae	Dakua	Threatened, commercial	14021	24965.4	1.2
<i>Swietenia macrophylla</i> King	Meliaceae	Mahogany	Commercial	17703	31546.7	1.5
<i>Gliricidia sepium</i>	Fabaceae	Gliricidia	Introduced, cultivated	132405	235946.4	11.0
				Vitilevu total	2150477.3	100.00
				(110X162m)		
				(=17620m ²)		
				(=1.782ha)		

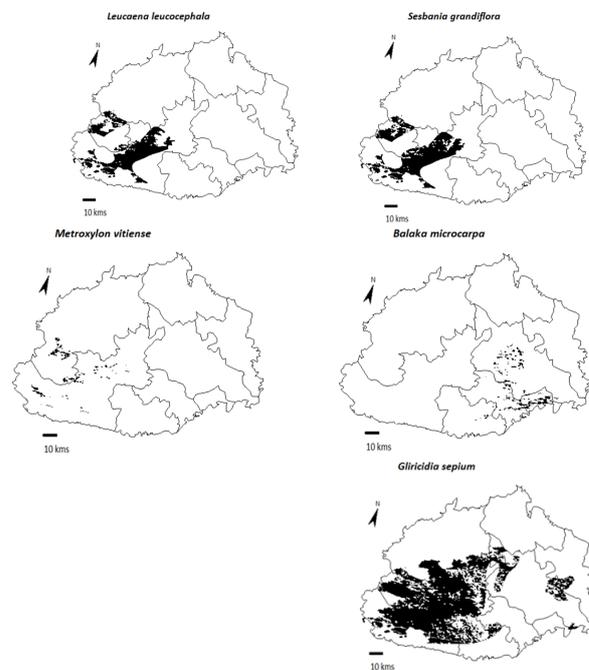


Figure 5. Potential areas to be planted per specie.

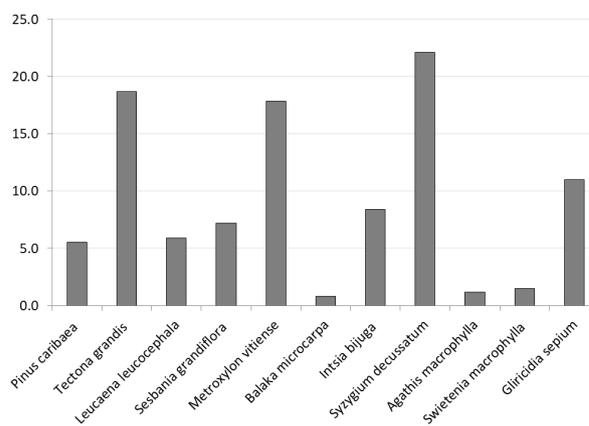


Figure 6. Total potential areas (%) to be planted per specie in *Vitilevu* island

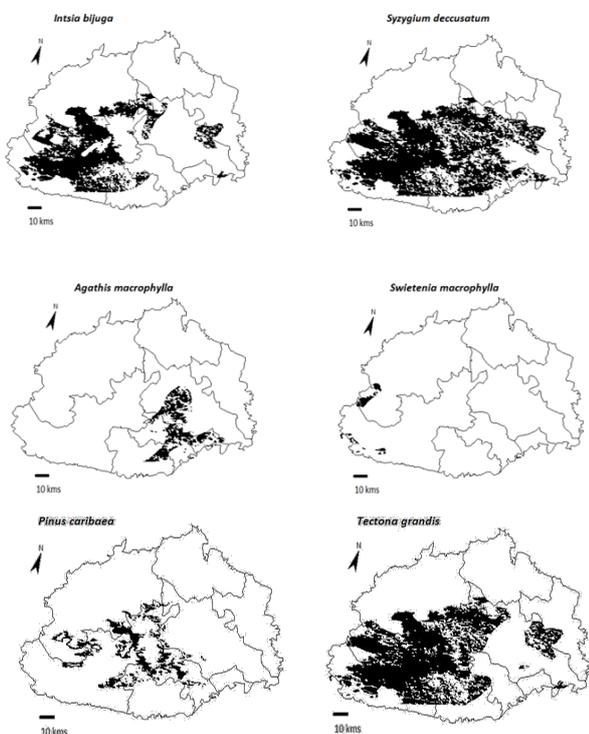


Table 3. Potential areas (ha) to be planted by specie and by province.

Province	Agathis	Balaka	Gliricidia	Intsia	Leucaena
Nadroga-Navosa	1.124	0	138642.309	108605.38	54011
Serua	3832.559	429.649	15443.479	14397.878	0
Namosi	11852.018	2402.27	1007.666	727.509	0
Naitasiri	22203.215	4300.71	18687.624	18686.781	0
Rewa	4884.623	3318.89	308.257	308.257	0
Ba	0	0	57695.763	45244.091	15453.9
Ra	0	0	22.199	22.199	0
Tailo'u	0	0	4139.13	4139.13	0
TOTAL	42773.539	10451.519	235946.427	192131.225	69464.9
Mahogany	Pinus	Metroxylon	Sesbania	Syzygium	Teak
2231.421	27540.25	3452.366	60346.996	145275.033	96310.783
0	3021.312	0	0	24020.442	41153.012
0	10270.83	0	0	29747.222	48525.89
0	2289.588	0	0	66201.633	136872.29
0	0	0	0	5557.337	17519.226
5207.492	12398.56	3591.461	18282.984	57695.763	106621.52
0	0	0	0	22.199	29989.444
0	0	0	0	6670.378	82696.614
7438.913	55520.54	7043.827	78629.982	335190.007	559688.779

4. RESULTS AND CONCLUSIONS

According to Figure 6, *Tectona grandis*, *Syzygium decussatum*, *Gliricidia sepium* and *Metroxylon vitiense* are the most promising species to plant in the island in order of importance. *Pinus caribaea* is more apt to be planted in Nadroga Navosa province (27540.248ha) followed by Ba (12398.563ha) and Namosi provinces (10270.831ha). *Tectona grandis* has high prospects on Ba (106621.516ha), Nadroga-Navosa (96310.783ha), Naitasiri (136872.29ha) and Tailevu (82696.614ha) provinces, *Leucaena leucocephala* in Nadroga-Navosa (54011.01ha) and Ba 15453.876ha) provinces, *Sesbania grandiflora* in Nadroga-Navosa (60346.998ha) and Ba provinces (18282.984ha), *Metroxylon vitiense* on Ba (3591.461ha) and Nadroga-Navosa (3452.366ha), *Balaka microcarpa* on Naitasiri (4300.705ha), Rewa (3318.891ha), Namosi (2402.269ha) and Serua (429.649ha) provinces, *Intsia bijuga* on Nadroga-Navosa (108605.376ha), Ba (45244.091ha), Naitasiri (18686.781ha) and Serua (14397.878ha) provinces, *Syzygium decussatum* in Nadroga-Navosa (145275.033ha), Naitasiri (66201.633ha), Ba (57695.763ha), Namosi (29747.222ha), and Serua (24020.442ha) provinces, *Agathis macrophylla* in Naitasiri (22203.215ha), Namosi (11852.018ha), Rewa (4884.623ha), and Serua (3832.559ha) provinces, and *Swietenia macrophylla* in Ba (5207.492ha) and Nadroga-Navosa (2231.421ha) provinces.

The genus *Syzygium* comprises about 1200 species (Chen and Craven 2015), most are evergreen trees and shrubs. Several species are grown as ornamental plants for their attractive glossy foliage, few produce edible fruits. *Gliricidia sp.* is a multipurpose tree that can be planted by cuttings or seedlings year round (Ratukalou 1998). *Intsia* is one of the most valued trees in the Pacific and *Tectona grandis* is an important tropical hardwood with a MAI of 4–17 m³/ha/year (Pandey and Brown 2000). At this stage this work provides planners and investors with a firsthand report of land potential for the planting of endangered tree species or of high commercial value in the island. The proposed simple model is robust but can be improved by the addition of other thematic layers (soil fertility, land tenure, accessibility, and conservation areas), and by field checking for calibration.

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