# Site suitability and land availability for *Endospermum medullosum* plantation on Espiritu Santo, Vanuatu

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SUMMARY

Site and soil characteristics associated with existing plantings of whitewood (*Endospermum medullosum* Euphorbiaceae) were characterised across Espiritu Santo Island in Vanuatu. Two hundred, generally small (most commonly around 0.5 ha), plantations dominated by whitewood have been planted across the eastern side of the island. These plantations range up to 20 years in age and provide a guide to the expected growth rates of whitewood in plantation in those areas. Site and growth data collected from a range of those plots were used to determine the characteristics associated with the most productive plantations. This association of site variables with growth was correlated with pre-existing resource mapping to estimate the area and locations of land suitable (in terms of sustainable productivity) for whitewood plantation on the island. Some of the characteristics used in that estimation included soil depth, drainage, soil erodibility, slope and existing land use. Using this method it was estimated that around 33 000 ha of land on Espiritu Santo, currently not used or native forest, is highly suitable for whitewood development.

Keywords: suitability assessment, resource mapping, site-species matching, land capability assessment

## Sites appropriés et disponibilité de la terre pour les plantations d'*Endospermum medullosum* sur l'île d'Espiritu Santo à Vanuatu

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Les particularités de la terre et des sites associés au plantations existantes de bois blanc (Endospermum medullosum Euphorbiaceae) ont été relevées au travers de l'île Espiritu Santo à Vanuatu. Deux cent plantations, généralement de petite taille (recouvrant environ 0.5 ha en moyenne) ont été établies le long de la face est de l'île. Ces plantations ont jusqu'à vingt ans d'âge et fournissent un guide pour la prédiction des taux de croissance du bois blanc dans ces régions. Des données de site et de croissance recueillies sur une sélection de ces terrains ont été utilisées pour déterminer les caractéristiques associées aux plantations les plus productives. Cette association de variables de site à la croissance a été comparée à un plan des ressources pré-existant pour estimer la superficie et la location de terres appropriées à la plantation de bois blanc sur l'île, en termes de productivité durable. Certaines des caractéristiques employées dans cette estimation comprenaient la profondeur du sol, son taux d'érosion, sa pente, son drainage et son usage présent. Cette méthode a permis d'estimer que 33 000 ha environ de terres sur Espiritu Santo sans usage actuel, ni hôtes d' une forêt native, sont très favorables au développement de plantations de bois blanc.

## Aptitud de sitio y disponibilidad de terrenos para la plantación de *Endospermum medullosum* en la isla de Espíritu Santo, Vanuatu

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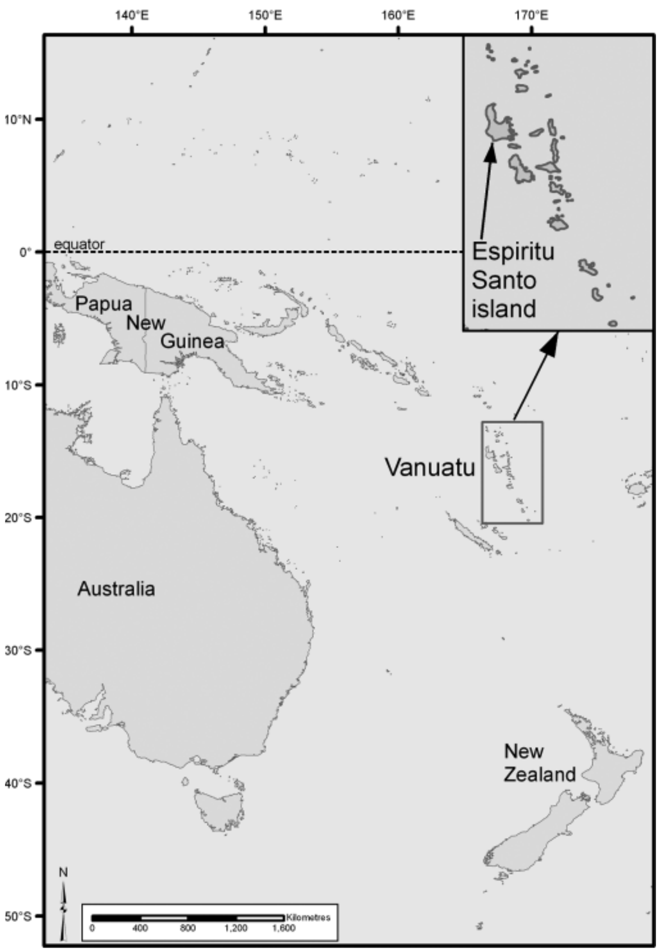
Se ha realizado una caracterización de sitio y del suelo asociada con las plantaciones existentes de madera blanca *(Endospermum medullosum*, Euphorbiaceae) en la isla de Espíritu Santo en Vanuatu. En la parte oriental de la isla se pueden encontrar actualmente unas doscientas plantaciones, predominantemente de madera blanca y normalmente de pequeño tamaño (alrededor de 0,5 ha por lo general). Estas plantaciones, que llegan a tener hasta 20 años de edad, sirven como indicador de las tasas de crecimiento esperadas para madera blanca en plantaciones en dichas áreas. Se utilizaron datos de sitio y de crecimiento tomados de una amplia muestra de entre estas parcelas para determinar las características asociadas a las plantaciones más productivas. Se realizó una correlación entre esta asociación de variables de sitio con el crecimiento y mapas de recursos preexistentes para estimar el área y la localización de terrenos adecuados (en términos de productividad sostenible) para la plantación de madera blanca en la isla. Algunas de las características utilizadas para dicha estimación fueron la profundidad del suelo, el drenaje, la susceptibilidad a la erosión del suelo, la pendiente y el uso actual del suelo. Por medio de este método se estimó que alrededor de 33.000 hectáreas de terreno en Espíritu Santo, que no se utilizan en la actualidad o que son bosques nativos, tienen una aptitud muy elevada para el crecimiento de madera blanca.

INTRODUCTION

Vanuatu is a Melanesian island republic in the south-west Pacific with a population of around 225 000. It consists of 80 islands spanning 850 km from 13°S to 22°S and covering 12,200 km$^2$ (Bellamy 1993). Espiritu Santo (or Santo, as it is most commonly called) is the largest island in the group and covers an area of around 4, 250 km$^2$, extending around 120 km from 14.5°S to 15.5°S (Figure 1). It is 1800 km east of Australia and has a population of around 48 000 (Simeoni 2011).

Forestry has been carried out across Vanuatu in the form of large-scale commercial logging as well as through small-scale native forest and plantation harvesting. The small scale agroforestry, community gardens (active and fallow) and plantations supply a wide range of products including building materials into the subsistence lifestyle of most Vanuatu people (Tacconi and Bennett 1997, Wyatt et al. 1999). Fears around the lack of sustainability of large-scale native forest harvesting led to a ban on log exports in 1993 and the withdrawal of many Timber Licences in 1994 (Wyatt *et al*. 1999). Subsequently a national forest policy was developed with the aim of sustainable forest management. It aimed to protect and develop the timber resource for both commercial forestry and to provide an income source for local communities (Wyatt *et al*. 1999, Wilkie *et al*. 2002).

FIGURE 1 *Location of Vanuatu and Espiritu Santo in south west pacific*




The Government of Vanuatu adopted the Vanuatu National Forest Policy (Department of Forests 1997) in 1998 which recognises that *"the importance of Vanuatu's forests can not be judged only from an economic perspective. Forests, land and people in Vanuatu are inseparably linked. The forests are a vital part of the country's cultural heritage and contribute to the welfare and economic development of the people"*. It also recognised the incapacity of native forest to sustainably meet demand and highlighted the need for enhanced productivity via plantations (Department of Forests 2001). The policy aimed to establish 20 000 ha of planting over the following 20 years.

## Climate

Espritu Santo lies in the tropics. The windward eastern side of the island is classified as a hot and humid equatorial climate (Quantin 1982) while the west coast is identified as tropical (with a short dry season) due to a rain shadow effect produced by the mountains that dominate the western part of the island. The high altitude areas are classed as perhumid i.e., permanently humid, constantly wet and cloudy. Annual average rainfall is recorded at the Luganville airport (the only long term recording station on the island) as 2252 mm. Rainfall peaks around January to April (when around 45% of the rain falls) and has a minimum from July to September (when around 12% of the rain falls). Rainfall exceeds potential (Penman) evaporation for all months of the year (Quantin 1982). Short term (three year) rainfall studies found an increase in rainfall with altitude to over 5000 mm above 600 m (Terry 2011). Temperatures (and humidity) are highest from November to April and lowest from June to August. However, there is little overall variation with just a 2.5 degree range in mean daily temperature between August (24.1°C) and January (26.6°C), a diurnal variation of around 6 degrees and average monthly relative humidity varying from around 79% to 86%.

Vanuatu and the surrounding areas are exposed, on average, to between 20 and 30 cyclones per decade, with 3 to 5 causing severe damage. All of Santo has been mapped as having a cyclone frequency (where winds exceed 64 knots) of twice every two years (Bellamy 1993), however the frequency of damage within a given area is much lower, around once a decade (Mueller-Dombois and Fosberg 1998). Cyclones lead to lower canopies and higher tree densities in native forests (Keppel *et al.* 2010) and this is likely to also be the case in terms of canopy height for plantations. Whitewood has good cyclone resistance at all ages (Department of Forests 2001, Thomson 2006). This is likely due to its canopy structure. Whitewood has a crown composed of widely spread whorls of branches and broad leaves which can be lost in high winds leaving relatively little surface area that could create stresses to snap the trunk. It also forms a relatively uniform canopy with other whitewood, ensuring that there are none of the weak points that occur with an uneven canopy.

## Soils

The higher altitude areas of Santo and the western parts of the island are dominated by steep and dissected topography with a relatively diverse range of shallow and unstable soils that pose severe limitations on agricultural and forestry use. Much of this area remains forested and is used mainly for subsistence agriculture. The east coast of Santo provides a stark contrast, being dominated by low to moderate slopes with soils that have formed from volcanic ash deposits laid down on a base of coral limestone. As volcanic ash is generally highly weatherable, under tropical conditions it soon weathers to the point where primary minerals are absent. The soils produced are physically fertile, that is the high levels of organic matter, nonsilicate (iron and aluminium sesquioxide) minerals and kaolinite clays lead to the formation of strong fine structure that allows rapid infiltration and good drainage, good moisture holding capacity and little impedance to root growth. However, these soils can also have the capacity to strongly bind anions leading to the fixation or sorption of phosphorus.

Quantin (1975) describes the soils on the eastern parts of Santo as dominated by mostly weakly to moderately unsaturated ferrallitic soils (French pedological classification). These have been re-interpreted as Alfisols (Hapludalfs) and Inceptisols (Dystropepts and Eutropepts) (Bellamy 1993). Recent soils derived from volcanic ash with a strong capacity for phosphorus sorption often produce phosphorus deficiency in crops grown on these soils. This has been observed on Santo for both pasture (Macfarlane and Shelton 1986) and maize (Melteras *et al.* 2004). Nitrogen and sulfur were also noted as deficient in some of these soils but critical ranges for existing soil tests were shown to be relatively poor in accurately predicting availability of those nutrients (Melteras *et al.* 2004).

## Forestry

The Vanuatu National Forest Policy aimed to establish 20 000 ha of plantation in the 20 years following 1997. In 2000 there was 2 910 ha of plantation in Vanuatu (Department of Forests 2001) and there was little change in that figure by 2003 (Bakeo *et al.* 2003). The estate consisted of 890 ha of *Pinus caribaea* with the remainder made up of plantation dominated by *Cordia alliodora*, *Endospermum medullosum* and *Swietenia macrophylla*. On Santo around 325 ha of plantation has been established within a 5 500 ha area proposed for wider planting within the Industrial Forestry Plantations (IFP) scheme (Department of Forests 2001). Another 250 ha (all whitewood) have been established privately by Melcoffee Sawmill Ltd and around 170 ha by farmers in small woodlots.

There is around 480 ha of whitewood-dominated plantation on Santo. The two relatively large plantings (IFP and Melcoffee Sawmill) account for around 300 ha of that with the remainder scattered across the eastern side of Santo in around 230 small community plantings with an average size of around 0.5 ha. These plantings arose from Vanuatu Department of Forests extension services to landowners, providing advice and guidance as well as seedlings for the establishment of plantations. Melcoffee Sawmill Ltd also provided seedlings and support to landowners.

## Suitability Assessment

Land suitability assessment is defined as the evaluation of land for a specific use, in this case for forestry (FAO 1984). This includes an assessment of productivity but must also take into account other factors including management limitations, sustainability and economics. Site factors that affect productivity are dominated by climatic factors such as rainfall and temperature and edaphic properties including drainage, rooting conditions and nutrient availability. Management factors include site accessibility, cyclone intensity and frequency, erosion potential and nutrient depletion hazard. Cyclone intensity and frequency has been treated as a management limitation in that it effects risk management but does not directly affect productivity (in a predictable manner). Some site factors that may be limitations to broad scale mechanised forestry (such as rock outcrop) may not be a limitation for small scale operations such as characterise community

TABLE 1 *recommended land suitability class definitions (FAO 1976)*

| Class | Designation | Definition |
|---|---|---|
| Class 1 | Highly Suitable | Land having no significant limitations to sustained application of the given land utilization type, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level |
| Class 2 | Moderately Suitable | Land having limitations which in aggregate are moderately severe for sustained application of the given land utilization type; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use will be appreciably inferior to that expected on Class S1 land |
| Class 3 | Marginally Suitable | Land having limitations which in aggregate are severe for sustained application of the given land utilization type and will so reduce productivity or benefits, or increase required inputs, that this expenditure will only be marginally justified. |
| Class 4 | Unsuitable | Includes land with severe limitations which preclude any possibilities of successful sustained forestry as well as limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost |

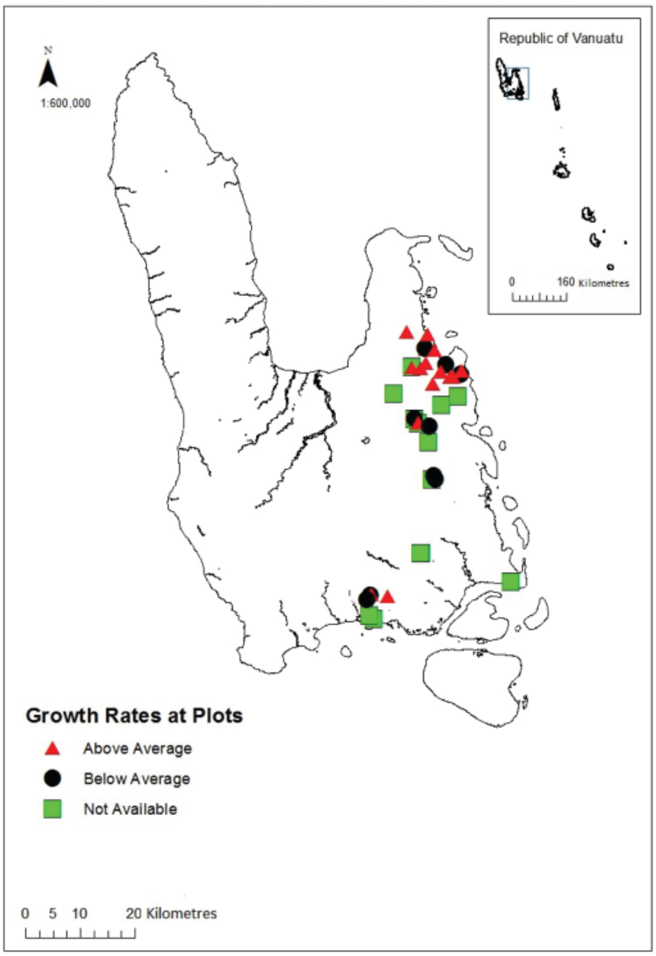
forestry in Vanuatu. The consideration of sustainability means that the assessment must take into account land degradation hazards.

The aim of this project was to identify site characteristics that were associated with high productivity in whitewood plantations and from that information determine the area of land on Santo suitable and potentially available for white-wood plantations.

METHODS

The soil and land characteristics were described across a wide geographic range of whitewood plantings on Santo (see Figure 2). Soil and site characteristics were described from auger cores and/or pits at 40 sites across the eastern part of Santo representative of the range of plantations (National Committee on Soil and Terrain 2009). The soil profile was described to the depth of the auger (110 cm) or to coral where the total soil depth was less than 110 cm. Reaction to Sodium fluoride (NaF) (Fieldes and Perrot 1966) was recorded from the topsoil and subsoil to determine likely phosphorus sorption levels (Alves and Lavorenti 2004).

FIGURE 2 *Soil profile (SP) description sites within white-wood plantations*




This initial set of site data provided the foundation for further studies. From this initial set of sites a representative subset of was chosen upon which to establish growth plots. The growth plots were established on sites selected to cover the range of observed variation in terms of north-south spread, altitude and soil characteristics. The whitewood productivity data collected was correlated with the soil and land character-istics collected at each site and a growth model was produced. The identification of the range of sites and soils upon which whitewood had been planted also allowed the establishment of various silvicultural trials on representative soil types. The assessment of whitewood nutritional requirements in relation to the ability of the common soil types to supply those needs was determined through fertiliser trials (Smith *et al.* 2012).

**Mapping methods**

Mapping data used for the project was derived from the Vanuatu Resource Information System (VANRIS) developed by a team of scientists from the CSIRO (Division of Tropical Crops and Pastures, Brisbane Australia) in collaboration with the Queensland Forest Service and the Vanuatu Department of Forestry in 1990 (Bellamy 1993). VANRIS provides detailed spatially-based information for all of Vanuatu incor-porating natural resources with population distribution and land use. Resource Mapping Units (RMU) within VANRIS delineate natural landscape units, data that was integral to the mapping of land suitable for whitewood plantation (Baldwin *et al.* 1992). The VANRIS mapping incorporated existing information including geological and soils mapping with climatic data and added air photo interpretation and stratified field sampling to create the RMUs.

The climatic, landform and soil categories that defined RMUs were classified according to their suitability for white-wood plantation as determined from existing plantations. The suitable areas were further delimited according to vegetation, with areas of existing forest and swamps excluded. Areas with scattered forest remnants and areas classed as thickets dominated by invader species such as *Hibiscus tilaceus*, *Acacia spirobis, Leucaena leucocephala* and the vine *Merrimea peltata* were included. Also included were areas of grassland and small areas with no vegetation cover at the time of original mapping.

A further analysis using land use intensity determined those areas that were 'suitable and potentially available'. The VANRIS project mapped land use intensity which was an attempt to take into account the village agricultural system of shifting agriculture, i.e., cropping followed by fallow. Gardening takes place on a piece of land for one to two years and then that plot is fallowed under natural vegetation for 5–15 years. Thus any analysis of land required for agriculture in an area must take into account the area currently under gardens as well as that under fallow. Whitewood plantations could be integrated into a taungya system utilising areas under longer term fallow where gardening would take place in the early years of the plantation (providing benefits to both the garden and the plantation) and a cash timber crop would be available at the end of the fallow. This would not work in some areas where the pressure on land high and the fallows are short. For this reason areas of high use intensity were excluded from our estimates of available land as were areas mapped as conservation, non-subsistence cash crops, cultivated land, and larger settlements.

## RESULTS

### Soils

The most common soil was a Hapludalf; the profile consisted of an average of 24cm (standard deviation 9.8cm) of very dark brown (10YR2/2) to very dark greyish brown (10YR3/2) light clay to silty clay loam topsoil with strong fine granular structure. This graded into a 51cm thick (sd 20cm) dark yellowish brown (10YR3/4) to dark brown (7.5YR3/3) light clay to silty light medium clay subsoil with strong fine polyhedral to subangular blocky structure. These soils are described as having field textures of from clay loam to light medium clays but they are often subplastic (Bennett 1989). No particle size analysis was carried out but it is likely that clay contents are higher than indicated by the field textures. Similar soils from Santo have been reported as having measured clay contents of 70–80% (Claridge Undated).

Soils that were described within the plantations were relatively consistent with the main variation being total depth. Where the topography is dissected the soil depth was reduced but areas of shallow soils also occur on flat lying terrain. The soils have excellent physical properties with good structure and drainage and good moisture holding capacity. The main physical constraint observed was the depth to coral on the shallower soils. Soils were generally moderately acidic with a mean field pH of 6.1 in the topsoil and 5.9 in the subsoil. The soil pH increased dramatically in the parts of the soil profile near to the underlying coral. A test for the presence of allophane (Fieldes and Perrot 1966) was carried out across the sites and returned an average rating of 1 for both the topsoil and subsoils of the described sites (on a scale of 0–4 where 1 was rated as a very weak reaction taking 2 minutes to become apparent). This test, though originally developed as a test for allophone is also indicative of phosphorus sorption in non-allophanic soils (Singh and Gilkes 1991, Gilkes and Hughes 1994, Alves and Lavorenti 2004).

Three representative sites were sampled for chemical analysis (results presented in Table 2). These soils had very low levels for available phosphorus according to general standards (Landon 1984). However total phosphorus levels are likely to be high and the applicability of the available phosphorus tests to whitewood requirements is unknown. Available measures of phosphorus have been shown to be highly predictive of response to phosphorus fertiliser for some species (Hunter *et al.* 1986) but relatively poor for others (Cromer *et al.* 2002). The total nitrogen levels were medium but tests of total nitrogen or nitrates and ammonium are poor indicators of the nitrogen availability (Landon 1984, Binkley and Hart 1989). The cations (Ca, Mg, K and Na) were considered to be at adequate levels and well balanced based on data in Peverill *et al* (1999). There was no significant short term growth response of whitewood in fertiliser trials as reported in this issue (Smith *et al.* 2012).

### Suitability prediction

Acceptable productivity was defined as mean annual wood volume increment of age 15 or greater of over 15m$^3$/ha/yr, based on plot measurements. Analysis of the data collected from the growth plots showed that all the plots could be fitted to the same growth model (Grant *et al.* 2012). This growth model predicts a mean annual wood volume increment of age 15 or greater of over 15m$^3$/ha/yr, except at very low stockings (Grant *et al.* 2012). The range of parameters described across the growth plots can therefore be used to create a set of soil and site characteristics that can deliver high whitewood growth. It does not, however, describe the entire envelope of environmental conditions that will produce good growth, because the limited set of site characteristics encompassed within existing plantations did not provide a set of growth plots that tested that envelope. The area on Santo that is suitable for whitewood growth is therefore possibly larger than that determined in this initial study. The range of site and soil characteristics described was combined with past reports on whitewood site requirements and management limitations to determine a set of limiting land qualities (FAO 1984, Thomson 2006) (Table 3). One of those prominent features in this cyclone prone area is windthrow risk. There is no published research that relates soil depth to windthrow risk for whitewood in Vanuatu. However, in light of the general relationship between soil depth and wind firmness (Wood *et al.* 2008), it seemed prudent to avoid shallow soils and suitability was downgraded according to soil depth (even though the productivities on some shallow soils appear high). This assessment may change as our understanding improves.

The area of Class 1 land – land highly suitable for whitewood plantations was determined using the criteria as set out in Table 3 and totalled 77 911 ha (Figure 3). This includes areas of anthropogenic vegetation such as coconuts farms and extensive grazing land, some of which could be turned to timber production. It also includes areas of subsistence gardens which maintain fallow periods of between seven to thirty years (Muller *et al.* 2011) depending on the location of the plots. Some of these areas could incorporate whitewood plantations within the fallow to provide a cash crop and still have the potential, if desired, to crop in the inter-row, at least in the early years of the rotation.

In order to more accurately determine how much of this land could be potentially available (rather than just suitable) other factors such as land use, and land use intensity were incorporated. The VANRIS stratification of land use allowed areas of high intensity use for subsistence farming, tree crops by large or smallholders, cash crops, and grazing to be identified and removed from the calculations. This found the area of land that is both suitable and available to be 32 903 hectares. This area is presented in Figure 3 along with areas of coconut plantation and grazing that are considered as being potentially available for conversion.

TABLE 2 *Nutrient contents at three sites selected across Santo*

| | North | | Central | | South | |
|---|---|---|---|---|---|---|
| | *Topsoil (0–10cm)* | *Subsoil (30–50cm)* | *Topsoil (0–10cm)* | *Subsoil (30–50cm)* | *Topsoil (0–10cm)* | *Subsoil (30–50cm)* |
| Bray 1 P (mg/kg) | 1.8 | 1.6 | 2.0 | 1.5 | 1.5 | 1.6 |
| Colwell P (mg/kg) | 21 | 67 | 40 | 55 | 56 | 170 |
| Morgan P (mg/kg) | 1.4 | 1 | 4.3 | 1 | 1 | 1 |
| S (mg/kg)[1] | 52.8 | 286.6 | 39.9 | 163.3 | 43.3 | 179.7 |
| pHw | 6.1 | 6.2 | 6.2 | 5.9 | 6.2 | 6.0 |
| Ca ($cmol^+$/kg)[2] | 17.1 | 4.9 | 18.2 | 8.2 | 11.1 | 2.5 |
| Mg ($cmol^+$/kg)[2] | 2.6 | 0.3 | 2.6 | 0.3 | 2.2 | 0.6 |
| K ($cmol^+$/kg)[2] | 1.16 | 0.25 | 1.52 | 0.18 | 0.38 | 0.23 |
| Na ($cmol^+$/kg)[2] | 0.11 | 0.15 | 0.10 | 0.20 | 0.09 | 0.06 |
| Al ($cmol^+$/kg)[3] | 0.01 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 |
| H ($cmol^+$/kg)[3] | 0.14 | 0.03 | 0.12 | 0.09 | 0.15 | 0.06 |
| ECEC ($cmol^+$/kg)[4] | 21.2 | 5.7 | 22.6 | 9.0 | 14.0 | 3.5 |
| Ca/Mg | 6 | 14 | 7 | 25 | 5 | 4 |
| Zn (mg/kg)[5] | 4.6 | 0.6 | 3.2 | 0.2 | 1.8 | 0.2 |
| Mn (mg/kg)[5] | 82 | 8 | 84 | 4 | 12 | 3 |
| Fe (mg/kg)[5] | 79 | 31 | 99 | 24 | 114 | 80 |
| Cu (mg/kg)[5] | 16.6 | 1.0 | 15.4 | 0.4 | 10.2 | 2.7 |
| B (mg/kg)[6] | 0.40 | 0.07 | 0.56 | 0.14 | 0.22 | 0.10 |
| Total C (%)[7] | 6.7 | 1.0 | 6.6 | 1.5 | 6.9 | 2.2 |
| Total N (%)[7] | 0.76 | 0.12 | 0.77 | 0.17 | 0.71 | 0.23 |
| C/N Ratio | 9 | 8 | 9 | 9 | 10 | 10 |

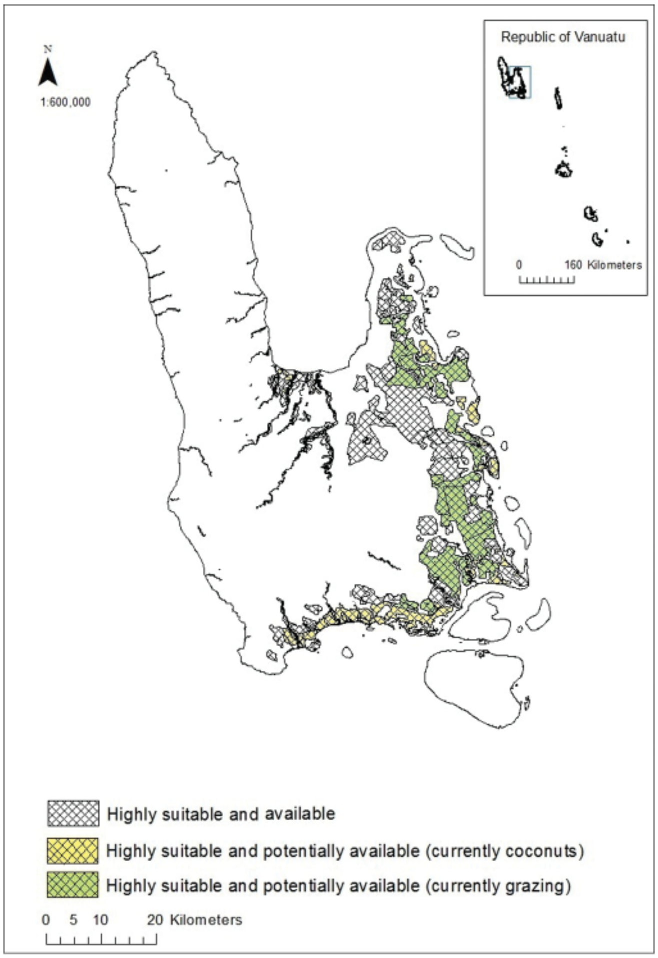
[1] KCl extract, [2] Ammonium acetate exchange, [3] KCl exchange, [4] Sum of exchangeable cations plus exchange acidity, [5] DPTA extract, [6] $CaCl_2$ extract, [7] LECO

TABLE 3

| Land quality | Suitability | | | |
|---|---|---|---|---|
| | **Highly suitable (Suitability Class 1)** | **Moderately suitable (Suitability Class 2)** | **Marginally suitable (Suitability Class 3)** | **Unsuitable (Suitability Class 4)** |
| Soil Depth | Deep >100cm | Moderate 50–100cm | Shallow 25–50cm | Shallow <25cm |
| Available Water Content | Very high | High | Moderate | Low |
| Drainage | Well drained | | Imperfectly drained | Poorly drained |
| Stone Content[1] | Slightly to moderately stony | Very stony (15–30%) | Extremely stony (>30%) | |
| ECEC[2] | > 5 cmol(+)/kg | | | |
| Available P[3] | > 20 ppm | | | |
| Total N[4] | > 0.2% | | | |
| Slope | 0–3% | 3–18% | | >18% |
| Soil Erodibility | Minimal | Moderate | | Severe |
| Climate Type[5] | E1/E2 | | | |

[1] Stone content is not likely to be a limiting factor for small-scale forestry.
[2] Sum of exchangeable cations plus exchange acidity in topsoil
[3] Colwell extract on topsoil
[4] Topsoil
[5] Wet Equatorial (MAR >2250 mm and with low seasonality).

Figure 3 *Availability of highly suitable land for whitewood plantation on Santo (land used for coconut growing or grazing may potentially be available for conversion)*




The area of Class 2 land – land moderately suitable for whitewood plantations totalled 5114 ha. The main limiting factors in these areas were soil depth (soils > 50 cm but < 100 cm), soil erodibility (moderate) and/or slope (slopes >3% but <18%). These areas may have reduced productivity (on the shallower soils) and/or have greater requirement for management to prevent land degradation (the more erodible soils and the sloping sites)

## DISCUSSION

Observations of existing plantations found high whitewood productivity on relatively deep, well structured and well drained soils. Land dominated by these soils on gentle slopes with low erodibility and minimal limitations, which is not presently forested, is suitable for plantation development, and totals around 78 000 ha on Santo.

The soils that were described in association with existing whitewood plantations did not exhibit a great deal of variation and productivity did not vary. The main variation observed was soil depth to the underlying coral basement. The relative uniformity of soil across the exiting plantation estate soil is likely to be due the intimate understanding the Ni-Vanuatu people have of soil and plant growth relationships. The sites that have been selected for planting whitewood are, in general, sites that are well suited to whitewood growth. However, this did mean that this project did not have the opportunity to observe the growth of whitewood plantation across the entire range of soil types present on Santo, or even those that occur on the eastern side of the island. However, the soil characteristics associated in this study with good plantation growth were applied to all those remaining soils when carrying out the assessment to produce a first approximation of suitable land across Santo. Further research and continued measures of the installed growth plots will provide a more accurate assessment. Another area that requires further research is that of nutrient flow through whitewood plantations. It is important that whitewood plantations do not lead to an unsustainable loss of nutrients from the system and it could even be expected that they may act in a similar manner to a period of fallow in restoring fertility. At this stage no assessment of risk of nutrient depletion has been included in the site suitability assessment.

This project relied strongly on existing resource mapping provided by VANRIS (Bellamy 1993). This system incorporates and builds on detailed soil information from previous mapping (Quantin 1982) along with climate and landform information. The climate soil and landform data does not become outdated and therefore the areas of suitable land that have been mapped are current. However, some of the other VANRIS information, particularly that based on the interpretation of vegetation and land use was derived from the then available 1984–1986 black and white aerial photography is likely to be indicative only. In the time since the original VANRIS mapping, vegetation associations have been altered (mostly through clearing of forest, leading to increased potential areas for whitewood plantation). At the same time areas used for subsistence agriculture have also increased in association with population and this may decrease the areas available for whitewood plantation.

This project has provided estimates areas and locations of land suitable for white wood plantations. However, this mapping has been based on information mapped at 1:50 000. Therefore the delineation of actual areas with potential for plantation is only accurate at that scale. More accurate site specific description and analysis should be undertaken on the ground before commencing any plantation development.

## CONCLUSION

This project examined existing whitewood plantations across Santo Island in Vanuatu and determined a set of site and soil characteristics that were associated with high productivity. An additional set of criteria applicable to sustainable land use, current land use and extant vegetation were added to define land suitable and available for whitewood plantation. These criteria were applied to existing land resource mapping to estimate the area and location of suitable and available land for whitewood plantation on the island. It was found that Santo island has around 77 000 ha areas of land that are highly suitable for whitewood plantation development located across the eastern side of Santo island. Around 33 000 ha of this is not currently intensively used.

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