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The International Forestry Review

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Cover photo: Four-year-old whitewood planted at 4 x 3 m at Victor's Farm, near Luganville, Vanuatu (Jerry Vanclay)

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  SMITH, W.J. 2001. Selection of tree species for arid environments. In: BLACKBURN, J.W. (ed.) *Multipurpose trees and shrubs for fuelwood and agroforestry*. CNRD Monograph No4. 366 pp.

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Editorial: Domesticating native tree species for development in small island nations

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ROLE OF FORESTS IN DEVELOPMENT

Forests play a key role in development in addition to the multiple roles they play in providing products for subsistence lifestyles and livelihoods for an estimated 1.6 billion people (Belcher 2005). They are often abundant in developing countries that have few other assets, are renewable if managed wisely, and can provide the capital and help build the skill base for other enterprises. However, the track record of developing countries with tropical forests in managing a transition to sustainable forest management is poor. Many forests have been overcut, and then poorly regenerated or converted to other land uses, and there are, sadly, too few illustrations of the way in which forests can play a significant and sustainable role in development (Salim and Ullsten 1999). Thus it is important to continue to work collaboratively to find ways to improve forest management and to develop value-adding forest industries that source logs from forests and plantations that are managed sustainably.

SMALL ISLAND NATIONS

The difficulties associated with sustainable forest management are compounded in small island states, where there are several challenges including barriers to market mechanisms, lack of infrastructure, logistical challenges of moving logs and timber between islands or overseas, and in some cases, severe weather (e.g. cyclones). These small nations may also have relatively small Forestry Departments with few resources to support the development of sustainable forest industries. Frequently, transaction costs in small island states are higher than in comparable continental nations, particularly with regard to trade. Typically, capital costs are higher, transport is slow and expensive, and economies of scale are harder to achieve. However, the durability of some tropical timbers means that with appropriate treatment and handling, they can be stockpiled, stored, and consolidated into container-sized shipments, conferring some advantages over other traded products. Thus value-added timber products can be attractive as an export industry for small island states where land use pressure is modest. However, to realize the greatest benefits of a timber industry, it is important to develop appropriate silvicultural systems to encourage the development of high quality logs as well to develop national capacity to add value in-country, and to export processed timber rather than logs.

NEED FOR PLANTATIONS

Global experience of timber exports from island nations reveals a depressing record of over-exploitation and under-investment in both reforestation and plantation development. In many cases island nations have seen little benefit from the pillage of their natural resources. Thus any attempt to foster the development of a sustainable timber industry should be underpinned by appropriate investment in silviculture, wood processing and forest policy. Any plans to harvest residual native forests should be guided by appropriate silviculture and growth studies, and supplemented with afforestation. Equally, plantation development efforts should be informed by species trials and domestication research, as well as by growth modelling and capacity building.

Many plantation development efforts are hampered by poor choice of species, so the need for thoughtful species selection and careful species-site matching cannot be overstated. Species selection should take into account potential growth rates and stem form, the capacity of the species to cope with local environmental factors as well as wood quality considerations such as easy of processing, durability, and market acceptance. An advantage of indigenous species is that consumers may already be familiar with the timber and the species should be well adapted to the local environment.

DOMESTICATING SUITABLE NATIVE SPECIES

Domestication is the process of taking a wild species, bringing it into cultivation and then improving the desired characteristics of the species (Leakey and Tomich 1999, Nichols and Vanclay 2012). For most tree species it usually involves identifying good seed sources from within the natural population and then developing appropriate propagation and silvicultural practices. For the most valuable timber and fibre species, the domestication process involves systematic characterization of genetic variation within the natural population, development of efficient mass propagation techniques, intensive genetic improvement and testing of wood properties programs and improved silvicultural and utilisation techniques. Domestication is an ongoing process in which genetic and cultivation enhancements are improved progressively and made available to those growing the trees. In small developing countries where resources are limited, choices need to be made about which species to prioritize for domestication and which elements of the domestication process are likely to return the greatest immediate benefits.

DEVELOPMENT ASSISTANCE TO HELP DRIVE THIS PROCESS IN DEVELOPING NATIONS

Many developing countries lack the resources and capacity to undertake the research and development associated with domesticating native and exotic species for plantation development. Over the years, many donors have provided support to developing countries for forest research, both directly and through multilateral partnerships such as the Center for International Forestry Research and the World Agroforestry Centre. In the case of Australia, for the past thirty years most of this has been provided through the Australian Centre for International Agricultural Research (ACIAR). ACIAR's mission is to enhance the productivity and sustainability of agricultural systems, for mutual benefit, through international research partnerships.

ACIAR works with developing countries to identify opportunities that have a clear research question. It then supports collaborative research programs linking research institutions in Australia and overseas to address these issues, strengthen local capacity and promote adoption of the research outcomes. Over the years, a considerable portion of ACIAR's forestry research projects have focussed on domestication of native and exotic tree species to enhance livelihoods and improve environmental and economic development outcomes in the partner countries. ACIAR's long-term investments enable sustained research and can enable insights not accessible in short-term research projects (e.g., Griffin 1988, Gregorio *et al.* 2012).

In the right circumstances, donor investment in tree domestication research can provide very high returns. An impact assessment (Fisher and Gordon 2007) found that investmentsby ACIAR in *Eucalyptus* and *Acacia* domestication research activities over a 13 year period in Vietnam provided a high return on investment (estimated at 32%), despite the long lag time before the benefits were realised. The research into tree domestication and improved plantation management in Vietnam has resulted in almost one million hectares of plantations based on Australian germplasm and thousands of farmers planting improved genetic material.

Vanuatu: an interesting case study

Vanuatu, a small Pacific Island nation with about 80 islands and 220,000 people, makes an interesting case study on the benefits from tree domestication research. Forests and trees are of great importance to the livelihoods of communities in many Pacific countries and subsistence farmers have planted trees in a variety of agroforestry systems for hundreds of years. In Vanuatu, all forests are owned by custom landowners.

In the 1990s and early 2000s, an average of 35,000 m^3 of sawlogs from native forests was harvested and processed in sawmills in Vanuatu each year. One of the most important species was a native tree known locally as whitewood (*Endospermum medulosum*) and local processors developed markets for value added products in Japan (Viranamangga *et al*. 2012). The Department of Forests raised whitewood seedlings and encouraged landowners to replant after logging, but very little reforestation occurred. One enterprising sawmiller established 270 hectares of whitewood plantations and commenced harvesting in 2011 when the trees were 17 years old. Insights from this experience guide current research (Viranamangga *et al*. 2012). The Vanuatu National Forest Policy sets a goal of establishing 20,000 hectares of commercial plantations and while there is some community interest in growing whitewood the current area of planted whitewood is only about 350 hectares.

Despite this history of using trees little research has been done on the domestication of important native timber species. Two of ACIAR's forestry projects in Vanuatu, with a combined investment of A$1.2 million over five years, are researching the growth and management of whitewood and the improved availability of whitewood germplasm. Whitewood is a fast growing hardwood species in the natural forest that is well suited to plantation and agroforestry situations and is able to survive cyclones without major damage. Improved knowledge of whitewood silviculture should enhance the benefits to both the landowners who grow the trees and the processing industries that will utilise them.

This special issue deals with a diverse series of insights derived from these ACIAR projects in Vanuatu, covering the constraints (Aru *et al*. 2012), establishment (Grant *et al.* 2012b, Smith *et al*. 2012), silviculture (Glencross *et al.* 2012, Grant *et al.* 2012a), genetics (Doran *et al*. 2012, Settle *et al.* 2012) and marketing opportunities (Viranamangga *et al.* 2012).

CONCLUSION

Many small developing countries including island nations such as Vanuatu have the potential to have a viable domestic forest industry based on planted wood. But in order to achieve this, there needs to be a structured approach to the domestication of suitable species. A modest investment in forest research programs can provide the necessary information and suitable germplasm to implement a planted forest program. In order to achieve such a domestication program, countries like Vanuatu need assistance from donor countries. The papers in this special issue demonstrate the benefits from collaborative research on tree domestication.

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Domestication of native tree species for timber plantations: key insights for tropical island nations

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SUMMARY

A review of tree domestication principles, practices and case studies illustrates the importance of a methodological approach to domestication. Domestication of new species involves of the entire value chain from identification of candidate species, through production and management, to uptake by communities and markets. Efforts to domesticate forest trees have often neglected the final step of adoption, with the result that many projects have resulted in mature trees without markets. Ensuring adoption and marketability is important for the success of any domestication effort, but especially in small island nations where local markets may be small, transport limited and transaction costs high.

Keywords: adoption, agroforestry, silviculture, species selection, tree breeding

Domestication d’espèces d’arbres indigènes pour les plantations de bois de construction: enseignements principaux pour les nations insulaires tropicales

J.D. NICHOLS et J.K. VANCLAY

L’examen des principes, des pratiques et des études de cas dans le domaine de la domestication des arbres met en évidence l’importance de l’adoption d’une approche méthodologique en matière de domestication. La domestication de nouvelles espèces concerne l’ensemble de la chaîne de valeur, de l’identification des espèces potentielles à la production et gestion, en passant par la mise en oeuvre par les communautés et les marchés. Les initiatives de domestication des arbres forestiers ont souvent négligé l’étape finale: l’adoption. Aussi beaucoup de projets ont-ils abouti à la production d’arbres à maturité, sans débouchés. Pour garantir le succès de toute initiative de domestication, tout particulièrement dans les petites nations insulaires où les marchés locaux peuvent être petits, les transports limités et les frais de transactions élevés, il est important de veiller à l’adoption et à la possibilité de commercialisation.

Domesticación de especies arbóreas nativas en plantaciones para madera: puntos claves para naciones insulares tropicales

J.D. NICHOLS y J.K. VANCLAY

Una revisión de los principios, prácticas y estudios de caso de domesticación de árboles ilustra la importancia de un planteamiento metodológico en cuanto a la domesticación. La domesticación de nuevas especies involucra a la totalidad de la cadena de valor: desde la identificación de especies candidatas a la aceptación por parte de comunidades y mercados, pasando antes por la producción y el manejo. Los esfuerzos para domesticar árboles forestales han descuidado a menudo el paso final de la adopción, resultando en muchos proyectos que logran árboles maduros pero no consiguen crear mercados. El asegurar la adopción y la comerciabilidad es importante para el éxito de cualquier intento de domesticación, pero más especialmente en pequeñas naciones insulares donde puede que los mercados locales sean pequeños, el transporte limitado y los costos de transacción elevados.

INTRODUCTION

Small island states feature prominently amongst the least developed nations, and many are economically vulnerable (McGillivray *et al.* 2010, Wittersheim 2011). Sustainable development may depend on adding value to local products to create employment, to displace imports and to generate exports. In many cases, especially in the tropics, opportunities that exist in the agricultural and forestry sectors are hampered by the poor state of knowledge of potential species and markets. Forest products are of particular interest because of their role in construction, in import substitution, and the relative simplicity of their transport and storage. Despite this potential role, there has been relatively little attention devoted to the process and practice of domesticating tree species for use in plantations, especially for non-industrial plantations.

Planted forests may take many forms, spanning a wide range including extremes such as the near-natural Damar (*Shorea javanica*) forests in Sumatra (e.g. Torquebiau 1985, Michon *et al.* 2007), to short-rotation *Eucalyptus* monoculture plantations in Brazil (Campinhos 1999) and to agroforestry plantings such as *Grevillea robusta* over coffee in Kenya (Lott *et al.* 2000). So it is appropriate to examine the broad scope of silvicultural and industrial options available to support an emerging industry, particularly given the constraints of small island States (Briguglio 1995). Wilkinson *et al.* (2000) offered a useful classification of 'plantation forestry', and discriminated between woodlots, sequential and intercropping systems (such as taungya, Jordan *et al.* 1992), wide row intercropping, dispersed trees and land rehabilitation. This classification emphasises the reality that industrial plantations with trees in straight lines may not be the preferred approach, and that a broader range of options warrant consideration.

Here, we examine domestication of forest tree species in the broad sense, considering the principles of domestication, reviewing case studies from several regions, and offering guidance specific to small island nations. We do not attempt a comprehensive review of all aspects of tree domestication, a considerable task not amenable to a journal article and addressed comprehensively elsewhere in the case of industrial plantations of exotic species (e.g., Libby 1973, Bradshaw and Strauss 2001) and multipurpose trees for agroforestry (e.g., Leakey *et al.* 1996, Leakey and Tomich 1999). Our focus is on domestication of native timber species in situ, in the humid tropics.

PRINCIPLES OF DOMESTICATION

Recent literature on domestication of forest trees is dominated by research on biotechnology especially molecular genetics (e.g., Boerjan 2005, Harfouche 2012), which, although important, is but one aspect of domestication (Leakey *et al.* 2012). Much of the earlier literature also dwells on propagation (e.g. Leakey *et al.* 1982). More recently, Simons and Leakey (2004) offered a more comprehensive assessment addressing 14 aspects:

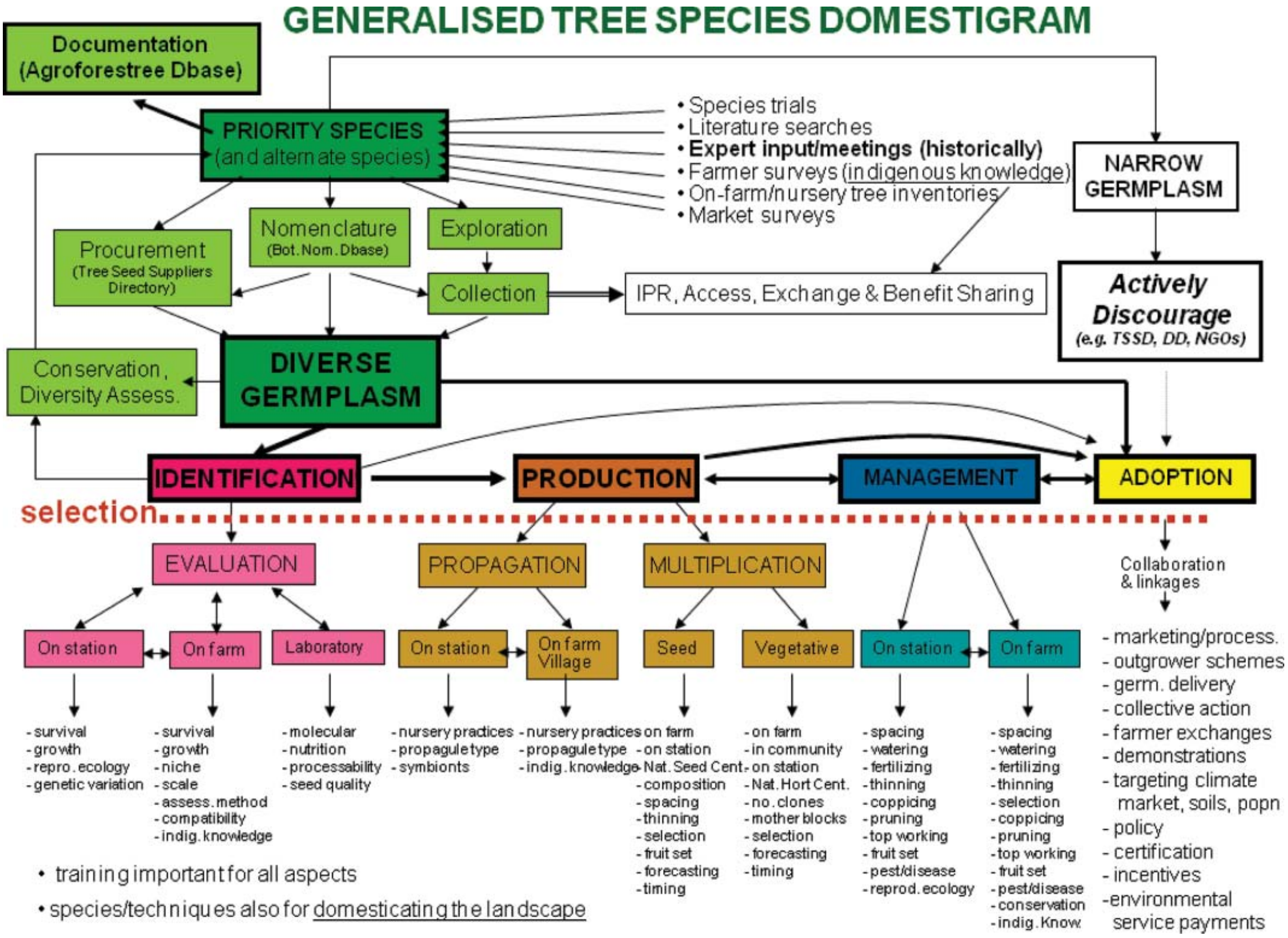
1. Reasons for domestication (home use, market, conservation of the species, agroecosystem diversification, improved livelihood strategies)
2. Tree uses required (products and services)
3. History and scale of cultivation (as native and exotic)
4. Natural distribution, intraspecific variation and ecogeographic survey information
5. Species biology (reproductive botany, ecology, invasiveness)
6. Scale and profile of target groups and recommendation domains (biophysical, market, cultural)
7. Collection, procurement or production of germplasm and knowledge (including ownership, attribution, benefit sharing, access and use)
8. Propagule types envisaged
9. Nursery production and multiplication
10. Tree productivity (biomass, timing, economics, risks)
11. Evaluation, both scientific and farmer participatory
12. Pests and diseases
13. Genetic gain and selection opportunities, methods and intensities
14. Dissemination, scaling up, adoption and diffusion.

Simons and Leakey (2004) concluded that the prevailing problem is that information is incomplete, and has led to suboptimal tree domestication strategies. While tree domestication work has increased, the documentation of the logic and the approach has been generally scant. Even when results are shared or published, it is typically the positive *outcomes* that are reported and not the successful *processes*. A few case studies of tree domestication strategies have been documented (Simons and Leakey 2004), and decision-frameworks have been offered for domestication of agroforestry fruit trees (e.g., Leakey and Akinnifesi 2008), but clear guidance for domestication of forest trees remains scarce.

Jamnadass *et al.* (2009) offered a useful 'domestigram' (Figure 1), indicating possible pathways for domestication. A notable feature of this diagram is the central chain involving identification, production, management and adoption, which is key to the domestication process. A 'whole of chain' approach is essential, and success with the domestication process may depend on the weakest link in this chain. Kalinganire *et al.* (2005) have observed that over-emphasis on a single aspect may lead to dysfunctional outcomes. For instance, they offer anecdotes highlighting that identification alone is not domestication, because there may be an inability to provide sufficient seed, and that an overemphasis on management to the neglect of adoption, may result in guidelines that are impractical in a large-scale situation, or which produce a yield far in excess of market needs.

Underwood (2006) is one of the few who has commented on the importance of encouragement: "incentives must be identified which will attract investment, resolve technical problems, enhance growth and development and lead to a self-sustaining industry-driven commercial enterprise capable of operating without direct financial input from governments". The challenge is to ensure that such incentives can be sustained (Enters *et al.* 2009).

FIGURE 1 *Domestigram indicating possible pathways for domestication of tree species (Jamnadass* et al. *2009).*



Leakey and Newton's (1994b) observations made two decades ago remain pertinent:

> "Opportunities are currently being lost because of a lack of awareness of the potential to domesticate forest tree species for the production of timber and non-timber products. What are the issues that have to be resolved to trigger this new revolution? From the viewpoint of a farmer, there are:
>
> - *the political and social issues,* such as how to acquire the right to own and protect a piece of land and the trees on it, and the need for incentives to plant trees;
> - *the economic issues,* such as what is the value of these trees in terms of their wood, other products and environmental services;
> - *the biological issues,* such as how to grow the trees wanted by farmers; how they can be made more desirable and productive, to the extent of satisfying the farmers' needs and even providing a surplus which could be sold to urban populations."

Scherr *et al.* (2002) emphasised the importance of engaging local business: "Private businesses including forestry industry, community organizations, and private financial and business service providers will necessarily play central roles. Business attention should be attracted first to the more promising sustainable forestry management (SFM) opportunities. Businesses that can identify the competitive advantages of forming partnerships and working with local producers will strengthen their long-term supply and cost position. Innovative financing strategies can be pursued with socially and environmentally responsible investors. Business leaders can play an active role in governments' policy reform."

Sometimes simple solutions can be effective in empowering the marketplace. In the Philippines, researchers observed that the immaturity of the marketplace led to confusion, unrealistic expectations, and created scope for excessive rent-taking. In this situation, the simple action of placing whiteboards in public spaces, and urging tree growers and log buyers to share details of their needs and expectations, helped the market to mature, and strengthened confidence and investment in forest products by both growers and processors (Cedamon *et al.* 2011).

The small-scale forestry amenable to small island states may preclude cost-effective participation in a commodity market, and it may be desirable for growers to concentrate on niche products. A recent review (Donovan *et al.* 2008) highlighted the importance of niche markets in developing community-based enterprises. Finally, it is important that the broader community feels engaged in, and understands the benefits of new initiatives. Leys and Vanclay (2011) discuss ways to foster a shared understanding amongst the broader community.

THE SCOPE FOR DOMESTICATION

Almost 7% of forests worldwide, some 271 million ha, are industrial plantations (Carle *et al.* 2009), potentially able to supply two-thirds of the world's demand for wood, but at potential risk of pests and disease because of the relatively few species and in some cases, the rather narrow genetic base. Amongst several thousand tree species in the world only about 30 have been extensively planted. Tropical timber plantations comprise some 50% *Eucalyptus*, 23% *Pinus*, 17% *Acacia* and 10% *Tectona* (Evans and Turnbull 2004). Varmola and Carle (2002) estimated that out of a net area of 56.3 million ha of tropical and subtropical plantations, there were approximately 32.3 million ha in hardwood plantations.

Evans (2009) argued that the prospects for substantial hardwood plantations in the tropics were "bleak" because of the need for long rotations, the high costs of establishment and maintenance, and potential disease risk. For instance, Meliaceae are handicapped by *Hypsipyla* shoot borers (Floyd and Hauxwell 1996, Mayhew and Newton 1998), and Dipterocarpaceae suffer from difficult establishment and erratic growth (Weinland 1998). The well-known exception for cabinet grade timber is *Tectona grandis* but for the most part tropical plantations are of the fast-growing "industrial" species, in spite of the large number of tropical species with premium timber.

For decades there have been calls for native rainforest trees to be domesticated and planted (Leakey and Newton 1994a, Evans and Turnbull 2004), as an alternative to large-scale monocultures which dominate in the tropics (Nichols and Gonzalez 1992, Gonzalez and Fisher 1994, Lamb 1998), but the norm remains a small number of exotic species grown as monocultures, despite the associated risks (Jactel *et al.* 2009). Kanowski and Borralho (2004) estimated that some 200 tree species have been subject to one breeding cycle and 60 species have been worked on more intensively. Notwithstanding continuing calls for greater diversity in planted forests (Diaci *et al.* 2011), current market forces tend to favour single species plantings (Nichols *et al.* 2006), and greater diversity and resilience of plantations will not be achieved without domesticating additional species.

Dramatic gains in productivity of plantations can be achieved through genetic improvement programs and targeted silvicultural techniques, such as use of fertilizers. For instance, Campinhos (1991) observed that *Eucalyptus grandis* productivity increased from 17.4 to 60 m^3/ha/yr through several stages of selection and vegetative propagation during the period 1966–90. Aracruz Celulose S.A. achieved increases in dry pulp yield from 5.9 to 10.9 t/ha/yr (Campinhos 1999). However, such genetic improvement programs are not always feasible: Willan (1988) estimated that such genetic improvement programs become profitable for forest enterprises with an annual planting program of at least 1000 ha/yr.

General principles to be followed in initiating the selection process are described briefly in Barnes and Simons (1994) and in detail in Zobel and Talbert (1984), Eldridge *et al.* (1994) and White *et al.* (2007). Key aspects of the process include the need for clarity about the traits to be improved (based on best information on probable end-use), and for comprehensive sampling of the existing resource. For example, in eucalypts if the objective is pulpwood, then basic density needs to be below 600 kg/m^3 and the wood should contain a minimum of extractives (Eldridge *et al.* 1994). Firewood needs to be produced close to where it will be burned and should be assessed in terms of tonnes (or preferably calorific value) per unit area rather than on volume. Sawn timber has its own requirements, including minimum sizes of logs and manageable growth stresses; and poles need to be straight, strong and not subject to splitting. Characteristics that are often measured are: survival, growth and form, wood density and fibre length (Eldridge *et al.* 1994) and, where there are serious issues of pests or diseases, resistance to those agencies. Case studies of intentional, organised domestication and recommended procedures include *Triplochiton scleroxylon* in Nigeria (Leakey *et al.* 1982), *Acacia mearnsii* and *Eucalyptus globulus* in China (Raymond 1987, 1988), and with hardwoods in low-rainfall areas (Harwood *et al.* 2001).

As Libby (1973) and Booth and Turnbull (1994) noted, the use of many tree species still follows a pattern thousands of years old, namely the use of "wild" seeds from existing native forests, with little effort to improve seed quality. Harvesting seed from desirable phenotypes can help to avoid truly poor seed sources (Cornelius *et al.* 2011), but such phenotypic selection is not always reliable. For instance, Weber *et al.* (2009) tested low-intensity phenotypic selection in *Calycophyllum spruceanum* in the Amazon, and found low heritability amongst progeny from selected versus randomly chosen trees. Thus a formal domestication strategy is always preferable to haphazard selection.

Tree improvement programs often begin simply by identifying a group of "mother trees", which are of desirable phenotypes, that have good form and appear to be healthy. From these are then developed selected, breeding, and propagation populations in a series of structured phases (White *et al.* 2007). As an example, the SPRIG project (Thomson *et al.* 2001, Thomson 2011) established a families and provenances trial of the main species considered in this issue, whitewood, *Endospermum medullosum.* They planted 6.25 ha in 1998–99 at the Shark Bay Research Station on the east coast of Santo Island, Vanuatu, with seedlings from seed collected throughout the islands of Vanuatu (Vutilolo *et al.* 2005). Seedlots collected from 97 families of whitewood were grouped into 11 provenances. Individual rows included six trees from a given family, in a row-column design. This layout enables, after initial assessment, an opportunity to create a seed orchard in which the best-performing progeny are able to cross fertilize each other. A preliminary analysis of survival and height, diameter and volume increment was then published (Vutilolo *et al.* 2005) and confirmed high potential of this species to benefit from breeding programs. A more recent study from the same experiment focused on growth and growth traits and wood density (Doran *et al.* 2012).

One aspect often neglected is the importance of conserving genetic resources during domestication efforts. Tree breeders have long been aware of the need to conserve wild gene resources (e.g., Zobel and Talbert 1984), but it is relatively recently that the topic has been discussed explicitly in the context of domestication efforts (e.g., Hollingsworth *et al.* 2005, Dawson *et al.* 2009). The SPRIG project found that whitewood populations with the best performance (from east and south Santo) were also the most threatened, because of agricultural development, logging permits and improved road access. Sadly, the whitewood population in Lorum Conservation Area was logged illegally not long after seeds were collected for use in the Shark Bay trials, which now double for conservation of genetic resources and for improvement. It is evident that conservation of genetic resources may need to be managed explicitly in domestication efforts.

EXAMPLES OF DOMESTICATION IN THE TROPICS

Since the progress and challenges of timber tree domestication varies with locality, it is insightful to review experience in diverse geographic areas. Here we briefly survey selected experience reported from Africa, the Americas, Asia, Australia and the Pacific, focussing on domestication in situ of native species for wood production.

Africa

Tropical Africa has many valuable species with potential for domestication. For example, Ghana has some 680 species of trees (Hawthorne 1990), but amongst 50,000 ha of hardwood plantations in Ghana, only 6,000 ha are of Meliaceae and mixed hardwoods, whilst the majority are exotic species including *Tectona grandis* (teak), *Cedrela odorata* (Mexican cedar*)*, *Gmelina arborea* (white teak) and *Hevea brasiliensis* (rubberwood, Odoom 1998).

Milicia excelsa (iroko) occurs across the rainforest zones of central Africa, from Tanzania to Senegal. Early generations of foresters recognised its superior qualities as a strong, attractive, multiple-use timber and described its ecological requirements as well as basic characteristics of its fruit and seeds, and experimented informally with nursery techniques (Taylor 1960, White 1966). *Milicia excelsa* occurs in native forests at low densities, only one or two trees per hectare, likely because it is attacked by a gall-forming psyllid. Domestication programs for *Milicia excelsa* have explored various lines of inquiry, including specific ecological requirements (Taylor 1960, Agyeman *et al.* 1999, Nichols *et al.* 1998, 1999a), ecophysiology (Appiah 2003), genetics (Ofori and Cobbinah 2007), natural resistance (Nichols *et al.* 2002), propagation (Ofori *et al.* 1996), performance in pure and mixed plantations (Nichols 1999b, Bosu *et al.* 2006, Bosu and Nkrumah 2011), silvicultural techniques (White 1966) and methods of controlling psyllids (Wagner *et al.* 1991).

Many other highly-valued species are also attacked by insect pests (e.g. *Khaya senegalensis* and other Meliaceae attacked by *Hypsipyla* shoot borers), creating difficulties for domesticating these species within their natural range (Lunz *et al.* 2009). Problems with insect pests, particularly *Hypsipyla* shoot borers, hamper large-scale uptake of Meliaceae in Africa, so plantings remain confined to research trials and small-scale plantings, but research continues and shows some promise (Nair 2007). *Khaya senegalensis* shows promise abroad, and extensive provenance trials have commenced in northern Australia (Nikles *et al.* 2008), but the species is rarely planted within its natural range in Africa.

Tropical Americas

Countries in tropical America which are large (e.g., Brazil) or diverse (e.g., Costa Rica), contain many rainforest tree species that are considered economically valuable. For instance, Costa Rica has 150 valuable timber species (Carpio-M 1992), most of them native, amongst a total of 1600 tree species. Considerable research has been done on native species in plantations in Costa Rica and Panama (Gonzalez and Fisher 1994, Newton *et al*. 1994, Haggar *et al.* 1998, Wishnie *et al.* 2007, Petit and Montagnini 2006, Hall *et al.* 2011a, 2011b), particularly on initial growth and behaviour in both pure and mixed stands, and on potential for carbon sequestration and environmental services. However, it appears that few operational plantings have been stimulated as a result of this research, and it remains unclear how best to empower uptake of early domestication research.

Streed *et al.* (2006) estimated that small scale plantings of native species on the southwest coast of Costa Rica could be profitable within fifteen years after plantation establishment. Piotto *et al.* (2010) reached the same conclusion after evaluating silvicultural and economic aspects of pure and mixed plantations in the Atlantic region of Costa Rica, and recorded the best growth after 15–16 years, amongst *Vochysia guatemalensis*, *Virola koschnyi*, *Jacaranda copaia*, *Terminalia amazonia* and *Hieronyma alchorneoides*. Although long-term tree improvement programs are not evident for these species, several have been planted at the scale of hundreds of hectares, with Sollis and Moya (2004a,b,c) recording 807 ha of *Hieronyma alchorneoides*, 947 ha of *Vochysia guatemalensis*, and 2282 ha of *Terminalia amazonia*.

Terminalia amazonia has long been regarded a premium species throughout its natural range within Mexico, Central America, the Caribbean and Brazil. As is often the case indigenous peoples and colonial foresters were well aware of the desirable properties of this and other native species and the ecology and silviculture of this species are well established (e.g., Marshall 1939). Since this is a long-lived pioneer species it has long seemed a candidate for domestication (Nichols 1994).

Hoch *et al*. (2012) offered a more pessimistic view of smallholder plantations, concluding that smallholder production of timber is generally unprofitable. This conclusion was drawn from the observation that only one percent of smallholders in externally promoted tree-planting programs in the

Amazon were ultimately able to produce and commercialize any plantation timber. These findings serve as a timely reminder to be realistic about benefits projected from afforestation projects. However, they also highlight the important distinction that those who participate in externally-funded programs may not be interested primarily in timber production. Byron (2001) emphasised that many assistance schemes have been ineffective because of an inaccurate view of smallholder decision-making and priorities.

Perhaps the most advanced case of "native timber species" domestication in the neotropics in recent years is provided by *Pachira quinata* (previously known as *Bombacopsis quinata*) an important broadleaf tree, deciduous in dry seasons, native from Central America and northern South America. The CAMCORE cooperative, based at North Carolina State University, USA, has collected seed since the mid-1980s and sampled populations in Nicaragua, Honduras, Costa Rica, Colombia and Venezuela (Kane *et al.* 1993, CAMCORE 2012). Nevertheless it is difficult to determine if significant areas have had operational plantations established.

Some species may function well in one system but fail totally in another, as the process of domestication proceeds. The widespread neotropical rainforest tree *Calophyllum brasiliense* was thought to have great potential in reforestation (Redondo-Brenes and Montagnini 2006) until pure plantations of the species suffered 100% mortality at 15 years of age (Piotto *et al.* 2010). Earlier indications of poor survival and slow growth on degraded pastures in southern Costa Rica (Carpenter *et al.* 2004) had apparently been disregarded. It appears that this species is best managed under a system of enrichment planting under secondary forest (Nelson *et al.* 2011).

Southeast Asia

There are more than 3000 tree species in southeast Asia, including about 470 species of dipterocarps (Kammesheidt 2011). Appanah and Weinland (1993) described many species with commercial potential for Malaysia, and Sosef *et al.* (1998) depicted some 1550 species in 309 genera for all of southeast Asia. With large areas of forest cleared entirely or partially and a substantial estate of monocultural plantations of *Acacia mangium*, *A. auriculiformis* and *Tectona grandis*, there are significant opportunities for planting native species. This has sometimes been done in line or "enrichment" plantings, notably the case of the Innoprise FACE Project in Sabah, Malaysia which is a large-scale line planting project of dipterocarps on 25,000 ha of degraded land, with a focus on carbon credits rather than timber production.

Vietnam naturally contains hundreds of rainforest tree species, including some highly-valued ones, particularly in the Diptocarpaceae (Chien 2006). Given the large-scale loss of forest due to war, agricultural development and population growth, some of these species are in fact endangered (Nghia 2000). In Vietnam large areas of degraded land have been planted to several Australian *Acacia* species, namely *A. mangium, A. auriculiformis* and a hybrid of these two species. These were planted in difficult situations, eroded sites in pastures dominated by *Imperata cylindrica,* where establishment of native trees would have been problematic, but the *Acacia* plantations succeeded and now provide a more hospitable environment for rainforest seedlings, with shade and improved nutrient status. Forest restoration projects continue to offer an opportunity to domesticate some of the many native rainforest tree species of Vietnam by underplanting them in plantations. In central Vietnam 8-year old stands of *Acacia auriculiformis* were thinned and the stands underplanted with commercially valuable native species, including *Dipterocarpus alatus, Hopea odorata, Parashorea chinensis, P. stellata, Scaphium lynchophorum* and *Tarrietia javanica* (McNamara *et al.* 2006, Lamb 2011). Understorey response to the *Acacia* nurse crop has varied among the native species, and will influence the rate at which the nitrogen-fixing treess are removed. This approach has proved popular, and several hundred hectares of forest have been established in this way.

Australia

Out of a continental area of greater than 750 million ha, perhaps two million ha of Australia were in rainforest in 1788 when European colonisation began, of which approximately one million remains as intact forest. High-value rainforest timbers from native forest were no longer available after tree harvesting ceased in 1988 in far north Queensland (Lamb *et al.* 2005). Interest in developing plantations of rainforest timbers, coupled with the desire to employ displaced timber workers led to the Community Rainforest Reforestation Program, but a general lack of knowledge and experience hampered these efforts (Vanclay 2006) and the outcome was at best 6800 ha of plantings, many of which were subsequently abandoned or neglected (Vize and Sexton 2005). Native conifers have received some attention, but most rainforest species in Australia have been neglected. One success story is the conifer *Araucaria cunninghamii* (Dieters *et al.* 2007), some 44,000 ha of which was planted by the Queensland Forest Service from the early 1900s, and which was recently sold into private management. During 1930–60, efforts were made to domesticate *Agathis robusta*, and some 780 ha were planted, but problems with thrips and coccid scale led to a cessation of this work in 1967 (Huth and Holzworth 2005). Published information on growth rates and basic silviculture indicate potential for species such as *Elaeocarpus grandis* and *Flindersia brayleyana* (Cameron and Jermyn 1991, Huynh 2002, Glencross and Nichols 2005, Grant *et al.* 2006, Lamb 2011) but to date there appears to have been little systematic work on the domestication and genetic improvement for most Australian rainforest species.

Booth and Turnbull (1994) describe an interesting case study of domestication over a period of more than 50 years, that of *Acacia auriculiformis*, native to Australia and Papua New Guinea. Early domestication efforts were haphazard, but by the 1980s several international organisations became involved in tree improvement and silviculture, and seed was eventually collected systematically throughout the range of the species by the Australian Tree Seed Centre with 3000 seedlots distributed to researchers (Gunn and Midgley 1991). Subsequently a system of seed orchards in Australia and Asia was established and tree improvement programmes developed. Today *A. auriculiformis*, either as a pure species or in hybrids with *A. mangium,* is a major component of the 3.8 million ha of Acacia plantations in Asia (FAO 2005). A recent analysis of the benefits of domestication research, not of *A. auriculiformis*, but of Australian trees for forestry and agroforestry in general, indicated an internal rate of return exceeding 50% (Lindner 2011), reflecting the value of considered and continuing domestication work.

In contrast, the demise of many *Eucalyptus dunnii* plantations in Australia reflects the importance of the 'whole of chain' approach indicated in the domestigram (Figure 1). Efforts to domesticate this species focused on the identification, production and management (e.g., Henson and Vanclay 2004, Smith and Henson 2007, Grant *et al.* 2010, Cassidy *et al.* 2012), but neglected key aspects of adoption (e.g., Leys and Vanclay 2010, 2011), creating marketing and social issues that ultimately contributed to the demise of many plantations.

South Pacific

Agroforestry gardens in Polynesia and Melanesia are noted for their rich diversity in plant species, including multipurpose trees, particularly nut and fruit trees (Thomson *et al.* 2001, Walter and Lebot 2007, Butaud *et al.* 2008, Thomson 2011). During 1996–2006, the South Pacific Regional Initiative on Forest Genetic Resources (SPRIG) project drew on this diversity and focussed on the domestication of key tree species in five countries: Solomon Islands, Vanuatu, Samoa, Fiji and Tonga (Thomson *et al.* 2001, Thomson 2006, 2011). SPRIG investigated and initiated tree improvement activities in many species including two *Canarium* species, *Terminalia richii* as well as *T. catappa* (beach almond), the latter with potential to supply large quantities of nuts as well as valuable timber and bark with medicinal properties, *Santalum austrocaledonicum*, *Flueggea flexuosa,* and a major effort in Vanuatu on whitewood, *Endospermum medullosum*, the focus of this special issue.

Some of the main lessons from the domestication work by SPRIG (Thomson *et al.* 2001) are:

- Selection of species is critical, and should be based on an inclusive process of interested parties, and selected from species already widely planted. The decision should be informed by biological characteristics such as intra-specific variation, early growth, early flowering and seed set, and ease of propagation.
- For developing countries, greater benefits accrue from the early phases of domesticating a greater number of promising species, than from a focus on intensive tree breeding of a single species. This is because the greatest single-step gains in improvement arise from selection of the best provenance or seed source.
- Indigenous species have several potential advantages over exotics, including familiarity and ready acceptance by local people; proven adaptation to local conditions; and contribution to biodiversity conservation values.
- The greatest progress in domesticating tree species will be made through a multidisciplinary, collaborative approach involving biological and social sciences.
- The involvement of research and development partners in all phases of the domestication process, including provision practical training, enhances the prospects for sustaining domestication work.
- High levels of trust and goodwill are needed between forestry research organizations with access to different parts of the natural range of shared species.

LESSONS FOR ISLAND NATIONS

In contrast to agroforestry, domestication efforts in plantation forestry appear to neglect adoption (Figure 1) rather too frequently, in contrast to contemporary agroforestry efforts where this adoption is emphasised (Scherr 1995, Mercer 2004, Simons and Leakey 2004, Asaah *et al.* 2011). Although there are examples where the forest product value chain is examined (e.g. Herbohn *et al.* 2009, Grant *et al.* 2012), these are the exception rather than the rule. Although long rotations in forestry make adoption research difficult, it also makes it more important, especially in the context of small island states that may lack economies of scale and efficient transportation, and experience other impediments that create friction in the marketplace.

Timber plantations are a long-term endeavour, and this means that domestication efforts require sustained commitment. Domestication of timber trees requires a brave but thoughtful 'best bet' in choice of species, requires adaptive management to adjust management to new situations (both biological and economic), requires innovation in gathering data and synthesising insights from diverse sources, and above all, requires sustained effort and investment to corral resources and maintain progress. Although there are examples where domestication has not yet succeeded (e.g., *Agathis robusta*), the evidence with other species suggests that sustained effort leads to success.

Perhaps the key lesson for island nations arising from this review is the need to take a holistic view of the whole stakeholder chain, and not to focus merely on the technological aspects of genetics and silviculture. In the long run, the less technical aspects such as smallholder attitudes to forestry, the competition for land, government policies and incentives, and the opportunities for processing, value-adding and export may all play a greater role in uptake and success of a viable enterprise. Proponents should not overlook the importance of conserving wild genetic resources.

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Constraints to whitewood (*Endospermum medullosum*) plantation development on Santo Island, Vanuatu

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SUMMARY

Valuable timber trees in accessible sites in Vanuatu have been mostly removed by logging. There are large areas where plantations would likely be successful. Yet plantation establishment among landholders in Vanuatu has been limited to date, even with considerable extension support. There has been little systematic investigation of why this has occurred. The purpose of this research was to identify constraints to whitewood (*Endospermum medullosum*) plantation development. A participatory social research approach was used on Espiritu Santo Island to look for trends in attitudes toward plantations. This was achieved through the use of mixed methods social research to survey 139 local landholders from 42 villages. Most landholders on Santo Island were not convinced that there are good reasons to plant whitewood, at least not in large extensions. Future efforts should be focused on the development of local capacity for plantation establishment, maintenance, processing and export marketing, at a variety of scales.

Keywords: sustainable forest management, agroforestry systems, traditional land-use, plantation development, livelihoods

Contraintes affectant le développement des plantations de bois blanc (*Endospermum medullosum*) sur l'île Santo, Vanuatu

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Les arbres de bois de coupe de valeur dans les sites accessibles à Vanuatu ont été pour la plupart éclaircis par la coupe. Il existe de vastes zones où les plantations seraient à même d'avoir du succès. Cependant, l'établissement des plantations a été limitée chez les propriétaires terriens de Vanuatu jusqu'à présent, malgré unsupport considérable pour les extensions. Il n'y a eu que très peu d'investigations systématiques pour comprendre les raisons de cette timidité. Le but de cette recherche a été d'identifier les contraintes affectant le développement des plantations de bois blanc (Endospermum medullosum) . Une approche de recherche sociale participationnelle a été utilisée sur l'île Espiritu Santo pour chercher des courants dans l'attitude vis à vis des plantations. Ils ont été obtenus en utilisant des méthodes mixtes de recherche sociale pour interviewer 139 propriétaires locaux provenant de 42 villages différents. La plupart des propriétaires de l'île Santo n'étaient pas convaincus de l'existence de bonnes raisons pour planter du bois blanc, du moins, pas en extensions larges. Les efforts futurs devraient se concentrer sur le développement de la capacité locale d'établir, de maintenir, de traiter , et d'effectuer le marketing des exportations des plantations, à une variété d'échelles.

Barreras al desarrollo de plantaciones de *Endospermum medullosum* en la isla de Espíritu Santo, Vanuatu

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En Vanuatu, los árboles de especies maderables valiosas han sido talados en su mayoría en los lugares accesibles. Existen grandes áreas donde las plantaciones tendrían una gran probabilidad de éxito. Sin embargo, el establecimiento de plantaciones en Vanuatu por parte de propietarios ha sido limitado hasta la fecha, a pesar del considerable apoyo de los servicios de extensión. Apenas se han realizado estudios sistemáticos para averiguar por qué sucede esto. El propósito de esta investigación fue identificar impedimentos al desarrollo de plantaciones de Endospermum medullosum. Se empleó un enfoque de investigación social participativa en la isla de Espíritu Santo, en busca de pautas de comportamiento y actitudes respecto de las plantaciones. Esto se logró mediante el empleo de una mezcla de métodos de investigación social a través de una encuesta a 139 propietarios locales residentes en 42 localidades. La mayoría de propietarios de la isla de Espíritu Santo no estaban convencidos de que existan buenas razones para plantar Endospermum medullosum, sobre todo en grandes extensiones. Los esfuerzos futuros deberían centrarse en el desarrollo a diferentes escalas de la capacidad local para el establecimiento de plantaciones, así como para el mantenimiento, procesamiento y comercialización para la exportación.

INTRODUCTION

Vanuatu's forests and people

Vanuatu is an archipelago of 83 islands in the south-west Pacific with approximately 36% forest cover (>10m tree height), another 34% in lower woody vegetation. The island chain is vulnerable to tropical cyclones between the months of January to April (Bakeo *et al.* 2003, Hickey 2008). The islands of Vanuatu have been settled for approximately three thousand years. Before European settlement the population of Vanuatu may have been as high as one million. Colonisation by European peoples caused steep declines in population due to disease, 'blackbirding' and other impacts. By the beginning of the nineteenth century the well-watered and fertile areas of the islands were supporting around 500,000 people. The current population is approximately 229,000, divided into around 110 different cultural-linguistic groups with 80% still living subsistence livelihoods (Regenvanu *et al.* 1997, Hickey 2008).

Colonial rule was instituted in 1906 with a condominium government shared between France and England, leading to massive changes in land-use and loss of traditional practices (Nari 2000). Since 1980 when independence was achieved, there has been a large escalation in land disputes, given that traditional patterns of ownership had been disrupted by Europeans followed by uncertain rules in a newly independent country. Until recently most land has been under customary communal tenure; estimates were that 97–98% of land in Vanuatu was in communal ownership (Nari 2000, Codippily 1996). Long-term leases for both ni-Van people and foreigners (especially for tourism development) have become problematic in that under the constitution lease agreements are not supposed to be prejudicial to the custom owners of the land, to other indigenous people or to the country as a whole but the government has not always enforced these provisions (Regenvanu 2008).

As in other Pacific Island nations, native stands of timber have been under considerable pressure from clearing for agriculture and for domestic and export timber production. During the period prior to colonial rule much deforestation took place for shifting cultivation and by the time of arrival of Europeans there were large cultivated areas and anthropomorphic grasslands. Sandalwood (*Santalum austrocaledonicum*) was heavily exploited from 1825 for export to China and other Asian countries. The exploitation of whitewood, *Endospermum medullosum*, from native forests, among other native tree species, has been an important economic activity and has virtually exhausted whitewood resources in accessible areas in native forest (Vutilolo *et al.* 2005, 2008).

Value of whitewood in plantations

In 1996 the Vanuatu government, through the Vanuatu National Forest policy, set a goal of establishing 20,000 hectares of forest plantations by 2023 (Department of Forests 1999). The Vanuatu forest industry has led the development of whitewood as a plantation species with private commercial scale plantations and associated processing infrastructure. Small community based plantings of whitewood have also expanded during the past decade in the form of agroforestry plantings or woodlots. The Department of Forests has also encouraged planting of the species by small-holder farmers by providing seedlings and silvicultural information (Thomson 2006).

This native species, a fast-growing pioneer species, and a primary target of loggers working in native forests, has been an obvious candidate for domestication since at least the mid-1980s. Its growth is quite rapid in the first five years or so (Thomson 2006), and reasonable estimates of production of 15–20 m^3/ha/yr for 15–20 years have been made (Bartlett 1996, European Union *et al.* 1998, DPI Forestry Queensland 2000, Thomson 2006). The South Pacific Regional Initiative on Forest Genetics (SPRIG) was an AusAID program that lasted from 1996 to 2006 and concentrated on conserving forest genetic resources and on the domestication of key tree species in Vanuatu, Solomon Islands, Fiji, Tonga and Samoa. Whitewood was the major species studied in Vanuatu and through this project and other initiatives in Vanuatu protocols for seed collection, nursery techniques, and plantation establishment were developed.

Whitewood is not durable in contact with the soil or moisture but can be employed for structural purposes as well as indoor uses where a plain, white, characterless appearance is desired. This latter characteristic has made it possible to sell material such as moulding into Japan at a premium price. A strategy for genetic conservation and tree improvement in whitewood was devised in 1999 (Corrigan 1999) and that same year a provenance trial/seed orchard was established near Shark Bay (SPRIG 1997, 2002). Growth rates are high, with mean annual increments of plantation whitewood reaching 25–29 m^3/ha/yr (Vutilolo *et al.* 2008, Grant *et al.* 2012), and the variation in growth by provenance and family is well understood (Vuitilolo *et al.* 2005, 2008, Doran *et al.* 2012).

The timber of whitewood is used locally, especially in preservative-treated form, for light construction, furniture and interior joinery, and there is a significant local value-adding industry providing sawn timber and edge-glued panels for export to Japan (Thompson 2006). There is a ban on round log exports to Japan by the Vanuatu government aimed at facilitating local employment opportunities and value-adding timber products prior to export (McGregor and McGregor 2010). Samples of plantation material have shown timber quality to be comparable to that from natural forest that is easily processed, white in colour and highly stable, producing acceptable quality timber for domestic purposes or that can be value-added into sawn boards and finger-jointed lumber-boards for export (SPRIG 2002). The amenability of the species to plantation silviculture, short rotation length (thinned at 5 to 10 years, 15 year final harvest) (Nichols 2003) and the high quality of plantation timber suggests that the species has sound potential to form the basis of a local plantation and value-adding industry.

The silvicultural prescriptions outlined in Thompson (2006) have been empirically tested and are being quantitatively verified by the current Australian Centre for International Agricultural Research (ACIAR) project, 'Improved silvicultural management of *Endospermum medullosum* (whitewood) for enhanced plantation forestry outcomes in Vanuatu'(see http://aciar.gov.au/project/FST/2005/089). Large investors have misgivings about traditional Melanesian customs regarding land and tree ownership, questioning the security of ownership (Bazeley and Mullen 2006). Finally local landholders are not certain of the price they will receive for any trees they might grow nor do they yet have the capacity to harvest and add value to timber products themselves.

Several islands of Vanuatu have significant areas suitable for plantations: Erromango (4 000 ha), Malekula (3 000 ha), Vanua Lava (2,000 ha) and Efate (2,000 ha) (Bazeley and Mullen 2006). On Santo island soil surveys combined with a Geographic Information System assessment by the authors reveal approximately 69,000 ha suitable for whitewood plantations. With the current stands of whitewood of approximately 400 ha on Santo, the plantation estate has only begun to be established. Since the 1980s there have been numerous studies and consultant reports on the potential to create a significant plantation resource of whitewood on Santo, particularly at a site called the Industrial Forestry Plantation, near Shark Bay (Leslie 1994, Bennett 1989, Keating 1989, European Union *et al.* 1998, DPI Forestry 2000, Department of Forests Vanuatu 2002, Nichols 2003, Bazeley and Mullen 2006). These have generally concluded that, with the high growth rate of whitewood, the presence of idle land, and availability of inexpensive labour, whitewood plantations would be a reasonable investment. These reports have suggested that a 5,000 ha piece of land near Shark Bay could in fact support a local plantation-based community, either through a large enterprise which supplies jobs or through smaller landholder-based plantings, where value is added locally. Neither of these options has yet taken place.

This paper addresses several questions:

(i) What areas of whitewood have already been established and how much whitewood do local landholders intend to plant? Are there other tree species that landholders have planted and-or intend to plant in the future?

(ii) If landholders were to establish whitewood plantations, what systems would they use? Would they combine their trees with traditional mixed agroforestry gardens, existing coconut plantations, or single crops like peanuts and kava? What spacings would they use?

(iii) What other land-uses are in competition with plantation forestry for livelihood support?

(iv) What are the constraints for individual landholders in establishing whitewood plantations?

(v) What mechanisms could help overcome the identified constraints that could improve livelihoods of indigenous people in Vanuatu?

METHODS

Case study regions

Espiritu Santo Island (often shortened to 'Santo') covers an area of 3 956 square kilometres. Most terrestrial areas were originally dominated by rainforest (Mueller-Dombois and Fosber 1998) and soils are predominantly highly fertile brown volcanic loams over ancient coral platforms (Melteras *et al.* 2008). The main population centre is Luganville with a population of approximately 10,700; the remainder reside in small villages and engage in subsistence farming. The island was divided into three main geographical regions, commonly referred to by local people, of relatively equal size from north to south, for comparison of existing and potential plantation areas between regions, and for developing regional insights on attitudes towards whitewood (Figure 1).

Participatory social research

Participatory social research techniques were employed to collect survey data from small landholders on Santo Island, Vanuatu. These included structured interviews, with a total of 139 interviews being conducted by ni-Vanuatu project staff throughout the year 2008. The advantages of having indigenous workers employed included ability to speak local languages, quickly develop trust among local people, and foster participation in the project. The ability to develop trust in communities was also considered an important criterion for effective participatory research by Leys and Vanclay (2010, 2011).

All local landholders from a village were invited to participate, to prevent bias that could have occurred through selective sampling. The mixed methods approach was considered the most suitable for obtaining information on areas of existing and potential plantings while eliciting additional information on reasons, rationalisations, arguments and constraints (Table 1) that would help the research team develop greater insights for predicting future plantation opportunities and mechanisms for further community engagement.

Survey design

Survey questions were developed through collaboration of all authors on the ACIAR project. This is a four-year project lead by Southern Cross University, focused on developing and providing information on best practices for management of plantations of whitewood. One of the objectives of the project

FIGURE 1 *Case study regions for plantation assessment of Whitewood on Santo Island, Vanuatu. (Map by Greg Luker, Geographic Information Systems Laboratory Manager, SCU, 10-12-2010)*

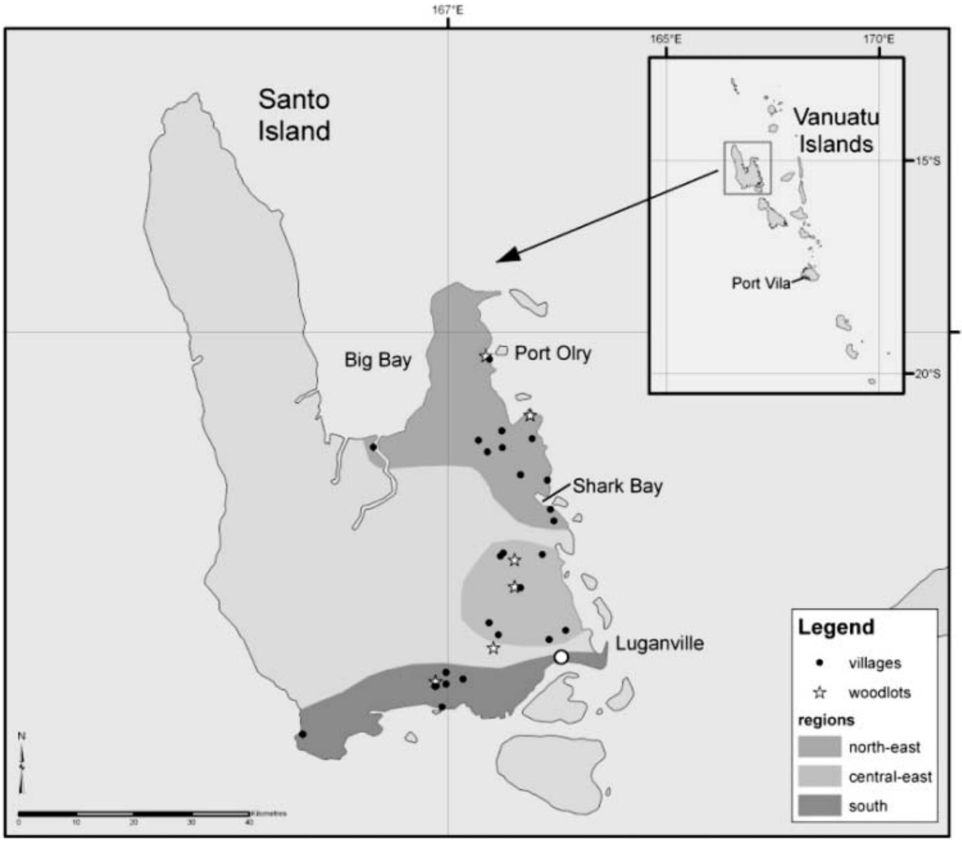


TABLE 1 *Synthesis of questions asked and analysis applied in Santo Island landholder survey*

Mixed method approach	Theme covered in questions	Analysis applied
Quantitative	Areas and age of whitewood plantings Spacing of whitewood trees in woodlots Types and areas of other tree species and food crops grown Additional areas of land available for whitewood versus areas willing to plant Number of people land areas support	Anova (Analysis of Variance) and descriptive statistics using SPSS (Statistical Package for the Social Sciences)
Qualitative	Attitudes towards whitewood plantations Inter-row crops grown and marketing details Reasons for tree/crop selections Type of land best suited for plantations	Thematic coding and inductive analysis

was to evaluate the effects of approximately 25 years of promotion of tree planting, specifically to assess the development of whitewood plantations and the intentions of landholders to establish more plantings.

The questions were designed to elicit information from landholders on areas currently planted to whitewood, land available for future whitewood planting, and subsistence crops grown under whitewood (Table 1). Questions related to attitudes towards plantation forestry, and marketing timber and crop produce to develop insights into interest and constraints for further whitewood plantation development. Landholders were asked if they would plant whitewood in monocultures, mixed species, or agroforestry combinations.

Categorical and quantitative data was analysed using analysis of variance techniques (Table 1). In addition, qualitative data was analysed using thematic coding to determine emerging themes in attitudes and constraints to plantation development among landholders (Leys and Vanclay 2010).

A total of 139 one-on-one interviews were conducted with participants from 42 villages across the three regions. These were held in the local language Bislama, however translation was done at the time to complete surveys in English. The average age of the respondents was 46 years, and 100% were male. The respondents were all local landholders as confirmed by the Department of Forests Vanuatu.

Given the large number of surveys completed in each of the regions, findings were considered representative of landholders from three major inhabited regions across Santo.

RESULTS

Land areas planted and available for whitewood plantations

Data on the distribution of whitewood areas planted and prepared to be planted by landholders from the three regions of Santo Island are presented in Table 2. The average areas of whitewood already established did not vary significantly across regions; although landholders from the central-east had the largest areas planted, on average at 1.0 hectares, and the south-east the smallest at 0.4 hectares. Notable among the responses was the finding that fewer than half of the landholders interviewed from the central-east and south-east regions were willing to plant additional areas of whitewood on remaining arable land (at 45% and 42% respectively), while the majority of respondents in the north-east said they were willing to plant more whitewood (80.2%). Respondents indicated that the major types of land available for future planting were 'flat' areas (92% of respondents), and also 'dark bush' areas (88%). Flat areas were described by participants as those areas that were not sloping or hilly, while dark bush areas were those that remained under dense natural forest, in contrast with brushy secondary forest. Fewer respondents considered areas such as their vegetable gardens (25%), hill country (9%) and pasture country (3%) as being suitable by their standards for plantations or woodlots, and less than 1% considered planting on the customary lands or leased land available.

The total area planted in whitewood amongst 139 landholders interviewed added up to 63 ha, as estimated by the landholders themselves (though it is not entirely clear that they had proper understanding of the size of a hectare), with average area planted to whitewood being less than one ha. Even if many more landholders were identified it is unlikely that more than a few hundred ha of whitewood plantations would exist in this small woodlot form. One enterprise, Melcoffee Sawmills, planted approximately 270 ha of whitewood in 1993, which is now being harvested. The Department of Forests Vanuatu does not currently have a data base that quantifies the actual number of trees or of ha established in plantations, either on Santo Island or in the main office in Port Vila, Efate.

Landholder attitudes towards whitewood plantation establishment

While 98% of surveyed landholders claimed they strongly supported the development of whitewood plantations in general, 6% of landholders who had grown them in the past did not plan to plant more in the future (Figure 2). Reasons given included lack of land area available for woodlots, and need to use land for food crops. Interestingly 37% of participants who had not grown whitewood in the past all planned to try them in the future.

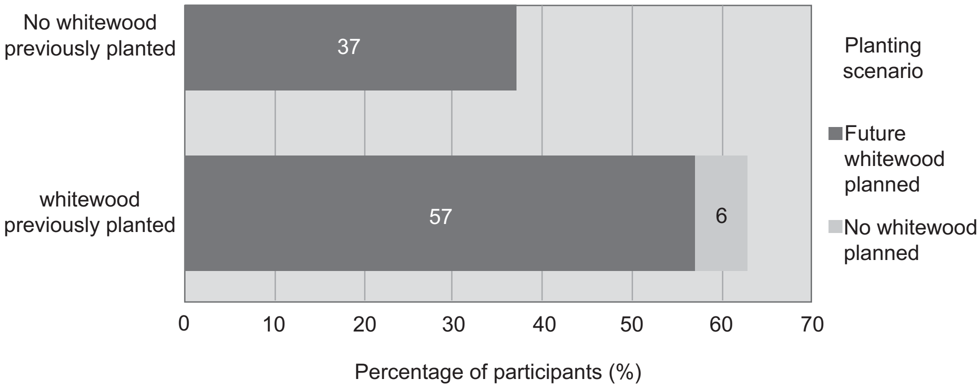
The majority of landholders felt the main reason for planting whitewood would be to generate income from timber sales (136 responses), while only three felt the major benefit would come from timber for housing or other on-farm uses, one for soil restoration through a fallow from market gardening, and five for replenishing the depleted timber resource on Santo Island.

TABLE 2 *Land areas planted and considered available for future planting to whitewood by land-holders surveyed on Santo Island, Vanuatu*

Aspect surveyed	Region of Santo			Total
	North-east	Central-east	South-east	
Land-holders surveyed (number)	42	46	51	139
Land-holders who have grown whitewood (numbers)	28	34	26	88
Land-holders willing to grow whitewood in future (numbers)	37	42	51	130
Total whitewood area planted (ha)	21.2	31.4	10.8	63.4
Average whitewood area planted (ha/ land-holder)	0.8 a	1.0 a	0.4 a	–
Additional arable land area available for plantations (total ha)	91	173	152	416
Area that land-holders are willing to plant to whitewood (total ha)	73	77	64	214
Additional area that land-holders are willing to plant to whitewood (%)	80	45	42	51
Average additional area potentially available (ha/land-holder)	2.5 b	4.7 d	3.0 bc	–

Note: For 'a' N=87, F=2.23, P=0.112 ; for 'b-d' N=128, F=3.23, P=0.043

FIGURE 2 *Comparison of past and planned whitewood plantation establishment among surveyed landholders on Santo Island (N=139)*



Whitewood silvicultural spacings used by small landholders

The most common tree spacing used in existing whitewood plantations across the three regions was 5m × 5m, being the distance between and within rows of trees, given by 57% of growers. However this contrasted with 59% of respondents who said they would prefer to use spacings of 8m × 6m in future plantings. This difference was based on grower experience where original plantings were considered too close and trees limited growth of the under-cover crops. Respondents and local forestry workers suggested that production of food crops could be improved if woodlots were thinned to let extra light in.

Cultural and livelihood factors influencing land-use

Of all the landholders surveyed, 41% indicated they grew tree species other than whitewood in small woodlots, with big-leaf mahogany (*Swietenia macrophylla)* the most common grown for timber and seed, followed by sandalwood (*Santalum album*), grown for oil and seed. It was found during the study that big-leaf mahogany apparently was the major species being promoted by local government forestry extension officers in some regions. No mention was made of trees being grown for medicinal qualities, which was unexpected considering that trees such as Nangai (*Canarium indicum* var. *indicum*) are commonly encountered, a species reported to have special medicinal qualities by Siwatibau *et al.* (1998).

A great diversity of crops are grown in traditional ni-Vanuatu agroforestry plantings (Walter and Lebot 2007). Landholders were found to grow many different types of food crops in agroforestry gardens during the first two to five years of a whitewood plantation. Produce was firstly used to support families' food needs, then excess production was sold at local markets (Figure 3). The most popular staple crops that had been grown were kumala (sweet potato) *Ipomoea batatas)*, 75% of landholders surveyed that had grown whitewood), island cabbage (*Abelmoschus manihot*, 59%) and island taro (*Colocasia esculenta*, 46%), manioc (*Manihot esculenta*, 42%) and corn (*Zea mays*, 35%). Landholders who had previously grown whitewood reported they would increase areas grown to these same crops underneath trees in the future as well as increase areas to other crops including peanuts (*Arachis hypogea*), yam (*Dioscorea alata*), spring onions (*Allium fistulosum*), Fiji taro (*Xanthosoma sagittifolium*) and Chinese cabbage (*Brassica rapa L. ssp chinensis*). Interestingly, landholders were planning not to expand areas planted to kava (*Piper methysticum*), bananas (*Musa sp.),* sugarcane (*Saccharum officinarum*), capsicum (*Capsicum annuum*), ginger (*Zingiber officinale*), tomatoes (*Lycopersicon esculentum*) and pineapples (*Ananas comosus*) (Figure 3).

The proportion of food crop production additional to family needs that was sold at local markets varied by crop type, but not significantly across regions except for peanuts (F=5.45, P<0.01), tomatoes (F=9.94, P<0.001) and sugarcane (F=30.0, P<0.001). Approximately 75% of kava grown was sold at market, while around one-third (average 34%; range 24 to 37%) of the volume of the remaining varieties of crop produce was sold to generate household income.

The average area of land under control of each survey respondent on Santo Island was higher on in the north-east region at 113 hectares, compared to the other two regions (central-east mean = 42.5ha, south mean = 75.9ha). However this difference was not significantly different between regions, with median values for these regions (north-east = 50ha, central-east = 15ha, and south = 50ha; Figure 4) suggesting the difference in means was due to some unusually large outliers. The average land area available for livelihood support is therefore relatively similar across regions. Further, there were no differences in the average number of people these total land areas supported (mean = 6 people per land-holding).

The level of education and skills in forest management was found to be somewhat limited, particularly in relation to silvicultural practices such as pruning and thinning, indicating that extension efforts had not been particularly effective. Researchers observed limited local knowledge and expertise in tree harvesting operations and timber marketing. There appears to be little collaborative capacity to develop mills and markets among landholders to date, other than through one milling company.

FIGURE 3 *Types of food crops being grown and planned to be grown under whitewood trees by landholders on Santo Island, Vanuatu (N=65)*

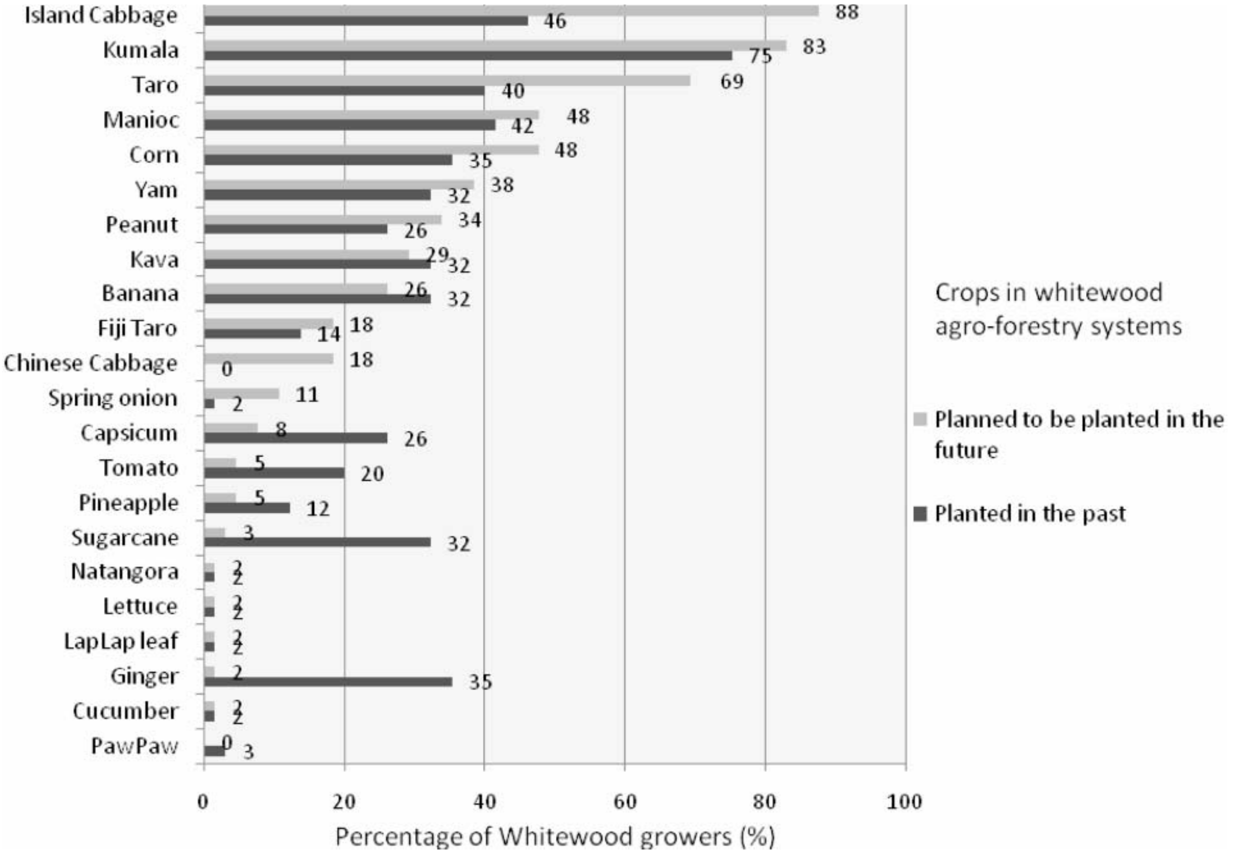
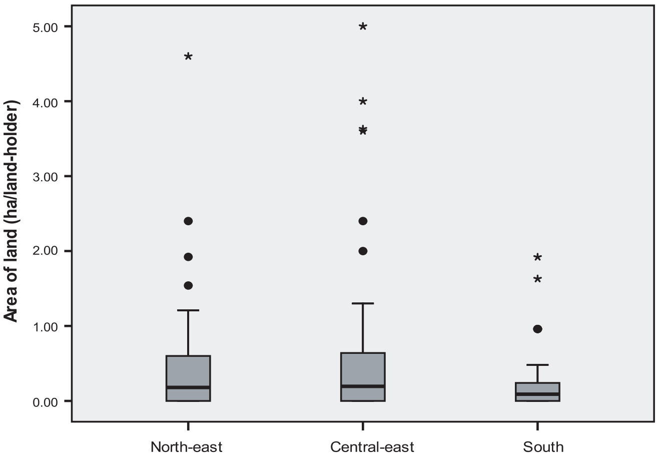


FIGURE 4 *Size of land-holdings across case regions for survey respondents on Santo Island (n=133, excluding 6 missing values). Note: Dark lines in box plots indicate medians; • and * indicate outlying values*



DISCUSSION

A participatory social research approach using landholder surveys on the island of Santo helped develop a sound understanding of ni-Vanuatu farmer attitudes towards the use of the native whitewood tree in plantation development. Even though the majority of respondents surveyed said they supported whitewood plantations (98%) mainly for the potential to generate cash income, many landholders had planted few trees themselves and had limited plans to do so. Future plantation establishment was also constrained by competition with other tree species, particularly big-leaf mahogany (*Swietenia* macrophylla) grown for its high-value timber and seed, and land competition for food crops. In regard to future plantings, landholders in the central-east region were least likely to plant more trees at only 23% of the additional land area available, being an extra 0.9ha/landholder compared to landholders in the north-east who were prepared to increase plantings by 1.7 ha per landholder, using some 80% of the additional arable land available.

Our findings suggest that additional plantings of woodlots will be well below those needed to achieve the target set by the Vanuatu National Forest Policy of 20 000 hectares by year 2023 (Bakeo *et al.* 2003). If significant increases in plantation areas are to be achieved, these will likely need to come from larger organisations, perhaps companies or government agencies, rather than small-landholders, who are generally struggling to produce adequate food supplies and supplementary produce for cash income.

The export market for whitewood products between the years of 2003–2004, specifically to Japan, has shrunk, given an on-going decline in sawnwood consumption. This has been in response to a slowing economy, increased competition from imported softwood, increasing availability of domestic log supplies, and the global financial crisis (ITTO 2009). According to McGregor and McGregor (2010) there have been no timber exports from Vanuatu to Japan since 2007 due to lack supply from natural forests and suspension of a pilot reforestation program. Timber export earnings declined from 15% in 2003 to 2.5% in 2008. New Caledonia has since emerged as the dominant export market for Vanuatu hardwoods. Nevertheless, whitewood is considered to provide a niche timber product with values projected to remain stable at around US\$819/m^3 as processed mouldings and other products for interior use as of June 2009 (McGregor and McGregor 2010) Another trend in timber marketing has been the large volume of New Zealand radiata pine (*Pinus radiata*) structural timber imported since year 2002 for use in the Vanuatu construction industry.

Another constraint to further whitewood planting by small landholders on Santo Island was found to be the preference given to big-leaf mahogany (*Swietenia* macrophylla) by this survey. This could be explained in part by the substantial body of research already conducted on this species (SPRIG 1997) and the existence of established markets for mahogany. Shono and Snook (2006) highlight the potential high growth rates of mahogany in plantations in the tropics, where it is not attacked by shoot borers (*Hypsipyla* spp.) which are found in areas where the tree is native (Mayhew and Newton 1998). Mahogany produces highly valued timber, with 2009 prices of US\$300/m^3 for finished lumber (ITTO 2009). While the *Hypsipyla* shoot borer has been found in Vanuatu (Floyd *et al.* 2003), it is too early to know whether the pest will create serious long-term problems.

This study developed further insights into indigenous forest management practices and food cropping. The most common silvicultural plantings were found to be 5m × 5m, however plans were to increase these to 8m × 6m (tree by row spacings) to create greater room for food crops such as kava. An average of 75% of kava produced was sold at market, and other crops such as island cabbage and taro, corn, manioc, peanuts, accounting for approximately one third of produce sold above household needs. The importance for creating livelihood balance between meeting basic food needs and regular cash flow from local marketing of excess food, against long-term investments in timber crops was made evident.

Further research and education is recommended for understanding attitudes toward plantation forestry amongst landholders, particularly the development of whitewood plantations. While Manley (2007) claims that the most successful community-based approaches are those that build on existing organisational and traditional structures, this study highlighted that cultural norm and customs can also create constraints to development that could benefit from external and independent assistance and management. These findings are supported in research by Richardson *et al.* (2011) and Nielsen and Reenberg (2010), who suggest that culture can act as a major barrier to livelihood improvement strategies, particularly in developing improved strategies for forest management and human adaptation to climate change.

The need for continued extension efforts to help develop skills and capacity in forest management and marketing among indigenous rural landholders of Vanuatu was found to be crucial for achieving long-term income enhancement and environmental protection. Educational programs that support livelihood decisions have been found in many other developing countries to offer the greatest opportunities (Vanclay *et al.* 2006), particularly those that incorporate an understanding of local value systems, provide technical support and work towards empowering the poor and disadvantaged through participatory decision making (Garen *et al.* 2009, McDermott and Schreckenberg 2009). Further, research is recommended in the processing and marketing of whitewood to ensure that the benefits of timber growing and processing are shared widely throughout the community. Community forestry is one option that can be explored for providing a more equitable sharing of resources between villagers (house-holders).

The need for landholders to have a better understanding of markets for whitewood came clearly out of the surveys done here. A study related to this project was implemented in 2011: assessment of the current value-chain of whitewood and exploration of opportunities for value-adding. This is research involving extensive interviews of landholders, loggers, sawmillers, and processors both on Santo and the island of Efate.

CONCLUSIONS

Possibilities exist for both the development of large-scale plantation forestry based around whitewood or smaller-scale community forests. To date, in spite of many consultancies having painted an optimistic picture of the industrial scale operations that might be developed, little has happened. This appears to be mainly due to concerns about lack of resource security under communal land ownership, as well as declining export markets in recent years.

The second possibility is community forestry, which can improve livelihoods and welfare of rural people, as well as improve conservation of natural forest systems through local participation and cooperation. Pagdee *et al.* (2006), in their meta-study of what makes community forest management successful, cited many factors with generally positive influences that are not currently present on Santo Island in Vanuatu: tenure security, clear ownership, congruence between biophysical and socioeconomic boundaries of resources, effective enforcement of rules and regulations, effective enforcement of rules and regulations, strong leadership within capable local organizations and common interests among community members. Thus, focus on improving performance in these areas may eventually enable community members to develop a viable whitewood plantation sector, in this environment where the biophysical conditions are highly suitable. It appears that primarily a lack of clear options for using and-or selling whitewood, either as standing trees, logs, or boards is a major factor impeding the development of more community plantations. The essentially subsistence culture of rural Santo, combined with other more familiar options for earning income, that is growing food crops or kava, also may partially explain the lack of more whitewood plantations.

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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

J.C. GRANT, T. MOFFATT, M. SETHY, B. GRIEVE et K. CONVERY

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

J.C. GRANT, T. MOFFATT, M. SETHY, B. GRIEVE y K. CONVERY

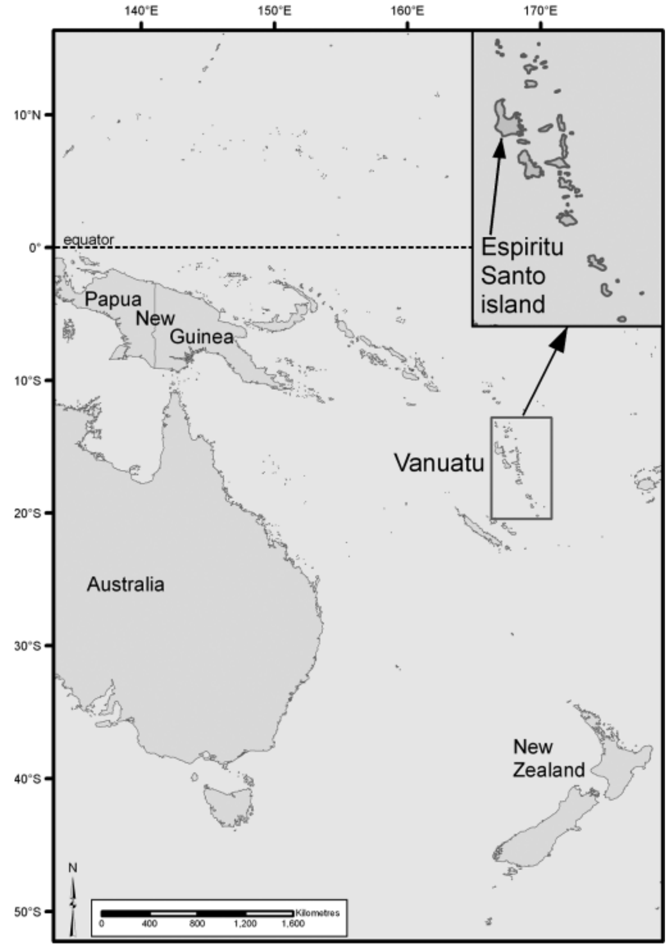
Se ha realizado una caracterización de sitio y del suelo asociada con las plantaciones existentes de madera blanca *(Endospermum medullosum*, Euphorbiaceae) en la isla de Espíritu Santo en Vanuatu. En la parte oriental de la isla se pueden encontrar actualmente unas doscientas plantaciones, predominantemente 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

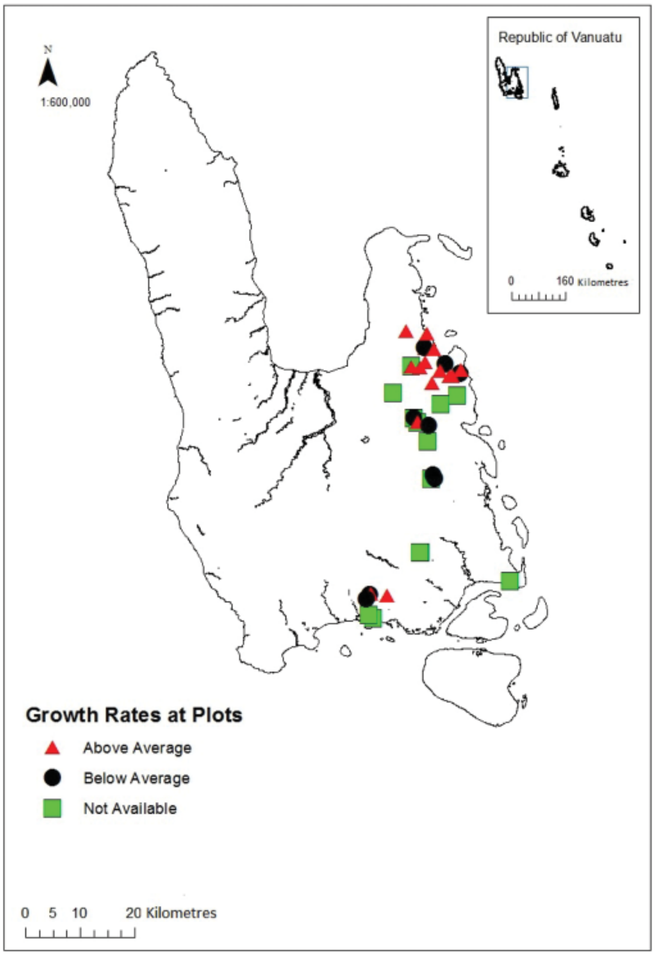
forestry in Vanuatu. The consideration of sustainability means that the assessment must take into account land degradation hazards.

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 whitewood 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 whitewood 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 characteristics 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 incorporating 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 whitewood 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.

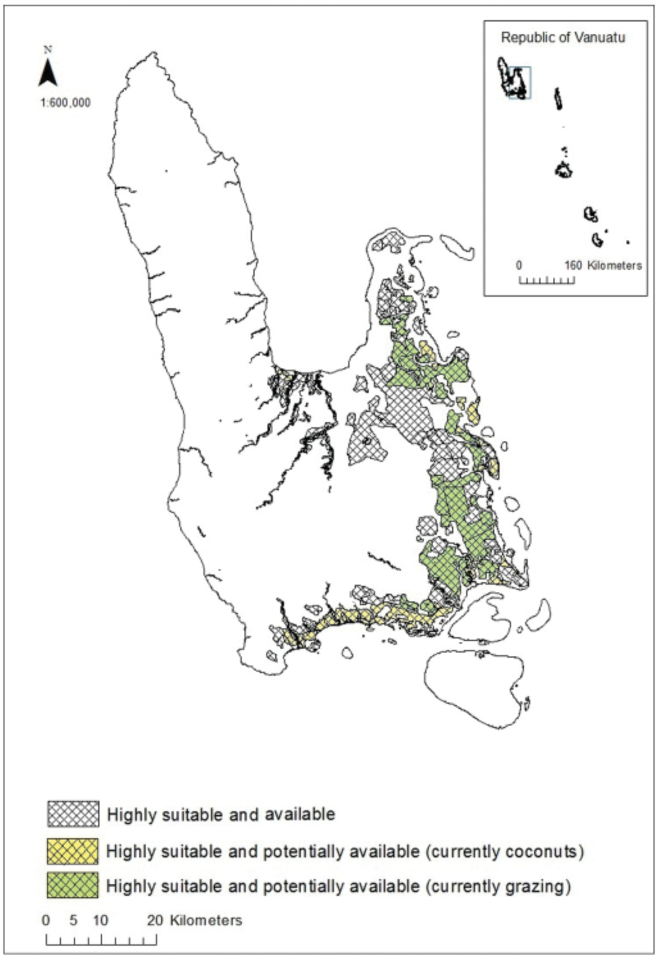
[2] Sum of exchangeable cations plus exchange acidity in topsoil

[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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A review of site-preparation, fertilizer and weeding practices for tropical plantation species with recommendations for whitewood (*Endospermum medullosum*) in Vanuatu

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SUMMARY

The development of plantations with a new species, such as is occurring with the endemic tree *Endospermum medullosum* (whitewood) in Vanuatu, requires the resolution of appropriate establishment techniques. Site preparation, fertilisation and weed control have a very large impact on plantation productivity and represent major risks to plantation success. Establishment techniques for tropical species are reviewed and preliminary site preparation and fertilisation trials for whitewood reported. Trials were established at a site on Espiritu Santo island using available general purpose fertiliser with and without micronutrients at two rates. There was no effect of fertiliser over various rates of complete fertiliser with and without micronutrients, designed to provide adequate phosphorus in volcanic ash soils. Ripping had no significant effect on growth, however insufficient hand clearing of vegetation resulted in lower growth due to competition and complete machine clearing of vines results in high temperatures and decreased survival. A serious issue for whitewood establishment in single species plantations is weed management, especially vine control (*Merremia* spp). The time needed for weed control is influenced by initial planting density and spacing. When inter-planted with mixed gardens of food crops, weed control is not an issue due to more regular tending.

Keywords: plantation establishment, nutrition, ripping, Merremia peltata, seedling survival

Examen de la préparation des sites, des pratiques de fertilisation et de désherbage pour le essences de plantations tropicales, avec des recommendations pour le bois blanc (*Endospermum medullosum*) à Vanuatu

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Le développement de plantations de nouvelles espèces, comme est la cas pour l'arbre endémique Endospermum Medullosum (bois blanc) à Vanuatu, nécessite une résolution de techniques d'établissement approppriées. La prépatation du site, la fertilisation et le contrôle des mauvaises herbes ont un impact important sur la production de la plantation et présentent des risques majeurs pour son succès. Les techniques d'établissement pour les essences tropicales sont examinées et des préparations de sites préliminaires ainsi que des essais de fertilisation pour le bois blanc sont notées. Les essais étaient établis sur un site sur l'île d'Espiritu Santo en utilisant les fertilisateurs généralement disponibles avec ou sans micro nutrients, créés pour fournir un phosphore adéquat dans les sols de cendres volcaniques. L'arrachement n'avait pas d'effet significatifs sur la croissance, mais un désherbage manuel insuffisant de la végétation résultait en une croissance plus faible dûe à la compétition; alors qu'un désherbage mécanique complet des vignes résultait en des températures trop élevées et une survie décrue. La gestion des mauvaises herbes, tout particulièrement le contrôle des vignes (Merremia spp) pose une question sérieuse pour l'établissement du bois blanc en plantations à espèce unique. Le temps requis pour le contrôle des mauvaises herbes est influencé par la densité et l'espacement initiaux de la plantation. Quant l'essence est plantée dans des jardins mixtes avec des récoltes alimentaires, le contrôle des mauvaises herbes n'est plus un problème du fait de la surveillance plus régulière.

Una revisión de las prácticas de preparación del sitio, fertilización y control de malezas para especies de plantaciones tropicales, con recomendaciones para madera blanca (*Endospermum medullosum*) en Vanuatu

R.G.B. SMITH, K. GLENCROSS, J.D. NICHOLS, J.C. GRANT y M. SETHY

El desarrollo de plantaciones con una nueva especie, como las del árbol endémico *Endospermum medullosum* (madera blanca) en Vanuatu, requiere técnicas de establecimiento adecuadas. La preparación del terreno, fertilización y control de malezas tienen un gran impacto en la productividad de las plantaciones y presentan riesgos importantes para su éxito. Se revisan diferentes técnicas de establecimiento de especies tropicales y se presentan resultados de ensayos preliminares de preparación del sitio y fertilización para madera blanca. Los ensayos se establecieron en un sitio en la isla de Espíritu Santo utilizando fertilizante genérico con y sin micronutrientes a dos niveles. No se encontró efecto alguno del fertilizante sobre las diferentes tasas de fertilizante completo con y sin micronutrientes, diseñado para proporcionar el fósforo adecuado en suelos de cenizas volcánicas. El uso de un escarificador no tuvo un efecto significativo sobre el crecimiento, mientras que una limpieza manual deficiente de la vegetación resultó en un menor crecimiento debido a la competencia y una limpieza mecanizada total de trepadoras se tradujo en altas temperaturas y menor supervivencia. Un grave problema en el establecimiento de plantaciones monoespecíficas de madera blanca es el control de malezas, y en particular de trepadoras *(Merremia* spp). El tiempo requerido para el control de malezas está relacionado con la densidad de plantación inicial y el espaciamiento. Cuando se planta en intercultivos de huertos mixtos de productos alimenticios, el control de malezas deja de ser un problema debido a recibir atención más regularmente.

INTRODUCTION

The first step in the establishment of a planted forest or plantation is ensuring the survival of the seedlings when transplanted into the field. This stage usually represents the greatest risk and requires large management inputs representing the majority of costs during a rotation. Tropical climates and landscapes are highly varied and tropical species have different requirements. Establishment silviculture must address species-specific requirements on particular site types. For species that have not previously been grown in plantations this requires development of silviculture protocols.

Establishment typically involves site preparation (cultivation), weed control and fertilisation, all of which can have a significant effect on successful establishment of planted forests. Whitewood (*Endospermum medullosum* L.S. Smith) is a species that requires adequate drainage and friable soils to grow very rapidly (Thompson 2006). Given these requirements for fertile and friable tropical sites, whitewood may be responsive to site preparation techniques, particularly cultivation and fertilisation.

Ripping is a mechanical cultivation technique that opens narrow channels into the subsoil to a depth of up to 1 m. Ripping to various depths has been demonstrated to greatly enhance survival rate, and more than double growth to age 19 months (Lacey *et al.* 2001, Graham *et al.* 2009). However ripping and cultivation may have little effect if existing uncultivated soil conditions are adequate (Smith *et al*. 2001, du Toit *et al*. 2010).

Two important and interrelated factors for plantation establishment are weed control and fertilisation. Most tropical soils are highly weathered, resulting in low levels of available nutrients (Lal 1997) and nutrient deficiencies can be asymptomatic (Webb *et al*. 2001). The application of fertilisers is the simplest method of ensuring an optimum supply of nutrients to plantations (Evans and Turnbull 2004). However different species responses to fertilisation can be complex and depend on soil fertility (Cameron *et al*. 1981, Webb *et al.* 2000).

Weed competition can develop rapidly and persistently in the tropics (Lowery *et al.* 1993,Graham *et al.* 2009). Control of weeds has been demonstrated to increase survival rates by up to 90% and volume growth by over 50% (Lowery *et al.* 1993). A review of long term studies in South Africa and Brazil showed increases in wood volume of 122% and 179% at harvest age of 29 and 10 years respectively, as a result of effective vegetation management (Wagner *et al*. 2006). The dominant weed species of most concern for plantation establishment in Vanuatu is *Merremia peltata*, a vigourous vine that covers large areas of potential plantation land and can cause significant damage to trees if not controlled.

We review literature on plantation establishment practices for tropical species relevant to whitewood and report preliminary results of silvicultural establishment trials undertaken in Vanuatu. We present results of ripping and fertiliser trials and discuss observations and literature relevant to establishment practices for planted whitewood forests in Vanuatu.

Literature review

Site preparation

Establishment of plantations requires some degree of site preparation and early maintenance to ensure high survival and rapid initial growth rates. Two operations in site preparation are clearing of existing vegetation and subsequent soil cultivation. The clearing of vegetation is undertaken by hand or by machinery. The aim is to remove sufficient existing vegetation to allow subsequent operations and reduce competition.

After planting areas are cleared, cultivation of soils is the next operation. Cultivation can reduce the bulk density of the soil and break up impermeable barriers (Goncalves *et al.* 2008) or high strength clay layers (Espinoza 2004), improving soil drainage and aeration and increasing downward penetration of juvenile roots (Goncalves *et al*. 2008, Evans and Turnbull 2004). Ripping is a mechanical cultivation technique that opens narrow channels into the subsoil to a depth of up to 1 m, but can also be used to shatter hard subsoil layers with the use of wings (Espinoza 2004). Ripping to various depths has been demonstrated to greatly enhance survival rate, and more than double growth to age 19 months (Lacey *et al.* 2001, Graham *et al.* 2009). However ripping and cultivation may have little effect if existing uncultivated soil conditions are adequate (Smith *et al*. 2001, du Toit *et al.* 2010). For instance, Costantini *et al*. (1995) reported a highly significant soil type by cultivation interaction. Improved growth response due to ripping was observed in hardsetting soils, but not in non-hardsetting soils. Evans and Turnbull (2004) also reported varied results due to cultivation on sites with differing initial characteristics. Where soils are heterogeneous within management units the decision to rip will depend on the area of each soil type. Lacey *et al.* (2001) found that on a site with heterogeneous soil types where ripping was both beneficial and not, the logistics of delineating the different soils and treating the areas as separate management units was more difficult and costly than applying a single ripping prescription across the whole area. On sites where soils are free draining and friable, conditions may be conducive to root development in young seedlings without the need for cultivation.

Weed control

Two important and interrelated factors of early plantation maintenance are (i) management of competing vegetation, and (ii) ensuring an optimum supply of nutrients (du Toit *et al*. 2010). Vegetation management is critical within those tropical plantations that demand an efficiency of wood production because weed competition can develop rapidly and persistently in the tropics (Lowery *et al.* 1993, Espinoza 2004, Otsamo *et al*. 1995). Early control of weeds in tropical plantations has been demonstrated to increase survival rates by up to 90% and volume growth by over 50% (as measured 2 years short of rotation length) (Lowery *et al.* 1993). A review of long term studies in South Africa and Brazil showed increases in wood volume of 122% and 179% at harvest age of 29 and 10 years respectively, as a result of effective vegetation management (Wagner *et al*. 2006). Weed competition can also influence wood properties (Watt 2009).

Within the tropics, weed control is commonly performed either manually or chemically. Manual weeding, using a machete or bushknife, can be performed with minimal training and requires minimal initial capital outlay, however ongoing labour costs can be high, and cutting weeds may provide only temporary control due to vigorous regrowth (see below for discussion of whitewood, Evans and Turnbull 2004). Chemical weed control with herbicides, if used effectively, may be superior to manual weeding (Lowery *et al.* 1993). For example, one chemical can be equal to three manual weeding operations (Anon 2001 cited in Evans and Turnbull 2004), and spot herbicide treatment increased the stem volume of *Eucalyptus grandis* by almost 50% when compared to manual weeding, but little difference between the two treatments was observed for *Pinus oocarpa* or *Gmelina arborea* (Lowery *et al.* 1993). Chemical treatments can be hazardous to health, and can damage crop trees or the surrounding environment if used inappropriately (Evans and Turnbull 2004). The problems of herbicide application are exacerbated in the tropics because the performance of some herbicides can be erratic and suitable application conditions may not occur for long periods (e.g. long periods of consistent wind or rain) (O'Gara 2010).

The use of chemical weed control may also result in high costs associated with training and supervision, to ensure appropriate use. Training and safety are particularly difficult for transfer to smallholders in the developing world. There are risks associated with use of imported chemicals: capital and equipment required may be unavailable, prices of chemicals and safety equipment may be much higher than in developed countries, and well developed supply chains to ensure chemicals are readily available may not be in place.

Weed control has two phases: control of ground weeds and clean and release operations (Evans and Turnbull 2004). Herbaceous and shrubby ground weeds will compete directly for sunlight, moisture and nutrients from time of planting. Control of ground weeds is required until the trees achieve site dominance at or near to canopy closure. Clean and release operations remove perennial vines, creepers and woody weeds that are likely to smother and kill young trees through their cumulative weight, shading and/or growth habit. Clean and release operations are particularly important for whitewood plantations in Vanuatu as fast growing exotic vine species, particularly *Merremia peltata*, can quickly smother young trees (Thomson 2006a), and can damage leaders beyond repair easily. Weed control within whitewood plantations must be performed for approximately the first 3 years, at a frequency of as little as every few weeks during the wet season (Thomson 2006a). Higher planting densities (closer spacing) can reduce weed control to shorter time frames. Four species tested in *Imperata* grasslands in Indonesia varied in the ability to suppress ground vegetation, but for all species there were significant linear relationships between closer tree spacing and reduced ground vegetation biomass (Otsamo 2002).

Initial spacing has been recommended at rates of 667–800 (Thomson 2006a), however higher rates may have advantages for lower cost and risks of establishment by reducing the long time of three years needed for tending. Some trials planted at 833 trees per hectare had achieved site capture by 2 years compared to 3 years at lower spacings. Some trial plots planted at 417 trees per hectare (a commonly used spacing on Santo, 8m × 3m) still required some tending at 3 years due to the very wide inter-row.

Higher stocking causes problems with unwillingness to thin (Glencross *et al* 2012). Successful alternatives to higher stockings of whitewood may be the use of interplanting with species for which there is a short term market. A preferred species for this purpose in many Pacific countries is *Flueggea flexuosa,* a tree that can be harvested as durable poles at an appropriate thinning age for whitewood (Thomson 2006a, b). This may also be effective in larger scale plantings.

Disruption to growth by weeds such as shrubs and grasses, in contrast to the case of vines, can be temporary if vegetation control is later restored. The risk of permanent damage from vines remains until canopy closure shades the vine growth. The amount of time to canopy closure is dependent on growth and spacing. As tree growth is relatively unaffected by spacing until trees approach canopy closure, spacing is the main determinant of the time to canopy closure. When evaluating the cost of extra trees against the cost of extra weed control events at wider spacings, consideration must also be given to the risk of damage from vines, risk from wind, as well as the wood quality benefits of closer spacing (see Glencross *et al.* 2012).

Cover crops

Weed control may be economically achieved using cover crops although this is not a commonly used technique (Lowery *et al.* 1993). Cover crops have been trialled for

Merremia control (Neil 1982), and have been trialled on Espiritu Santo island in whitewood (Vira 1992). Cover crops can be more economic than hand weeding where weeds that present different management problems take over after initial clearing. For example, after clearing of *Merremia* at Lorum, piko (*Solanum torvum*) became widely established across the site, presenting access and safety issues (due to thorns and wasps). When used as cover crops, particular families such as grasses and legumes have the advantage of being controllable with a selective herbicide. An alternative to cover cropping is a single species cash crop such as peanut. Intercropping can improve the growth of trees (Haggar *et al*. 2003, Dhyani and Tripathi 1999) as well as other economic and operational advantages; it allows wider initial spacing and so alleviates the need for thinning in the short term, provides short term returns to landholders or investors, and these early returns can offset costs of, and integrate operations needed for weed control and stand tending during the early years of plantation establishment. In contrast, if a forage cover crop were utilised, grazing would not be possible (due to possible tree damage from cattle) until approximately the time productivity (and weed problems) began to decline due to shading. Fencing would also be a major cost for some sites. Use of shade tolerant pastures later in the rotation may be another method to increase cash flow and control weed build-up, however light levels under whitewood at various stockings are unknown, and therefore the suitability for various pasture species are also currently unknown.

Merremia peltata

During the first year after planting of whitewood in Vanuatu, the hand tending of weeds at very productive sites was required at intervals as short as two weeks to ensure control of *Merremia* vine during the very active growing season. Even at such high frequencies of manual weed control there was damage from *Merremia* in some experimental plantings. This occurred where vines deformed tree leaders and tree boles became severely distorted. Once vines are in trees and near tree foliage, vine control is best achieved by manual methods, as spray drift can easily damage trees and represents a high risk. *Merremia* is shade intolerant so once site capture is achieved or trees are tall enough risk is reduced. In fact forestry has been suggested as a strategy for managing *Merremia* by shading it out (Kirkham 2004).

In pastoral systems *Merremia* can be controlled by cattle and herbicides (Anon 1993). Good palatability means grazing can be used as an economic technique in reducing cover in pasture cover crop or tree establishment (Anon 1993). In sites where fencing is not established this may not be economic. Biocontrol of *Merremia* may be another possibility. There are issues concerning the status of Merremia as an exotic or native species in different countries. Ecological studies of *Merremia* suggest it plays a role in maintaining diversity after disturbance events such as cyclones (Kirkham 2004). However a fungicide biocontrol agent developed from a naturally occurring fungus would be neither invasive nor detrimental (to *Merremia*) in non-target areas (Paynter *et al.* 2006).

Fertilisation

Most tropical soils are highly weathered, resulting in low levels of available nutrients (Lal 1997) and nutrient deficiencies can be asymptomatic (Webb *et al*. 2001). The problem is exacerbated in intensively managed plantations that lose nutrients to each successive rotation (Powers 1999, Mackensen and Folster 2000, Gonçalves *et al*. 2008). This is less of a problem with longer rotations for solid wood products such as whitewood compared to short rotations of less than 10 years (Goncalves *et al.* 2008, Smethurst 2010). The application of fertilisers is the simplest method of ensuring an optimum supply of nutrients to plantations (Evans and Turnbull 2004), although there is a risk that fertiliser, if applied incorrectly can benefit weeds rather than crop trees and therefore actually be detrimental to plantation establishment.

For long rotation crops overall productivity will be largely determined by inherent site quality (West 2006, Grant *et al*. 2012a), but nutrient additions can be useful at establishment to accelerate growth of seedlings that are not yet able to exploit site soil resources efficiently (du Toit *et al*. 2010). Rapid early growth is important in competing with weeds up until canopy closure, after which nutrients are recycled (Binkley *et al*. 1997) and competing vegetation is shaded out. In some cases small additions of nutrients can dramatically increase growth.

Growth responses to the addition of nutrients will vary depending on inherent soil fertility and the nutrient requirements of different species (Evans and Turnbull 2004, Webb *et al.* 2000, Ogbonnaya and Kinako 1999, Otsamo *et al*. 1997, du Toit *et al*. 2010). Species responses to fertilisation can be complex. For example, in Australia, improved growth of *Pinus caribaea* var. *hondurensis* due to the addition of several nutrients was only observed if the requirements for phosphorous had been satisfied, with some nutrients causing negative growth response when applied without phosphorous (Cameron *et al*. 1981). In a study on the growth response of four tropical plantation timber species to the addition of phosphorous, Webb *et al*. (2000) observed a strong growth response in two of the species (*Cedrela odorata* and *Agathis robusta*), but little or no response in the other two species (*Flindersia breyleyana* and *Castanospermum australe*). Similarly, Otsamo (1997) observed response in only some of four species when NPK fertiliser was applied at 1 month and 1 year after planting in Imperata grasslands. Boron is often deficient in soils derived from volcanic ash (Ladrach 1992, Grant *et al* this volume), as is the case in Vanuatu. Boron is important in structural aspects of plant growth and has been shown to be important in disease resistance in eucalypts (Smith 2007).

Supply of nutrients through the use of fertiliser treatments is costly (Evans and Turnbull 2004, Mackensen *et al.* 2000), and may result in neutral or even negative growth response (Dell *et al.* 2001). Multiple field trials are required to determine growth responses to particular nutrients, and whether these growth responses render fertilising economically worthwhile (Webb *et al.* 2001, Evans and Turnbull 2004, Smethurst 2010). As with herbicides, fertiliser may not be available in some countries or areas and laboratory facilities for soil and foliar analysis are even less available, making diagnostic tests difficult.

Time of planting

Tropical plantations are often established in climates with a dry season. In these climates planting is best undertaken at the start of the rainy season, allowing maximum opportunity for trees to become established under ideal growing conditions (Ladrach 1992). However, around the onset of the rain season can include periods of high temperatures in between patches of rain. If planting is undertaken at the start of the rainy season then seedlings are also most vulnerable at this time. Therefore there are risks of drought periods and high temperatures causing heat stress and transplant shock. High temperatures are exacerbated by dark organic surface soil layers, such as those on Santo, especially when areas are completely cleared. Partial clearing therefore provides some protection.

While the risk of dry periods and high temperatures are difficult to predict, survival can be enhanced by planting drought-hardened seedlings (Thomas 2009) or use of watering or gels to reduce transplant shock (Thomas 2008). The converse of rapid onset of rains can also present difficulties. Operations such as ripping and cultivation require soil moisture contents to be adequate (but not excessive) and therefore must take place after the onset of rainfall. Preparation and planting must be complete before site access becomes difficult due to excess rain.

METHODS

Site description: Lorum

The trial site was located at Shark Bay in north east Santo Island. It was a large contiguous area largely covered in *Merremia peltata*, with little woody vegetation or other weeds. The intention was that lines would be cleared by bulldozer but the presence of interconnecting vines meant that much of the site was almost completely cleared and windrowed. Ripping only took place in a very small area (see below the ripping trial). The site was cleared by bulldozer and trials were laid out and plots marked in September, and planted in October 2008 using containerised seedlings grown from locally collected unimproved seed. Weeding began two weeks after planting and continued at intervals of several weeks for two years. Infill planting necessary due to mortality (due to high temperatures) was undertaken in December 2008 using the same batch of plants that had been grown on to larger containers. Fertiliser treatments were applied in late January 2009. A representative soil was described and sampled from a soil pit (down to coral, Table 1) according to standards defined by the National Committee on Soil and Terrain (2009). Reaction to NaF (Fieldes and Perrot 1966) was recorded as an indicator of phosphorus sorption levels (Alves and Lavorenti 2004). Colour was Munsell (2000). More detailed site and soil descriptions are given in Grant *et al*. (2012b) and Glencross *et al*. (2012)

Site preparation trial

A trial comparing growth of ripped versus unripped plots (30 m by 30 m) in two replicate blocks at Lorum was established and height growth and survival compared after 1 and 2 years. The ripping treatments were arranged in a complete randomised block design with one plot in each pair randomly selected for ripping.

Several different techniques of site clearing were used to establish trial plantings at other locations during 2008 (Glencross *et al*. 2012). Observations revealed several important aspects for successful and efficient establishment of whitewood. Each of the following methods of site preparation was used in establishing different trials: a bulldozer cleared large areas at Lorum to establish a large plot silvicultural regime trial; bulldozer cleared 2 metre wide strips within scrub at 8 metre spacing between strips; hand cleared areas in gardens; and hand cleared areas in scrub.

Establishment fertiliser trial

Most soils suitable for whitewood on Santo were thought to be likely phosphorus deficient as they are commonly strongly phosphorus-fixing (Grant *et al*. 2012). Initial establishment of whitewood trials had been successful without fertiliser, and no information was available about whitewood nutrition, therefore establishment fertiliser treatments of a complete general purpose fertiliser with and without micronutrients were applied to test for accelerated early growth. Only one general purpose fertiliser was available locally. Laboratory facilities for soil and foliar analysis are even less available, making diagnostic tests difficult. Therefore an approach that

TABLE 1 *Lorum soil pit description*

Horizon; depth; colour; texture/structure; pH; reaction
A1, 0–3cm, very dark brown (7.5YR2.5/2) loam, with strong fine granular structure, field pH 6.0.
A3, 3–18, dark brown (7.5YR3/3) clay loam with moderate fine angular blocky structure, field pH 6.0, very weak reaction to NaF
B1, 18–38, dark brown (7.5YR3/4) clay loam with moderate fine angular blocky structure, field pH 6.0, very weak reaction to NaF
B2, 38–65, dark brown (7.5YR3/4) heavy clay loam with moderate fine angular blocky structure, field pH 6.0, weak reaction to NaF
BC, 65 90+, Coral substrate with some penetration by B2 material field pH 9.0.

*Well drained soils. Field texture is underestimating the clay content in these subplastic soils.

uses several levels of a general purpose complete fertiliser was considered most appropriate initially. Boron is often deficient in soils derived from volcanic ash (Ladrach 1992, Grant *et al* this volume). Boron is important in structural aspects of plant growth and has been shown to be important in disease resistance in eucalypts (Smith 2007). Also a soil analysis was undertaken at Lorum (Appendix A). Phosphorus was indicated as possibly low as well as B and Zn. The treatments used the only available fertiliser on Santo called Crop King. A micronutrient mix was also added that was imported for the trial.

Crop King is 12% N, 12% P, 17% K + 2.5% Mg + 0.3% B. It was applied at 50gm per tree (single fertiliser treatment) to get 6g P per tree, which is broadly recommended for plantations. Micronutrients were applied as 0.23gm elemental Zn (as zinc sulphate heptahydrate) and 0.06g of elemental B (as borate) per tree (plus the additional B in the Crop King). The double treatment used two times the Crop King rate, with or without the micronutrients (Table 2). Fertiliser was applied on the soil surface 15cm from the base of the tree on the downhill side after infill planting took place. The trial used a complete randomised design with 4 replicates of each treatment.

Statistical analysis

Differences in average tree height and average tree DBH per plot up to age 3 in the fertiliser trial were analysed using ANOVA. Differences in average tree height per plot in the ripping trial were assessed using a t-test.

RESULTS AND DISCUSSION

Site preparation

There was no significant effect of ripping on growth (mean height at age 1 was 1.44m ripped and 1.57m control; $t_1 = -0.94$, p=0.26) or survival (mean survival at age 1 was 84% ripped and 81% control; $t_1 = -0.38$, p=0.36). This is in accord with several authors who found ripping and cultivation may have little effect if existing uncultivated soil conditions are adequate (Smith *et al*. 2001, du Toit *et al*. 2010, Costantini *et al*. 1995, Evans and Turnbull 2004)

An additional consequence of mechanical clearing and ripping on sites where vines such as merremia are a common weed species, was that large areas of soil become exposed. At Lorum where large open areas were cleared using mechanical methods there was mortality, thought to be due to heat stress, particularly the exposure of the dark soils to intense sun, desiccation and the resulting high temperatures on young newly planted whitewood seedlings. It appears that some vegetation left between rows acts to protect seedlings from high temperatures and wind.

TABLE 2 *TABLE 2 Fertiliser treatments* applied at Lorum trial site Shark Bay*

Code	Treatment
NoFert	No fertiliser
CK50	Crop King 50 gm/tree
CK50+	Crop King 50 gm/tree + micro
CK100+	Crop King 100 gm/tree + micro

* Crop King is 12% N, 12% P, 17% K + 2.5% Mg + 0.3% B. Micro is 0.23 gm elemental Zn (as zinc sulphate heptahydrate) and 0.06g of elemental B (as borate) per tree.

At the other extreme, at sites where very low impact site preparation techniques were applied, tree growth was observed to be adversely affected by high levels of competition from surrounding vegetation. One site that used hand clearing around young trees, suffered reduced growth and high mortality from competition as the weeds and remnant woody vegetation was not cleared sufficiently far from planted trees. These observations indicate that a balance needs to be struck during the establishment phase, between complete removal of vegetation resulting in excessive exposure and insufficient removal resulting in excessive competition.

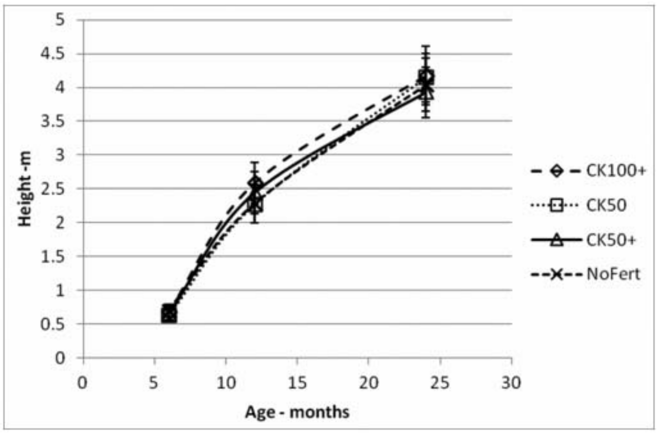
Fertiliser

There was no significant difference in growth between any fertiliser treatments up to 2 years old (Figure 1) (ANOVA: height 2 yrs - $F_{3,23}$ 0.191. p=0.901; DBH 2 yrs - $F_{3,23}$ 0.3845, p=0.765). It is possible that some fertiliser was washed away as it was placed on the soil surface, however the soils are very well structured and infiltration was very good. Soils have not been used for mechanised agriculture and the site had lain fallow for some time, therefore nutrient levels are unlikely to have been depleted. It is possible that competing vegetation took up some of the fertiliser applied, however growth rates were reasonable given the level of silviculture with unimproved seed and were similar across sites (Glencross *et al*. 2012).

CONCLUSIONS

Ripping and fertilisation had no impact on early survival or growth of whitewood. Soils fertility and structure appear

FIGURE 1 *Relative height growth for fertiliser treatments. Error bars are standard errors*



adequate for achieving moderate growth rates with no augmentation. The site quality of all available land for plantation development on Santo appears to be of a similar quality (Grant *et al*. 2012b) which is an advantage for the establishment of whitewood. Minimal costs for establishment will translate into profitable plantation development. More work is required to quantify the optimum level of vegetation removal and management under various site situations, especially Merremia, as this was observed to be important in plantation survival and growth.

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APPENDIX 1

	Nutrient		**Units**	***A1053/1***	***A1053/2***
Soluble Tests & Morgan 1 Extract	Calcium	Ca	ppm	1102	965
	Magnesium	Mg	ppm	162	114
	Potassium	K	ppm	350	247
	Phosphorus (Morgan)	P	ppm	0.2	0.1
	Phosphorus (Bray 1)	P	ppm	1	1
Soluble Tests & Colwell + Bray 2 Phoshorus Extract	Phosphorus (Colwell)	P	ppm	40	29
	Phosphorus (Bray 2)	P	ppm	13	5
	Sulphate Sulphur	S	ppm	30	31
	pH (1:5 water)		units	6.00	5.91
	Conductivity (1:5 water)		µS/cm	181	123
	Organic Matter		%	9.32	6.44
Ammonium Acetate Equiv. Extract	Calcium	Ca	cmol$^+$/Kg	18.98	10.64
	Magnesium	Mg	cmol$^+$/Kg	2.97	1.50
	Potassium	K	cmol$^+$/Kg	1.80	0.98
	Sodium	Na	cmol$^+$/Kg	0.10	0.08
	Aluminium	Al	cmol$^+$/Kg	0.01	0.00
Acidity Titration	Hydrogen	H$^+$	cmol$^+$/Kg	0.18	0.13
	Cation Exchange Capacity		cmol$^+$/Kg	24.04	13.33
Percent Base Saturation	Calcium	Ca	%	79.0	79.8
	Magnesium	Mg	%	12.4	11.2
	Potassium	K	%	7.5	7.4
	Sodium	Na	%	0.4	0.6
	Aluminium	Al	%	0.02	0.000
	Hydrogen	H+	%	0.7	1.0
	Calcium/ Magnesium Ratio		ratio	6.39	7.10
	K:Mg		ratio	0.60	
Micronutrients-DTPA +Hot CaCl$_2$ Extracts	Zinc	Zn	ppm	2.6	1.8
	Manganese	Mn	ppm	129.1	43.8
	Iron	Fe	ppm	69.5	40.6
	Copper	Cu	ppm	10.6	5.6
	Boron	B	ppm	0.22	0.13
CaCl$_2$ Extract	Silicon	Si	ppm	19.7	15.2
Total Nutrients	Total Carbon	C	%	5.33	3.68
	Total Nitrogen	N	%	0.60	0.41
	Carbon/ Nitrogen Ratio		ratio	8.8	9.0
	Approx clay content			32.5	40
	base status			73.4	33.0
	base status			Eutrophic	Eutrophic
	base saturation (with ECEC)			99.2	99.0

Spacing affects stem form, early growth and branching in young whitewood (*Endospermum medullosum*) plantations in Vanuatu

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SUMMARY

This paper investigates the early growth response, branching and stem quality of *Endospermum medullosum* (whitewood) at different spacings. Whitewood plantings were established at stockings of 400–833 trees per hectare and early growth, tree stem quality and branching were quantified up to age 3 years. Growth, number of live branches and branch size were negatively correlated with stocking. The stocking of trees of acceptable quality had high spatial variation. Initial spacing in whitewood plantations can be used to manipulate branch size, crown rise and stem size; all of which are important for development of pruning and thinning regimes to produce high quality logs. If unimproved whitewood stock is used, to ensure that there are 300 stems per hectare of acceptable quality to produce sawlogs, more than 600 trees per hectare should be established at planting.

Keywords: Plantation establishment, stocking, canopy development, pruning, wood quality

L'espacement affecte la forme des troncs, la croissance de départ et les branches dans les plantations de jeune bois blanc (*Endospermun medullosum*) à Vanuatu

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Cet article étudie la réponse de la croissance de départ, de la qualité des branches et des troncs de l'Endospermum Medullosum (bois blanc) à différents espacements. Les plantations de bois blanc avaient été établies en populations de 400–833 arbres par hectare, et la croissance de départ, la qualité du développement des branches et des troncs étaient quantifiés jusqu'à l'âge de trois ans. La croissance, le nombre de branches en vie et leur taille révélaient une corrélation négative avec la population. La plantation d'arbres de qualité acceptable connaissait une variation spatiale importante. L'espacement initial dans les plantations de bois blanc peut être utilisé pour manipuler la taille des branches, la pousse de la cime et la taille des troncs, lesquels sont tous importants pour le développement de régimes d'élagage et de coupe pour produire des bûches de bonne qualité. Si une source de bois blanc non amélioré est utilisée, il faudrait établir 600 arbres par hectare lors de la plantation initiale pour obtenir 300 individus par hectare d'une qualité acceptable pour la production de bois de coupe.

El espaciamiento afecta a la forma del tallo, el crecimiento inicial y la ramificación en plantaciones jóvenes de madera blanca (*Endospermum medullosum*) en Vanuatu

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Este artículo investiga el crecimiento inicial, la ramificación y la calidad del tallo de *Endospermum medullosum* (madera blanca) bajo diferentes espaciamientos. Se establecieron plantaciones de madera blanca en densidades de 400 a 833 árboles por hectárea y se midió el crecimiento inicial, la calidad del tallo y la ramificación hasta los tres años de edad. Se encontró una correlación negativa entre la densidad de plantación y el crecimiento, el número de ramas vivas y el tamaño de las ramas. Se observó una gran variación espacial en la densidad de plantación de árboles con una calidad aceptable. En plantaciones de madera blanca se puede utilizar el espaciamiento inicial para manipular el tamaño de las ramas, la altura de la copa y el tamaño del tallo, siendo todas estas características importantes en el régimen de podas y raleos para producir trozas de alta calidad. Si se utilizan plántulas no mejoradas de madera blanca, es necesario establecer inicialmente más de 600 árboles por hectárea, para asegurar la obtención de 300 fustes por hectárea de calidad aceptable para madera de aserrío.

INTRODUCTION

Whitewood (*Endospermum medullosum*) from natural forests in Vanuatu is highly regarded as a furniture and internal joinery timber; it machines and works well, making it suitable for many purposes including mouldings, boards, veneer and plywood manufacture (Viranamangga *et al.* 2012). The natural forest resource in Vanuatu is severely depleted and replacement with plantations has begun to ensure future wood supply (Viji *et al.* 2001), however trees grown in plantations differ from native forests in many ways (West 2006). The development of high value plantations in the tropics has a long tradition with species such as teak and mahogany (Mayhew and Newton 1998, Bhat 2000, Jagels 2006), however the use of native species is often limited by a lack of silvicultural information (Condit *et al.* 1993). Introduced plantation species have been tried in Vanuatu, but have struggled due to cyclones and forest health issues (Thompson 2011). In comparison, whitewood has shown excellent plantation potential with rapid growth, tolerance to cyclone damage and brown root rot (*Phellinus noxious*) in Vanuatu (Thompson 2006).

Log size, stem shape and internal defects are influenced by stand management of plantations; primarily spacing, pruning and thinning. Log size is determined by tree diameter growth, which is controlled by tree density (Ola-Adams 1990). Initial spacing is therefore important for early growth and thinning important to maintain or increase growth later in the rotation (Kanninen *et al.* 2004). However, there are trade-offs. Even though the result is slower early growth, higher initial stockings are commonly used for several important purposes: to rapidly capture the site by suppressing weed competition (Evans and Turnbull 2004); to increase the number of trees with high quality stem shape available to select for pruning; and to restrict branch growth and therefore increase wood quality outcomes from pruning.

Stand management silvicultural prescriptions are in various stages of development for many tropical species (James and del Lungo 2005, Evans and Turnbull 2004, Kanninen *et al.* 2004, Jagels 2006). The need to define silvicultural prescriptions is most pronounced for plantations of new species (Glencross and Nichols 2005, Smith and Brennan 2006, Vanclay 2010, Nichols and Vanclay 2012), such as whitewood, where little is known about the growth, wood properties and future markets for plantation grown trees. Perez and Kanninen (2005) also point out that it is difficult to make comparisons of management regimes and growth responses to silvicultural practices and site conditions to other regions. Therefore, when undertaking a plantation program it is important to base silvicultural decisions on local data and species, rather than relying on general principles from other species and other regions.

Spacing, thinning and wood quality have a role in wind firmness (Grant *et al.* (2012) describes the wind environment of Espiritu Santo Island). Lower height to diameter ratios and higher strength characteristics (correlated with wood density) confer greater resistance to breakage and uprooting (Read *et al.* 2011, Cremer 1982, Gardiner *et al.* 2008). The main influence on individual tree growth of higher stocking is restricting diameter growth. Therefore at higher stocking, height to DBH ratios are increased, reducing mechanical strength and increasing risk of stem damage. In natural forest trees in New Caledonia, height: diameter ratios ranged from 44–72 for angiosperms and 72–85 in two conifer species (Read *et al.* 2011). However it is not clear if this will be sufficient in the wind environment of Vanuatu and with the wood mechanical properties of whitewood. Stands are also more susceptible to wind damage after thinning as stands are opened up (Gardiner *et al.* 2008).

Investors and growers often struggle to develop sufficient log value from plantation-grown trees to justify the required investment, particularly for large saw-log regimes which require long rotations (Brown and Beadle 2008). Log value is largely determined by the quantity and pricing of the products that may be recovered after conversion, minus the costs of growing, harvesting and processing (Cassidy *et al.* 2012). Internal defects are often very different in trees grown in plantations to those in natural forest (Jagels 2006). Studies of the wood quality of new plantation species often report poor wood quality due to inappropriate silviculture resulting in significant downgrading of timber, especially because of knots and other branch related defects (Forrester *et al.* 2010). Pruning is undertaken to enhance wood value; however, pruning is a costly and challenging silvicultural intervention and decisions can have an affect on growth and economic returns to growers (Montagu *et al.* 2003). Branching characteristics will inform the timing and height to which branches are removed. Pruning is often undertaken in the first 5 years of growth in highly productive plantations (West 2006).

For forest growers the total wood value realised is largely determined by log size, stem shape (stem form) and the distribution of internal defects (Montagu *et al.* 2003, Palmer 2010, Todoroki 2003). Our objective was to examine the influence of spacing on the growth, stem quality and branching characteristic of whitewood grown in silvicultural experimental trials across Espiritu Santo Island, Vanuatu (Santo). The implications of stand management as it affects wood quality and product value are discussed.

METHODS

Silviculture trials were established at 5 different locations on Espiritu Santo Island, Vanuatu. A spacing trial was established initially in 1995 at Loro, and a series of spacing and thinning trials and demonstration plots in 2007–9 across the Island. Details of the trials planted in 2007–9 and treatments at each site are contained in Table 1.

Early growth was measured as tree diameter at breast height (DBH).

Tree selection for pruning and thinning

Stem form was assessed at Victor and Kelsai at age 4 years on the basis of straightness, and the degree of defects in the merchantable section of the stem (0–6 m), which generally

TABLE 1 *Site and trial details*

Trial	**Victor**	**Kelsai**	**Jubilee Farm**	**Lorum**	**Loro $_1$.**
Location	Central Santo	Shark Bay	Luganville	Shark Bay	Shark Bay
Plant Date	Feb 2008	Mar 2008	Apr 2008	Oct 2008	1995
Previous land use	Garden	Garden	Coconut, garden	Bush	
Area (spacing)	0.5	2 × 1 ha	0.5	2.5	1.5
Spacings - m	4 × 3, 4 × 6	8 × 3; 6 × 3	8 × 6	4 × 3; 4 × 4; 8 × 3.	2 × 4; 2 × 6; 2 × 8; 2 × 10; 4 × 4; 4 × 6; 4 × 8; 4 × 10; 6 × 6; 6 × 8; 6 × 10.
Replications	6	0	0	8	2
Treatments	Unthinned Thinned to 415 tph at age 2.8.	(8 × 3) garden for 2 years		To be thinned	Variable plot size
Design	RCB			RCB	RCB
Measurements	DBH, branch, stem quality	DBH, branch, stem quality	DBH	DBH, Ht age 1, 2, 3	DBh, Ht age 2,4,9.

1. planted by QFRI staff 1995 (Walker *et al*. 1996).

resulted from the presence of large branches or bends in the stem. Trees were classified into one of three groups:

Crop trees: were the straightest, free of defects and suitable for pruning;

Minor defect trees: minor stem deviations, minor deformities on trunk, largest branch <50 mm diameter, lean <5% but were deemed as merchantable. These could be pruned but would result in lower quality products (the cost of pruning is less likely to be recouped).

Cull trees: had a major defect in the lower section of the stem (ramicorns, double leaders, very large branches >50 mm, severe stem deviations, broken tops) and were considered unmerchantable.

The questions of interest were; the total number and spatial variation of crop or merchantable trees available for pruning at each stocking, and the proportion of trees in each stem classes at both stockings. The optimum number of trees for final harvest in a solid wood regime on high quality sites to ensure full utilisation of the site while maintaining growth rates and is generally considered to be about 200–400 trees per hectare (West 2006). Therefore 200 trees per hectare was used as an indication of adequate stocking. A total of 732 trees were assessed in two stockings and three spacings (Victors: 4 × 3, Kelsai: 6 × 4, 8 × 3).

Canopy development

All branches in the lower 4 m of the stem (3 m at Lorum) were assessed as being dead or alive. Branch diameter was measured at a point just past (20 mm) the branch collar swelling (Table 2). Approximately 30 sample trees in each stand were selected across the range of diameter classes within each stand (spacing). Measure trees were surrounded by buffers at least 6 m wide from plantation edges or any change in spacing. Plot sizes in experimental trials ranged from 480 m^2 in 4 × 3 m treatments to 700 m^2 in the 8 × 3 m plots.

Data analysis

Differences in mean plot DBH between the four spacing and thinning treatments at Kelsai and Victor were analysed for each measure date separately using ANOVA in SPSS. The effect of growth and spacing at Loro was modelled by fitting linear or logarithmic regressions in Excel with DBH as the dependent variable and stocking as the independent variable. A model was fitted for each age separately. The model chosen was that with the greatest correlation coefficient (model selection and residuals were checked using visual inspection of plots). Differences in the frequency of trees in the three

TABLE 2 *Branch data collection sites*

Site	**Age years**	**n trees**	**Stocking trees/ha**	**Spacing m × m**	**Average DBHcm**
Jubilee Farm	3.1	30	208	8 × 6	18.5
Victor	3.3	33	417	4 × 6	18.0
Kelsai	3.8	34	417	8 × 3	17.6
Kelsai	3.8	32	556	6 × 3	16.3
Lorum	2.8	33	625	8 × 2	13.0
Victor	3.4	25	833	4 × 3	16.5

classes between the two different spacings at 417 stocking at Kelsai and the 833 stocking at Victors were analysed using chi-squared tests. Relationships between DBH, maximum branch size, branch size and number of live branches and stocking were modelled using linear regression in Excel and plots were also checked visually. Initial stocking was used as the independent variable for mean branch size per tree and number of live branches. DBH was the independent variable against maximum branch size.

RESULTS

Growth

The spacing trial at Loro showed no effect of spacing on DBH at age 2 years (Figure 1). The difference in DBH between lowest and highest stocking was less than a centimetre. At this early stage, a linear regression with slope approaching zero being the best fit ($r^2 = 0.085$) for DBH across spacing treatments. By age 4 years the best fit model was logarithmic ($r^2 = 0.52$). The difference in DBH between stockings of 1250 and 625 tph was only 0.35 cm compared to 3.32 cm between 166 and 625 tph. By age 8 the non-linear suppressive effect of higher stocking on DBH was apparent across all stockings and best represented by a logarithmic regression ($r^2 = 0.55$), the difference between 1250 and 625 compared to 625 and 166 were 5.9 and 8.3 cm respectively (Figure 1). Different rectangularities appeared to have no discernable effect on DBH growth. In the only stocking with square and rectangular spacing treatments (625 tph; 4 m × 4 m, 8 m × 2 m), the rectangular spacing had smaller mean DBH than the square spacing at all ages. Other similar stockings with varied rectangularities showed similar results.

The results from the trials planted in 2008 showed a similar growth trend to the Loro spacing trial planted in 1995. At Lorum, survival and growth were unaffected by spacing up to age 3 years (data not shown). At Victors and Kelsai, there was a significant difference in DBH growth between spacing treatments at age 4 years (Figure 2, ANOVA: $F_{3,25}$ 9.803. $p<0.001$). The thinned treatment at Kelsai (6 × 4) and the wider spacing at Victor (8 × 3) were significantly greater than the other two treatments at 4.3 years age.

Tree selection for pruning and thinning

The number of defect-free trees suitable for pruning and producing high quality final crop trees was highly variable (Table 3). There were on average in each spacing treatment between 40 and 65% of trees without defect per plot. However, spatial variation was considerable; ranging from 24 to 75% in individual plots. This has implications for site occupancy. Defect free final crop trees were as low as 100/ha in one plot.

The overall proportion of trees within each of the classes was significantly different between the two spacings (both 417 trees per hectare) at Kelsai ($p<0.001$), but was not significantly different between 833 trees per hectare at Victors and the 6 × 4 spacing at Kelsai ($p=0.49$). The proportion of unmerchantable trees was significantly lower in the thinned stand at Victors ($p<0.05$) compared to the unthinned, however when the cull trees were excluded from the analysis the proportion of minor defect trees was not significantly different.

Canopy development

The maximum branch diameter per tree was positively correlated with tree DBH ($r^2 = 0.35$. Figure 3). Maximum

FIGURE 1 *DBH at various spacings at the Loro spacing trial. Each point represents the mean of two replicate plots, spacings are listed in Table 1. Series are measurement ages; the trees were planted in 1995 and measured at age 2.1, 3.1, 4.1, and 8.7 years*

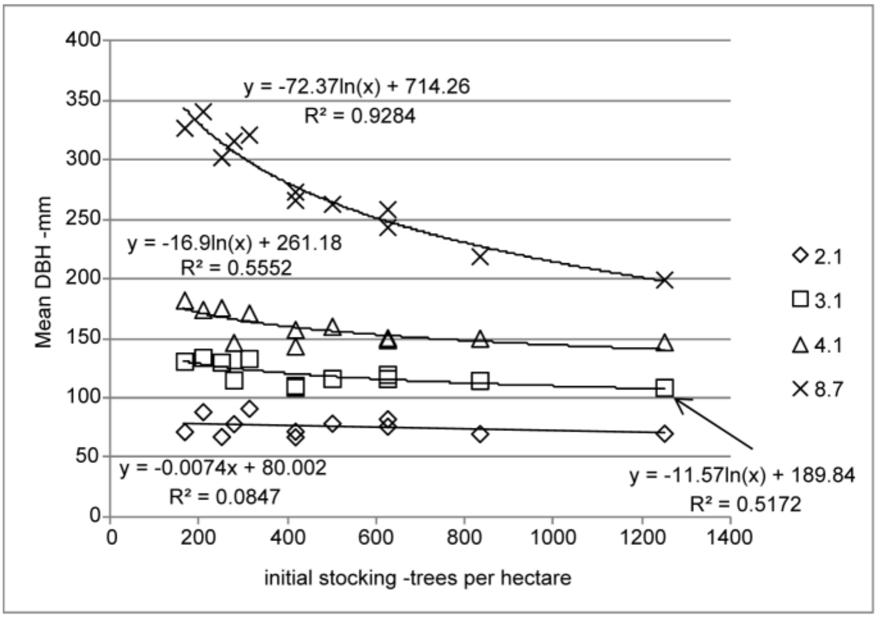


FIGURE 2 *DBH growth of two spacings at Victor and Kelsai sites. were significantly different between spacings by age 4. Error bars are standard error of the mean*

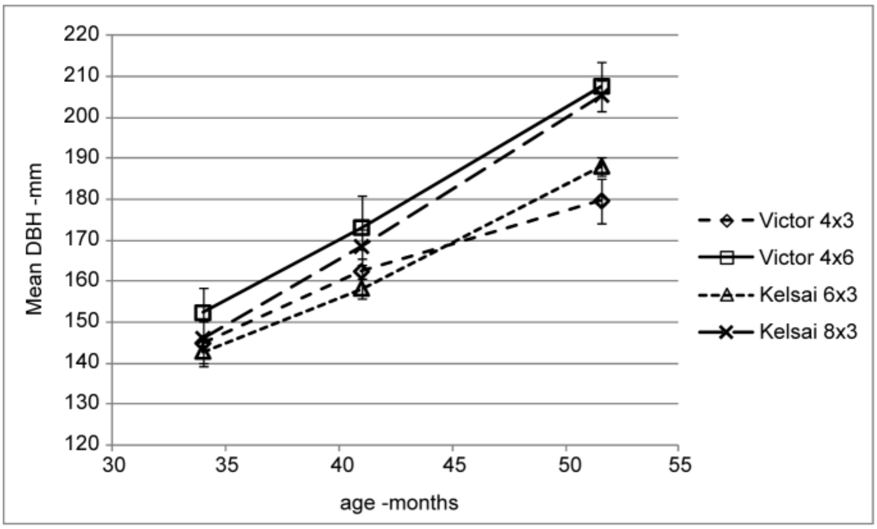
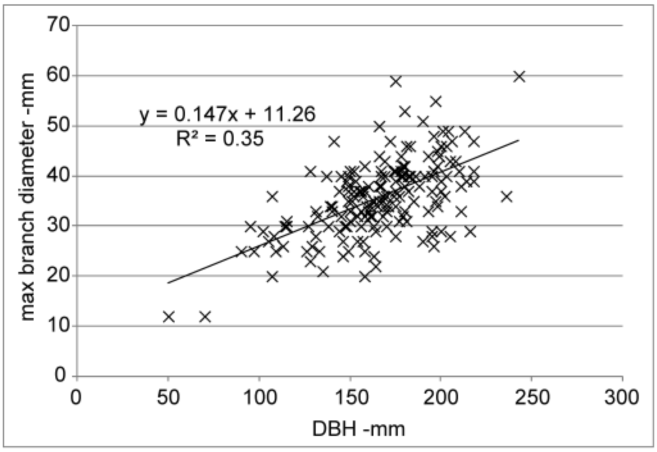


TABLE 3 *Mean number of merchantable trees per hectare without defect in 29 plots planted at two stockings*

Intial stocking - trees /ha		417	833
Spacing - m		6x4	4x3
Defect free trees	Minimum	101	235
	Mean	237	354
	Maximum	336	563
Defect free plus Minor defect	Minimum	277	641
	Mean	394	743
	Maximum	416	790

diameters ranged from 25 mm in trees of 100 mm diameter to 50 mm for trees of 250 mm DBH. Mean branch diameter (Figure 4) and the number of live branches (Figure 5) were negatively correlated to initial stocking ($r^2 = 0.78$, $r^2 = 0.54$ respectively). Lower stockings produced larger mean branch diameter, maximum branch diameter and larger numbers of live branches. The average branch diameters were only below 25 mm at 625 and 833 stockings. Maximum branch diameter was closely correlated to the mean diameters and is above 25 mm for all stockings.

FIGURE 3 *The relationship between maximum branch diameter and diameter at beast height (DBH at 1.3 m height)*



DISCUSSION

Growth rate and the characteristics of the canopy will influence key decisions about stand management, including weed control, pruning and thinning. Understanding those growth characteristics for a given species will help forest growers make informed decisions about the timing and intensity of silvicultural interventions, anticipate operational requirements and better predict production costs. The growth, stem quality and branching characteristic of whitewood grown in

FIGURE 4 *Average branch diameter at 3 sites and five stocking rates. Sample site details are contained in Table 2*

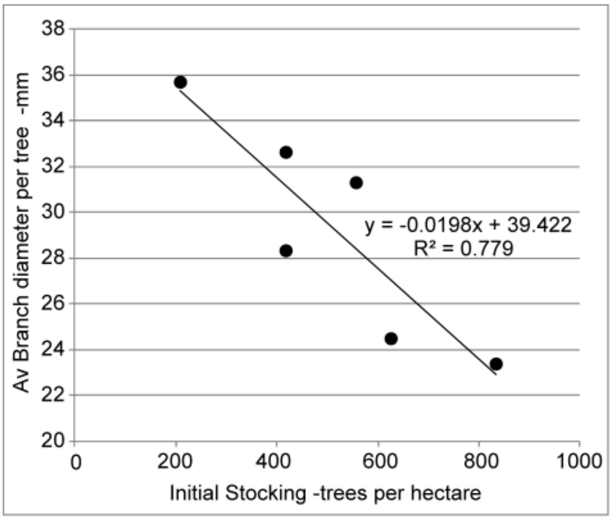
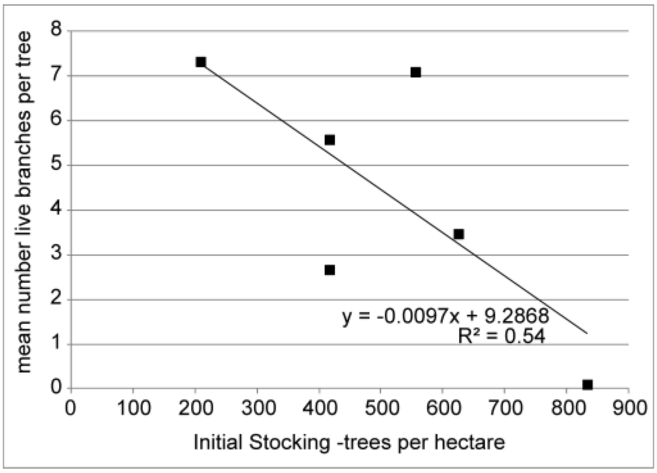


FIGURE 5 *Mean number of live branches per tree related to stocking. Sample site details are contained in Table 2*



silvicultural experimental trials and demonstration plots across Espiritu Santo, Vanuatu indicate that the species has many favourable plantation traits; including early rapid growth and a tendency to form smaller branches at higher stocking rates (over 500 trees per hectare). Whitewood planted at higher stocking has shown a capacity to initiate branch death and branch shedding. The implications of these traits are that forest growers may use spacing and thinning to produce positive effects on log size, defect levels (knot size) and therefore wood quality.

In many solid wood plantation programs, growers plant over 1000 trees per hectare to ensure rapid site capture and sufficient crop trees of the desired form. In Vanuatu, the planting of over 600 trees per hectare has been seen as overstocking; where woodlots and plantations are generally planted at < 500 trees per hectare (Grant *et al.* 2012). A survey of landholders showed that even lower stockings may be preferred in future (Aru *et al.* 2012).

Growth

The early growth of whitewood was affected by stocking. The competition and subsequent reduction in DBH growth was related to initial stocking and was consistent across several trials on Santo. At Loro the curves fitted to DBH growth showed a pattern of increasing effect of stocking with age (Figure 1). At age 2 the curve is linear and horizontal and DBH is unaffected by stocking. By age 3 stockings below approximately 300 trees/ha have slightly greater DBH than those greater than 400 trees/ha, which are largely unaffected by the stocking. By age 8 the DBH is affected by all stockings.

Similar results were found in trials at Kelsia and Victor (Figure 2). At initial stockings from 417 to 833 the early growth was unaffected by stocking until after age 3, when mean DBH started to decline in stands with 555 and 833 trees per hectare compared to stand with 417. At age 4.3 years the DBH of stands stocked at 417 and those thinned from 833 to 417 were significantly greater than higher stocked stands. Stem diameters did not differ significantly in stands with 55 and 833 stems/ha at age 4.3 years.

When whitewood is established at stockings less than 400 trees/ha accelerated growth can be achieved after approximately age 3. For stands established at stockings between 417 to 833 trees/ha thinning after age 4 will significantly increase growth, however the pruning regime will be very important (see below). Once pruning has been undertaken thinning is needed to maximise the growth on the pruned trees. As with initial spacing, thinning can influence wood properties and tree shape by increasing branch size and increasing stem taper (Pinkard and Neilsen 2003).

Stem quality

Tree stem quality was found to be highly spatially variable (Table 3). 200 trees/ha is used as the lower end of an acceptable number to ensure full utilisation of the site. Of 23 plots with initial stocking of 417, 6 (25% of the trial) had less than 200 crop trees. When minor defect trees were included, all plots had sufficient trees, however while these trees are prunable, they will produce a lower quality log product. However, with an initial stocking of 833, all plots had over 200 crop trees.

High spatial variation in stem quality suggests that higher stocking may be need to be used to mitigate the risks of poor stem quality, particularly within a stand specifically managed for sawlogs. The markets for final and intermediate products will also have a bearing on the timing and economic incentives for activities like thinning and pruning. If a commercial thinning event is possible, then growers will be more likely to plant densely and undertake thinning (Viranamangga *et al.* 2012). The proportion of stems of a higher quality (crop trees) was not significantly different between the lower stocking at Kelsai and the higher stocking at Victors. Similar results were found in subtropical eucalypts (Smith and Brennan 2006), where the proportion of quality crop trees in the stand was consistent between stockings. The conclusion drawn was that high enough initial stocking and a pre-commercial thin should be used to increase stand quality, especially in unimproved genetic material. The comparison of the stand quality between thinned and unthinned stands at Victor showed there were no unmerchantable stems retained after thinning, however the proportion of minor defect trees remained comparable. This is due to the need to maintain spacing within the stand and therefore some trees with minor defect need to be retained.

The proportion of minor defect trees was significantly lower in the 8 × 3 m spacing at Kelsai. It seems unlikely the minor difference in rectangularity of spacing was causal. The main difference in management was the planting of gardens between the rows in the 8 × 3 m spacing block but not in the 6 × 4. Tending gardens around the planted trees does eliminate weed problems, especially merremia, which causes many form problems when vine stalks deform trees stems. It should be noted the measures were only on one site, there was considerable variation, and the stands had very small numbers of un-merchantable stems. The use of gardening also has other potential benefits for plantation systems in terms of establishment cost (Grant *et al.* 2012, Smith *et al.* 2012).

Canopy Development

While stand level stem form can be improved by selection, branch development is more influenced by the availability of light as a result of spacing (Alcorn *et al.* 2007). The production of large branches needs to be controlled by spacing and pruning as large branches are slower to occlude, are more difficult to prune and can result in large downgrade of timber quality.

Branching in whitewood was controlled by stocking with larger branches developing at lower stockings (Figure 4). There is also a consistent relationship between maximum branch diameter and DBH (Figure 3). If stocking is used to control branch diameter it will restrict DBH growth. This can be managed in two ways. Branches can be pruned before growth is effected and the stand then thinned, or stands can be allowed to develop with growth effected (reduced DBH increment) and thinned after self-pruning has occurred. The loss of growth before a clear bole has formed reduces the size of the defect core, making the log more valuable. The increased value must be evaluated against the slower growth and resulting longer time to attain a final crop.

Pruning

Canopy dynamics strongly influence the quality and quantity of wood produced (Montagu *et al.* 2003, Jagels 2006). The quantity of high quality wood produced can be increased through the manipulation of the canopy by pruning and thinning. Pruning branches restricts the proportion of branch related defect wood in the core of the stem and facilitates the production of clear wood with no reduction in growth rate, provided no more than 50 percent of the leaf area is removed (Montagu *et al.* 2003, Forrester *et al.* 2010). There is therefore a trade-off between pruning and loss of growth due to removal of leaf area.

The object of pruning is to minimise the diameter of the defect core which is determined by the diameter after all branches have occluded termed the diameter over occlusion. The whorled growth habit of whitewood will result in very large diameters over occlusion at lower whorls if branches are allowed to develop at low stockings. However young trees can have a large investment in leaf area on the first whorl if branches are allowed to develop. The distribution of leaf area will be important for the scheduling of pruning. If large proportion of leaf area is contained in the first whorl, pruning may reduce growth such that trees are affected by competition.

The optimal time to prune depends on the leaf area development of the stand. The LAI generally increases until neighbouring canopies meet and the canopy closes, following which the LAI reaches equilibrium or gradually declines (Beadle and Long 1985, Cromer *et al.* 1993). After canopy closure the lower canopy is shaded and eventually its leaves are unable to maintain a positive carbon balance. This results in leaf and branch death. Dead branches can lead to numerous defects, including knots, decay and in some eucalypts kino-trace defect (Wardlaw and Neilsen1999); however branches can occlude without defect in many other species (Smith *et al.* 2006, Evans and Turnbull 2004, O'Hara 2007). The timing of pruning will depend on the development of branches and if necessary stocking can be used to control branch development in whitewood.

More work is needed to determine the effect of various pruning regimes on growth in young trees and to devise pruning schedules that optimise growth and defect core diameter. Where whitewood is planted at low stockings pruning will be required.

Self-pruning

Whitewood is efficient at self-pruning (Thompson 2006, Viranamangga *et al.* 2012). Trees that received only minimal pruning and early tending had clear boles and harvestable and merchantable timber by age 15 harvest (Viranamangga *et al.* 2012). In some species lower canopy branches remain alive to a greater extent than others (Alcorn *et al.* 2007), and some species retain dead branches more than others (Evans and Turnbull 2004, Montagu *et al.* 2003). Whitewood branch death appears to be influenced by higher stocking (Figure 5) and smaller branches would be expected to occlude more rapidly than larger. Subtropical eucalypts exhibit a range of canopy dynamics (Alcorn *et al.* 2008), however for four species with a range of behaviours, dead branches occluded at the same rate whether they were pruned or not (Smith *et al.* 2006). The clear boles and observations indicate that whitewood branches will self-prune (Thompson 2006). There were also a number of large trees that had self-pruned (no branches on the lower stem) that were omitted from the branch size analysis. The important implication is that if the canopy can be forced to rise then self-pruning will occur more rapidly, minimising the diameter of the defect core (Smith *et al.* 2010). The canopy behaviour of whitewood will determine the optimum management regime, although the difference in log quality between pruned and unpruned trees is as yet unclear.

Thinning

If higher stocking is used for many of the reasons discussed above, then it will be necessary to thin the stand. Thinning will be a particularly important part of many silvicultural regimes designed to produce sawlogs in the shortest possible time (West 2006). Thinning generally aims to remove the less valuable trees and redistribute the site resources to the most valuable crop trees in a stand to increase value rather than volume (Long *et al.* 2004, Cassidy *et al.* 2012). In the non-commercially thinned site at Victors, by age four, the retained trees had increased diameter growth comparable to plots planted at low initial stocking at Kelsai (Figure 2). The value of higher stocking and a non-commerical thin needs to be evaluated based on the reduced risks and increased stand quality compared to lower stocking.

As happened at Victors, thinning often results in increased individual tree size. Thus the aim of an optimal thinning regime is to balance the need for individual growth and therefore stand value, whilst not under-utilising the site resources, reducing wood quality or foregoing volume production (Smith and Brennan 2006). However, productivity and value of thinned and pruned stands may vary greatly depending on the age and intensity of thinning and the conditions of the site (Medhurst *et al.* 2001).

Costs and the absence of markets for thinnings are disincentives for thinning (Evans and Turnbull 2004, Smith and Brennan 2006), even though lack of thinning in fast-growing plantations leads to lower individual tree growth and therefore plantation value (Medhurst *et al.* 2001, Cassidy *et al.* 2012). Thinning costs need to be justified by the higher value product mix at the end of a shorter rotation returning a significantly higher net value (Nolan *et al.* 2005).

An optimal thinning regime in whitewood will depend on markets for thinning and for final products. Both of these are not known, although markets for natural forest whitewood do exist (Viranamangga *et al.* 2012). Market uncertainty is not uncommon in solid wood sawlog regimes due to the long time frames (Smith and Brennan 2006, Kanninen *et al.* 2004), however large high quality pruned logs offer the greatest flexibility in terms of products and the lowest conversion costs for processors, and therefore higher returns and least market risk for growers (Montagu *et al.* 2003, Donnelly *et al.* 2003). In the absence of a market for small roundwood, a non-commerical thinning will return greater value at the end of rotation, removing low quality and low value trees, reallocating site resources to higher quality pruned trees and therefore bringing forward final harvest. It is possible to produce high quality logs using several different stand management regimes which may suit different grower situations such as agroforestry or industrial-scale plantings. The important factor is the supply of resource of consistent quality.

CONCLUSIONS

Spacing in whitewood plantations will influence growth and canopy characteristics that are crucial in solid wood production. Our results show higher stocking (closer initial spacing) results in:

- less rapid early diameter growth;
- greater availability of sufficient high quality trees for pruning and intermediate thinning crops;
- restricted branch growth, increasing the time available for pruning and therefore minimising branch related defects.

Lower stocking (wider initial spacing) results in:

- maximises individual tree diameter growth and therefore log size and value, minimising the time to thinning and final harvest;
- larger branches and longer holding of live branches lower on the stem,
- reduced planting costs.

Maximum and average branch diameter and the number of live branches were all negatively correlated with stocking. Therefore, if whitewood is grown at lower stockings, such as in agro-forestry systems, special care must be taken to ensure timely pruning is undertaken to prevent large branches developing. The number of trees with acceptable stem quality for pruning was positively correlated to stocking but was highly variable between plots. If whitewood is planted at higher stockings, to maximise the production of high quality products and ensure full utilisation of the site, thinning will be required. If planted at low stockings, pruning will be required in the first three years to reduce the presence of large branches in the merchantable part of the stem.

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Silvicultural implications arising from a simple simulation model for *Endospermum medullosum* in Vanuatu

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SUMMARY

Whitewood (*Endospermum medullosum*) is a tree species that shows promise for plantation timber production in Vanuatu, but few growth data are available to inform yield forecasts. Three simple relationships summarizing stand dynamics, namely height-age, diameter-height-stocking, and mortality-basal area relationships, were calibrated with data from 15 plots to form the basis of a model for silvicultural and management decisions. Despite the simplicity of the model, it offers predictions consistent with independent data. The model suggests that the optimal silviculture involves planting 635 stems/ha, thinning at 20 and 26 years, and clearfelling at age 36 when trees have a diameter of 55 cm dbh. However, many options offer a net present value within 5% of this nominal optimum. The flexibility to vary the timing and intensity of harvests over a wide range while maintaining good financial returns, coupled with good growth and timber properties, suggests that whitewood warrants further domestication and promotion in Vanuatu.

Keywords: Whitewood, Endospermum medullosum, growth model, yield forecast, silviculture, simulation

Implications à dimensions sylviculturelles émanant d'un simple modèle de simulation pour l'Endospermum medullosum à Vanuatu

J.G. GRANT, K. GLENCROSS, J.D. NICHOLS, G. PALMER, M. SETHY et J.K. VANCLAY

Le bois blanc (*Endospermum medullosum*) est une essence d'arbre prometteuse pour la production de bois de coupe en plantations à Vanuatu, mais peu de données de croissance sont disponibles pour informer les prédictions de production. Trois relations simples, synthétisant la dynamique des plants: âge et hauteur, la relation diamètre/hauteur, et les relations entre la mortalité et la base, ont été calibrées avec des données provenant de 15 plants, pour former la base d'un modèle destiné à informer les décisions de sylviculture et de gestion. Malgré la simplicité du modèle, ce dernier offre des prédictions confirmées par des données indépendantes. Le modèle suggère qu'une sylviculture optimale comprendrait la plantation de 635 individus par ha, un élagage à 20 et 26 ans, et une coupe à 36 ans, quand les arbres auraient atteint un diamètre de 55 cm dbh. Toutefois, plusieurs options présentent une valeur actuelle nette dans une marge à 5% de cet optimum nominal. La flexibilité de varier le moment et l'intensité des récoltes sur une grande surface, tout en préservant des bénéfices financiers appréciables, ainsi qu'une croissance solide et des propriétés du bois maintenues,suggèrent que le bois blanc mérite une domestication et une promotion plus poussées à Vanuatu.

Implicaciones silvícolas resultantes de un modelo de simulación simple para *Endospermum medullosum* en Vanuatu

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Madera blanca *(Endospermum medullosum)* es una especie arbórea prometedora en Vanuatu para la producción de madera en plantaciones, pero hasta la fecha son pocos los datos de crecimiento disponibles como para poder hacer pronósticos sobre el rendimiento. Se calibraron tres relaciones simples que resumen la dinámica de un rodal, como son las relaciones entre altura-edad, diámetro-altura-existencias, y mortalidad-área basal, por medio de datos de 15 parcelas, los cuales constituirían la base de un modelo de decisiones silviculturales y de gestión. A pesar de su simplicidad, el modelo ofrece predicciones compatibles con datos independientes. El modelo sugiere que la silvicultura óptima consiste en la plantación de 635 árboles/ha, la realización de raleos a los 20 y 26 años, y una tala rasa a los 36 años, cuando los árboles han alcanzado un DAP de 55 cm. Sin embargo, son muchas las opciones que ofrecen un valor actual neto dentro del 5% de este óptimo nominal. Esta flexibilidad de poder variar el turno y la intensidad de las talas dentro de un amplio intervalo, manteniendo a la vez un excelente rendimiento financieros, junto con un aceptable crecimiento y unas buenas propiedades de la madera, sugiere que madera blanca merece ser domesticada y fomentada en Vanuatu.

INTRODUCTION

One of the challenges in domesticating a tree species is the provision of reliable estimates of growth and commercial utility (Nichols and Vanclay 2012). Objective forecasts require a growth model, but most modelling approaches are demanding of data (Vanclay 1991, Weiskittel 2011). However, Vanclay (2010) has recently proposed an approach that allows objective forecasts with minimal data. The innovation in this approach was to identify three robust uni-variate relationships that can be extrapolated safely and can be calibrated with modest amounts of data that are easily obtainable. These relationships include height-age, height-diameter (Vanclay 2009a) and self-thinning relationships (Vanclay and Sands 2009) that describe the major dynamics of young plantations, and are consistent with information routinely gathered for plantation management and monitoring. This paper seeks to demonstrate the approach with whitewood (*Endospermum medullosum*) plantings on the island of Espiritu Santo in Vanuatu (Thomson 2006), and to explore the implications arising from the model for the future management of whitewood plantings in the south west Pacific region.

The Government of Vanuatu adopted a National Forest Policy in 1998 (Department of Forests 1999) that aimed to establish 20,000ha of plantation, but the implementation of this has progressed slowly (Aru *et al.* 2012). Whitewood was identified as having good plantation potential, with fast growth and advantageous wood properties (Thomson and Uwamariya 2003, Thomson 2006, Tungun 2002, Viranamangga *et al*. 2012). Relatively detailed soil and resource mapping had been carried out and is available on a spatial database (Bellamy 1993, Quantin 1982). This information was used to stratify the existing plantations and select a subset representative of the geographic range, soil type, age class, silviculture and general health of the plantations (Grant *et al.* 2012). This subset of sites was investigated for the establishment of growth plots and twenty eight circular 0.05 ha plots (22.6 m radius) were established within these plantations during 2007/2008 and regularly remeasured. Eleven of these 28 plots have incomplete details regarding planting date and silviculture, and two are mixed-species plots, so the remaining 15 plots formed the basis for model development.

COMPONENTS OF THE MODEL

The simulation model is based on a published model (Vanclay 2010) and comprises three key components: a growth model to predict stand dynamics; several mensurational relationships to infer total and merchantable volume, and some financial tools to allow basic economic analyses.

Stand dynamics

The growth model relies on three equations that estimate height (H, equation 1), diameter (D, 2), and self-thinning relationships (3):

$$H = \beta_1 (t-0.5)^{0.5} \qquad [1]$$

$$D = \beta_2 (H-1.3)/\ln N \qquad [2]$$

$$dN/N = -2(G/G_{max})^3 dD/D \qquad [3]$$

where t is age (years), H is top height (m), N is stocking (stems/ha), D is diameter (mean dbh over bark, cm), G is the observed stand basal area (m^2/ha), and G_{max} is the maximum carrying capacity of the site (m^2/ha). Equation 1 estimates top height from the time since planting, using a simple uni-variate relationship (Vanclay 2010). There are many other more flexible equations, but Zeide's (1993) comprehensive analysis led him to conclude that the top height growth trajectory is inherently imprecise and should be viewed as a broad alley rather than a single line. Zeide (1993) clearly favoured a few two-parameter equations, all of which preserved one common feature: that growth expansion is proportional to the current size of a tree, a feature of equation 1. Whilst these two-parameter equations are superior when sufficient calibration data are available, they have limited utility in the early stages of domestication when few growth data are available. Equation 1 offers a first approximation that allows objective and defensible growth predictions to be made with very few calibration data (Vanclay 2010).

Equation 2 establishes the relationship between mean tree size and stand density, and predicts stand mean diameter from top height and stocking. Extensive empirical testing has demonstrated that this relationship remains stable over long periods for even-aged stands, across a wide range of species and sites (Vanclay 2009a).

Equation 3 predicts the expected reduction in stocking likely to be observed per unit of diameter increment, given the estimates carrying capacity of the site (i.e., maximum attainable stand basal area; Vanclay and Sands 2009). This equation is derived from successive differences of self-thinning trajectory as stands approach the self-thinning frontier (Reineke 1933, Yoda 1963), and the coefficient of –2 implies the existence of a limiting basal area (Vanclay and Sands 2009), a concept widely applied in growth models (e.g., Skovsgaard and Vanclay 2008). This relationship implies that as a stand approaches the limiting density, any diameter growth will be matched by a corresponding reduction in stocking, and that this mortality increases with the cube of the basal area. Thus it predicts negligible mortality at low basal areas, with mortality rates increasing so that stand density can never greatly exceed the specified maximum basal area.

These three relationships are of interest because they are robust in data-poor situations, are easy to calibrate, and are safe to extrapolate, but it is emphasised that these offer reliable approximations rather than the precise estimates obtainable from more sophisticated site-specific models. Each of these three relationships relies on a single estimated parameter, a design feature that aligns with biology, and that confers robustness despite limited data. These relationships account for the main plant dynamics that occur within monospecific plantings, and rely on stand-level data that are routinely gathered for forest monitoring and management.

Mensurational and financial aspects

Key mensurational relationships are derived from published literature. West (2004, p.42) offered a generic equation to estimate total under-bark stem volume:

$$V_u = 0.281\ (D/100)^{1.91}\ H^{1.02} \qquad [4]$$

where V_u is total stem volume (m^3, under bark), D is stem diameter (cm dbh over bark), and H is tree height (m). Total stem volume is significantly more than sawlog portion, so it is appropriate to apply a reduction to adjust for the prevailing utilization standards. Shiver and Brister (1992) offered a convenient equation to estimate stem volume to a nominated utilization limit:

$$V_d = V_u\ (1 – d^{3.4138} D^{–3.3125}) \qquad [5]$$

where V_d is the volume to a nominated merchantable diameter limit d (cm, under bark).

Financial analyses and optimization studies require estimates of the sawlog values. Such data are often difficult to obtain, and are locally specific as they depend on species, infrastructure and local markets. In the absence of real data, estimates of intrinsic value may indicate the relative utility of sawlog material of different dimensions. Sutton's (1973) review of price-size gradients revealed large differences in prices, but revealed that an inverse relationship often exists between size and stumpage value, a pattern also evident in other studies (Vanclay 1985). Thus the intrinsic value of whitewood logs is estimated as

$$Val = \beta_3 + \beta_4/D \qquad [6]$$

where *Val* is the intrinsic log value ($/$m^3$).

CALIBRATING THE MODEL: DATA AND METHODS

The growth model was calibrated using the 15 plots established in Santo during 1994–2004, and remeasured on three or four occasions during 2008–2011. Table 1 offers a brief overview of the scope of these plots, whilst a more complete listing is provided in Table 2. Table 1 summarises the means and ranges of all measures, whereas Table 2 reports particular measures, and thus the means may differ between these two tables. Top height was estimated as the mean of the tallest two trees within the 0.05 ha plot, except in a few instances where the largest measurement appeared to be in error and the 2nd and 3rd tallest trees were used to derive top height. Stocking refers to all species on any plot, but unless otherwise indicated, mean diameters refer only to whitewood trees. The soils in these plots have been described by Grant *et al.* (2012).

TABLE 1 *Summary of data available for model calibration*

Variable	Min	Mean	Max
Age (years)	4	12	18
Initial Stocking† (N/ha)	167	594	2500
Top height (m)	8	20	26
Diameter (cm dbh)	12	29	46
Basal area (m^2/ha)	4	27	50

† Initial stocking based on nominal spacing between trees, not on trees/plot.

Most plots used in the analysis are pure whitewood, but a few plots contain some fruit trees. For instance, in plot 17, two out of 19 trees are smaller fruit trees, and in plot 25, three out of 25 trees are smaller fruit trees, but because of the young age (<14 years) and wide spacing (5 × 5 m), the consequences for whitewood growth is assumed to be minimal. In Plot 13, every 6th tree is a Natangura (*Metroxylon warburgii*, a palm sometimes used for 'vegetable ivory'), and the initial stocking is high enough (2500 stems/ha) that competition is inevitable, but the fruit trees are of comparable size (whitewood 26.9, fruit trees 25.2 cm dbh in 2008) so whitewood growth trends should remain indicative. Where plots contain other species, the stockings and basal areas report all trees, but mean diameters and top heights are based on whitewood trees only.

Although these data span a reasonable range of conditions (Table 1), they represent a modest database for constructing models, encompass a range much smaller than the norm (Vanclay *et al.* 1995), and lack designed experiments that enable efficient calibration of density-dependent responses (Vanclay 2006). In particular, the calibration data includes only one plot that had been thinned during monitoring (horizontal line in Figure 1), and few plots with natural mortality (diagonal lines in Figure 1). Thus this simulation model should be viewed as an indicative first approximation rather than a definitive and durable model. Nonetheless, simple models such as this have an important role to inform stakeholders and assist planning.

These data were used to fit Equations 1 and 2, and parameter estimates are presented in Table 3. Figure 2 illustrates the fitted equation $H=5.3(age–0.5)^{0.5}$ along with the calibration data on which it is based. The standard errors reported in Table 3 recognise that remeasures are not independent, and represent standard errors derived from the 15 plot values rather than from the 51 remeasures. Similarly, the confidence intervals reported in Table 3 represent that 2nd largest and 2nd smallest plot trends, and are thus non-parametric 75% confidence intervals. Probability theory suggests that 15 plots should partition the range of possible scenarios into 16, and the expectation is that about 2/16ths of possible scenarios would be greater than the 2nd greatest value, and that about 12/16ths or 75% of possible scenarios would occur between the 2nd greatest and 2nd smallest values. Whilst 75% confidence intervals are a little unconventional (the norm being 95%), they nonetheless serve as useful indicators of the utility of estimates presented in Table 3.

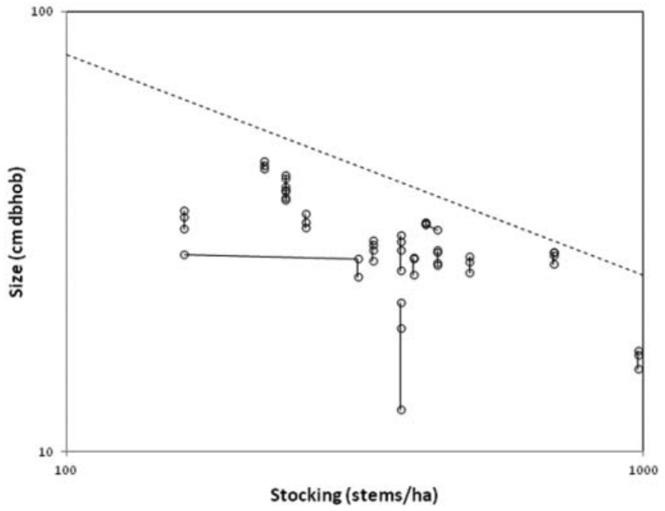
In Figure 2, four plots (apparently with highest and lowest site index) have been plotted with distinct symbols (+plots 3 and 17, × plots 5 and 6). Dashed lines indicate the same relationship fitted independently to the plots with the second greatest and second smallest values, and serve as non-parametric 75% confidence intervals. These apparent site differences are rather small, and may simply reflect natural variation and sampling errors.

TABLE 2 *Summary of selected plot data*

Plot No	Year planted	Spacing (m)	Nominal initial stocking	No of trees in plot 2008		Whitewood mean dbh (cm)		Top height 2010	Basal area 2010	Eqn 1 β_1	Eqn 2 β_2
				All	Whitewood	2008	2010				
1	1994	5 × 5	400	23	22	32	33	22	36	5.5	9.7
3	1998	8 × 3	417	22	22	26	28	25	30	6.7	7.7
4	1998	8 × 3	417	20	20	25	28	19	24	5.2	9.7
5	1995	5 × 5	400	13	13	32	35	20	25	5.1	10.3
6	2001	3 × 3	1111	50	49	15	17	16	23	5.0	8.7
7	2004	3 × 4	833	18	18	12	22	16	14	5.8	9.1
12	1995	5 × 5	400	13	12	34	37	24	26	5.8	9.7
13	1993	2 × 2	2500	42	35	27	29	26	50	6.0	8.3
14	1996	4 × 4	625	20	19	27	31	23	29	6.0	8.7
17	1998	5 × 5	400	19	17	29	31	24	27	6.8	8.4
22	1998	6 × 2	833	16	16	25	28	21	10	5.5	9.9
24	1993	6 × 10	167	12	12	37	39	23	29	5.3	10.7
25	1997	5 × 5	400	25	22	27	29	22	33	5.8	9.0
26	1998	5 × 10	200	8	8	32	35	20	16	5.4	9.7
27	1995	10 × 5	200	13	11	44	46	23	37	5.9	11.6
Average		4 × 4	620	21	20	26	29	22	27	5.7	9.4

Figure 3 illustrates the diameter growth pattern with respect to age (left), and with respect to the height-stocking index documented by Vanclay (2009a, right). The parameter 9.3 obtained from calibrating this relationship is the same as that of Queensland rainforest timber species *Flindersia brayleyana* (Vanclay 2009a), which has several ecological characteristics similar to whitewood. Several individual plot trajectories exhibit a slope less than the general trend D = 9.3(H–1.3)/Ln(N), and growth plots should be maintained so that these trajectories can be monitored. Four plots are marked with distinct symbols (+, ×), with plots 24 and 27 (shown as +) and plots 3 and 13 (shown as ×). Some of these differences appear density related, as plots 24 and 27 are amongst the lowest stocking (160 – 200 stems/ha) whereas plot 13 had a high initial stocking (2500 stems/ha) and heavy thinning.

FIGURE 1 *Size-density diagram illustrates the range of data available for model calibration. The dashed line indicates the assumed limiting basal area Gmax=50 m²/ha (Table 3)*

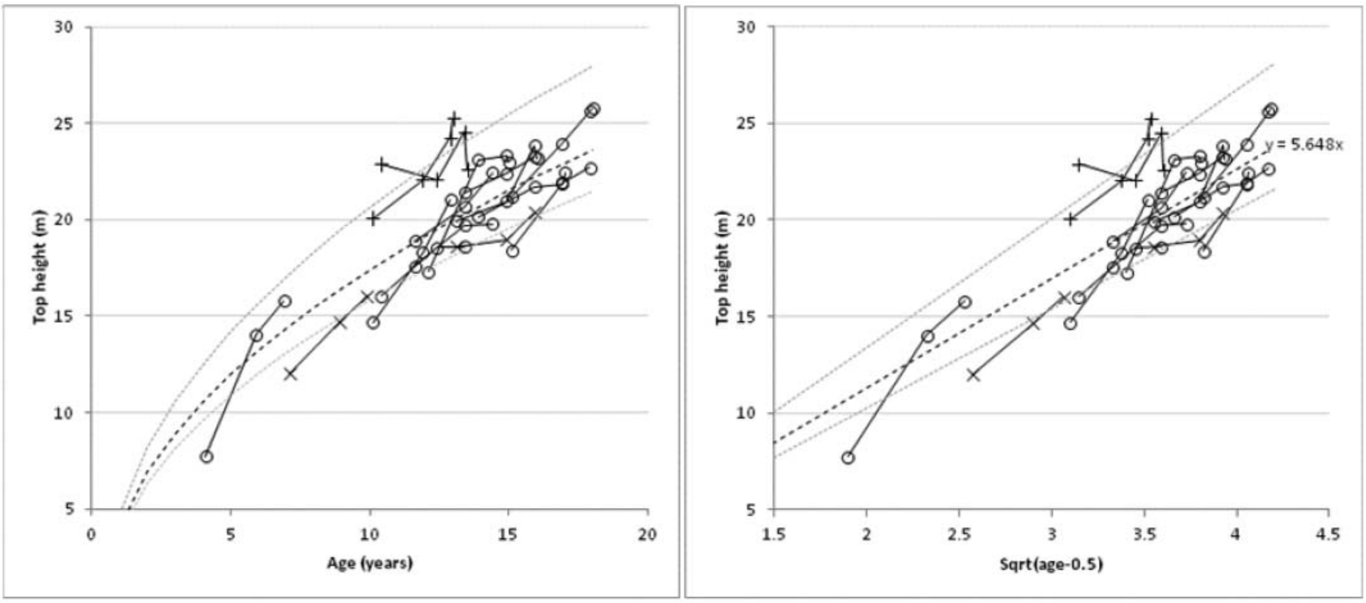


In Figure 3, Plot 27 (top right, shown as +) appears particularly anomalous, and there are several plausible explanations. Its large diameters (Table 2) may have formed buttresses, the plot area may be incorrect (with 13 trees when 10 are expected, given the nominal spacing), or the two smaller trees of non-target species (*Hernandia moerenhoutinana* and *Pometia pinnata*) may not compete (and hence could be omitted from the stocking count) – any of these explanations would move these points closer to the general trend. However, the most likely explanation is errors in height

TABLE 3 *Parameter estimates for growth equations (Equations 1–3)*

Equation	Parameter	Estimate	Standard error	Non-parametric 75% confidence interval
1	β_1	5.6	0.52	5.1, 6.7
2	β_2	9.3	1.00	8.3, 10.6
3	G_{max}	50		
6	β_3	100		
6	β_4	1500		

FIGURE 2 *Height growth patterns showing trends for the mean (dashed line) and extreme plots (dotted lines)*



measurements, as the height estimates for this plot are particularly variable, both within the plot, and from measure to measure. This plot 27 has been omitted from the calculation of β_2 as 9.3.

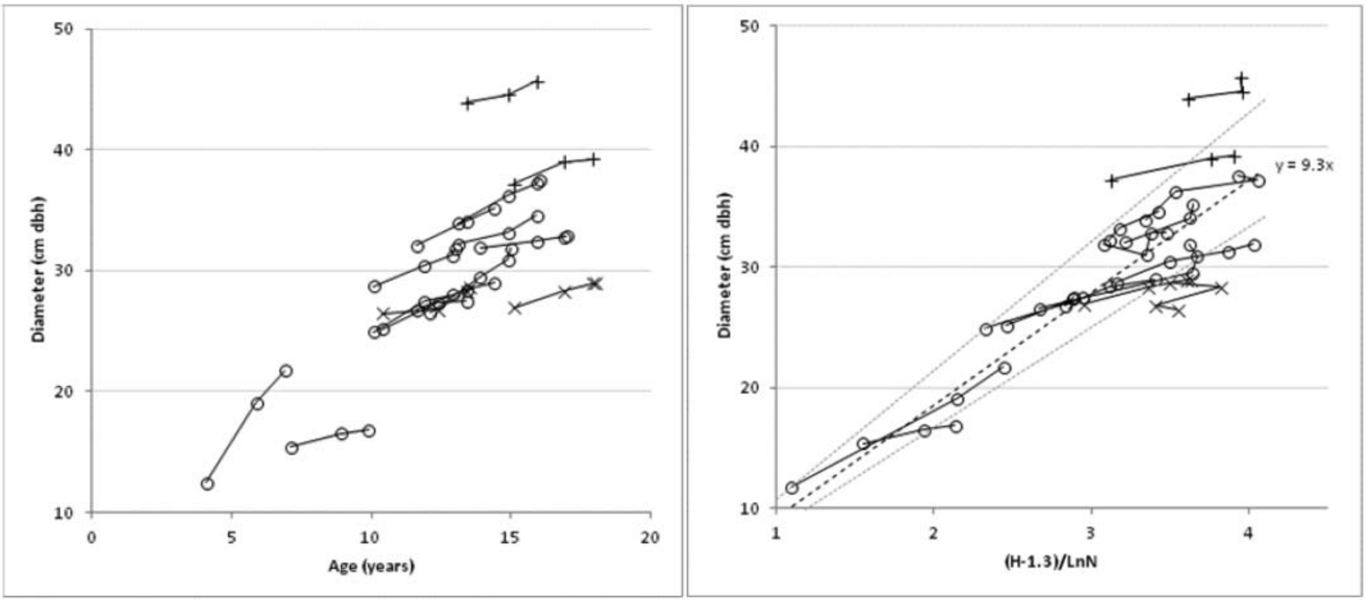
Data observed in plantations in Vanuatu are uninformative about the maximum basal area required for Equation 3, so estimates have been derived from other sources. Data published for whitewood in comparable locations (Jaffre and Veillon 1995, Keppel *et al.* 2010) suggest that 50 m^2/ha is a reasonable estimate of maximum basal area, a value that is consistent with that observed in other tropical hardwood plantations (e.g., Perez and Kanninen 2005). Figure 1 illustrates that all existing plot data in Vanuatu remain well below this assumed maximum basal area.

Similarly, it has proved impossible to gather reliable local data to inform calibration of equation 6, but anecdotal data suggest that the simple relationship Val=100–1500/D seems to apply in Santo, and assigns nil value to stems less than 15 cm diameter, \$50/m^3 to a stem of 30 cm diameter, and \$80/m^3 to a stem of 75 cm diameter.

TESTING THE MODEL

Although whitewood has been viewed as a research priority for some time (Siwatibau and Boland 2002), there are few independent data with which to test the model. Ngoro (1988) reported that plantings in the Solomon Islands attain 30 m

Figure 3 *Diameter growth patterns*



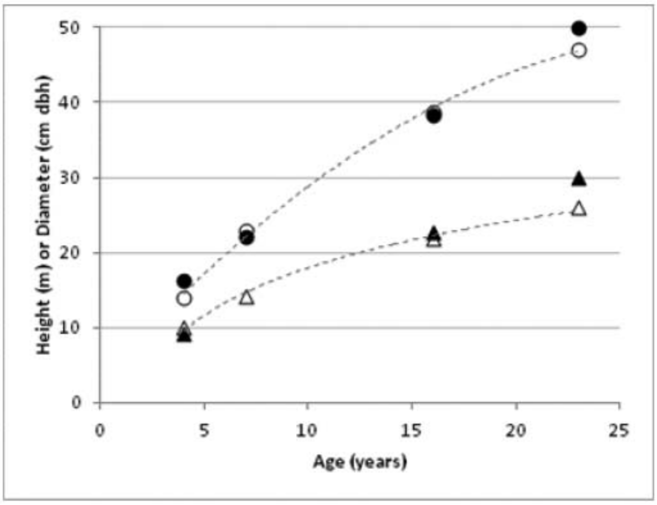
height and 50 cm diameter in 23 years, comparable to that expected in agroforestry situations in Vanuatu (with 190 stems/ha, the model predicts 27 m height and 46 cm dbh at age 23). Burslem and Whitmore (1996) record 2.7% mortality amongst stems over 10 cm dbh (excluding cyclone damage), similar to that predicted by the model for stands and stands with basal area approaching 40 m^2/ha. Marten (1972) reported that 6.6 year old plantations at Guadalcanal attained 22 cm dbh, the same as that of model predictions with 208 stems/ha (Table 4).

In Santo, Vutilolo *et al.* (2005) reported that the plantings of the East Coast Santo provenance attained a height of 9.2 m and a diameter of 16.3 cm dbh (range 16.1–16.8) in 4 year old trials planted with 833 stems/ha and reduced to an average of 633 stems/ha through natural mortality. This contrasts with model predictions of 10.4 m height and 14 cm dbh at age 4 with 633 stems/ha. A 2010 remeasure of 16 year old trial plantings at Lorum indicated a top height of 23 m, a mean diameter of 38 cm dbh, and a stocking of 190 stems/ha (Glencross, pers. comm.). This compares closely with simulations which suggest 22 m height and 39 cm diameter at age 16 (Figure 4).

IMPLICATIONS ARISING FROM THE MODEL

The model requires some financial data to offer useful silvicultural guidance, as the basic mensurational relationships do not offer a useful basis for optimization (Figure 5). Without financial data, the model tends to favour high initial stockings for what is essentially firewood production (Figure 5), and disregards the high natural mortality and small stem sizes that result when stocking exceeds 1000 stems/ha. To obtain more realistic guidance, it is necessary to introduce the possibility of a thinning, to recognise financial aspects of production, and to optimise for value rather than volume production (i.e., NPV rather than MAI). Hence to obtain useful insights from the model, it is necessary to discount future production, to assign a cost to each seedling, recognise annual maintenance costs (e.g., annual lease payments), and to deal with the intrinsic size-dependent value of the sawlogs harvested.

FIGURE 4 *Observed (% [black triangles]) and predicted heights (+ [white triangles]) and diameters (#,) [circles])*



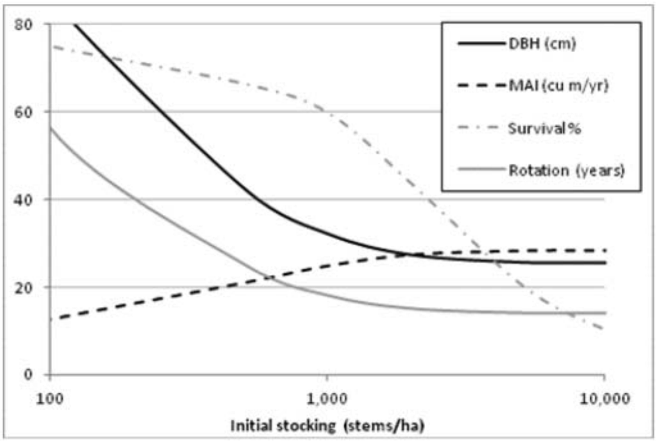
Given the assumed intrinsic value (Equation 6), a utilization limit of 15 cm small end diameter, an establishment cost of $165/ha plus $4.40/tree, plus a pruning cost of $0.90/tree, an annual maintenance cost of $5/year (Glencross, pers comm.), and a discount rate of 5%, the model predicts an optimal silvicultural regime with an initial stocking of 635 stems/ha, two thinnings at age 20 and 26 years, and a clearfall at age 36 yielding 134 stems at 55 cm dbh. However, the optimum is a broad plateau, with a wide range of conditions (e.g., initial stocking ±30%) that offer returns within 5% of the optimum (Table 5).

This regime would harvest 160 trees at 25 cm dbh after 20 years, 141 trees at 29 cm dbh at age 26, and clearfell 133 trees at 55 cm dbh at age 36. In total, 434 stems would be harvested, with about a third of the 635 planted stems lost to mortality. This estimated mortality is strongly dependent on the calibration of the model which assumes a maximum basal area of 50 m^2/ha based on literature (Jaffre and Veillon 1995, Keppel *et al.* 2010). This may be a conservative estimate, but any higher value would improve the prognosis presented in Table 5.

TABLE 4 *Independent observed data contrasted with model predictions*

		Attribute			Difference	
Source	**Age**	**Stem/ha**	**Height**	**Dbh**	**Height**	**Dbh**
Vutilolo *et al.* (2005)	4	633	9	16		
predicted	4	633	11	13	–15%	18%
Marten (1972)	7	?	?	22		
predicted	7	250	14	22	?	0%
Lorum trials	16	190	23	38		
predicted	16	190	22	37	3%	3%
Ngoro (1988)	23	?	30	50		
predicted	23	190	27	46	10%	8%
Average difference					–6%	7%

FIGURE 5 *Effect of initial stocking on production, assuming no thinning*



This regime is close to those recommended by Thomson (2006) who advocated planting 666–800 stems/ha, with a view to a final crop of 150–250 stems. He also observed that mature specimens commonly exhibit diameters of 50–80 cm dbh, and occasionally attain sizes exceeding 1 metre diameter above buttresses. Thomson also anticipated a mean annual increment (MAI) of 20–30 m^3/ha/yr, consistent with model projections. The prognosis in Table 5 more promising than that foreshadowed by Bartlett (2012), who envisaged an MAI of 19 m3/ha/yr with a 17 year rotation.

Some landholders have expressed a preference for lower stockings (Thomson 2006), with initial stockings of 200 (8× 6 m) to 400 (5×5 m) stems/ha being suggested, so these deserve examination. Table 6 examines a near-optimal single-thinning rotation with these two alternatives. It also examines the theoretical optimal direct regime without thinning.

Table 6 illustrates that the stocking reductions in the wide-spaced options are partially offset by greater growth, but that there remains a net reduction in mean annual increment and in value produced (NPV). However, these reductions in timber productions may be offset by other opportunities, such as better pasture for livestock, or for agroforestry opportunities.

TABLE 5 *Apparent optimal regime based on simulations*

Activity	**Year**	**Optimum**	**Range within 5% of optimum NPV**
Plant	0	635	430–900 stems/ha
First Thin	20	33%	Year 15–25; 10–60% removal
2nd Thin	26	50%	Year 21–33; 7–80% removal
Harvest	36	clearfall	Year 28–45
NPV	36	$8,472	>$8,053
DBH at harvest	36	55	
MAI	36	23	

TABLE 6 *Examination of wide-spacing options*

Attribute	**Wide-spacing regimes**			**Direct regime**
Initial stocking (stems/ha)	606	400	208	440
Age of first thinning	21	24	27	-
Stems removed	53%	51%	45%	-
Age of clearfell (years)	33	34	35	27
NPV ($/ha)	8257	7949	6586	7280
Dbh at maturity (cm)	51	54	59	45
Stocking at final harvest	182	145	100	293
MAI (m^3/ha/ann)	22	20	16	20

The model presented here deals only with mean diameters, and does not account for the natural variation in stem size. With suitable data for calibration, accounting for such variation is a relatively simple enhancement (Vanclay 2009b), but would not be expected to alter conclusions substantially.

Whilst this is model is based on a robust approach (Vanclay 2009a,b 2010; Vanclay and Sands 2009), it is based on a small number of plots, monitored for a relatively short interval, so these results should be interpreted cautiously. Although model results are consistent with observed data, model predictions represent a considerable extrapolation. The logical approach is to maintain a modest monitoring effort, and to revise the model when a significant departure from predictions is observed (Vanclay 1991). Such a revision may involve development of a more sophisticated model built on the more extensive data that should then be available.

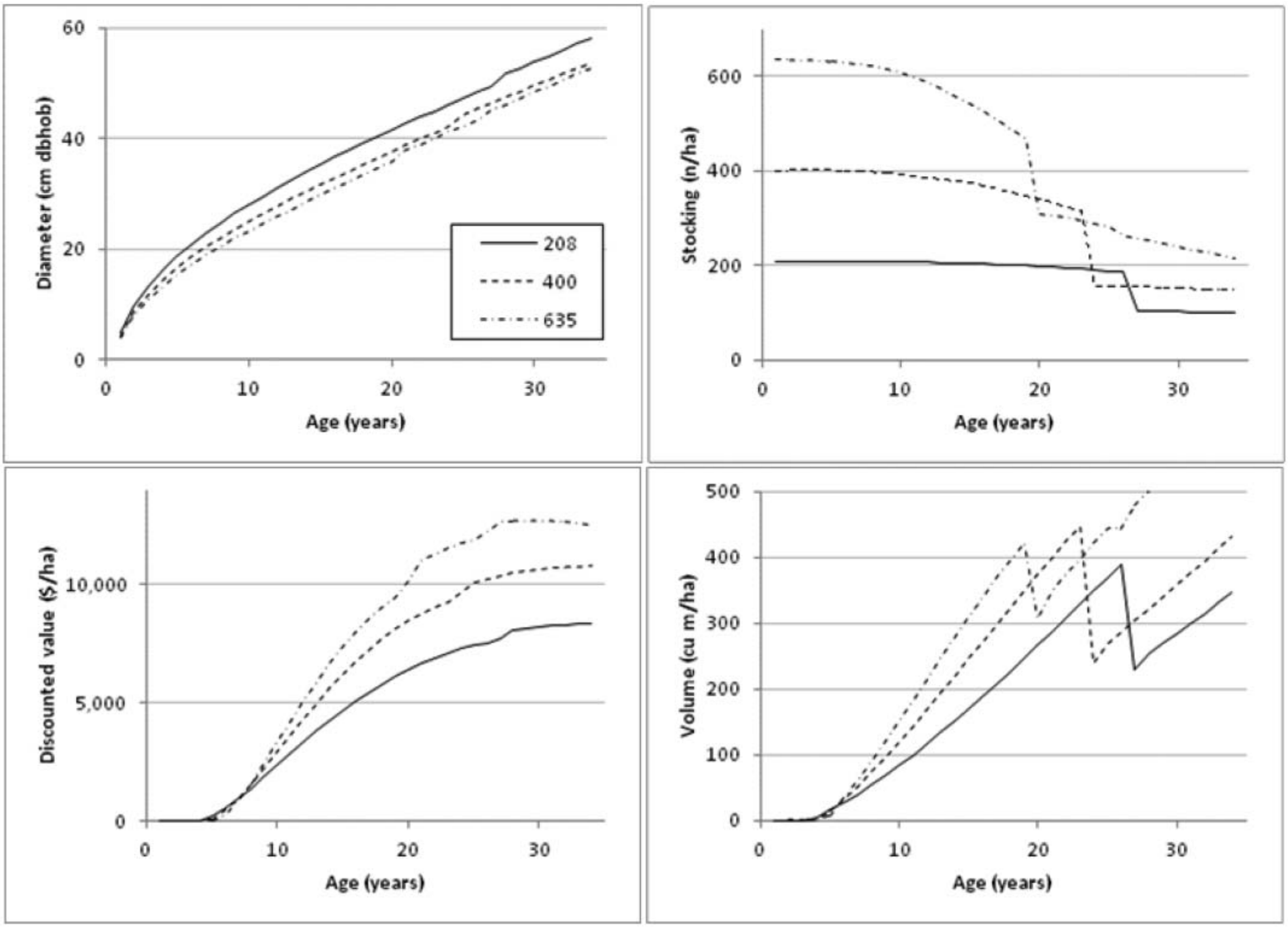
The model also takes no account of site productivity (Skovsgaard and Vanclay 2008), despite clear indications of site differences (Figure 2). Although it is a relatively simple matter to incorporate site index in the model, it may not be easy to determine site index in the field prior to planting. In many cases, soil properties offer a good guide to site productivity (e.g., Grant *et al.* 2010), but soils amenable to plantation forestry in Santo are rather uniform (Grant *et al.* 2012). Plant functional attributes (Vanclay *et al.* 1997) of associated vegetation may offer some insights into likely site productivity.

USING THE MODEL

The model is available from the authors as an Excel spreadsheet (Figure 7). In Figure 7, the left pane reports the simulated data, and the right pane includes the model parameters (top right, shaded grey, password protected), utilisation and financial data (such as small end diameter and establishment costs), silvicultural data (such as initial number of plants and age of thinning), and a summary of simulation results (bottom right, shaded grey). The parameters in the 'silviculture' pane may be set by the user, or determined automatically using Excel's solver (as in the case of Figure 7).

Data displayed in the left pane is self-explanatory, and clearly labelled.

FIGURE 6 *Different stockings (top right) lead to relatively small differences in stem diameter (top left), larger differences in stand volume (bottom right) and large differences in discounted value (bottom left, excluding costs)*



The model also displays a graph of selected key data (Figure 8), and it is a simple matter for users to use Excel's capability to create additional graphs. Figure 8 illustrates the stocking, diameter, basal area and stand volume predicted with the optimal silvicultural regime (Table 5).

Figure 8 triggers a question about the diameter growth trajectory. There are few studies on long-term growth of this species, but amongst the scant publications are some observations that the "high growth rates of young trees is not maintained" (e.g., Burslem and Whitmore 1996). However, this species is generally classified as a "long-lived pioneer" (Whitmore 1975, Leps *et al.* 2001), such species often exhibit strong diameter increment until a sudden death (Metcalf *et al.* 2009), and attain large diameters (Sheil *et al.* 2006, Thomson 2006), so the trajectory illustrated in Figure 8 seems plausible.

PATHWAYS FOR IMPROVEMENT

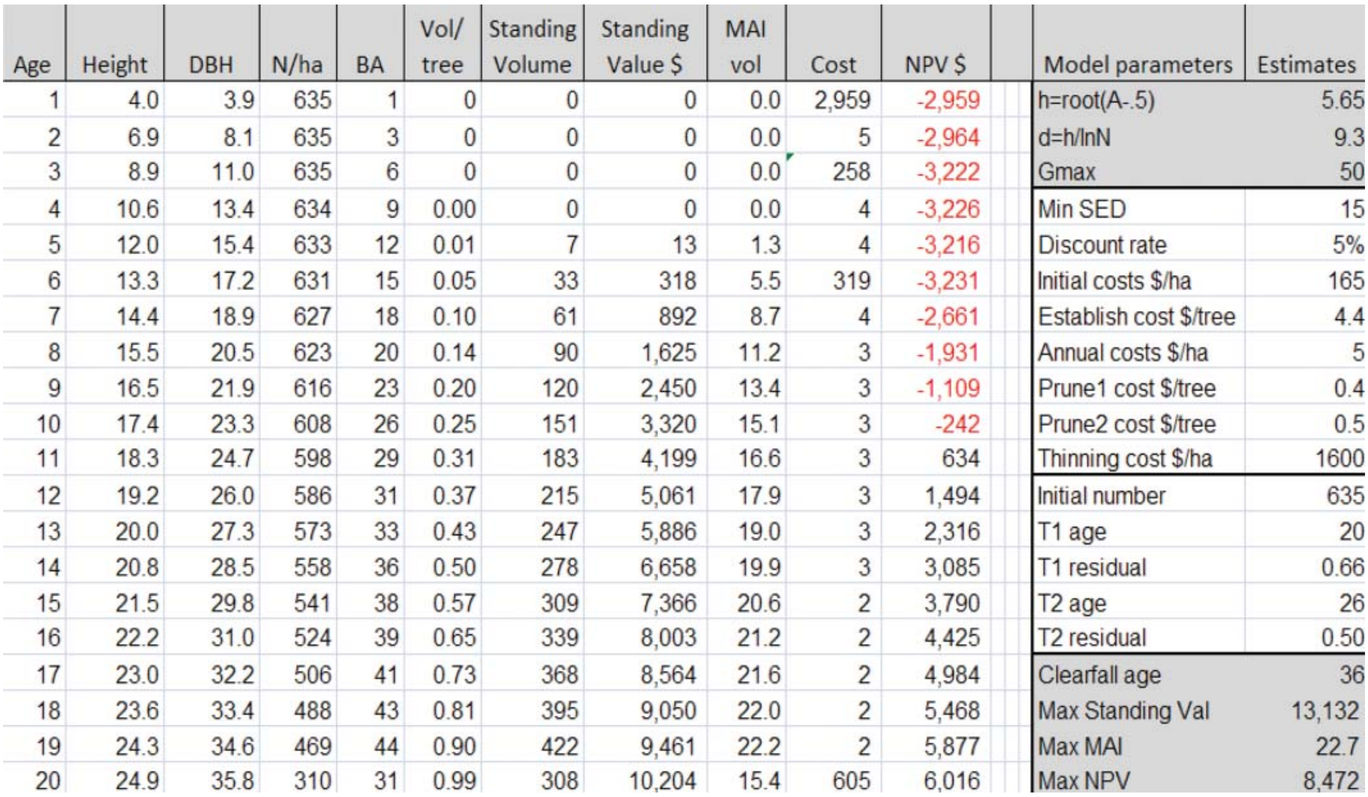
Domestication of Whitewood

There is a temptation for many specialists to fine-tune parameters and techniques within their own domain of expertise, and while there are many important improvements that can be made along the whitewood value chain (ranging from weed control methods to choice of discount rate), the greatest need is to create a market. Unless there is viable market comprising growers, processors and consumers, most planted whitewood trees will not realize their full value, and these finer details will be largely irrelevant. There is sufficient knowledge about this species (Thomson 2006) to offer informed 'best bets' to guide the market, and the priority should be to facilitate the formation of a viable market, because the nature of this market will greatly overshadow any finessing of other assumptions. Stimulating understanding and confidence about opportunities (including growth rates, wood qualities, market opportunities) throughout the value chain are important steps in assisting the market to mature (Herbohn *et al*. 203).

Model enhancements

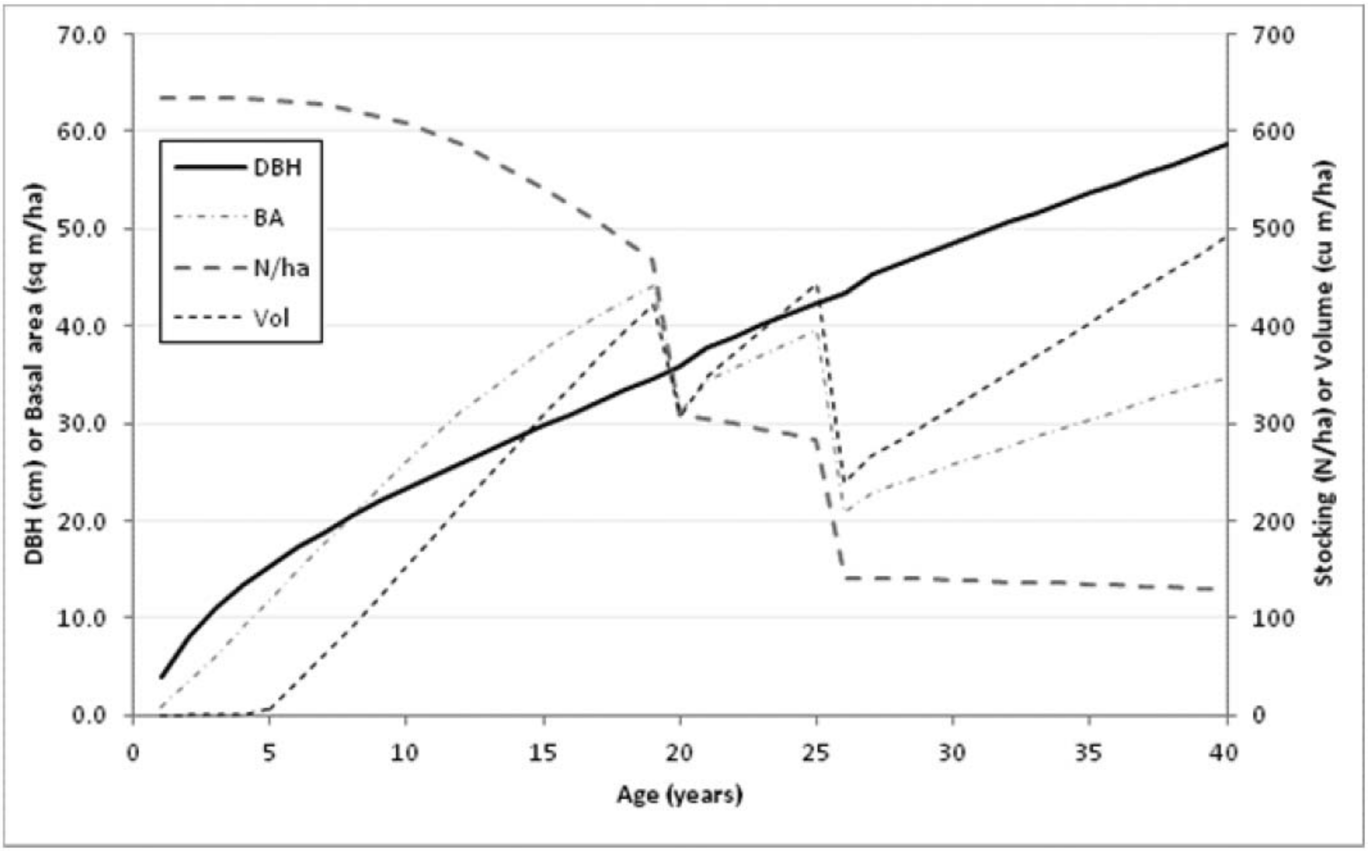
The model presented here is a simple model, intended to offer a first approximation, but if it is to assist the domestication process, it should be as accurate as possible, and updated as new data become available. Several aspects of the model are weak, and could easily be improved and customised for

FIGURE 7 *Screen image from the whitewood model*



Age	Height	DBH	N/ha	BA	Vol/ tree	Standing Volume	Standing Value $	MAI vol	Cost	NPV $	Model parameters	Estimates
1	4.0	3.9	635	1	0	0	0	0.0	2,959	-2,959	h=root(A-.5)	5.65
2	6.9	8.1	635	3	0	0	0	0.0	5	-2,964	d=h/lnN	9.3
3	8.9	11.0	635	6	0	0	0	0.0	258	-3,222	Gmax	50
4	10.6	13.4	634	9	0.00	0	0	0.0	4	-3,226	Min SED	15
5	12.0	15.4	633	12	0.01	7	13	1.3	4	-3,216	Discount rate	5%
6	13.3	17.2	631	15	0.05	33	318	5.5	319	-3,231	Initial costs $/ha	165
7	14.4	18.9	627	18	0.10	61	892	8.7	4	-2,661	Establish cost $/tree	4.4
8	15.5	20.5	623	20	0.14	90	1,625	11.2	3	-1,931	Annual costs $/ha	5
9	16.5	21.9	616	23	0.20	120	2,450	13.4	3	-1,109	Prune1 cost $/tree	0.4
10	17.4	23.3	608	26	0.25	151	3,320	15.1	3	-242	Prune2 cost $/tree	0.5
11	18.3	24.7	598	29	0.31	183	4,199	16.6	3	634	Thinning cost $/ha	1600
12	19.2	26.0	586	31	0.37	215	5,061	17.9	3	1,494	Initial number	635
13	20.0	27.3	573	33	0.43	247	5,886	19.0	3	2,316	T1 age	20
14	20.8	28.5	558	36	0.50	278	6,658	19.9	3	3,085	T1 residual	0.66
15	21.5	29.8	541	38	0.57	309	7,366	20.6	2	3,790	T2 age	26
16	22.2	31.0	524	39	0.65	339	8,003	21.2	2	4,425	T2 residual	0.50
17	23.0	32.2	506	41	0.73	368	8,564	21.6	2	4,984	Clearfall age	36
18	23.6	33.4	488	43	0.81	395	9,050	22.0	2	5,468	Max Standing Val	13,132
19	24.3	34.6	469	44	0.90	422	9,461	22.2	2	5,877	Max MAI	22.7
20	24.9	35.8	310	31	0.99	308	10,204	15.4	605	6,016	Max NPV	8,472

FIGURE 8 *Simulated outputs for the optimal silviculture defined in Table 5*



Vanuatu. Several aspects warrant attention, listed here in priority order:

1. Volume equations (equations 4 and 5) are generic equations developed for other situations, and it is a relatively straightforward task (amenable as a student project) to acquire the data and create a model specifically for this species in Santo.
2. The assumed maximum basal area (50 m^2/ha) has major consequences for the simulated self-thinning of plantations, and is based on observations made by others, for other purposes, in other locations. A few unthinned plots monitored for several years would help refine this estimate (Skovsgaard and Vanclay 2008).
3. The height growth equation is generic, and whilst it is robust, it does not account for the particular traits of the species. A small investment in developing a specific equation for whitewood in Vanuatu would greatly increase the utility of, and confidence in predictions.

DISCUSSION

The apparent simplicity of the model and its basis in three uni-variate relationships belies the care taken in establishing and testing these relationships for a wide range of species and sites (Vanclay 2009a, 2010, Vanclay and Sands 2009). Similarly, a mere 15 plots may seem insufficient to calibrate a model and defies conventional advice regarding models for tropical forests (Vanclay 1991, Weiskittel *et al.* 2011), but the uni-variate nature of these relationships makes them inherently robust and amenable to calibration with minimal data. The simulation portrayed in Figure 8 is a bold prediction that represents a considerable extrapolation beyond the data-space represented within the calibration data (Vanclay *et al.* 1995), but is presented in an explicit and testable form consistent with scientific principles. Although reliant on a series of assumptions, the model represents the best objective advice for the management of whitewood plantings. However, it would be unwise to assume without further monitoring the 37-year regime outlined in Table 5. Instead, Table 5 should be viewed as a 'best bet' to guide an adaptive management approach (Sayer and Campbell 2003, Schreiber *et al.* 2004), and on-going monitoring should continually test the adequacy of the model. Fortunately, Tables 5 and 6 suggest that there is a broad plateau of near-optimal regimes that offer plantation managers great flexibility to vary silvicultural decisions and to seize market opportunities without compromising financial viability.

CONCLUSION

Findings from this study suggest that a useful growth model can be constructed from a modest database using Vanclay's (2010) equations. Tests with independent published data suggest that model predictions are reasonable, but these published data are insufficient in number and quality to allow formal statistical tests. The model appears adequate for mid-term planning, but monitoring should be continued, and should inform periodic review of the growth model.

The model suggests that an optimal silviculture for whitewood may be to plant 635 stems/ha, two thinning at age 20 and 26 years, and a clearfall at age 36 yielding 133 stems at 55 cm dbh. Alternatively, if the market for thinnings is weak, it may be preferable to plant 400 stems/ha, have a single thinning at age 24, and to clearfell at age 34 to yield 145 stems at 54 cm dbh. In either case, the projected financial returns are relatively insensitive to minor variations in these regimes, allowing forest managers considerable flexibility in selecting the initial spacing, the timing of harvests and the intensity of thinnings.

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Basic density, diameter and radial variation of Vanuatu Whitewood (*Endospermum medullosum*): potential for breeding in a low density, tropical hardwood

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SUMMARY

Vanuatu whitewood (*Endospermum medullosum* L.S. Smith) is an economically important timber species for Vanuatu. Inter- and intra-provenance genetic parameters for stem diameter at breast height, basic density and radial variation in density, were estimated for two provenances selected from a 12.4-year-old open-pollinated seed orchard on Espiritu Santo Island, Vanuatu. Kole provenance exhibited the highest mean basic density, greatest mean diameter and greatest radial variation in density across the stem.

Mean basic density at breast height was 345±2 kg/m^3. Growth rings were not visually discernable and colour was homogenous across all samples. For radial variation determination, each pith-bark core was sectioned into four equi-length subcores (A-D). Subcore density increased consistently and significantly from pith to bark, with mean basic density of 308±3, 327±3, 343±3 and 359±3 kg/m^3 for cores A-D respectively.

The narrow-sense heritability estimate ($\hat{h}^2$) was low (0.26±0.2) for diameter, with a moderate coefficient of additive genetic variation (CV_A= 17.61%). Estimated $\hat{h}^2$ for density was moderate (0.49±0.24), with a low coefficient of additive genetic variation (CV_A= 5.39%). Though the precision of these estimates is modest, reflective of the small sample size, indications are that the heritable genetic variation in both growth and quality traits will result in economic gain from a recurrent selection and breeding program.

Keywords: density, diameter, radial variation, heritabilities, genetic correlation

La densité de base, le diamètre et la variation radiale de Vanuatu blancs (*medullosum Endospermum*). Trait-trait corrélations dans une faible densité, des feuillus tropicaux

D.J. SETTLE, T. PAGE, D. BUSH, J. DORAN, M. SETHY et I. VIJI

Vanuatu whitewood est une espèce de bois économiquement importants pour le Vanuatu. Les paramètres génétiques pour le diamètre de la tige (DBH), la densité de base (DEN) et de la variation radiale (RadVar) ont été estimés en deux provenances pendant 12,4 années sur l'élevage de la population *Endospermum medullosum* L.S. Smith à pollinisation libre sur île d'Espiritu Santo, au Vanuatu. La provenance Kole a été exposée au plus haut de la densité moyenne de base, au plus haut diamètre moyen et à la plus grande variation de la densité dans la tige.

Les estimations d'héritabilité ($\hat{h}^2$) (0,26±0,2) ont été faibles pour le DBH, avec une variation phénotypique modérée (CV_A = 17,61%) et une estimation de l'héritabilité (0,49±0,24) ce qui étaient modérées pour la densité, avec une variation phénotypique faible (CV_A = 5,39%). La densité moyenne de base à hauteur de poitrine était de 345 (SE±2) kg/m^3, et a augmenté de façon constante 308 (SE±3), 327 (SE±3), 343 (SE±3) et 359 (SE±3) kg/m^3 et significative de la moelle à l'écorce.

La faible taille de l'échantillon disponible peut avoir réduit la précision, toutefois il est prévu que le gain économique dû à la croissance et aux caractères de qualité peuvent être obtenue à partir d'une sélection récurrente et programme d'élevage étant donné les variations génétiques héréditaires indiqué dans cette étude.

Variabilidad de la densidad basica en el diametro y en las secciones radiales de *Endospermum medullosum* (Vanuetu whitewood). Correlaciones entre los caracteres biologicos de una especie tropical de baja densidad.

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La madera blanca (*Endospermum medullosum* L.S. Smith) es una especie maderera de importancia económica para Vanuatu. Se estimaron parámetros genéticos dentro y entre procedencias para diámetro de tallos a la altura del pecho, densidad básica y variación radial en densidad para dos procedencias seleccionadas de un huerto de semillas de polinización abierta de 12.4 años de antigüedad en la isla de Espiritu Santo, Vanuatu. La procedencia Kole exhibió la mayor densidad básica, el mayor diámetro medio y la mayor variación radial en densidad a lo largo del tallo.

La densidad básica media a la altura del pecho fue 345±2 kg/m^3. No se pudieron discernir anillos de crecimiento en las muestras. Para la determinación de la variación radial, cada núcleo de médula de la corteza se seccionó en sub-núcleos de igual longitud (A-D). La densidad de sub-núcleos incrementó consistente y signficativamente de médula a corteza con los núcleos (A-D) exhibiendo una densidad media básica de 308±3, 327±3, 343±3 y 359±3 kg/m^3 respectivamente.

Las estimas de heredabilidad ($\hat{h}^2$ 0.26±0.2) fueron bajas para el diámetro, con un coeficiente moderado de variación genética aditiva (CV_A = 17.61%). Las estimas de heredabilidad ($\hat{h}^2$ 0.49±0.24) fueron moderadas para la densidad, con un coeficiente bajo de variación genética aditiva (CV_A = 5.39%).

El pequeño tamaño de muestra puede reducir la precisión de estas estimas. Se espera que dada la variación genética heredable indicada en este estudio, sería posible una ganancia económica tanto en caracteres de crecimiento como de calidad a través de una selección recurrente y un programa de cultivo.

INTRODUCTION

Endospermum medullosum L.S. Smith (family Euphorbiaceae), commonly known as Vanuatu whitewood, New Guinea Basswood or Sessendok, is a fast growing pioneer species, with a distribution ranging from Eastern Indonesia, New Guinea, Solomon Islands and Vanuatu (Guerrero and Welzen 2011). Whitewood is recognised as an economically important timber species in Vanuatu, comprising 60–70% of all harvested logs between 1990 and 2004 (Page 2009).

The primary demand for whitewood comes from the Japanese consumer market. Prior to the 2011 Tōhoku-Oki earthquake, the Japanese market for Vanuatu whitewood was valued as US$3.9 million per annum for sawn timber (Page 2009). Whitewood is valued in Japan for its pale colour and smooth grain (G. Palmer, Southern Cross University, pers. comm. DEC 2011). The Vanuatu Forest Policy identifies forestry and timber production as vital for supporting sustainable livelihoods in Vanuatu and sets a national target of 20,000 ha of timber plantations by 2020 (Mele 2011). The Policy identifies whitewood as an ideal forestry species due to its rapid growth, cyclone resistance (Thomson 2006, Page 2009, McGregor and McGregor 2010, Page and Awarau 2012), resistance to brown root rot (*Phellinus noxius*) (Neil 1986, Ivory and Daruhi 1993, Ramsden *et al.* 2002) and the existence of an established export market (Page 2009, McGregor and McGregor 2010, Mele 2011). McGregor and McGregor (2010) estimate that 3,000–5,000 ha of whitewood plantation forests, harvested on a 20–25 year rotation, would produce approximately 50,000 m^3 of timber annually with an estimated annual export value of $USD35 million (approximately 6% of current GDP).

However, major concerns exist for the future security of whitewood. A decade ago, FAO noted that the majority of natural stands had been logged-out, leaving only small pockets in the relatively inaccessible, central, elevated areas of Vanuatu. They predicted that given the then-current rates of utilization, the whitewood forests of Vanuatu would be effectively exhausted within 10–14 years (FAO *et al.* 2001). That this trajectory of unsustainable logging has continued is evident in a recent survey conducted of the status of wild subpopulations from which the genetic resources examined here were drawn: many have disappeared in the recent past (see Doran *et al.* 2012). The future of conserving and developing whitewood will be through establishment of commercial plantations.

The primary objective of whitewood plantation management is the production of large diameter logs for production of knot-free clearwood (Thomson 2006). A secondary objective is to improve wood quality via breeding for increased wood density (Doran *et al.* 2012, Thomson 2006). Whitewood air-dried density at 12% moisture content is estimated to be between 365–450 kg/m^3 (Keating and Bolza 1982, Thomson 2006), and mean basic density reported as 330 (±21) kg/m^3 (Doran *et al.* 2012). These estimates have been based on limited numbers of samples from either unknown origin (Keating and Bolza 1982, Thomson 2006) or a single subpopulation (Doran *et al.* 2012). Although this emerging resource forms a crucial component of Vanuatu's sawlog industry, and despite extensive economic investment by the Australian Centre for International Agricultural Research (ACIAR) and Vanuatu Department of Forestry (VDoF), the absence of accurate information on wood density variation, the relationship between wood quality and growth and potential for genetic improvement represents a serious gap in the knowledge for this species.

Tree diameter, measured at breast height (DBH) is an economically important trait as it separates logs into different production systems with disparate cost and revenue structures (Panshin and De Zeeuw 1964, White *et al.* 2007, Blackburn *et al.* 2011). For higher density species, greater DBH equates to greater recovery of higher-value select and standard grade sawn boards as a proportion of log volume (Blackburn *et al.* 2011).

Defined as the mass of oven-dry material per unit of volume (Williamson and Wiemann 2010), basic wood density (DEN) is another important selection criterion that is correlated with numerous morphological, mechanical, physiological and ecological properties of wood (Chave *et al.* 2006). DEN is indicative of strength and stress grades, it influences sawn timber recovery, and pulp and paper production (Panshin and de Zeeuw 1964). Density is inversly correlated with porosity (Shmulsky and Jones 1990) with denser wood tending to exhibit a finer texture (Montes *et al.* 2008). Density is phenotypically correlated with heartwood darkness, (e.g., in *Acacia melanoxylon* Bradbury *et al.* 2011) and sapwood yellowness, (e.g., in *Eucalyptus dunnii*, Vanclay *et al.* 2008). These characteristics are potentially important for whitewood as whitewood's popularity in the current Japanese market is for its pale colour and fine grain.

Narrow-sense heritability ($\hat{h}^2$) can be defined as the proportion of phenotypic variation in a trait that is attributable to additive genetic differences and that can be transmitted to subsequent generations. It is therefore a key parameter for determining whether or not recurrent selection and breeding will result in genetic gain. Narrow-sense heritability is generally low for growth traits (e.g., DBH) and moderate to high for wood property traits (e.g., DEN) (Falconer and Mackay 1981, White *et al.* 2007) in both softwood and hardwood species. Both DEN and heritability generally increase with radial distance from the pith for both softwoods (Wu *et al.* 2008, Gapare *et al.* 2009, Raymond and Henson 2010) and hardwoods (Butterfield *et al.* 1993, Hein *et al.* 2012). However the opposite can be true for some species (Bush *et al.* 2011). Genetic correlations between DBH and DEN are often strongly negative for coniferous species (Wu *et al.* 2008, Raymond and Henson 2010, Gapare *et al.* 2012).

For hardwood species, although the sign and the genetic correlation coefficients vary between species and sites, there is generally a weak, yet positive relationship between DBH and DEN (Stackpole *et al.* 2010, Hein *et al.* 2012). Correlations range between 0.08 for sixteen year old *E. globulus* (Stackpole *et al.* 2010) and -0.05 for eighteen-year-old *Acacia melanoxylon* in Tasmania (Bradbury *et al.* 2011) Wu *et al.* (2011) reported a correlation of 0.05 between these traits for 4 year old *E. urophylla* x *E. grandis* clones in Changle, South China while Quang *et al.* (2010) report a correlation of –0.50 in nine year old *Eucalyptus urophylla* in Vietnam.

Simultaneously increasing both growth (DBH) and DEN is the objective of many tree breeding programs (Borralho *et al.* 1993, Li *et al.* 1999, Wu *et al.* 2008, Gapare *et al.* 2009, 2011) as log value is primarily a function of size and density. Realised gain has been demonstrated in several softwood species: 162% increase in dollar value as a result of volume and sawn timber improvement (Cumbie *et al.* 2012) combined with 7%–12% increase in stand volume at age of rotation for *Pinus taeda* (Li *et al.* 1999), 11.5% increase in DBH of *P. radiata* (Carson *et al.* 1999), and 5.1% increase in two years height for *P. banksiana* (Rudolph *et al.* 1989). There are also several reports for realised gains in DBH for some hardwoods: 19% in *Eucalyptus pellita* (Leksono *et al.* 2008) and 28.2% in second generation progeny trial of *Acacia auriculiformis* in Thailand (Luangviriyasaeng and Pinyopusarerk 2002). These findings highlight the importance of quantifying genetic variation of both growth and wood property traits early in the domestication phase of a species.

The aim of this study is to quantify within-species genetic variation in the mean basic density (DEN) trait, within the Shark Bay *E. medullosum* provenance-progeny trial. Furthermore we aim to characterise patterns of radial variation (RadVar) in wood density, and estimate heritabilities and determine the presence and strength of genetic correlations between these traits and diameter at breast height (DBH). This information will contribute directly to future whitewood breeding objectives.

MATERIALS & METHODS

Sample population

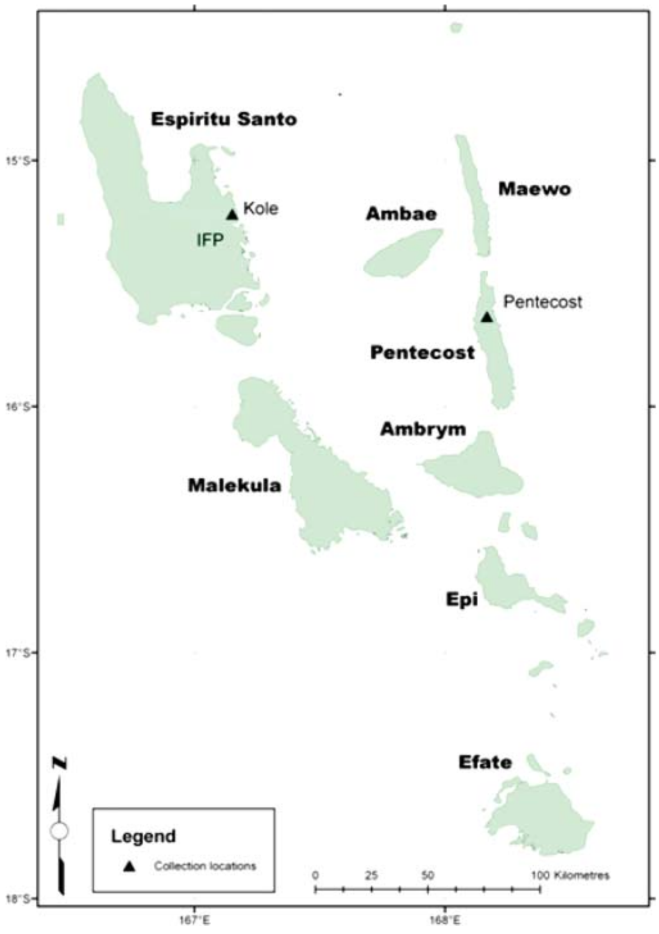
Measurements and samples were collected from an *E. medullosum* provenance-progeny trial established at the Industrial Forestry Plantation (IFP) located at the Shark Bay Research Station, Espiritu Santo Island, Vanuatu (15°13′S, 167°09′E, alt. 100 m) (Figure 1). The whitewood trial was established across a 6.25 hectare site between December 1998 and January 1999, as a randomised complete block design of eight blocks. Initial stocking was 833 trees per hectare with trees initially spaced 2 m within rows and 6 m between rows. Each block consisted of 100, six-tree lineplots, each plot comprising a single, open-pollinated family (Vutilolo *et al.* 2008). Families were drawn from 15 provenances. Blocks 1–5 of the trial were progressively thinned at ages 5, 6 (Vutilolo *et al.* 2008) and 11 years from six trees per plot to 5, 2 and 1 tree respectively. Blocks 6–8 self-thinned up until age 11 years, at which time family plots were also reduced to a single tree. This resulted in a final overall stocking density of 139 stems/ha (Vutilolo *et al.* 2008, Doran *et al.* 2012) at 11.4 years. Thinning selection was based on an index including growth and form traits.

In this wood-property study, eight trees from each of ten families from two provenances, Kole and Pentecost, were sampled at age 12.4 years giving an initial total of 160 sample trees: however, due to the mortality of one tree in each of three Pentecost families MT12, MT13 and MT19, 157 trees were sampled (Table 1). The trees were sampled after final-thinning and were effectively single-tree plots replicated in each of the eight blocks. The provenances were selected due to their contrasting (respectively high and low ranking) growth performance measured as diameter at breast height (DBH) at both 4 (Vutilolo *et al.* 2008) and 11 years (Doran *et al.* 2012).

Sampling

Trees were 12.4 years of age and approximately average of 18 m height at time of sampling. Cores of 12 mm diameter were taken using a motorised (Tanaka TED 262R) coring drill-bit (CSIRO Tree-Cor) (Downes *et al.* 1997). Breast height (1.3 m) was chosen as point of DEN core-sampling for this species based on the findings of Doran *et al.* (2012), who demonstrated that density decreased with increasing sampling height and breast height was strongly correlated (r^2=0.99) with whole tree density. Tree diameter (DBH) was determined at breast height over bark and a single core was taken to half tree diameter from bark to pith along a consistent (west-east) orientation for each sample tree. Upon extraction, each core was labeled with individual tree identity and immediately immersed in water to achieve and maintain fiber saturation point. All cores were stored within sealed, air-tight plastic containers and maintained in immersed, refrigerated conditions until determination of density.

FIGURE 1 *Location of two* E. medullosum *provenances included in this experiment, Kole and Pentecost and the location of the IFP provenance trial in which the provenances were sampled (Doran* et al. *2012).*



Basic Density

In order to asses radial variation (RadVar), and as growth rings were not discernable, cores were sectioned into four equal-length subcores and labeled A (pith) to D (bark) and the volume of each subcore, (A-D), was determined using the water displacement method (TAPPI 2011).

Samples were then dried at 105°C in a fan forced oven (LABEC ODWF36) until two consecutive weight measurements were within 0.01 g. Subcore density was determined as the oven dried weight of each subcore (A-D) divided by the green volume of each subcore (TAPPI 2011). Whole-disk density was estimated as the density of each subcore weighted to represent annuli of a disk as described in Muller-Landau (2004) and Williamson and Wiemann (2010).

Statistical Analysis

Fixed and random effect parameters for DBH, DEN and RadVar were estimated using a mixed–model implemented in ASREML version 3 (VSN International, Hemel Hempstead, UK) as follows:

$$y_{ijk} = \mu + \boldsymbol{\alpha}_i + \boldsymbol{\beta}_j + \mathbf{F}_{k(i)} + \mathbf{e}_{ijk} \qquad [1]$$

where y_{ijk} is the phenotypic value of the *k*th family in the *j*th block of the *i*th provenance, μ is the overall mean, $\boldsymbol{\alpha}_i$ is the fixed effect of *i*th Provenance ($i=1,2$), $\boldsymbol{\beta}_j$ is the effect of the fixed, *j*th complete-block ($j=1,\ldots 8$), $\boldsymbol{F}_{k(i)}$ is the random effect of the *k*th family ($k=1,\ldots 20$) nested within the *j*th provenance and **e** is the residual variance.

BLUPs (best linear unbiased predictors) were predicted for the random effect of family-within-provenance and BLUEs (best linear unbiased estimators) were estimated for the fixed effect of Provenance. Likelihood ratio tests (LRT) (Stram and Lee 1994) were used to test for significance of family-within-provenance effects. Log Likelihood was estimated as LRT = 2(Log Lp+g – Log Lp) where Log Lp+g is the Log-likelihood with the family term and p+g degrees of freedom and Log Lp is the Log-likelihood without the family term with p degrees of freedom. The LRT was distributed as a χ^2_q with q degrees of freedom. The Log-likelihoods were compared using the LMERConvenienceFunctions package in R (Tremblay 2011).

For each trait (DBH, DEN, and RadVar) narrow-sense heritability (σ^2_f) were estimated as follows:

$$\hat{h}^2 = \frac{3\sigma^2}{\sigma_f^2 + \sigma_e^2} \qquad [2]$$

The default assumption that open-pollinated families are-maternal half-siblings is likely to be flawed: to allow for the likelihood of partial inbreeding (Squillace 1974, Falconer and Mackay 1981) additive genetic variance was estimated at $3\sigma^2_f$ i.e., the coefficient for relationship for the open pollinated families was assumed to be 0.33, as is common for tropical hardwood species (Hodge *et al.* 2002, Hodge and Dvorak 2004). Standard errors of heritability estimates were made using the Taylor series method which is implemented in ASREML (Gilmour *et al.* 2006).

The coefficient of additive genetic variation (CV_A) provides a standardised measure of the amount of variation relative to the trait mean. The higher the coefficient of additive genetic variation is for any trait, the higher is that traits' relative variation (Houle 1992, Cornelius 1994, Garcia-Gonzalez *et al.* 2012).

It was estimated as,

$$CV_A = \left(\frac{\sigma_f^2}{\bar{x}}\right) * 100 \qquad [3]$$

where

CV_A	coefficient of additive genetic variation
σ^2_f	square root of the additive (family) genetic variance for the trait and
$\bar{x}$	population mean for the trait

Bivariate genetic correlations (r_G) between DBH, DEN and subcore (A-D) density were obtained from the estimated additive covariance and variance components as:

$$r_G = \frac{\sigma_{a_x a_y}}{\sqrt{\left(\sigma^2_{a_x}\sigma^2_{a_y}\right)}} \qquad [4]$$

where

$\sigma_{a_x a_y}$	additive genetic covariance between traits (*x* and *y*)
$\sigma^2_{a_x}$	additive genetic variation component for trait *x*
$\sigma^2_{a_y}$	additive genetic variation component for trait *y*

Standard errors were obtained by Taylor series expansion using ASREML (Gilmour *et al.* 2006).

Intra- and inter-provenance (Kole and Pentecost) differences in the mean density of subcores (A-D) were determined using a two-way ANOVA (R Development Core Team 2011).

Estimates of predictive genetic gain (PGG) in a hypothetical whitewood breeding population were calculated as outlined in White *et al*. (2007), pp 422–423. Predicted genetic gain (PGG) was calculated for a hypothetical open-pollinated, clonal seed orchard based on the best 15% of families in the study population. Families were selected on the basis of BLUP density, with the proviso that no families with DBH below the population mean were selected.

RESULTS

Provenance and overall trait means

Trait means for individual families are presented in Table 1. Provenance and overall trait means, ranges and coefficients of variation are presented in Table 2 and Figure 2 (DBH) and Table 3 and Figure 3 (DEN).

The overall mean for DBH was 32.5 cm with a 29.7 cm range in diameter between trees. Pentecost exhibited a significantly, p<0.001, lower DBH than Kole (30.6 cm and 34.3 cm respectively) (Table 2). Mean basic density was 345 kg/m^3 across both provenances with a 143 kg/m^3 variation. DEN was significantly, (p<0.001), lower in Pentecost (328 kg/m^3) than Kole (361 kg/m^3) (Table 3). Family means ranged between 28.2 cm and 37.7 cm for DBH (Fig. 2) and 302 kg/m^3 to 390 kg/m^3 for DEN (Fig. 3). No significant intra-provenance DBH variation was found in either provenance (Fig. 2). Significant (p<0.01) family-within-provenance DEN variation was present in Kole but not in Pentecost. All Kole family means for DEN were greater than all Pentecost families (Fig. 3).

Radial variation

Basic wood density increased consistently and significantly (p<0.001) across all subcores from pith to bark (subcores A-D), exhibiting an overall radial variation of 256 kg/m^3 (199–455 kg/m^3). Across all samples, mean basic wood density was measured at 308, 327, 343 and 359 kg/m^3 across the four subcores from pith to bark (annuli A to D respectively) (Fig. 4). Mean subcore DEN was higher for each Kole subcore than each corresponding Pentecost subcore (Fig. 4). Kole exhibited a greater range in density for subcore A, however Pentecost exhibited a greater range for subcores B, C and D. Significant (p<0.001) within provenance radial variation (Tukey's HSD test) was observed in both Kole ($F_{(3,316)}$ 35.871, p<0.001) and Pentecost ($F_{(3,308)}$ 38.899, p<0.001) provenances (Fig. 4) *viz.* the mean density of each subcore was significantly (p<0.001) different from all other subcores within the same provenance.

FIGURE 2 *Mean DBH (cm) for twenty, open-pollinated, half-sib families, (ten in each of two provenances: Kole, east Santo (white columns) and Pentecost (black columns). All trees were 12.4 years of age and sourced from* E. medullosum *provenance-progeny trial in Vanuatu*

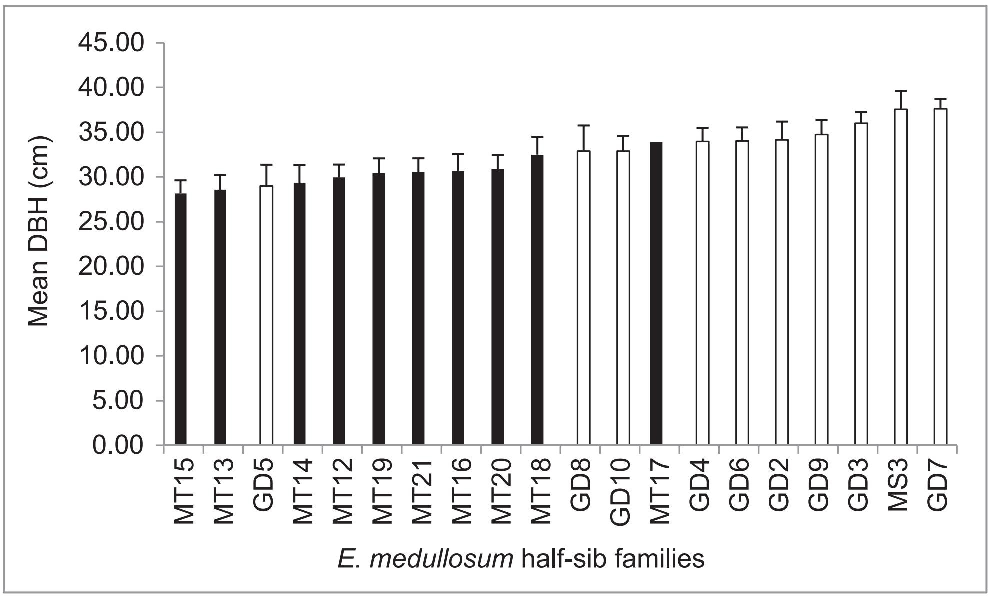


FIGURE 3 *Mean basic density (kg/m^3) for twenty, open-pollinated, half-sib families, (ten in each of two provenances: Kole, east Santo (white columns) and Pentecost (black columns). All trees were 12.4 years of age and sourced from* E. medullosum *provenance-progeny trial in Vanuatu*

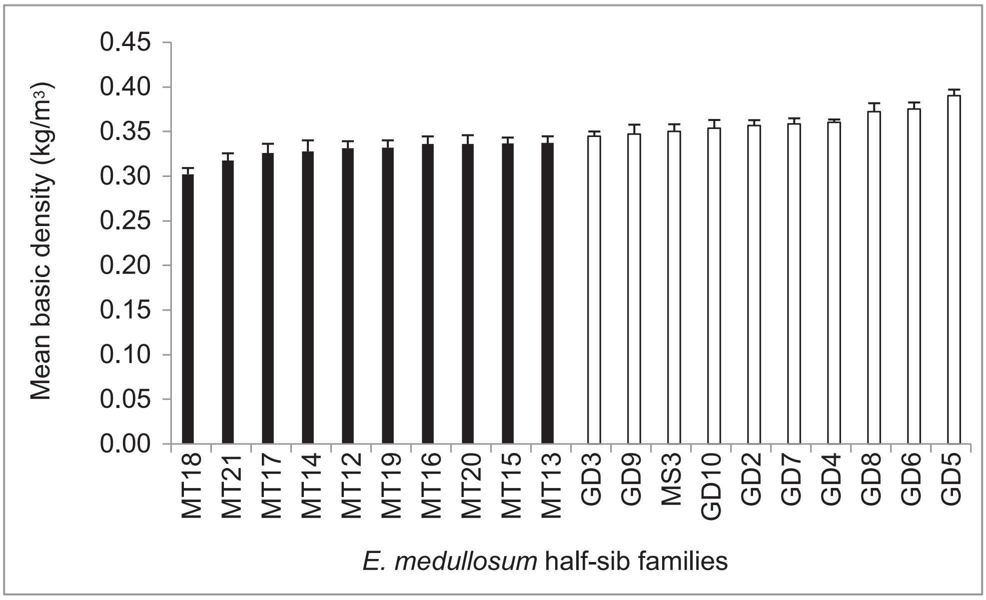


TABLE 1 *Diameter at breast height (DBH), density (DEN) and subcore (A - D) family means, in two provenances of 12.4-years-old* E. medullosum *provenance-progeny trial in Vanuatu*

Provenance	Family	DBH (cm)	DEN (kg/m^3)	A (kg/m^3)	B (kg/m^3)	C (kg/m^3)	D (kg/m^3)
KOLE	GD10	34.15	354	337	337	357	364
	GD2	35.70	357	326	340	371	358
	GD3	34.60	345	302	322	343	362
	GD4	35.14	360	317	352	357	372
	GD5	35.90	390	344	368	385	410
	GD6	32.45	375	317	355	381	388
	GD7	32.16	358	319	340	364	368
	GD8	33.53	373	336	357	363	391
	GD9	35.69	347	337	346	343	354
	MS3	33.60	350	314	339	352	358
PENTECOST	MT12	32.60	332	261	315	321	356
	MT13	29.89	337	291	323	330	356
	MT14	30.76	328	307	298	316	352
	MT15	31.76	337	286	306	330	362
	MT16	30.51	336	295	322	340	345
	MT17	28.09	326	289	293	332	340
	MT18	30.03	302	266	287	302	314
	MT19	32.04	332	308	325	331	340
	MT20	30.96	336	293	319	330	354
	MT21	29.36	317	303	304	316	326
	MT12	32.60	332	261	315	321	356
	MT13	29.89	337	291	323	330	356

Genetic parameters

Narrow-sense heritability ($\hat{h}^2$) and additive genetic coefficient of variation (CV_A) for DBH was 0.26±0.20 and 17.61% respectively (Table 2). Narrow-sense heritability ($\hat{h}^2$) and additive genetic coefficient of variation (CV_A) for DEN was 0.41±0.20 and 5.39% respectively (Table 3). Both DEN and $\hat{h}^2$ increased with distance from pith (Table 4). CV_A estimates were low to moderate for all traits across both provenances. Kole exhibited higher CV_A than Pentecost for both DEN and DBH.

Log likelihood test results indicate that family-within-provenance is a highly significant determinant of density. The test statistic is 2 × LogL difference = 2 * (459.995 – 455.063)

TABLE 2 *DBH, means, range, significance of provenance (F test), standard deviation, additive genetic variance (σ^2_A), narrow sense heritabilities $\hat{h}^2$, associated standard errors and coefficients of variation (CV_A) in two provenances of 12.4-years-old* E. medullosum *provenance-progeny trial in Vanuatu*

DBH (cm)	**Pentecost**	**Kole**	**All Groups**
N	77	80	157
Mean (SE)	30.56(0.59)	34.29(0.63)	32.46 (0.46)
Range (Min-Max)	20.50–46.50	16.80–43.20	16.80–46.50
Standard Deviation	5.202	5.619	5.715
Additive Variance (σ^2_A)	1.4	10.5	11.189
Coefficient of Variation (CV_A)	16.39%	17.02%	17.61%
$\hat{h}^2$ (standard error)			0.26 (0.20)
F probability			0.001

FIGURE 4 *Radial variation (pith - bark) in basic density (kg/m^3) across four subcores (A - D) in two provenances, Pentecost (black) Kole (grey) sampled in a* E. medullosum *provenance-progeny trial in Vanuatu*

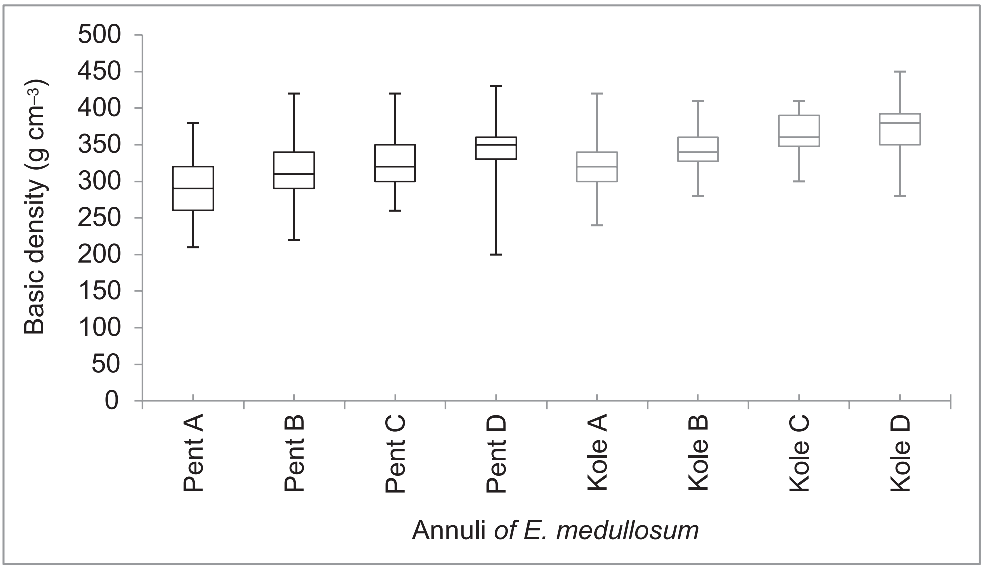


TABLE 3 *DEN, means, range, significance of provenance (F test), standard deviation, additive genetic variance (σ^2_A), narrow sense heritabilities $\hat{h}^2$, associated standard errors and coefficients of variation (CV_A) in two provenances of 12.4-years-old* E. medullosum *provenance-progeny trial in Vanuatu*

DEN kg/m^3	**Pentecost**	**Kole**	**All Groups**
N	77	80	157
Mean (SE)	328(3)	361(3)	345(2)
Range (Min-Max)	0.26–0.39	0.31–0.41	0.26–0.41
Standard Deviation	0.025	0.003	0.068
Additive Variance (SE) σ^2_A	0.05(0.007)	0.02(0.01)	0.03(0.006)
Coefficient of Variation (CV_A)	6.10%	4.40%	5.39%
$\hat{h}^2$ (SE)			0.49(0.24)
F probability			<0.001

TABLE 4 *Subcores A-D means, ranges (min.-max), additive variance estimates coefficient of additive genetic variation (CV_A) and heritabilities of* E. medullosum *provenance-progeny trial in Vanuatu*

Subcore	A (pith)	B	C	D
N	157	157	157	157
Mean (kg/m^3) (SE)	308(3)	328(3)	343(3)	359(3)
Range (kg/m^3)	207–420	219–418	259–417	199–455
Additive Variance	53.89	168.92	231.46	514.93
CV_A	2.39%	3.97%	4.43%	6.33%
$\hat{h}^2$ (SE)	0.03 (0.14)	0.18 (0.18)	0.31 (0.21)	0.50 (0.24)
F probability	<0.001	<0.001	<0.001	0.002

= 9.864, which has $p<0.001$ against the Chi-square distribution with 0.5 degrees of freedom.

Predicted genetic gain (PGG) indicated an 8% gain in DEN with a hypothetical CSO select subpopulation, comprised of families GD8, GD6 and GD5, exhibiting a combined mean DEN 28 kg/m^3 higher than the population mean (μ) (365 kg/m^3 and 337 kg/m^3 respectively). The resultant PGG in DBH was also positive, 3% (Fig. 5 and Fig. 6).

Phenotypic and genetic correlations

Phenotypic (r_P) correlations were all positive with the exception of DBH-D which was negative (Table 5). Significant phenotypic correlations were identified for all trait (DBH * DEN *A-D) combinations, excluding DBH-DEN, and DBH-D. Trait-trait correlations (Table 6) could not be determined in most cases: those involving DBH were all indeterminate and others had high associated standard errors (Table 6). However, moderate to strong trait-trait correlations were identified between DEN-C (0.9±0.1), B-C (0.75±0.3), C-D (0.91±0.19).

DISCUSSION

The mean basic density, radial variation in density and trait-trait correlations of *E. medullosum* have been quantified and reported here for the first time. *Endospermum medullosum* produces a low density timber (345 kg/m^3), which varies significantly between individuals (range of 143 kg/m^3) and populations (328 and 361 kg/m^3 for Pentecost and Kole populations respectively). Radial variation in wood density was also significant with a 16.5% increase in wood density from the inner to outer wood. Moderate heritability estimates for wood density ($\hat{h}^2$ 0.49±0.24) in this species enables this trait to be included in efforts to bring about its domesticaiton. The results of this study found the mean basic density of whitewood to be within the upper estimates provided by

FIGURE 5 *DBH BLUPs for ten open-pollinated families in each of two provenances, Kole (white columns) and Pentecost (black columns) (total of twenty families). All trees were 12.4 years of age and sourced from* E. medullosum *provenance-progeny trial in Vanuatu. X axis set at population mean (μ)*

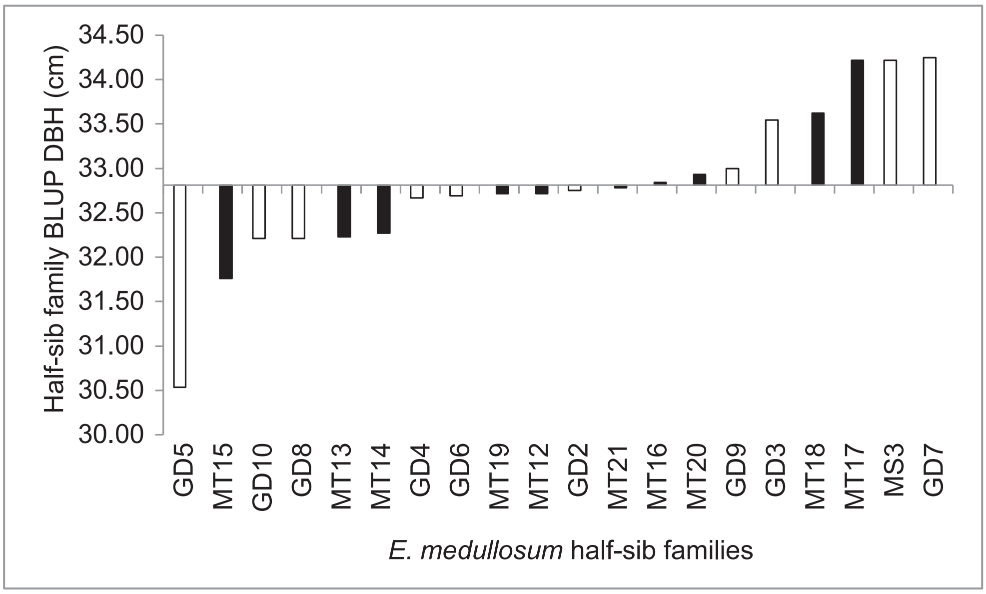


FIGURE 6 *DEN BLUPs for ten open-pollinated families in each of two provenances, Kole (white columns) and Pentecost (black columns) (total of twenty families). All trees were 12.4 years of age and sourced from* E. medullosum *provenance-progeny trial in Vanuatu. X axis set at population mean (μ)*

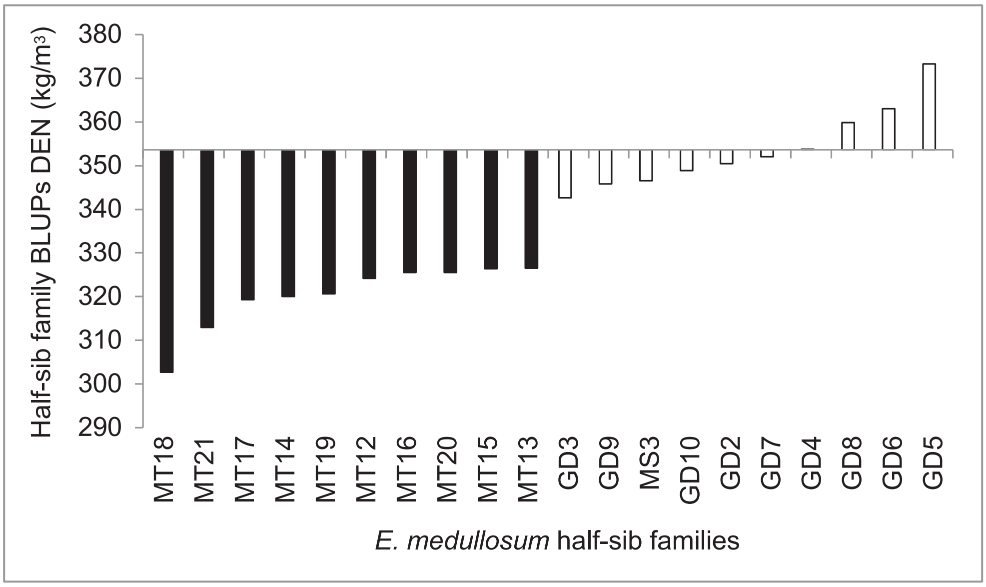


TABLE 5 *Pearson's phenotypic (r_P) and genetic correlations (r_G) (SE) between pairs of traits in 12.4-year-old* E. medullosum *provenance-progeny trial in Vanuatu*

	DBH	DEN	A	B	C
Phenotypic correlation, (r_P)					
DEN	0.15				
A	0.16*	0.56**			
B	0.27*	0.81**	0.61**		
C	0.23*	0.90**	0.56**	0.76**	
D	–0.03	0.86**	0.24*	0.47**	0.61**
Genetic correlation,(r_G)					
DEN	N.D.				
A	N.D.	0.6 (1.36)			
B	N.D.	N.D.	0.18 (1.47)		
C	N.D.	0.9 (0.10)	–0.03 (1.56)	0.75 (0.30)	
D	N.D.	N.D.	N.D.	N.D.	0.91 (0.19)

ND not determined due to non-convergence of ASREML algorithm
**$p<0.001$, *$p<0.05$ (phenotypic correlations significantly different from zero)

Thomson (2006) and Doran *et al.* (2012). The density result ranks whitewood with other low density southeast Asian, tropical Euphorbiaceae including *Endospermum peltatum* (300 kg/m³), *Macaranga sampsoni* (330 kg/m³) and *Macaranga myriantha* (400 kg/m³) (Chave *et al*. 2009, Zanne *et al.* 2009).

Provenance rankings

There were significant ($p<0.001$) differences found between the two provenances sampled for both DEN and DBH, indicating that there is scope for future breeding objectives to be based on provenance-level selection for genetic improvement of these traits. The apparent superiority of Kole in DBH is consistent with previous studies measuring the same family provenance trial (Doran *et al.* 2012, Vutilolo *et al.* 2008). Santo Island provenances, such as Kole, have been shown to exhibit superior DBH at age 4 (Vutilolo *et al.* 2008), 11.4 (Doran *et al.* 2012) and now 12.4 years in the IFP plantation on Espiritu Santo Island. The close proximity of the IFP trial to the origin of Kole provenance (Fig. 1) may indicate greater local adaptation to this region by Kole. However, as environmental variation undoubtedly exists across Vanuatu's numerous islands, Genotype by Environment (GxE) experiments, established across varying climatic and edaphic conditions (White *et al.* 2007) will be necessary to test the assumption of superiority of Santo provenances and identify whether or not other locally specialised provenances exist (Doran *et al*. 2012).

Variation in wood density

At the time of this study the trees were approximately half rotation age (20–25 years) (Thomson 2006). Greater variation in density was found within trees (radially at breast height) than between trees, families or provenances. This large pith-to-bark increase in density is characteristic of tropical pioneer angiosperm species (Wiemann and Williamson 1988, Butterfield *et al.* 1993, Raymond and Henson 2010, Lachenbruch *et al.* 2011). Juvenile trees, such as those sampled in this experiment, are adapting to changing hydraulic and mechanical demands placed upon wood due to growth. Therefore any radial variation in wood structure is likely to be a reflection of ontogenetic changes (Lachenbruch *et al.* 2011) and would be expected to decrease as age increases. Predicted genetic gains for density also indicated that a small positive gain in diameter was also achievable. Breeding whitewood for higher density could be a desirable breeding objective as improved density may increase options for end usage (Kataoka *et al.* 2004). However high density can result in utilisation problems such as splitting during nailing, shelling along the heartwood/sapwood interface and poor nail penetration, as has been found in mature slash × Caribbean pine, a hybrid-with comparable density to whitewood (Harding and Copley 2000).

Wood grain and colour are a product of density and maturity of the tree (Butterfield *et al.* 1993, Chave *et al.* 2006, Lachenbruch *et al.* 2011). Outerwood often has wider cambial cells and therefore is uneven and rough in texture. Mature heartwood has more consistent cambial spacings which produces a finer grain (Panshin and de Zeeuw 1964). As whitewood has historically been sourced from the wild (FAO *et al.* 2001, Page 2009), it is likely that historic whitewood stocks were of a greater age and DBH, and therefore consisted almost entirely of heartwood (Lachenbruch *et al.* 2011) from which whitewood earned its reputation as a fine-grained species. Breeding for higher density may improve wood colour and grain (Vanclay *et al.* 2008, Bradbury *et al.* 2010), which may be a further breeding objective trait for future assessment.

The proportion of heartwood to sapwood for trees was not measured, in this study. However, due to the relatively young age of the trees (12.4 y), it is probable that this proportion is lower than that of larger, wild-harvested trees. Without significant genetic and silvicultural intervention, whitewood growers are likely to follow the global trend of harvesting trees of a younger age (Lachenbruch *et al.* 2011) and also increasingly market thinned material to maximize the rate of return on investment in land and silviculture. This will result in an inevitable increase in the proportion of sapwood to heartwood. Genetic variation in heartwood to sapwood ratio has been found in eucalypts (see Bush *et al*. 2011), and therefore, further research is required to determine if this is an issue for whitewood since a higher proportion of sapwood may have the potential to degrade the grain and texture qualities for which whitewood is popular. If whitewood is to persist as a quality decorative timber, these issues will need to be addressed or alternative markets found for thinnings, e.g., fuel for clean energy production utilising woody biomass in Japan (Yamamoto 2011). Future breeding objectives for whitewood should focus primarily on increasing the proportion of heartwood to sapwood and secondly breeding for larger diameter and increased density.

Genetic estimates

Genetic improvement of a given trait through recurrent breeding and selection is a function of its heritability and variability (White *et al.* 2007). Typically wood quality traits have high $\hat{h}^2$ but low CV_A while traits associated with overall fitness have low $\hat{h}^2$ and high CV_A (Garcia-Gonzalez *et al.* 2012). The results from this study adhere to this trend. CV_A estimates for DBH (17.6%) were double that for DEN (8.7%) whilst heritability estimates were lower for DBH than DEN (0.26±0.20 and 0.49±0.24 respectively). Species of comparable basic density to whitewood, e.g., *Eucalyptus nitens*, have been shown to have similar heritabilities for both DEN and DBH (Hamilton *et al.* 2009). The moderate heritabilities and coefficients of phenotypic variation for DEN and DBH in this study indicate that there is scope for genetic gain through selection for both these traits. The large between-provenance variation indicates that there is enough genetic variation should breeders choose to select for high or low DEN.

The limited number of individuals per family and families per provenance sampled in this study are likely to reduce precision of genetic correlation estimates. For heritability and correlation estimates to be considered precise and widely applicable, it is desirable that they be based on a large number of families, a large number of trees per family and for tests to be conducted across a range of sites to quantify genotype-by-environment interaction (White *et al.* 2007). This study should be considered as preliminary: more precise estimates involving a wider range of genetic material should proceed as the genetic improvement program progresses. The apparent absence of either phenotypic or genotypic correlations between DBH and DEN, is encouraging and suggests that improvement of these traits might proceed in tandem without adverse effect, though again, this finding should be checked by more precisely determining genetic correlations in future. Adverse genetic correlations between growth and wood property traits in some *Pinus* spp., particularly *P. radiata*, (Wu *et al.* 2008, Kumar *et al.* 2008, Raymond and Henson 2010, Gapare *et al.* 2011) have been a serious impediment to progress, particularly as the adverse correlation (i.e., high growth correlated to high proportions of juvenile wood with low density and strength) was not identified until well after selection for growth had taken place, necessitating expensive and time-consuming remedial restructuring of breeding populations.

Concluding remarks

The aim of this study was to quantify basic wood density, identify patterns of radial variation and phenotypic correlations and provide initial heritability estimates for these wood properties in Vanuatu whitewood. The material included in this preliminary study was chosen to represent the total phenotypic range in variability for DBH in order to identify any genetic relationship between DBH and DEN. The number of trees available to represent each of the two provenances was restricted, which has undoubtedly reduced the precision of the genetic parameter estimates, particularly genetic correlations. However, the study has indicated significant provenance- and family-within-provenance variation in traits of economic significance in *E. medullosum* at approximately half rotation age. Both levels of selection have the potential to result in significant genetic gain. The future success of the whitewood breeding program is well-served by the relatively broad range of genetic resources incorporated in the IFP germplasm. Given the demise of many of the wild stands from which the material was originally drawn, this is an important resource for future improvement of *E. medullosum* growth and wood properties. Future breeding programs would best be served by exploiting genetic variation in DBH and DEN to improve log size and quality. The authors recommend genetic variation analysis of DBH, DEN and RadVar for all families in the whitewood trial at 15 years (2014) and 20 years (2019). This would provide breeders with a snapshot of trends in genetic variation at 50% (this study), 75% and 100% of harvest age. Age-age genetic correlations between those years, this study and earlier studies (Doran *et al*. 2012, Thomson 2006, Vutilolo *et al*. 2008) will provide whitewood breeders the information needed to asses and select for improved families, provenances and traits at appropriate ages (White *et al.* 2007).

This study has again demonstrated open-pollinated families from Kole provenance, East Santo as exhibiting superior phenotypic trait means although GxE experiments will be necessary to test this pattern across a range of edaphatic conditions. This early identification of Espiritu Santo Island provenances, e.g., Kole, as exhibiting superior trait means will have direct benefits for the Vanuatu whitewood industry, as Espiritu Santo island, being the largest of Vanuatu's islands, has been identified as the centre for future whitewood production (Mele 2011). For Espiritu Santo at least, this early identification of superior genetic material could lead to earlier distribution of improved germplasm and in turn greater realised gain in less time.

Finally, as Vanuatu now has an accurate estimate of basic density for whitewood, reliable accounting of carbon stocks sequestered within Vanuatu's whitewood forests can be determined (Wiemann and Williamson 1989, Baker *et al.* 2004, Chave *et al.* 2006, Williamson and Wiemann 2010). This information could aid Vanuatu in accessing carbon payments for avoided deforestation, offering diversified revenue for landholders.

Taken as a whole, this study has successfully identified the potential for significant genetic gain in wood quality (DEN) and stem volume production (DBH) in Vanuatu Whitewood.

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Variation in growth traits and wood density in whitewood (*Endospermum medullosum*): a major timber species in Vanuatu

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SUMMARY

A breeding program aimed at increasing economic value of whitewood plantations in Vanuatu and conserving declining genetic resources will take direction from the results of this study. Genetic parameters for stem diameter breast height over bark (DBHOB), straightness and branching were estimated in an 11.4-year-old whitewood breeding population on Espiritu Santo Island. Wood density variation in one subpopulation was also studied. Trees with the fastest growth and best form were from Espiritu Santo. Growth and form trait heritability estimates ($\hat{h}^2$ = 0.10–0.16) were low to moderate, with moderate phenotypic variation (CV_P = 17–36%). DBHOB at 11.4-years and 4-years were very closely genetically correlated (r_A = 1.00 ± 0.17). Mean unextracted wood basic density at breast height was 330 (SD±21) kg/m^3, or similar to mature-tree densities. Economic gain in growth traits can be expected from a recurrent selection and breeding program given the heritable genetic variation indicated in this study. Conserving genetic diversity in this species is a high priority.

Keywords: volume, diameter, height, form, heritabilities, genetic correlations

Variation de traits de croissance et de densité du bois pour le bois blanc (*Endospermum Medullosum*), une essence de bois majeure à Vanuatu

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Un élevage de production visant à accroître la valeur économique des plantations de bois blanc à Vanuatu et à conserver les ressources génétiques déclinantes va prendre sa direction à partir des résultats de cette étude. Les paramètres génétiques pour le diamètre du tronc à hauteur de poitrine écorce inclue (DBHOB), la droiture et le branchage ont été estimés dans une population de production de bois blanc de 11.4 ans sur l'île d'Espiritu Santo. La variation de densité du bois dans une population différente a elle aussi été étudiée. Les arbres à croissance la plus rapide et les plus droits provenaient d'Espiritu Santo. Les estimations de croissance et d' héritabilité des traits ($\hat{h}^2$ = 0.10–0.16) étaient de basses à modérées, avec une variation phénotypique modérée (CV_P = 17–36%). Les DBHOB à 11.4 ans et à 4 ans faisaient preuve d'une corrélation génétique très proche (r_A = 1.00±0.17). La densité de base moyenne du bois non extrait à hauteur de poitrine ètait de 330 (SD±21) kg/m^3, ou semblable aux densités des arbres mûrs. Le gain économique provenant des traits de croissance peut être attendu d'une sélection récurrente et d'un élevage de production basé sur la variation génétique d'héritabilité indiquée dans cette étude. La conservation de la diversité génétique de cette espèce est une haute priorité.

Variación en las características de crecimiento y densidad de la madera en madera blanca (*Endospermum medullosum*): una de las principales especies maderables de Vanuatu

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Los resultados de este estudio guiarán un programa de mejora dirigido a incrementar el valor económico de las plantaciones de madera blanca en Vanuatu y a conservar unos recursos genéticos actualmente en declive. Se estimaron parámetros genéticos para el fuste como el diámetro a la altura del pecho con corteza (DAPcc), la rectitud y la ramosidad de una población de mejora de madera blanca de 11,4 años de edad, en la isla de Espíritu Santo. También se estudió la variación en la densidad de la madera en una subpoblación. Los árboles con el crecimiento más rápido y mejor forma procedían de Espíritu Santo. Las heredabilidades estimadas para los rasgos de crecimiento y forma ($\hat{h}^2$ = 0,10–0,16) fueron bajas a moderadas, con una variación fenotípica moderada (CV_P = 17–36%). Se encontró una correlación genética muy fuerte (r_A = 1,00 ±0,17) entre el DAPcc a los 11,4 años y los 4 años. La densidad básica media de la madera (no libre de extractos) a la altura del pecho fue de 330 (SD±21) kg/m^3, o similar a las densidades de árboles maduros. En virtud de la variación genética heredable encontrada en este estudio se pueden esperar ganancias económicas en las características de crecimiento mediante una selección continua y un programa de mejoramiento. Se considera que la conservación de la diversidad genética de esta especie tiene una alta prioridad.

INTRODUCTION

Endospermum medullosum L.S. Smith (family Euphorbiaceae), with the common name whitewood in Vanuatu, is described in detail by Thomson (2001, 2006). It is typically a tall forest tree with a long, straight bole, to 45 m in total height, sometimes with steep buttresses, and usually in the 50 cm to 100 cm diameter range after 30 years. The species is dioecious, insect pollinated, with fruits that are fleshy drupes consumed and dispersed by birds and flying foxes. *E. medullosum* occurs naturally in Indonesia (West Papua), Papua New Guinea, Solomon Islands and in Vanuatu (Corrigan *et al*. 2000). It is predominantly a pioneer species of lowland to mid-elevation sites in humid tropical climates of high rainfall (2,500–4,500 mm/year) and short to no dry season. The wood of *E. medullosum* is of commercial value, although rather soft, of low density (365–450 kg/m^3 air-dry density at 12% moisture content) and strength and lacking durability in the ground (Keating and Bolza 1982, Thomson 2006). The wood works and dries easily and is readily treated with preservatives and stains making it suitable for many purposes including mouldings, boards, joinery, furniture and for veneer and plywood manufacture (Gunn *et al*. 2004).

In Vanuatu, *E. medullosum* occurs naturally on more than a dozen islands from Erromango (circa 19°S latitude) in the south of the archipelago to the Banks Group (c.14°S) in the north (Vutilolo *et al*. 2008). Annual harvesting of whitewood averaged c. 20,000 m^3 between 1990 and 2004 but declined dramatically thereafter. Unsustainable commercial exploitation in most parts of its natural range has resulted in its disappearance from or occurrence at very low frequency in all but the most inaccessible stands (Vutilolo *et al*. 2008). By 2008 whitewood accounted for only 20% of the 11,000 m^3 of wood harvested commercially throughout Vanuatu (Page 2009). Dwindling supplies of whitewood logs has reduced important export income and has led to the importation of most timber needed by the domestic market (Mele 2011).

Plantation and woodlot establishment and agroforestry is seen as crucial for ensuring an ongoing supply of forest products to support sustainable livelihoods in Vanuatu. The Vanuatu Forest Policy (Anon 2011, Mele 2011) includes a target of 20,000 ha of plantations and woodlots by the year 2020 - the total area of plantations was estimated at 4,800 ha in 2006. Whitewood has been identified in this policy as a key candidate plantation species with good timber properties at a young age (rotation length of 15 years anticipated) coupled with rapid growth rate, high cyclone resistance, relative freedom from serious pests and diseases and an established export market to Japan (Nichols *et al*. this publication). However, despite its market potential and highly suitable land being available for plantation development on islands like Espiritu Santo, planting of whitewood woodlots has been slow (less than 500 ha planted to date). Aru *et al*. (2012) suggest that increased training of landholders in all aspects of the value-chain for whitewood and the promotion/adoption of community forestry principles is the preferred way to facilitate increased establishment of whitewood woodlots.

The Vanuatu Department of Forests (VDoF) has implemented a tree improvement programme for Vanuatu whitewood, aimed at increasing the economic value of the industry. A key objective of the strategy is the progressive provision of more productive germplasm to growers while conserving genetic resources both *in*- and *ex- situ*. This program is focussed on enhancing grower uptake, increasing planting rates and conserving genetic resources. This work started during AusAID's South Pacific Regional Initiative on Forest Genetic Resources Project (SPRIG) (Thomson 2003) with the establishment in December 1998- January 1999 of two (one major and one minor) provenance/family trials of whitewood on the Industrial Forestry Plantations (IFP) site near Shark Bay on the east coast of Espiritu Santo. Statistically significant and heritable provenance and family-within-provenance variation in growth (height, diameter and volume) traits was found in the major trial at 4 years-of-age (Viji 2005, Vutilolo *et al*. 2008).

In this study we (i) determine patterns of genetic variation in diameter at breast height over bark and form in the IFP trials (ii) assess relationships of these (11.4-year) measures to the earlier (4-year) measures and (iii) quantify variation in unextracted wood basic density in a single bulked provenance seedlot. This latter task was undertaken to provide information in support of future plans to undertake a detailed study of genetic variation in this trait throughout the trials.

MATERIALS AND METHODS

Trial site, genetic materials and experimental designs

Two provenance/family trials of whitewood were established on IFP land near Shark Bay on the east coast of Espiritu Santo – one major and one minor (Figure 1). Summary details of the two whitewood provenance/family trials at IFP including a description of the planting site, trial design, provenances and families compared, thinning schedules and the previous measure at 4 years-of-age are given in Tables 1 and 2. A total of 110 open-pollinated families from 15 different provenances are included in the two trials (Figure 1). These include whitewood provenances on the islands of Ambae (West), Maewo, Malekula (Uri-Wiaru), and Pentecost (Central), two separate provenances (Forari and Teouma) on

TABLE 1 *Details of the two whitewood trials establish by VDoF at IFP, Espiritu Santo under the auspices of the SPRIG project*

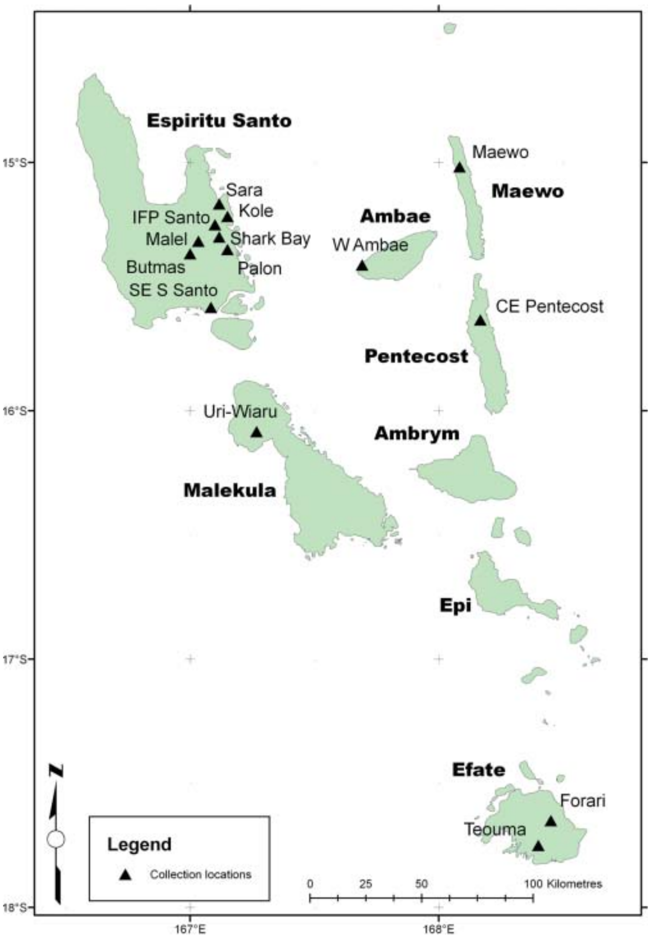
Trial details	Major trial	Minor trial
Date planted	12/1998 and 01/99	01/1999
Location	15°15’S 167°04’E	
Altitude	200 m	
Slope	Flat (<3°)	
Soils	Weakly humic ferralitic cambisols, neutral pH 5.5–6 and of generally good fertility	
Annual rainfall	c. 3500 mm (summer-dominant)	
Statistical design	Latinised row-column design	
Spacing (stocking)	6 m between rows and 2 m within rows (833 stems per ha)	
Trial area	6.25 ha including buffers	1.05 ha including buffers
No. of replicates	8	6
Trees per plot	6	
Previous measure at 4 years-of-age (Jan 2003)	Height, DBHOB, volume and form	
Thinning schedule	2003, removal of 1 tree/plot 10/2004, removal of a further 3 trees/plot 10/2005, removal of 1 tree/plot in reps 6 to 8 to create a Provenance SSO of 2.7 ha	No formal thinning regime but trial underwent substantial self-thinning
Age at measure, June 2010	11.4 years	

TABLE 2 *Summary details of the 110 whitewood seedlots in the provenance-progeny trials established at IFP, Espiritu Santo in 1998/99 with comment on the conservation status of the wild stands of origin*

Island	Provenance name	Conservation status of wild stand	No of families (major trial)	No of families (minor trial)	No common to both
Ambae	West Ambae	V	6	0	0
Efate	Forari	X	13	1	1
Efate	Teouma	X	7	3	0
Maewo	Maewo	P	10	2	0
Malekula	Uri-Wiaru	X	8	1	0
Pentecost	Central Pentecost	X	20	4	3
Espiritu Santo	Butmas, Central Santo	X	1	1	0
Espiritu Santo	IFP Plantation	planted	1	0	0
Espiritu Santo	Kole, East Santo	E	11	0	0
Espiritu Santo	Malel, Central Santo	X	6	3	2
Espiritu Santo	Palon, East Santo	X	1	1	0
Espiritu Santo	South Santo (mapped as SE S Santo)	P	1	0	0
Espiritu Santo	Sara, East Santo	X	1	1	0
Espiritu Santo	Southeast Santo (mapped as SE S Santo)	P	8	2	1
Espiritu Santo	Shark Bay, East Santo	X	3	2	1
Totals			**97**	**21**	**8**

Conservation status code: ‘X’- populations which are no longer known to exist in the wild due to harvesting or changes in land use; ‘E’- endangered populations at serious risk of disappearing within one or two decades; ‘V’- vulnerable populations not presently endangered but at risk over a longer period through continued depletion, or potential changes in land use; ‘P’ – populations not currently considered endangered or vulnerable.

FIGURE 1 *Location of provenances in the whitewood provenance/family trials established at Industrial Forestry Plantations (IFP), Espiritu Santo in 1998/99. The contiguous major and minor trial sites are in close proximity to IFP Santo*



Efate, and eight small natural provenances and one planted one (SBC 13) on Espiritu Santo. The Espiritu Santo provenances were grouped by region (region-of-provenance) by Viji (2005) but are treated separately here. Further details of the main trial and earlier measures are given in Viji (2005) and Vutilolo *et al*. (2008).

Diameter measurements and form scores

Data were collected at age 11.4-years on stem diameter at breast height over bark (DBHOB) [at 1.3m above ground] and subjective assessment of tree form (5 levels from 5 excellent to 1 extremely poor) and branching habit (3 levels from 3 excellent to 1 poor) (Table 3).

The 4-year data from the main trial (Viji 2005) was available for comparison with the 11.4-year data collected in this study.

Estimation of wood volume

Calculation of wood volume was based on a volume equation. It was determined from 20 selected trees from a single row of 95 trees planted as a buffer to a similarly fast-growing plot of *Terminalia catappa* adjacent to replicates 1–5. Selection proceeded by separating the 95 trees into six DBHOB size-classes and making a stratified random selection from each size-class to represent the spread of sizes in the population. The buffer trees were from an operational seedlot derived from populations on the east coast of Espiritu Santo, one of the better performing regions-of-provenance (Viji 2005).

Once felled, each of the 20 trees were measured for total height and diameter over bark recorded at the base of the log (30 cm above ground), 10%, 30%, 50% and 70% of tree height. For each tree, Huber's formula ($V= \pi Lmd^2/4$ where L is the length of the billet and md is its mid-diameter) (West 2004) was used to calculate the volume of individual billets (i.e., 0–10%, 10–30%, 30–50% and 50–70%) and the formula for volume of a cone ($\pi r^2L/3$) was applied to the top section above 70% of tree height. The estimate of volume per individual tree was taken as the sum of the volume of each billet from that tree.

Statistical analysis

Restricted maximum likelihood analysis of variance in each measured trait was carried out using a general linear mixed-model of the form:

$$y = \mathbf{X}b + \mathbf{Z}u + e \qquad [1]$$

where y is the vector of observations on n traits, b and u are vectors of fixed and random effects respectively, **X** and **Z** are incidence matrices for fixed and random model terms and e is a vector of random residual terms. Variants of this model were implemented in ASREML (VSN International, Hemel Hempstead) as follows:

i) Preliminary investigation of pooling major and minor trial data

An exploratory analysis of genotype-by-site interaction (GxE) between the spatially contiguous 'major' and 'minor' trials was carried out on the common families. Differences between the thinning treatments in the two trials are confounded at the replicate level - replicates 1 to 5 in the main trial having been selectively thinned to two trees per plot with replicates 6 to 8 thinned to one tree per plot and the six replicates in the minor trial having self-thinned. The vector b (Eq. 1) contained sub-vectors for fixed effects including trial, family, trial-by-family interaction and replicate-within-trial, while u contained sub-vectors for the random residual effects which were estimated separately for each trial to investigate homogeneity. Since there was no indication of genotype-by-site interaction, the decision was made to jointly analyse the data in subsequent analyses. This benefits the precision of estimation for the common families and increases the generally low sample of families per provenance available in each trial if analysed separately.

ii) Variation and genetic parameter estimation among and within islands, provenances and families

Vector b (Eq. 1) contained sub-vectors for fixed effects of replicate and island, and u contained sub-vectors for the

TABLE 3 *Scoring system applied to individual trees in the IFP whitewood trials at 11.4 years-of-age: (a) scoring for stem form/straightness and (b) scoring for branching habit*

(a) Stem form/straightness scores

Rating	Description
5	Excellent tree, very straight
4	Good tree, one minor deviation from straightness
3	Fair tree, two deviations from straightness
2	Poor tree, three to four deviations from straightness
1	Extremely poor tree, five or more deviations from straightness and inclusive of major faults like multiple leaders, ramicorns, large hollows/swellings

(b) Branching habit

Rating	Description
3	Excellent - small diameter branches (relative to tree size), branch angle close to horizontal, good branch occlusion, long internode length, low incidence of branching, no ramicorns, no green branches at low height on bole.
2	Good – medium diameter branches, branch angle horizontal to moderately inclined, branch occlusion fair, long-intermediate internode length, low incidence of branching, no ramicorns, no green branches at low height on bole
1	Poor – large diameter branches and/or major defects such as poor branch occlusion/hollows/decay/termites; large branch stubs; high incidence of double whorls, short internode length-high incidence of branching; ramicorns; retention of green branches to a low height on the bole

random effects of provenance-within island, family-within provenance, plot and incomplete blocks (rows and columns). Provenance was treated as a random effect because the sample of families for some provenances was very small, and parameter estimates for these poorly sampled provenances will be regressed towards the mean.

Bivariate genetic correlation estimates between traits x and y were obtained from the estimated additive covariance and variance components as:

$$r_G = \frac{\sigma_{a_x a_y}}{\sqrt{\sigma^2_{a_x} \sigma^2_{a_y}}} \qquad [2]$$

where $\sigma_{a_x a_y}$ is the additive (family) genetic covariance component between traits, and σ_{a_x} and σ_{a_y} are the additive variance components for traits x and y respectively.

Narrow-sense heritability was estimated as:

$$\hat{h}^2 = \frac{\rho \sigma_a^2}{\sigma_a^2 + \sigma_p^2 + \sigma_e^2}, \qquad [3]$$

where σ_a^2 is the additive (family) variance, σ_p^2 is the plot variance, σ_e^2 is the error variance and ρ represents a coefficient of relationship of 1/3 accommodating some mixed-mating effects such as full-sibs and inbreeding , effectively causing families to be more related than are true half-sibs. The software estimates standard errors of variance components using the Taylor-series expansion method.

Determination of wood density

Wood discs 50 mm thick were taken from each of the 20 trees felled for volume estimation. Wood discs were taken at the base, breast height, 10%, 30%, 50% and 70% of tree height for half of the samples, while for the remaining 10 trees, a single wood disc was taken at breast height only. The 70 wood disc samples were reduced by band saw to a north to south, bark to bark, wood block approximately 50 mm square including the pith. Bark was removed, cut surfaces planed smooth and each sample was labelled by aluminium tag and then immersed in water to avoid splitting.

After one week, the blocks were re-sawn into defect free, 15–20 mm thick wedges with a width of approximately 50 mm at the outer edge. Smaller wedges were processed and measured whole and wedges longer than 140 mm were sectioned for ease of measurement. Wedge samples were immersed in water and later weighed and volume measured green (swelled) by immersion in water. The wood samples were first air-dried and later oven-dried for determination of wood basic density without removing extractives in accordance with Standards Association of Australia (1981).

Whole tree weighted basic densities of eight of the ten intensively sampled trees (two trees were omitted due to loss of labels during drying) were calculated by combining section (billet) volume with sectional average density to calculate a whole-tree weight, which was divided by whole-tree volume.

RESULTS

Volume equation and stand mean annual increment

Volume over-bark (VOB) as determined by Huber's standard sectional method for the 20 felled trees gave a mean of 0.6 m^3 per stem. Applying a second-order polynomial equation (dbh [cm] versus Huber's Volume [m^3]) to the data provided an R^2 of 0.99 from a regression relationship:

$$V_{Huber}=0.0007DBHOB^2 - 0.0007DBHOB - 0.0328 \quad [4]$$

Stem volume was modelled for all standing trees in the trial (including the minor trial) using Eq.4. Trial standing volume was estimated on this basis at 954 m^3. At age 11.4 years and assuming a stand area of 6.67 ha (major plus minor trial area excluding buffers) the estimated mean annual volume increment (MAI) was 12.5 m^3/ha/year.

Trial-by-family interaction

Preliminary analysis indicated no significant trial-by-genotype interaction between the spatially contiguous major and minor trials. For the families common to both trials, the trial term was non-significant for all traits ($p \geq 0.31$) as was the trial-by-family term ($p \geq 0.09$). Replicate-within-trial was significant for all traits ($p \leq 0.03$) except branching and family was significant for the growth traits ($p<0.001$) but not branching nor form ($p \geq 0.06$). Trial residual variance was homogenous for all traits $\frac{\sigma^2_{e\,(major)}}{\sigma^2_{e\,(minor)}}$ and ranged between 77 and 99%. Data from the minor and major trials were therefore pooled for the main analysis.

Island and provenance variation in DBHOB and form

The applied general linear model assumed provenances nested within islands. The majority of growth and branch trait variance was partitioned at the island level, with relatively small and imprecisely estimated provenance-level variance components, while there was little variation at the island- and provenance-level for form (Table 4). Considerable variance was partitioned into the incomplete blocks (row and column) for DBHOB at 4- and 11.4- years, and the column term aided in partitioning variance in the branching and form models. Inspection of replicate means for each trait revealed that

TABLE 4 *Summary of mixed model analysis of diameter at breast height over bark (DBHOB), height, branch and form traits at 11.4-year and 4 year measures with narrow-sense heritability $\hat{h}^2$, coefficient of phenotypic variation (CV_P) and predicted means for each island*

Trait		**DBHOB 11.4 y**		**DBHOB 4 y**		**Height 4 y**		**Branching 11.4 y**		**Form 11.4 y**	
Fixed term	**d.f.**	**χ stat**	**χ prob.**	**χ stat**	**χ prob.**	**χ stat**	**χ prob.**	**χ stat**	**χ prob.**	**χ stat**	**χ prob.**
Replicate	13	128.6	<0.001	26.9	<0.001	50.06	<0.001	40.11	<0.001	53.6	<0.001
Island	5	110.7	<0.001	18.6	0.002	14.9	0.011	10.61	0.06	5.1	0.40
Random term - variance component (standard error)											
Row-within-replicate		1.52	(0.53)	0.12	(0.08)	0.03	(0.02)	-ve (dropped)		0.00	(0.00)
Column (across replicates)		2.32	(0.68)	1.64	(0.42)	0.32	(0.08)	0.03	(0.01)	0.01	(0.00)
Plot σ^2_p		3.94	(0.83)	1.84	(0.20)	0.50	(0.04)	0.03	(0.01)	0.06	(0.02)
Provenance-within-island		0.23	(0.39)	0.15	(0.15)	0.06	(0.05)	0.01	(0.01)	0.01	(0.01)
Family-within-prov.σ^2_a		1.12	(0.42)	0.12	(0.09)	0.07	(0.03)	0.01	(0.00)	0.01	(0.01)
Residual σ^2_e		15.44	(0.81)	6.70	(0.18)	0.95	(0.03)	0.24	(0.01)	0.35	(0.02)
Heritability $\hat{h}^2$		0.16	(0.07)	0.04	(0.03)	0.14	(0.04)	0.13	(0.06)	0.10	(0.05)
CV_P		19%		22%		17%		36%		25%	
Estimated means (Island)											
Ambae		31.36		15.44		8.82		1.56		2.67	
Efate		28.14		15.40		8.16		1.67		2.53	
Maewo		28.21		14.65		8.31		1.61		2.56	
Malekula		30.28		15.11		8.67		1.54		2.64	
Pentecost		29.35		15.03		8.44		1.57		2.57	
Espiritu Santo		33.42		16.28		8.96		1.42		2.71	
Average s.e.		*0.90*		*0.57*		*0.35*		*0.13*		*0.13*	

replicates 1–8 (the major trial) were slightly better than 9–14 (the minor trial) for each trait at 11.4 years, reflecting the differences in thinning between the two with selective in the major and self-thinning in the minor trial. The differences, however, were surprisingly subtle. For example, 32.4 cm (major) versus 31.0 cm (minor) with s.e. 1.7 cm for mean DBHOB and 1.62 (major) versus 1.56 (minor) with s.e. 0.10 for mean branch score.

Genetic parameter estimates

Variance component and narrow-sense heritability ($\hat{h}^2$) estimates for all traits at 4- and 11.4- years are given in Table 4. There was significant family-level (additive) variance for all traits, resulting in low narrow-sense heritability estimates ranging between 0.10 and 0.16. An exception was DBHOB at 4-years, which had a family variance parameter close to zero. The coefficients of phenotypic variation were moderate (range 17–36%) for all traits.

Genetic correlations between growth trait measures ranged from low (e.g., 0.10 ± 0.29 between DBHOB and form at 11.4 years) to high (e.g., 1.00 ± 0.17 between DBHOB at 11.4 years and DBHOB at 4 years) (Table 5).

Variation in wood density in buffer trees of a bulked single-provenance seedlot

Wood basic density decreased up the stem and there did not appear to be any association between tree size traits and unextracted wood basic density at any of the sampling heights nor with whole tree density (Tables 6 and 7). Sampling at breast height appears to give the best overall estimate of whole tree density, with r^2 of 0.99 and bias (overestimate of density) of circa +6%. Sampling at 30% of tree height gave a lower mean bias (-2%) but a weaker linear relationship (r^2=0.86). Wood basic density at breast height was determined for 19 of the 20 felled buffer trees. The mean unextracted basic density (±standard deviation) of these samples was 330 (± 21) kg/m^3 with a range of 284–364 kg/m^3.

DISCUSSION

Island, provenance and family rankings

Variation amongst islands was significant for the growth traits, indicating that island-level selection will result in some genetic improvement. Families from Espiritu Santo gave the best diameter growth at 11.4 years while those from Maewo and Forari on Efate were the poorest. It should be noted, however, that the trial site is on Espiritu Santo and the magnitude and practical implications of GxE interaction in this species are still unknown. Form scores for the Espiritu Santo families were mostly better than the other islands while the reverse was true for branching score. The very high genetic correlation for diameter growth between the 4-year and 11.4-year measures bodes well for early selection for growth traits, which is directly associated with volume production in future seedling seed orchards.

Families of Espiritu Santo origin dominated rankings for DBHOB, form and branching traits. Of the 18 top families, ranked by a simple index formed by summing across growth and form trait ranks, only one, from West Ambae, was from outside Espiritu Santo. However, selection of trees-within-family as candidate plus trees for seed collection also needed to cater for seeding periodicity amongst the females and the dioecious character of the species, as many of the selected trees were non seed-bearing males. This required the listing of four to seven top ranked trees within each family, from a maximum of 8 to 14 trees per family available after earlier thinning.

Despite pooling of data from the major and minor trials, eight provenances in this IFP trial were represented by fewer than ten families. Where possible, recognising the scarcity of remaining wild trees in some of these subpopulations (Tale 2), progeny testing involving larger family samples would be desirable to confirm provenance performance.

Volume growth

The estimated mean annual volume increment (MAI) for the trial trees of 12.5 m^3/ha/year for this reportedly fast growing (Grant *et al*. 2012) tropical species was surprisingly low. One inherent problem with estimating MAI from first generation provenance-progeny trials is the large proportion of poorly-performing provenances and families. It is tempting to extrapolate the performance of the best performing provenances from South Santo to the entire site in which case the estimate of growth rate would be 18.3 m^3/ha/year. This assumption would only hold if site factors were not limiting in the absence of the large areas of less-intense competition occupied by the poorer provenances. In this case it is reasonable to assume that the trial has produced less wood than a commercial plantation might have, since the trial was not

TABLE 5 *Genetic correlations between pairs of traits and standard errors of correlation*

Genetic correlations (standard error)	Form 11.4 y	Branching 4 y	Height 4 y	DBHOB 4 y
DBHOB 11.4y	0.10 (0.29)	–0.10 (0.28)	0.55 (0.2)	1.00 (0.17)
Form 11.4 y		0.40 (0.30)	*	–0.08 (0.35)
Branching 11.4 y			*	–0.01 (0.24)
Height 4 y				0.98 (0.11)

* could not be determined

TABLE 6 *Basic density and standard deviation at six sampling heights along the stem of 20 buffer trees of the one bulked provenance seedlot surrounding replicates 1–5 in the IFP whitewood trials at 11.4 years-of-age*

Sample height	Basic Density (kg/m^3)	Stdev (kg/m^3)	R^2 (sample vs. whole tree density)	Mean bias (%)	n
Base	338	33	0.36	+13	8
Breast height	330	21	0.99	+6	19
10%	327	21	0.93	+6	9
30%	299	30	0.86	−2	10
50%	290	17	0.58	−6	8
70%	277	16	0.85	−11	8
Mean of all samples	313	31			62

TABLE 7 *Tree size, whole tree basic density and variation in basic density with tree height in eight buffer trees of the one bulked provenance seedlot surrounding replicates 1–5 in the IFP whitewood trials at 11.4 years-of-age (* signifies a missing value)*

					Wood basic density by sample height (kg/m^3)				
DBHOB (cm)	**Height (m)**	**Tree volume (m^3)**	**Whole tree density (kg/m^3)**	**Base**	**Breast height**	**10% Height**	**30% Height**	**50% Height**	**70% Height**
49	20.3	1.59	297	332	316	313	*	290	261
40.1	18.3	1.12	298	326	315	315	302	276	264
36	18	0.77	307	*	325	327	309	278	269
30.8	16.8	0.61	324	377	346	351	317	292	287
30.6	17.7	0.64	321	355	338	332	309	321	297
26.5	16.4	0.45	305	348	*	328	297	284	265
26.3	17.5	0.43	334	*	346	364	329	305	303
22.6	16	0.32	290	359	308	299	*	270	267
		Means	**310**	**350**	**328**	**329**	**311**	**290**	**277**

fertilised and was thinned and managed for seed production rather than timber production. It is possible that thinning was carried out late and not at the optimal time, as evidenced by the very minor difference between the selectively- and self-thinned parts of the trial: the self-thinned portion may have been slow to recover increment post-thinning.

As for many other tree species, the MAI of whitewood is not static but increases over time, particularly between years 7 and 15 (Grant *et al*. 2012) and, therefore, this provides further support for the prediction that the MAI of this IFP trial may approach 19 m^3/ha/year at year 17.

Genetic parameters

Single-site heritability estimates were moderate to low for growth (0.16) and form (0.10) traits at 11.4 years, similar to estimates for these traits reported in other species, for example, *Eucalyptus* (Eldridge *et al*. 1993, Borralho *et al*. 1992) and *Pinus* (Atwood *et al*. 2002, Gapare *et al*. 2010), but lower than that found for *Tectona grandis* (Narayanan *et al*. 2009, Monteuuis *et al*. 2011). This coupled with moderate coefficients of phenotypic variation indicate that prospects for genetic improvement by recurrent selection and breeding are promising. Precision of estimation was moderately high in all but the 4-year DBHOB. As the data are drawn from a single site only, upward bias in these estimates is expected as the environmental (genotype-by-site, GxE) component of variation cannot be quantified. Plans to establish second generation progeny trials across a range of sites from the selected individuals in this study will provide a future opportunity to quantify GxE interactions.

Diameter at breast height over bark at the 4- and 11.4-year measures were very closely correlated (genetic correlation of 1.00 ±0.17). Similar age-age genetic correlations were found for growth traits in *Acacia auriculiformis* (Hai *et al*. 2008), *Eucalyptus globulus* (Borralho *et al*. 1992, Stackpole *et al*. 2010) and *Pinus taeda* (Williams and Megraw 1994). In whitewood this correlation is encouraging as early selection for diameter/volume growth and early thinning in seedling seed orchards can be incorporated into the breeding strategy. Growth and form traits were not strongly correlated (−0.10±0.28 for branching and 0.10±0.29 for form) though they had high standard errors of correlation. Given this low correlation it is possible these traits can be improved independently of one another. Similarly, branching and form traits were only moderately correlated (0.40±0.30).

Variation in wood basic density

Basic density influences many properties of wood, including its sawing and working features. It provides a good indication of the strength, stiffness and toughness of the timber as well as a guide to the severity of shrinkage (Eldridge *et al*. 1993). Wood basic density has usually been found to be under moderate to strong genetic control (e.g., in *Eucalyptus* species (Downes and Raymond 1997)), though usually with a low coefficient of variation, and is often regarded as the single most important wood property criterion for timber selection (Panshin and de Zeeuw 1980).

Given whitewood's reputation for producing low-density timber of low strength it is important to quantify genetic variation in wood density in this species and the potential for increasing it through selection and breeding. Non-destructive (coring) sampling of the major IFP provenance/family trial is therefore recommended to determine genetic parameters for wood basic density in *E. medullosum*. The preliminary investigation reported here of variation in wood density in one provenance from a bulked seedlot was undertaken to inform the sampling strategy applied in any larger study.

Basic density decreased with increasing stem height. The best linear relationship between whole tree density and density at the various sampling heights was with the samples taken at breast height (r^2=0.99) but with an upward bias indicated of about 6% at this age. Breast height non-destructive coring in any latter studies, apart from its convenience, can also be justified as it represents the density of the butt log which is the most valuable part of any tree and perhaps more so in young whitewood. The upper wood of whitewood less than 20 years old is of poor quality (low density, wandering pith) and difficult to market even when preservative treated (N. Croucher, Vanuatu sawmiller, pers. comm. 2010).

An air-dry density range for mature whitewood trees of 365–450 kg/m^3 at 12% moisture content has been reported earlier (Keating and Bolza 1982, Thomson 2006). This is equivalent to a range in basic density of 292–360 kg/m^3 using Greenhill and Dadswell's (1940) formula to convert air dry densities to basic densities. In this study, most samples (n=19 samples/trees) were taken at breast height where basic density ranged from 284–364 kg/m^3, with a mean (±standard deviation) of 330 (±21) kg/m^3. This is an almost identical range to that given in the literature for mature trees. There was no evidence in this data of a relationship between growth rate and wood basic density in whitewood trees of 11.4 years-of-age.

CONCLUSIONS

This study has demonstrated considerable island- and family-level variation in traits of economic significance in *E. medullosum*. Both island- and family-level selection in a recurrent selection and breeding program should result in genetic gain. The study has also underlined the importance of genetic conservation of a wide range of genetic material of this species, which like so many other timber species in the Pacific (see Elevitch 2006 for numerous examples), has suffered subpopulation degradation and extinction due to over harvesting. In this study, material from highly threatened subpopulations (e.g., Sara, which is now entirely depleted, see Table 2) have performed well. Though conducted on a modest scale, this breeding program is an important means for conserving the genes of this subpopulation. Maintenance of genetic diversity in wild populations through a conservation strategy is recommended to ensure the availability of germplasm for long-term improvement.

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Plantation-grown whitewood timber in Vanuatu: challenges and opportunities for export and domestic use

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SUMMARY

Whitewood (*Endospermum medullosum)* is a useful timber species, previously sourced from native forests and now available from plantations in Vanuatu. However, plantation-grown whitewood will have about 30% more knotty wood than previously experienced in logs from native forest. This will impact on the economics of growing and processing whitewood, and on potential uses of the timber. Opportunities to add value to knotty wood are to produce large section structural lumber, to recover short lengths of clear wood for furniture, and to treat heartwood with preservative chemicals to enable structural use in exposed and in-ground applications.

Keywords: *Endospermum medullosum*, value-adding, plantations, Vanuatu

Bois de coupe de bois blanc de plantations à Vanuatu: défis et opportunités pour l'exportation et l'usage domestique

R. VIRANAMANGGA, G. PALMER et K. GLENCROSS

Le bois blanc (*Endospermum medullosum*) est une essence utile, qui provenait auparavant de forêts natives et qui est maintenant disponible en plantation à Vanuatu. Cependant, le bois blanc cultivé en plantation aura un bois 30% plus noueux que le bois obtenu auparavant en provenance des forêts natives. Cela va impacter l'économie de la croissance et de la préparation du bois blanc, ainsi que ses utilisations potentielles. Des opportunités pour ajouter de la valeur aux bois noueux consistent à produire de coupes structurelles à section large, pour récupérer des petites longueurs de bois clair pour le mobilier, et à traiter le coeur du bois avec des produits préservatifs, pour permettre une utilisation structurale dans des applications exposées et dans la terre.

La madera de *Endospermum medullosum* de plantaciones en Vanuatu: retos y oportunidades para la exportación y su uso doméstico

R. VIRANAMANGGA, G. PALMER y K. GLENCROSS

La madera blanca (*Endospermum medullosum*) es una especie maderable de considerable utilidad, que previamente se aprovechaba del bosque natural y ahora se encuentra disponible procedente de plantaciones en Vanuatu. Sin embargo, la madera de *E. medullosum* de plantaciones contiene cerca de un 30% más de nudos que la de trozas procedentes de bosque natural. Esto tendrá un impacto económico en las operaciones silvícolas y de procesamiento de *E. medullosum*, y en los usos potenciales que se le pueden dar a esta madera. Las opciones para agregar valor a la madera con nudos son el producir madera para la construcción de grandes secciones, el despiezar en pequeñas longitudes de madera libre de nudos para ebanistería, y el tratar el duramen con conservantes químicos que permitan su uso estructural al aire libre y bajo el suelo.

INTRODUCTION

Sustained production of wood products can provide cash for goods and services not available from subsistence agriculture, and thus help rural poor people to overcome poverty and satisfy aspirations (Scherr *et al.* 2003). In addition, domestic wood production and processing may strengthen the balance of trade through export earnings and reduced timber imports. The viability of a timber industry depends on wood properties, the resource available, processing opportunities and market potential. Here we draw on published literature, interviews with industry stakeholders, and a sawing study to examine product development opportunities for plantation grown *Endospermum medullosum* (whitewood) in Vanuatu.

REVIEW

Whitewood is one of the tallest tree species in Vanuatu's forests, and remains one of Vanuatu's premium native timber species. While it typically grows to a height of 40 m, individual trees can attain 60 m in height with a clear bole of 15–30 m and a diameter (above buttress) of 60–100 cm (Thomson 2006). It supplied over half the country's annual log production (Vutilolo *et al.* 2005) until the natural forest was almost exhausted in the early 1990s (McGregor and McGregor 2010).

Whitewood is a light hardwood with a density of 400–450 kg/m^3 and may have conspicuous growth rings (Groves and Wood 1998). It is readily accepted by wood manufacturing industries in both domestic and export markets, and is used locally as a structural timber, in furniture and cabinet making, as veneer and plywood, and for carving. It is susceptible to blue-stain fungi, pinhole borers, marine borers and termites. Logs should be sawn within two days of felling and sawn wood should be air dried to avoid blue-stain. Alternatively, whitewood can be vacuum/pressure treated with copper chrome arsenate (CCA) or copper azole (e.g., Tanalith).

Whitewood is currently sourced from plantations and native forest on Espiritu Santo in the north of Vanuatu, and in smaller quantities from native forests on Efate Island, where the capital Port Vila is located (Figure 1). Most processing of whitewood is by portable sawmill with just one stationary sawmill on Santo (Melcoffee Sawmill Company). First grade green whitewood timbers are sold to timber yards, value-adding processors and to consumers at the prices indicated in Table 1. One pressure treatment plant on Efate operates sporadically, once or twice a month due to limited supply of whitewood timber. Three pressure treatment plants on Santo are fully operational and exert some price control in domestic markets because of whitewood's susceptibility to degrade.

Whitewood secured a niche market for mouldings in Japan during the 1990s, because of its weight, appearance and workability (Thomson 2006), but these exports ceased in 2008 (McGregor and McGregor 2010). The majority of whitewood harvested in the 1990s was exported to Japan by Melcoffee Sawmill Company as kiln dried material at a free on board (FOB) price of \$766–1094 /m^3 for clear boards, \$656 /m^3 for finger-jointed laminated boards and up to \$1,116 /m^3 for laminated board. Currently domestic markets exist for defect-free (clear) wood, and demand exceeds supply.

In Vanuatu, imported softwood is sold at an average price of \$740/m^3 retail, and softwood imports amounted to \$2.1 million in 2011 (Vanuatu National Statistics Office 2012). This represents approximately 5,000 m^3 domestic consumption, mainly in the centres of Port Vila and Luganville. An informal survey of sawn softwood products on sale in Luganville indicated that imported softwood from New Zealand was generally non-structural grades, and highlights a need to educate consumers about timber grades, particularly given the cyclonic conditions that regularly occur in Vanuatu.

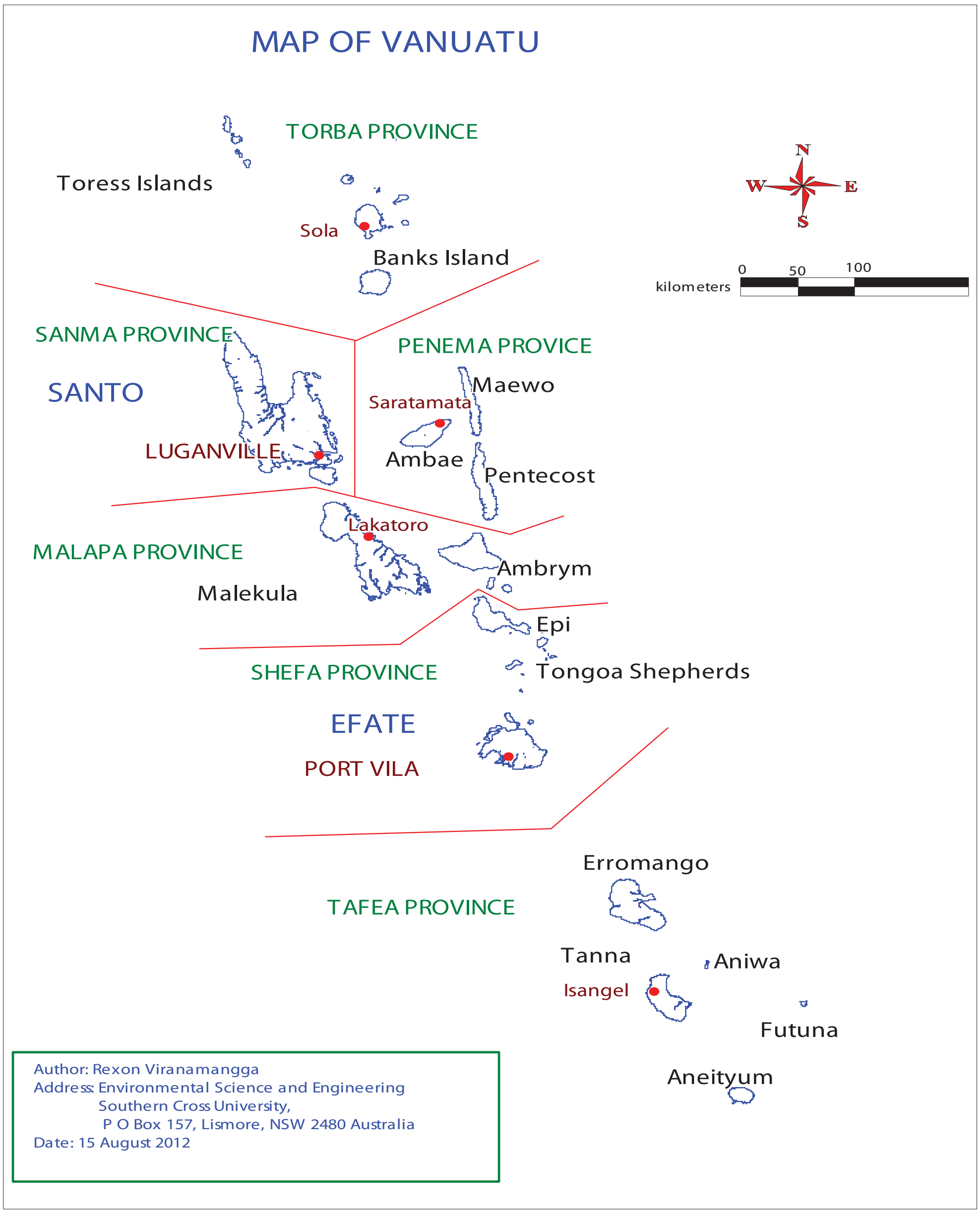
Several issues appear to contribute to the demand for softwood, despite its poor strength. Imported softwood is supplied dry, dressed and in standard 6 m lengths, providing a stable and easily handled product. It is readily available, and commonly delivered to site by hardware stores. Most builders lack sufficient knowledge of timber grading and durability and choose softwood for its convenience rather than strength. Consumers complain that treated whitewood is less durable than imported softwood, a consequence of whitewood treatment aimed at preventing degrade during trade, rather than during service.

In addition, domestic timber demand is greatest in the capital Port Vila, where imports are common and domestic supply is limited, whilst most of the whitewood supply is from Santo 200 kms away by sea. Demand for whitewood on Santo is comparatively small, and unable to support local value-adding because throughput is insufficient to recover capital costs. However, local demand for whitewood is sufficiently strong that it sells at a premium, with the Melanesian Commerce and Industries selling treated whitewood timber at prices higher higher than the average price of NZ pine.

The formerly abundant native forest timber contributed to wasteful practices of selling only the clear boards and discarding lower grade timber. This was possible, because recovery of clear boards from native forest logs was about 50% (personal communication, Neil Croucher, Melcoffee Sawmill Company). Despite the current restricted supply, these wasteful practices have continued, with timber yards purchasing primarily clear grade and rarely second grade timbers. Lower grade timbers are either left at the processing site or scavenged by local people for firewood and temporary structures. This is inefficient, both in terms of utilsation and economics, and it is critical to change these customs to gain resource and economic efficiencies. The sawmill study reported here establishes recovery by grade from plantation material.

A future whitewood industry in Vanuatu will depend on plantation production. Growth rates of about 20 m^3/hectare/year make whitewood plantations a viable proposition (Grant *et al.* 2012). Domestic demand of 5,000 m^3 is currently supplied by imported softwood, and could be displaced by plantation grown whitewood. Annual production of whitewood sawlogs could reach 14,000 m^3/year within 10 years, sufficient to support a viable wood industry if this wood is of sufficient quality. However, plantation growth conditions and harvest age mean this new resource will differ in dimensions and character from the previous native forest resource,

FIGURE 1 *Map of Vanuatu showing the islands of Espirtu Santa and Efate*



and create significant challenges in processing and product development (Nichols and Vanclay 2012).

At current pricing, whitewood is competitive with imported softwood, and security of supply appears to be the main market driver. Existing whitewood plantations in Vanuatu are scattered and will hamper efficient and consistent supply of logs to processors. Most of the current plantation area of 730 hectares is located on the east coast of Santo Island (470 ha), with the remainder of the resource fragmented among 270 sites on 12 islands. Future plantation establishment should expand the estate near processors, and any new developments should be informed by the plantation resource. Efficiencies may be gained by devising preliminary processing in the forest with finishing at a centralised plant. In addition, low cost methods to protect sawnwood from blue staining are needed to encourage improved utilisation of this resource.

TABLE 1 *Lumber prices in Vanuatu*

Stage of processing	Port Vila (capital city) ($/m³)	Espiritu Santo ($/m³)
1st grade, green off saw	$380–$490	$425–$493
1st grade air dried,	$658–$767	$822
1st grade pressure treated	$930	$531

SAWMILL STUDY

Methods

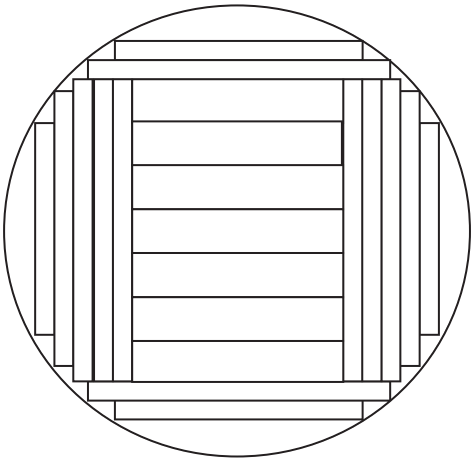
The viability of the plantation industry depends in part on the ability of sawmillers to secure adequate recovery from smaller plantation material, so a sawmill study was conducted to examine sawn wood recovery by grade classes, to investigate mechanical properties of plantation material, and to test the penetration of preservative into whitewood heartwood.

Six whitewood trees were selected in a 16-year-old plantation established by the Melcoffee Sawmill Company at Lorum on the south east coast of Santo Island. This plantation had been established at wide spacing (10 m × 4 m) and manually pruned to approximately 6 m. The six trees, chosen to sample the range in diameter at breast height of the stand, were felled and cross cut in the forest to maximize the yield of straight logs and then transported by road to the Melcoffee sawmill. The average small end diameter of logs was 29.0 cm (range19.2–42.8 cm). The logs were sawn to produce 25 mm boards from the outer clear wood sections, and 50 mm thick random width boards from the knotty, pith-included core (Figure 2), using a primary break-down band saw and a secondary circular rip saw.

The resulting sawn wood was strip stacked and air-dried under cover. Following air drying for 8 weeks, all sawn boards were visually graded by students of the Agricultural College at Luganville under supervision of experienced project staff. Whole boards were sorted into one of four appearance grades: (1) clear wood, (2) clear on one face and edges, (3) knotty wood excluding pith, and (4) pith inclusions. The dimensions of each board were measured using a cloth tape (length) and ruler (thickness and width). Each board was then marked to define clear sections in decimetre lengths between defects, simulating cross cutting.

A random sub sample of 30 boards, nominally 100 × 50 mm was selected from the sawn timber and tested for strength and stiffness in bending. Sample selection and tests were conducted according to the specifications in Australian and New Zealand standard AS/NZS 4063:1992 *Timber – Stress-graded – In-grade strength and stiffness evaluation*. The data derived from these tests were used to calculate basic working stress (R_{basic}) and characteristic stiffness (E_k) in bending and compared to current structural grade specifications used in Australia. Structural grade specifications are determined by the weaker timber in any sample to ensure the whole batch meets the minimum requirement. AS/NZS 4063:1992 *Timber – Stress-graded – In-grade strength and stiffness evaluation* uses the 5th percentile ranked value for various mechanical properties of a population, which is further scaled to account for a safety factor. This means that culling the weakest pieces from a batch of wood increases the overall grade, so the trial examined potential for such culling of whitewood sawnwood. Each board was visually sorted into 4 structural grades, defined as (1) clear wood, (2)boards with small knots (<50 mm diameter) only, (3) boards with large knots (>50 mm), and (4) boards with included pith.

FIGURE 2 *Typical saw pattern recovering 25 mm thick boards free of defect in random widths and 50 mm thick boards where defect is likely*



Samples of sawn (4 pieces of 100 mm × 100 mm) and round (2 pieces >100 mm diameter) whitewood were selected from different trees and transported to Australia where they were pressure vacuum treated with Koppers Tanalith E in the Southern Cross University research facility (Lloyd *et al.* 2011). The ends of each sample were coated with a sealant prior to treatment. Penetration of preservative was assessed qualitatively on cross cut sections after treatment.

Study results

A log volume of 6.35 m^3 (green, over bark) was processed to recover 1.91 m^3 of sawnwood (green off saw), a recovery rate of 30% after docking to nominal sale lengths (i.e., multiples of 0.3 m plus 100 mm over cut allowance). Maximum length was 4 m and minimum length was 2.8 m.

Table 2 shows the proportions of sawn volume recovered for each grade defined, and highlights the lower recovery expected from a young plantation resource (35% clear wood recovery compared to 50% from native forest material), despite pruning the plantation trees at a young age.

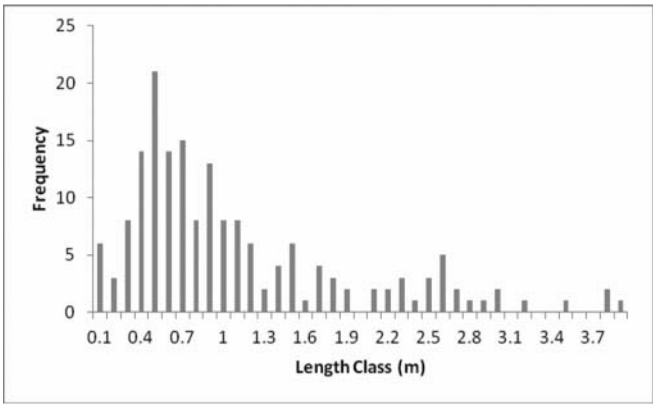
After simulated cross cutting to remove all defects, the recovery of clear wood as a proportion of all sawn timber was determined to be 83%. The distribution of clear wood piece length recovered from simulated cross cutting is shown in Figure 3. The short lengths of clear wood recovered from longer knotty material (Figure 3) reveal the potential to produce clear 'shorts' for furniture joinery.

The basic working stress (R_{basic}) for the sample was 2.3 MPa and characteristic stiffness (E_k) 3812 MPa. The distribution of strength values by visually sorted structural grade is shown in Figure 3. The wide variety in the data indicates

TABLE 2 *Proportion of over bark stem volume recovered in each appearance grade*

Appearance Grade	No of pieces	Proportion of volume (%)
1 = clear faces and edges	25	32%
2 = clear on one face and both edges	2	3%
3 = knotty excluding pith	37	34%
4 = pith included	32	31%
Total	96	100%

FIGURE 3 *Frequency distribution (number of pieces) of clear wood recovered from knotty wood after cross cutting to remove defects*

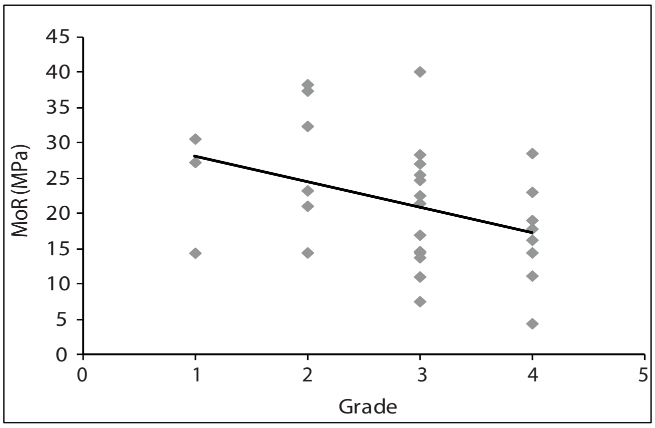


some potential for genetic improvement to achieve higher strength from selected superior trees (Doran *et al.* 2012).

Because of the way that structural grades are determined, culing the weaker pieces from a batch increases the grade of structural outturn. The distribution of strength by grade class shown in Figure 4 indicates that whilst many pieces of whitewood exceed common structural grades used in Australia (AS 1720.1 Timber Structure Part 1 Design Methods), other weaker pieces reduce batch averages. Since all visual grade classes displayed some weaker pieces, it appears that visual grading cannot presently be used to reliably select structural characters. However, structural products may be attainable if a suitable sorting mechanism can be devised. This may be as simple as, for example, measuring wood density if this is the limiting factor.

The stiffness (modulus of elasticity) of whitewood indicates that a sectional dimension of 90 ×45 mm whitewood is approximately equivalent to 70 × 35 mm Australian softwood in a commonly used grade (MGP 10 – Plantation Timber Assoc. Australia, 1996). In respect of strength however, a section of 150 × 60 mm whitewood equates to 70 × 35 mm of material graded as MGP 10. While these sectional comparisons indicate less efficient utilisation of whitewood, it is noteworthy that large sections offer opportunities to utilise the pith by sawing this defect into single boxed sections fully enclosing the pith, and the impact of larger knot defects can be more readily accommodated in large sections. Further research is required to establish mechanical properties in these large sizes to develop building design specifications using knotty structural whitewood.

FIGURE 4 *Grade versus modulus of rupture for 30 samples of nominally 100 mm × 50 mm whitewood, sorted into grades: 1 = clear wood, 2 = small knots (<50 mm) 3 = some large knots (>50 mm) 4 = pith included*



Whitewood has low durability to biological degradation, but will readily take chemical preservative treatment (Groves and Wood 1998). This capacity represents a significant opportunity to add value to whitewood in Vanuatu, since outdoor and in ground products may be produced from any part of a log. Figure 5 illustrates that good penetration of preservative (Tanalith E) can be achieved into whitewood sapwood and heartwood. The end sections shown are from a piece 100 mm × 100 mm × 1 m long, cross cut at its mid-point. The pith is evident as a small circular section near the top of the image and is surrounded by heartwood. Irregular penetration of preservative is indicated by wood of lighter green colour. The sample shown was selected as the poorest penetration pattern achieved amongst six samples. Further research is required to test the efficacy of this preservative treatment in service.

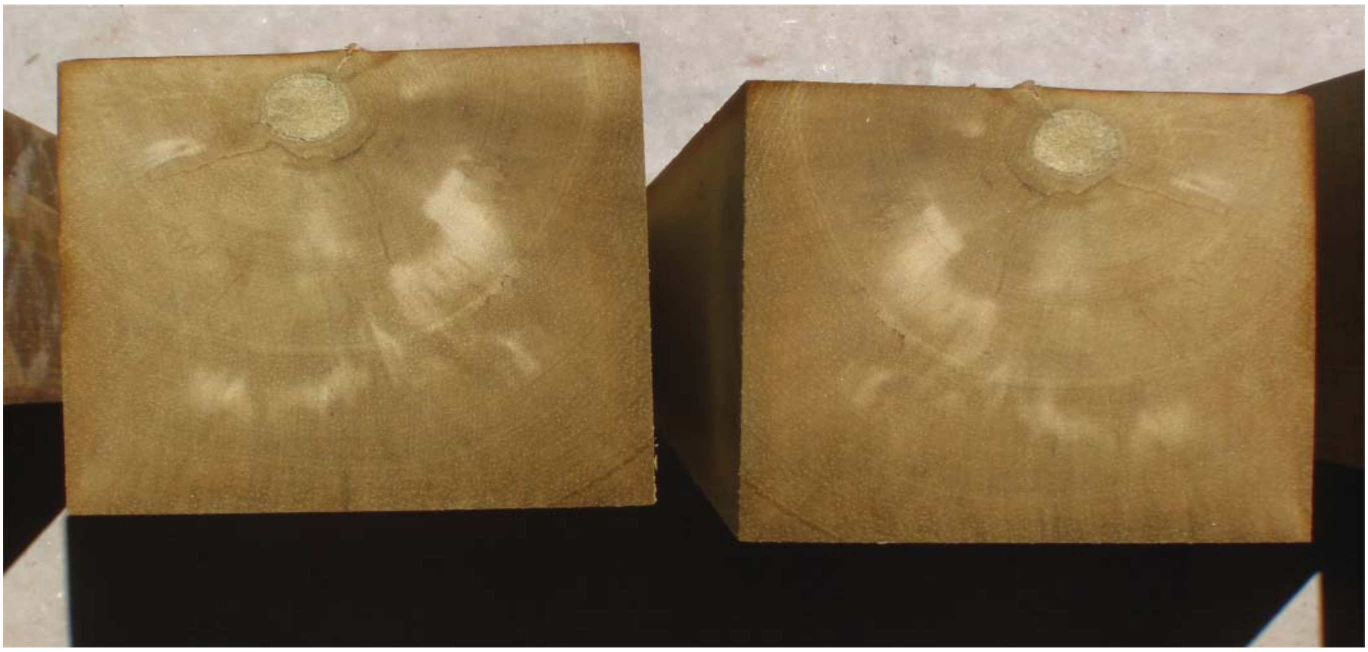
DISCUSSION AND CONCLUSION

The study illustrates the importance of recovering value from knotty and pith-included wood, which comprise over 65% of the wood sawn from plantation logs. Two options for utilising this knotty wood are to develop structural products, and to produce short clear lengths for furniture manufacturing. The potential of structural products depend on the mechanical properties of large-section sawnwood, on strength sorting technology and on the provision of engineering and design information for builders. Technical aspects need to be accompanied by an education program for wood users and building material suppliers so that they are adequately informed about structural strength, timber durability and degradation.

The development of a whitewood production and processing industry will also depend on expanding processing capacity to achieve economies of scale. At present the processes that add greatest value are air drying and preservative treatment. The latter are not easily achieved in a portable saw mill context and require significant investment in infrastructure. Nonetheless, at a small scale wood can be protected from borers and blue stain by spraying and dip diffusion of preservative chemicals for interior use. Exterior and ground contact uses demand pressure and vacuum processes to ensure effective treatment.

This study has revealed a lack of resource base to supply the whitewood production and value-adding processing industry in Vanuatu. Successful establishment of a small-scale resource has been achieved, but a larger-scale resource is needed before significant domestic and export markets can be redeveloped or investment into value-adding process infrastructure can be attracted. Softwood imports remain relatively

FIGURE 5 *Penetration of copper based preservative (Tanalith E.) into the heartwood of whitewood*



small (5,000 m^3 in 2011) and former exports of whitewood (3,000 m^3 in 2003) reveal the potential for a larger processing industry. The primary challenges in the short term to secure sufficient plantation resource near processing facilities, and to develop in-field pre-processing to facilitate efficient transport of wood for final processing in centralised plants.

ACKNOWLEDGEMENTS

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Developing establishment guidelines for *Shorea palosapis* in smallholder plantings in the Philippines

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SUMMARY

A series of trials examining fertilizer-shading interactions on the island of Leyte (Philippines, 11°N) revealed that the endemic dipterocarp mayapis (*Shorea palosapis*) benefits from shade trees, either directly above or to the east, during the early stages of plantation establishment. Although it can attain 2 cm/year diameter increment in plantations, mayapis exhibits poor growth and survival under wide spacing, when waterlogged and in exposed bare soil. Indications that early growth can be hampered by high soil temperatures warrant further research and development of practical planting techniques for smallholders.

Keywords: establishment, endemic tree species, fertilizer-shade interaction, nurse crop

Développement de lignes de conduite pour l'établissement du Shorea palosapis dans des petites plantations des Philippines

N.O. GREGORIO, J.L. HERBOHN et J.K. VANCLAY

Une série d'essais examinant les interactions engrais/ombre sur l'île de Leyte (Philippines, 11 degrés N) a révélé que le dipterocarp mayapis (Shorea palosapis) endémique profite des arbres offrant un ombrage, directement au dessus ou vers l'est, pendant les premiers stades de son établissement en plantation. Bien qu'il puisse atteindre des croissances de diamètre de 2 cm/an dans les plantations, le mayapis connait maigre croissance et survie quant il est trop espacé, noyé ou exposé sur la terre nue. Des indications que la croissance initiale peut être empêchée par des fortes températures du sol encouragent une recherche plus poussée et un développement de techniques pratiques de plantation pour les petits exploitants.

Elaboración de directrices para el establecimiento de *Shorea palosapis* en plantaciones de pequeños propietarios de Filipinas

N.O. GREGORIO, J.L. HERBOHN y J.K. VANCLAY

Una serie de ensayos que examinaron las interacciones entre sombreado y fertilizante en la isla de Leyte (Filipinas, 11°N), revelaron que durante las etapas iniciales del establecimiento de la plantación, la dipterocarpácea endémica mayapis (*Shorea palosapis*) se beneficia de la presencia de árboles de sombra, ya sea directamente por encima o bien localizada al este. Aunque incremento diamétrico en plantaciones puede alcanzar los 2 cm/año, mayapis muestra un crecimiento y una supervivencia pobres bajo espaciamientos amplios, así como en los suelos anegados o los desnudos y expuestos. Ciertos indicios de que el crecimiento inicial puede verse obstaculizado por altas temperaturas del suelo merecen investigación adicional y el desarrollo de técnicas de plantación prácticas para pequeños propietarios.

INTRODUCTION

During the past decade, the Philippine government's policies on forest management have shifted from a focus on large-scale, timber-oriented industrial forestry to multiple-product, people-oriented small-scale tree farming (Mangaoang 2002). Small-scale forestry has been promoted as an effective approach to solve the widespread loss of forest, promising poverty alleviation while increasing environmental protection. It is envisaged that smallholder tree crops can benefit the rural economy (Nichols and Vanclay 2012) and ensure the supply of plantation timber (Dy and Bautista 1999, Guiang 2001). However, previous research undertaken in Leyte Island indicates that only about 30% of the potential timber yield is being realized by smallholder tree farmers (Herbohn *et al*. 2009a). Lack of appropriate silviculture, inadequate site-species matching and inferior germplasm contribute to low financial returns from smallholder tree plantations (Herbohn *et al*. 2009b). This study forms part of a larger project that addresses these issues (Herbohn and Harrison 2005).

Existing tree farms on Leyte Island comprise almost entirely two exotic species – gmelina (*Gmelina arborea*) and mahogany (*Swietenia macrophylla*) (Herbohn *et al*. 2009a). These species were widely planted during the National Forestation Program (NFP) of the Department of Environment and Natural Resources (DENR) during the 1990s (Harrison *et al*. 2004). Although these exotics dominate most tree farms and reforestation projects, some areas have been planted with longer rotation species including dipterocarps (Cedamon *et al*. 2011), and there is interest in domesticating indigenous tree species (Mangaoang and Pasa 2003). Local and national laws have been enacted to promote planting of native trees, the most recent being the National Greening Program which aims to establish 1.5 billion native trees during the next five years (DENR 2011). There have been several local and national initiatives to promote planting of native trees, including trials of the "Rainforestation Farming System" (known locally as Rainforestation) established on Leyte Island in the mid-1990s (Milan *et al.* 2004). Under this system, fast growing native species were planted first with successional species and then with dipterocarps and fruit trees in the subsequent year.

Mayapis (*Shorea palosapis* (Blanco) Merr.), a native forest hardwood endemic to the Philippines, is a prime candidate for domestication. It has long been recognised as a prime timber species (Nablo 1940, Reyes 1959), it is one of the species most preferred by farmers (Santos *et al.* 2003), has one of the highest growth rates amongst dipterocarps in cultivation (Milan *et al*. 2004), and is on the IUCN Red List (Ashton 1998). Despite past exploitation, mayapis remains one of the most widespread dipterocarps on Leyte, occurring naturally on a wide range of sites from 100–800 m elevation (Langenberger 2006). Previous work on reforestation has recognised its potential, categorising it as a "superb, all purpose" tree (Schulte 1996). However, further work is needed, as planting stock is problematic and site requirements remain ill-defined. Mayapis has recalcitrant seeds typical of dipterocarps, viable for 3–7 days after collection, so most plantings rely on wildlings. Paler and Alcober (1991) and Zabala (1993) reported some success with rooted cuttings, but these techniques have not yet been operationalized. In his review of dipterocarp plantations, Weinland (1998) recognised the challenges of effective establishment, and called for "controlled (artificial) experiments . . . for base line information on the light requirements of species to be complemented by field trials where shade from natural vegetation is manipulated". Our trials (Gregorio *et al*. 2009) address this question, and seek to inform future reforestation efforts with this species, specifically with regard to establishment procedures.

Some guides advocate that mayapis "can be planted directly in open areas" (Visayas State University c.1995) and is "pioneer-like, least susceptible to drought and performing best in open areas" (Marohn 2008), whilst others recommend it as a shade-loving tree that should be planted during the second year of a rainforestation effort (Margraf and Milan 1996). Otsamo (1998) recommended *Paraserianthes falcataria* as a nurse tree to assist establishment of "fast-growing plantations on *Imperata* grasslands using dipterocarps with wide ecological tolerance". It has long been observed that shade can improve the nutrient balance in tree seedlings (Bevege and Richards 1970), and this concept is applied commercially with agroforestry coffee typically grown under shade with minimal fertilizer input, whilst industrial coffee tends to be grown in full sun with fertilizer and irrigation (DaMatta *et al*. 2007). In this study, we explore the utility of both artificial shade and nurse trees in facilitating plantation establishment.

Bruzon (1978) reported that potted mayapis grew better with fertilizer, and recommended 1–2g NPK per seedling, but others have shown that fertilizer may have no effect, or may even be detrimental to *Shorea* seedlings if it interferes with ectomycorrhizae (e.g., Turner *et al*. 1993). Our study includes fertilizer applications to provide preliminary guidance for plantation establishment.

METHODS

A series of trials was established at Leyte Leyte (11°N 124°E, Figure 1) to explore several aspects of the silviculture of mayapis (*Shorea palosapis*) and its interactions with three other species of interest to smallholders (narra, *Pterocarpus indicus;* falcata, *Paraserianthes falcataria;* mahogany, *Swietenia macrophylla*). These species were chosen to evaluate well-documented synergies between nitrogen-fixing and other species (Forrester *et al*. 2006) in both native and exotic species. Two trials employed clinal designs (Vanclay *et al.* 1995, Vanclay 2006a) to investigate specific responses to a wide range of spacing and species composition, and these offer some insights into early growth of mayapis. A third trial specifically examined shade and fertilizer responses of mayapis, in an attempt to resolve contradictions observed in the literature. The experiments were established in 1.2 ha of former pasture land in the municipality of Leyte in Leyte Island, Philippines. Figure 2 shows the location of the study site and

FIGURE 1 *Trial location in Leyte Leyte, Philippines*

FIGURE 2 *Google Earth image (4 July 2011), showing variable spacing trial (top), mixture trial (centre, mayapis in south-west corner), and shading+fertilizer trial (bottom). Oval indicates watercourse causing seasonal waterlogging*

distribution of the three field trials within the experiment area.

Collection of seeds and production of seedlings for the trials

Suitable mayapis mother trees were identified using the database of premium native trees (Gregorio *et al*. 2010) and seeds were collected from four mother trees in the forest reservation of Visayas State University (VSU) in Leyte Island. Seeds were sown directly in polybags filled with a potting medium comprising 60% forest soil, 20% mudpress and 20% rice-hulls. Fungicide was applied weekly through overhead sprays until seeds germinated, and subsequent watering, weeding and pest control applied as needed. Since the potting medium was relatively fertile, no fertiliser was added to the pots. Seedlings were hardened ten weeks after germination by exposure to full sunlight and reduced watering. Also, seedlings were placed on elevated beds to promote air-pruning of roots. The hardening process lasted for one month after which 500 seedlings with relatively uniform height and base diameter were selected for the trial.

Two of the trials included mahogany, falcata and narra and these seedlings were propagated together with the mayapis. Mahogany seeds were collected from five phenotypically superior mother trees from the VSU forest reservation. Narra and falcata seeds were purchased from Bukidnon Forest Industries, a company producing genetically superior seeds of timber species. Seeds of narra and falcata were sown in germination boxes with pasteurised medium composed of 60% soil and 40% sand. Young seedlings were potted to individual polybags after a pair of leaves formed. Because seeds of mahogany are relatively large, these were sown directly to individual pots. The pots were placed on elevated beds and hardened by exposing to sunlight and reducing water application. A total of 250 seedlings with relatively uniform height and diameter were selected from each species for the field trials.

Experimental design and treatments

The shading trial employed a randomized complete block design with two replicates and 15 treatment combinations (5 shade levels and 3 fertilizer rates). Shade treatments included an untreated control, nurse trees and artificial screens (light, medium and dense). Screens measuring 60 × 60 cm were assembled from 4 cm bamboo slats to provide dense, medium and light dappled shade with densities of 90%, 60% and 30%

respectively. Kakawate (*Gliricidia sepium* (Jacq.) Steud.) was used as shade tree as is common practice in agroforestry plantings locally. Fertilizer treatments included control (no fertilizer), 'light' (65 g) and 'heavy' (130 g of 14-14-14 fertiliser per seedling). Fifteen plots were established in each replicate with each plot comprising 12 seedlings at a uniform spacing of 3 × 3 m.

Four species were planted in the mixed species trial – mayapis (native and non-nitrogen fixing); mahogany (exotic and non-nitrogen fixing); narra (native and nitrogen fixing) and falcata (exotic and nitrogen fixing). The planting layout was designed to facilitate investigation of inter- and intra-specific competition (Vanclay 2006a), with four plots each planted with 100 seedlings spaced at 3 × 3 m, with the species mix varying systematically across the plot. The same four species were planted in the variable spacing trial, which employed a rectangular layout with spacing varying continuously from 0.6 m at the centre to 7.5 m at the perimeter of the trial, offering a compact way to evaluate a wide range of spacings (Vanclay 2006a).

The experiment was established on private land previously used as livestock pasture, arranged through a Memorandum of Agreement with the owner. The adjacent areas were irrigated rice fields and smallholder agricultural farms planted to annual crops. Brushing was undertaken to remove established vegetation including pioneer trees, shrubs and tall grasses. Stems of trees and brushes were removed while grasses were allowed to decompose on the site. Experiments were laid out using a compass and tape measure, and planting locations were marked with stakes. Seedlings were planted into holes approximately 0.3 m wide and 0.3 m deep. A fence was constructed around the planting to protect from stray animals. Quarterly plantation maintenance included removal of weeds within one meter radius from the base of the seedlings.

Treatments

Cuttings of the shade tree *G. sepium* were planted two months before the planting of mayapis seedlings, by which time the cuttings were well established and offered considerable shade to mayapis seedlings. Shade screens were installed immediately after planting, directly above the seedlings and fastened to three bamboo poles at the height of approximately 0.3 m above the shoot tip. Screens were adjusted regularly as seedlings grew to maintain 0.3 m clearance between the screen and the seedling. Because growth rates differed, this adjustment of screens were not synchronous for all seedlings. Both the shade screens and the shade trees were removed 18 months after planting.

Fertiliser treatments were applied 45 days after planting, when seedlings should have formed new roots capable of absorbing the nutrients applied. Doses were prepared by weighing and dispensing into sealed, labelled plastic bags which were emptied and distributed in a trench 5 cm deep, surrounding and approximately 12 cm from the base of the seedling. In the mixed species and variable spacing trials, all seedlings received 130 g of 14-14-14 fertiliser 45 days after planting.

Tree parameters including total height, base diameter, diameter at breast height (dbh), and maximum photosynthesis were measured. Seedling health was also monitored and recorded. Measurement of dbh commenced 2 years after planting. Photosynthesis measurements commenced when seedlings were 6 months old and were repeated regularly using a LI-COR LI-6400 portable photosynthesis system (Herbohn *et al*. 2009b). Height and diameter measurements were taken at 2-month and 3-month intervals for the first 6–24 months, after which measurement frequency was reduced to 6 monthly. Calipers were used to measure basal diameter, while dbh was measured using a diameter tape. Seedling height was measured initially with a metre rule, and with a hypsometer once seedlings exceeded 1 m tall.

RESULTS AND DISCUSSION

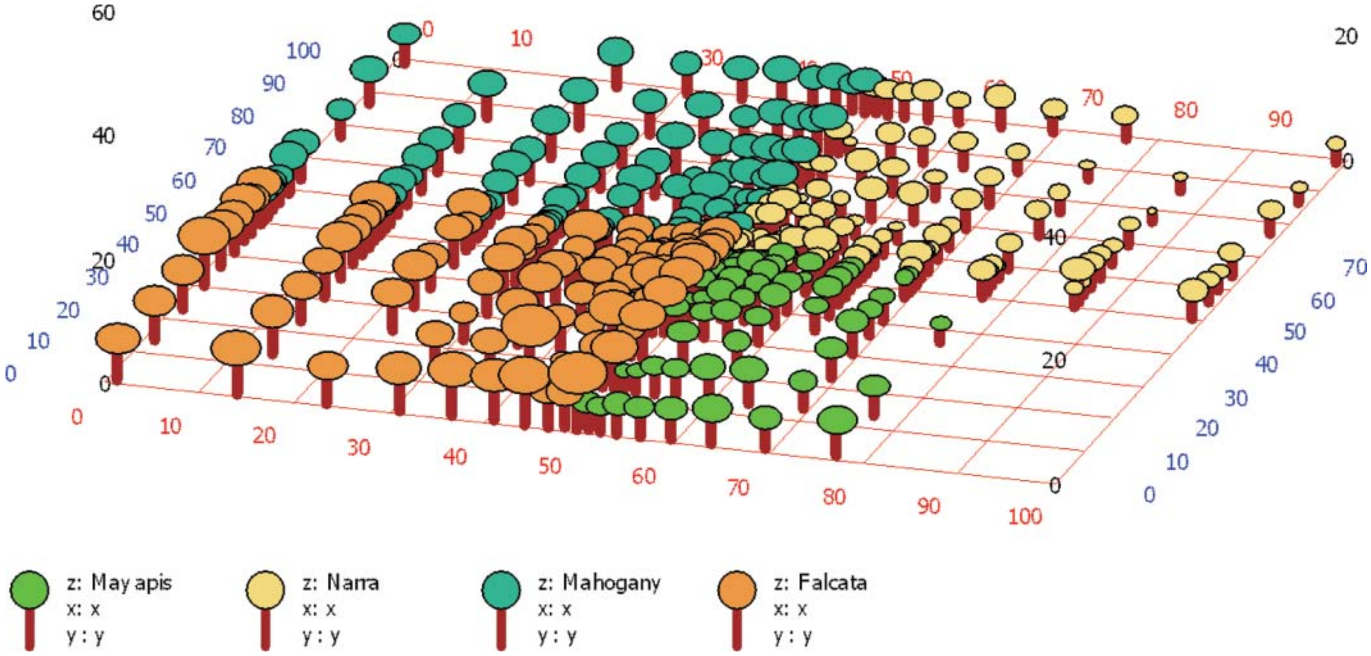
Mayapis suffered high mortality in all three trials, averaging about 40% mortality, partly because of harsh conditions during the first year after planting. While this mortality detracts somewhat from the utility of the trials, the surviving trees nonetheless convey much useful information about the behaviour of this species in plantations. The pattern of mortality in the spacing trial (Figure 3) is a reminder that mortality is often spatially clustered (Ashton and Hall 1992) and suggests that mayapis may perform better at closer spacings.

Survival of mayapis trees was slightly better in the mixed species trial (Figure 4), but mayapis performed better (both survival and growth) in the monoculture part of the trial, and worse in the mixed species composition at the centre of the trial (correlation r=–0.54). This trial offers insufficient evidence to assert that mayapis thrives best in a high density monoculture, but does reveal indicative trends that warrant further research.

While the spacing (Figure 3) and mixture trials (Figure 4) suggest some growth characteristics of mayapis, the main thrust was the shading and fertilizer trial (Figure 5) that sought to inform establishment practices. Unfortunately, four-year survival of this planting was poor (52%), with most of the mayapis in the north-east corner of the trial dying (Figure 6), apparently due to harsh conditions in the year following planting and seasonal waterlogging in subsequent years. Initial site surveys in 2007 suggested a relatively uniform and suitable site, but it subsequently appeared that the north-east corner of this trial is liable to seasonal waterlogging, which may contribute to the high mortality rate experienced in parts of this trial (Figure 2).

Although the loss of many trees is disappointing, and detracts from the design (a randomised complete block with two replications), the trial nonetheless conveys much information, and warrants analysis. However, caution is needed in the analysis, because several factors are confounded. A simple summary of the data offers a good overview (Table 1): either fertilizer or shade improves growth, but the effects are not additive so there is little benefit from both shade and fertilizer. Nurse trees appear effective, but the benefit derived by the

FIGURE 3 *Spacing trial showing death of Mayapis at wide spacings (bottom right)*



shade tree from the fertilizer may lead to increased competition for the crop tree (i.e., in Table 1, application of fertilizer halved the mean size of mayapis under nurse trees from 8 to 4 cm) – such fertilizer-weed interactions have been recorded elsewhere (e.g., Roth and Newton1996). In Table 1, some treatments (e.g., 30%, 60% or 90% overhead shade; light or heavy fertilizer) have been amalgamated to provide representative samples, but treatment differences remain non-significant at the usual statistical thresholds (P>0.05).

Treatment differences in Table 1 are not statistically significant because of large within-treatment variation, caused in part by seasonal waterlogging in the north-east corner, poor health of some mayapis, and site variation. For instance, there is a strong correlation between tree size (dbh) and distance

FIGURE 4 *Many of the blanks near the centre of the mixed species trial are due to the death of mayapis trees, which appears to exhibit better survival and growth is better as a monoculture (top left)*

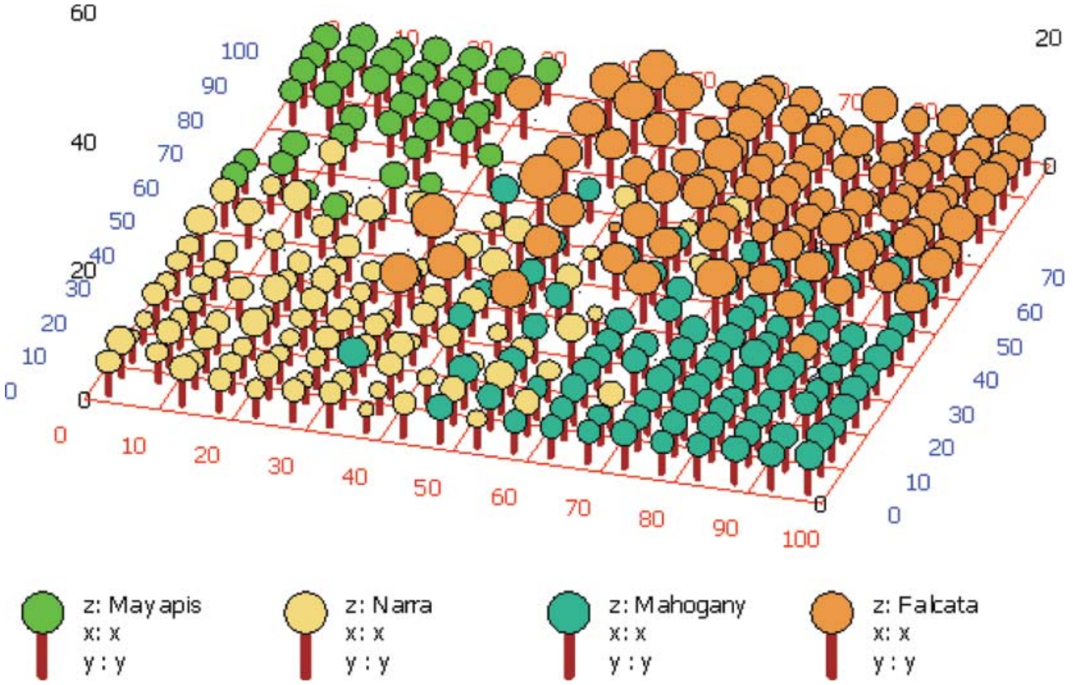
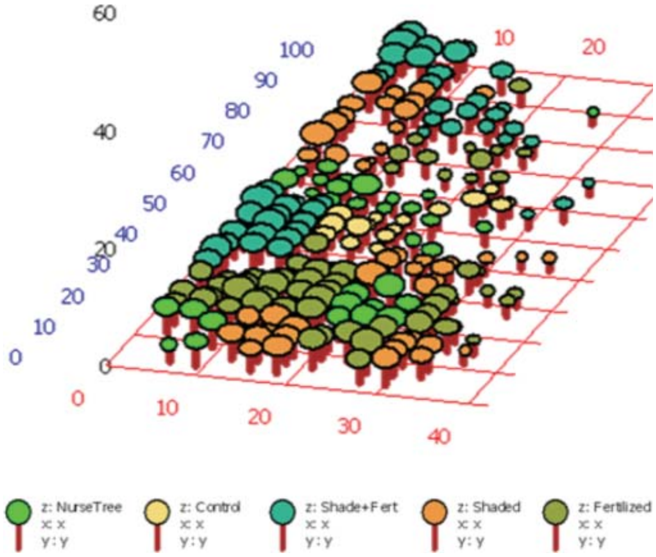


FIGURE 5 *Shading trial, photographed in November 2008 (left), and October 2009 (right)*

from the waterlogged north-east corner (r=0.57), with visual assessment of tree health (dead=0, vigorous=5; r=0.55), and with the basal area of mayapis in the eight nearest planting positions (r=0.82). There are different ways to deal with such issues. For instance, distance from north-east corner could be included in a regression as a covariate, or all planting positions thought to suffer waterlogging could be excluded from the analysis. Similarly, tree health could be used as a criterion to omit some trees from the analysis (e.g., health 1 or 2 are likely to die, so omit), could be included explicitly as a covariate, or could be included implicitly through the assumption that health is an outcome of treatment. Fortunately, in this case, the implications for mayapis planting remain the same for all these alternatives. However, the correlation with basal area is different and need not imply that mayapis prefers crowded stands: instead it reflects the fact that trees are likely to be big if their neighbours are big because tree size within each 12-tree treatment subplot should be similar, and because any site variation means that trees close together should be more similar than trees far apart.

FIGURE 6 *Shading and fertilizer trial, showing poor survival of mayapis in north-east corner (at top right of diagram)*



The analysis that makes best use of all available data is to include distance from waterlogging (i.e., from north-east corner) and health as co-variates, and to fit a linear regression model. This model was fitted to individual tree measurements, using ARC (Cook and Weisberg 1999). The resulting model that includes all treatments is:

$$\text{Sqrt(DBH)} = \beta_0 + \beta_1\text{Distance} + \beta_2\text{Health} + \beta_3/\text{Fert.Shade} + \beta_4\text{Nurse} + \beta_5\text{Nurse/Fert} \qquad (1)$$

where *Distance* is the number of planting positions from the north-east corner, *Health* is a visual assessment of tree vigour (0=dead, 5=vigorous), *Fert* is fertilizer treatment (1=none, 2=light, 3=heavy), *Shade* reflects the density of the cage (0=none, 1=30%, 2=60%, 3=90%) and *Nurse* indicates the presence of a shade tree (0=no, 1=yes). The square-root transformation of dbh is desirable to satisfy conventional statistical assumptions (normally-distributed residuals). All parameter are significant (Table 2) and trend in ways consistent with established silvicultural understanding.

TABLE 1 *Mean diameter (cm dbh) versus aggregated treatment at age 4 years (April 2012; all 206 surviving trees)*

Fertilizer	**Shade**			**Mean**
	None	**Overhead**	**Nurse tree**	
Unfertilized	4.5	6.5	8.2	6.3
Fertilized	6.8	6.9	4.0	6.4
Mean	6.0	6.8	5.6	6.4

TABLE 2 *Parameter estimates for Equation 1*

Variable	Estimate	Std. Error	Student's t	p-value
Constant	–0.634	0.232	–2.73	0.007
Distance	0.038	0.004	8.97	<.001
Health	0.457	0.047	9.66	<.001
1/Fert.Shade	–0.294	0.121	–2.44	0.016
Nurse	–0.582	0.188	–3.09	0.002
Nurse/Fert	0.955	0.281	3.40	0.001

Table 3 offers a more accessible insight than the parameters listed in Table 2, and presents the diameters expected for a healthy mayapis in the centre of the trial (at median distance from the waterlogged corner). Equation 1 is consistent with the results shown in Table 1, implying that either shading or fertilizer improves growth, but that there is little benefit in both fertilizer and shade. Nurse trees offer an efficient way to provide shade and stimulate growth, but fertilizer may stimulate the nurse tree to the detriment of the crop tree (e.g., in the rightmost column of Table 3, more fertilizer means smaller trees).

Several variants of this analysis were investigated, including the omission of treatment subplots affected by waterlogging, the removal of health and/or distance as a covariate, and the use of treatment means rather than individual trees, but all lead to conclusions similar to Table 3, but with different error estimates (and thus different implications for statistical significance). We also considered the use of spatially-explicit competition indices (Vanclay 2006b) as explanatory variables, but they conveyed no significant improvement over Equation (1). Since the present analysis is concerned less with testing for significance and more for calibrating well-established trends, Equation (1) seems appropriate.

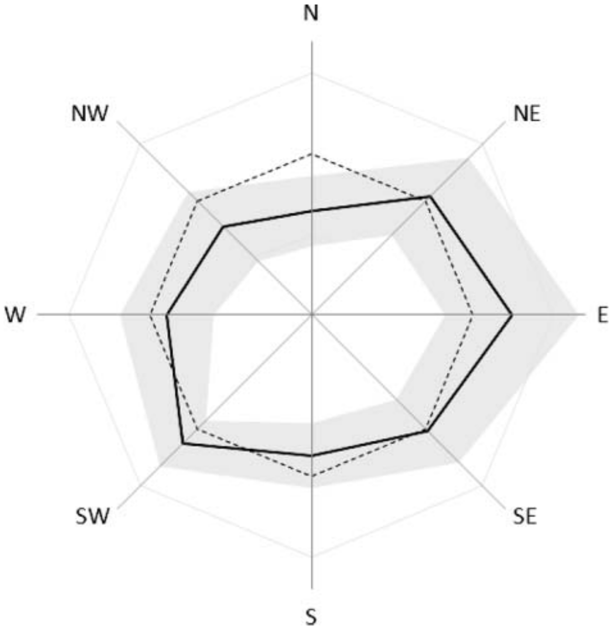
Equation 1 is not quite the full story. The 2009 photograph (Figure 5) is oriented towards the southeast, and it is evident that mayapis to the left of the foreground person are taller than those to the right, despite receiving the same treatment, perhaps because they receive morning shade. An analysis of inter-treatment shading by shade trees reveals a small but non-significant effect (Figure 7).

Mayapis (in unshaded treatments) with shade trees to their west or north are smaller than average, so it seems that they suffer competition without deriving benefit. But mayapis with shade trees to the east are slightly larger than the average, so apparently derive benefit from morning shade. Although this trend is not statistically significant (in Figure 7 or in Equation 1), it is logical and indicates that mayapis may derive benefit from alternative planting schemes, such as alternate rows (especially with rows oriented north-south). Such a scheme with alternate rows may help overcome resistance to practical uptake of mixed species plantings (Nichols *et al*. 2006).

TABLE 3 *Expected mayapis dbh (cm) implied by equation (1)*

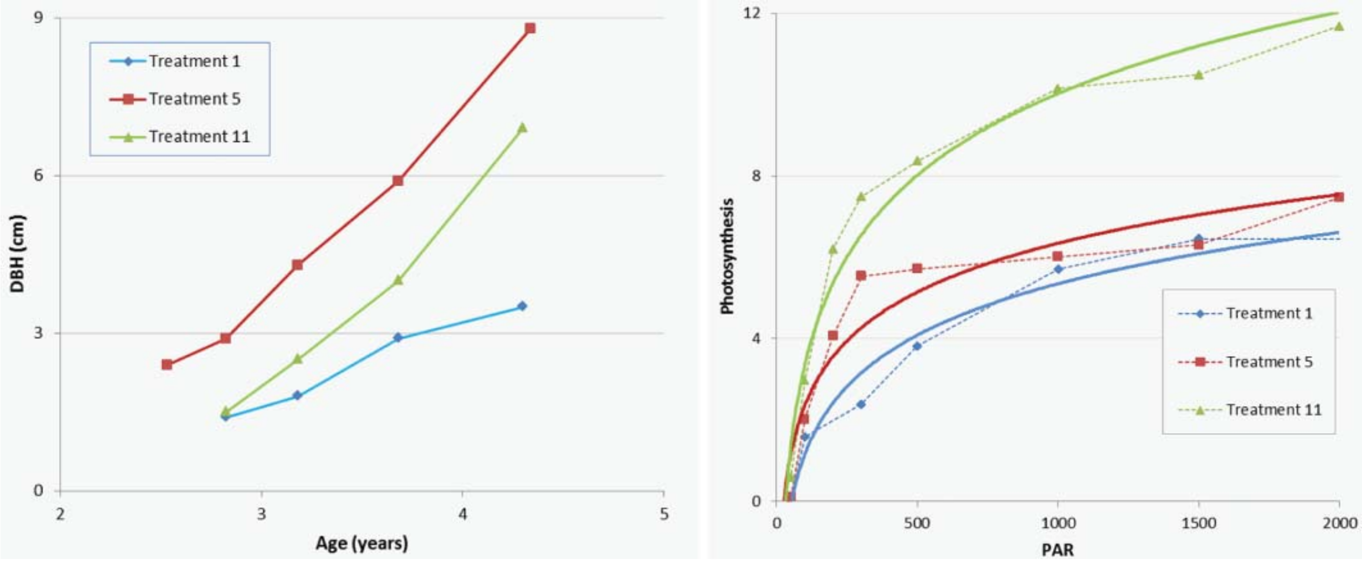
Fertilizer	Shading				Nurse tree
	None	30%	60%	90%	
None	6.3	7.0	7.3	7.4	8.3
Light	7.0	7.4	7.6	7.6	6.5
Heavy	7.3	7.6	7.6	7.7	5.9

FIGURE 7 *Relative size of mayapis receiving shade from adjacent shade trees. Black line shows relative size of mayapis trees; grey shading indicates 95% confidence interval; dotted line is the reference (average) tree diameter. Shade from the north is detrimental: both the black trend line and grey confidence interval remain less than the overall average*



In an attempt to better understand the response of mayapis to the various treatments, we investigated the light curves of three of the treatments, the control, shade tree and fertilizer (Figure 8), because they are strong contrasts. Each of these treatments have 10–12 trees that reached breast height and have 3 or more measurements at dbh by 4 years of age. Figure 8 illustrates the growth pattern of the median tree, and the corresponding light response curve. It is evident that the greatest instantaneous photosynthesis is exhibited by fertilized trees, but that overall the best performance is achieved by mayapis with shade trees. Our interpretation makes an analogy to the race between the hare and the tortoise: even though fertilised trees exhibit higher instantaneous photosynthesis, they cannot sustain this performance throughout the heat of the day, and overall achieve lower growth than shade trees that sustain lower photosynthesis throughout a greater proportion of the day. Observations suggest that photosynthesis in mayapis leaves shuts down at around 34°C, an air temperature commonly reached in the exposed areas of the site. Shade cover invariably leads to cooler air temperatures and thus photosynthesis in shade treatments would have continued for a longer period during hotter periods. The shape of the light response curves whereby there is a rapid increase in

FIGURE 8 *Growth curves (left) and light response curves (right) of the median tree in three treatments (1=no shade, no fertilizer; 5=shade tree, no fertilizer; 11=no shade, with fertilizer)*



photosynthesis from 0 to 400 µmol m-2 s-1PAR means that reasonably high levels of photosynthesis still occur even in partial shade.

Mycorrhizae have been shown to confer tolerance to drought and high soil temperature (Lee 1996) and thus to improve early growth (Turjaman *et al*. 2005). Bruzon (2002) recorded that mulching increased height growth of seedlings by 70%, perhaps by moderating soil temperatures.

Understanding the biophysical factors that affect the establishment and early success of mayapis is only one step in the development of successful silviculture for a new plantation species. A further critical requirement is ready availability of seedlings. Currently mayapis seedlings are seldom available in tree nurseries, as is the case with most native species in the Philippines (Mangaoang and Pasa 2003, Gregorio *et al*. 2008). This is partly due to a lack of germplasm (i.e., mayapis only fruits irregularly and there are few natural forest areas from which wildings can be collected). While germplasm remains difficult to obtain, government nurseries are probably best placed to supply planting material because of their greater ability to access germplasm and propagate less commonly produced species compared to smallholder and community nurseries (Gregorio *et al*. 2008), especially given that farmers have little knowledge of tree nursery systems (Baynes *et al.* 2011a).

Given the shift away from industrial forestry systems in the Philippines, the domestication of mayapis will involve planting as part of smallholder and community forestry systems. The silviculture for mayapis will however differ from that of commonly grown exotic species such as gmelina and mahogany. As such, for mayapis to be successfully adopted in these systems, culturally appropriate extension programs will need to be developed (Baynes *et al*. 2011a; Baynes *et al.* 2011b).

CONCLUSIONS

Mayapis benefits from shade trees, either directly above or to the east, that provide midday or morning shade. Mayapis exhibits poor growth and survival under wide spacing, when waterlogged and in bare soil exposed to full sunlight. Light response curves suggest that fertilizer helps to increase the peak photosysnthesis, whilst shade trees modify the microenvironment and allow mayapis to photosynthesise actively for longer each day.

Trial plantings exhibited an average survival of only about 50%, not sufficient for operational plantings by smallholders. Further research is needed to explore the interaction of soil temperature and mycorrhiza on seedling survival and growth. Further study is also needed to explore the feasibility of operational mixed-species plantings with mayapis, possibly as alternate rows of mayapis and shade trees.

ACKNOWLEDGEMENTS

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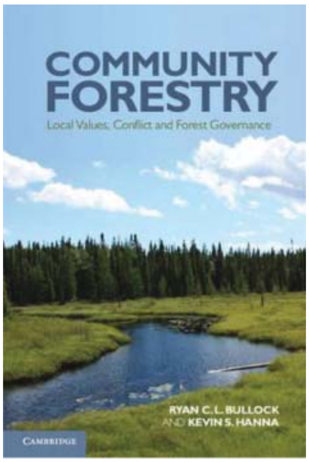
Reviews

Community Forestry: Local Values, Conflict and Forest Governance

Ryan C.L. Bullock and Kevin S. Hanna

Cambridge University Press, 2012, 186 pages, ISBN-10: 0521137586, 13: 978-0521137584. £66.50 (hardback), £28.49 (paperback)



When I began my professorial career in 1988 at Lakehead University, I knew nothing about community forests. That didn't prevent me from putting community forests on my emerging research agenda, despite advice from many quarters that it was nobody's priority theme for sustainable forest management and policy in Ontario at that time. In addition to starting some research on the topic, I even went so far as to write to the Minister of Natural Resources to urge her and the Ministry to get on with community-forest policy and programming. That did not go over well with the Ministry's senior staff!

But community forestry (I do prefer the term "community forest", but since the book under review is entitled Community Forestry, I shall use the term) has continued to grow in both scholarship and practice. I dropped the theme from my research for many years, but have been so pleased to see other scholars in Canada – e.g.: Tom Beckley and Sara Teitelbaum at University of New Brunswick; Kevin Hanna, Scott Slocombe and Ryan Bullock at University of Waterloo and Wilfred Laurier University; George Hoberg and Lisa Ambus at University of British Columbia – pick up the ball. With "Community Forestry: Local Values, Conflict and Forest Governance", Bullock and Hanna have generated the next, and most welcome, major instalment of scholarly documentation from the Canadian academic community.

As soon as I knew about the book in summer 2012, I had to have a copy, in no small part because we are presently ginning up some community-forest initiatives in my province of Nova Scotia. The book is comprised of nine chapters – three are general, including the compulsory introduction and conclusion as well as a concept analysis in chapter two, and six give place-based accounts of experiences with community involvement in forest management. Those places include New England states in the USA, the Canadian provinces of Ontario and British Columbia, New Mexico, and finally Sweden and Finland. I say "community involvement in forest management" because some of the material presented is not, in my opinion, relevant to the concept of community forestry.

In the New England chapter, the authors focus on the concept of the town forest. In Ontario, some relative successes are presented – e.g., Westwind Forest Stewardship Inc, Algonquin Forestry Authority – as well as some less-than-successful initiatives – e.g., Wendaban Stewardship Authority, the Ontario Community Forest Pilot Progam. For British Columbian experience, which is substantial in comparison with all other Canadian provinces, the authors chose Creston Valley Forest Corporation and the communities of Denman and Cortes Islands on the Pacific coast. The New Mexico chapter profiles Catron County and the conflicts associated with managing the Gila National Forest. The Fennoscandian chapter offers insights on national forest policy and how communities have tried to become influential in forest use and management. Each case-study chapter consists of descriptive accounts as well as analytical materials linking back to the concepts developed in chapter two.

For my liking, chapter two is by far the best. That may just be a personal preference, as I gravitate more strongly toward conceptual discourse than I do descriptive accounts. The chapter explores the implementation facets of community forestry and delves into the dimensions of conflict that make community forestry both desirable and difficult. After chapter two, the placed-based stories can be sampled in any order the reader desires.

The book is definitely worth acquiring – or at least borrowing for a glance-through. It is not without some significant faults. One deals with choice of places and themes to cover. Bullock and Hanna appropriately broaden the overall conception of community forestry to embrace a wide range of circumstances associated with resource governance and forest-land use and management. However, in my opinion, there is no justification for including a chapter on Sweden and Finland when, by the authors' own admission, they are not addressing the conception of community forestry that the rest of the book covers. The chapter remains a good read on the recent developments of forest policy in those countries and how community people have – or have not – managed to become more influential in defining policy direction, but its inclusion in this book on community forestry was a strange decision.

Another set of faults has to do with error. One never expects 100% freedom from error in a new book, but some of the slip-ups in this book, written by accomplished scholars and published by a reputable house, are annoying. Here are some examples: (a) on pages 62 and 63, the Algonquin Forestry Authority is inaccurately called the Algonquin Forest Authority; (b) on page 80, Patrick Matakala's PhD thesis, undertaken at University of British Columbia, is wrongly attached to Lakehead University; (c) in chapter three, Edmund Zavitz's landmark publication entitled "Fifty Years of Reforestation in Ontario" is pegged at 1909, when in fact it was a 1960 publication; (d) on page 142, the Jobs and Biodiversity Coalition is given the abbreviation JBC, and then cited as JCB several times on page 143; (e) Sweden and Finland are referred to as Scandinavian countries, whereas careful use would call them Fennoscandian or Nordic, as Finland is not normally included in Scandinavia.

The writing style makes the book accessible overall. Occasionally, a sentence stands out that should serve as an enduring quote – e.g., from page 144: “What is difficult to measure is the significance or impact of facilitating dialogue; and this may be the most important immediate success of what is in essence a tenure-less community forestry model”. There are puzzling passages upon occasion, such as the couple of mentions of interviews in the case-study chapters without any prior indication that the cases are based on original research by the authors. And there are passages that betray a less-than-scholarly treatment of the writing enterprise – e.g., on page 129, we read “If we put flippancy aside . . .” – I would have expected no flippancy in the first place. Later, on page 136, we read “Many will disagree with this, and that’s fine, but . . .” – this feels too much like a casual conversation rather than formal scholarly discourse. The book is sprinkled with a few black-and-white photos which do break up the visual monotony of the text but provide little insight into community forestry.

Having said all that, I would still buy the book for my own use and that of my students. Forest-policy stakeholders as well as community leaders and a wide range of scholars should find the book worthwhile. It is definitely informative and appropriately balanced between caution and hope for the future of community forestry in the developed world.

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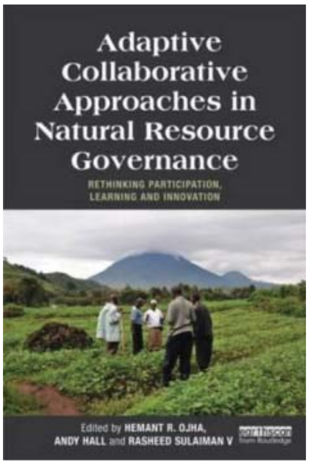
Adaptive Collaborative Approaches in Natural Resource Governance: Rethinking Participation, Learning and Innovation

Hemant Ojha, Andy Hall, and Rasheed Sulaiman V. (Editors)

Earthscan. 2013. 327 pages. ISBN-10: 041569910X ISBN-13: 978-0415699105 £34.99



This is a remarkable volume of articles that examines on the ground challenges of research and action in diverse political contexts, building on this to make a substantive theoretical contribution and challenge the epistemology of natural resource and development practice. It is recommended reading for academics, development and natural resource use practioners, donors, community organizations, government personnel and staff of international organizations. All these actors will find this to be a highly readable volume that is both informative and innovative.

Particularly notable is the focus on the significance and transformative potential of learning, an arena much talked about in theory and practice but that sadly often ends up being no more than a shelf full of knowledge products (reports, case studies, etc). As a number of the cases studies in this volume describe in intimate detail, the realities of practice include political pressures that undermine processes of reflection, adaptative innovation and learning. These pressures exist and emerge because learning and innovation challenge existing relations of power, by empowering actors such as the poor and vulnerable. Adaptive Collaborative Approaches (ACAs) have also served to highlight that top down and pre-packaged technological approaches often promoted by donors are not likely to produce the expected improvements in local livelihoods. Rather such changes are more likely to result from adapting actions to local context through learning.

One area in which the book is a bit weak is with respect to the governance impacts of ACAs. The general consensus is that there are five key principles of governance: legitimacy and voice; performance, direction, accountability and fairness. Whether the ACAs described in this book impacted these principles and natural resource governance processes is important from the perspective of both theory and practice. As many of the case studies in the book are based on projects implemented over an extended period of time, it appears they could have provided a fruitful opportunity to examine these linkages.

The book chapters hint at more profound governance impacts but do not explore this in depth. A number of cases studies highlight participatory approaches and their capacity to empower forest peoples. Yet, they do not address whether this then results in more participatory forms of governance of natural resources that were sustained over time. A number of chapters, point to the important role of multistakeholder dialogues played in enabling more effective implementation of ACAs and achievement of project results. Whether this then led to greater government responsiveness to local needs, more accountability or transparency (all issues of vital importance for natural resource governance) is not addressed in much depth. In other words, while the volume does contribute to rethinking participation, learning and innovation, it does not do the same with respect to natural resource governance. This book would have been stronger and made an even more useful contribution to the growing body of literature on natural resource governance had it addressed more specifically how ACAs can or cannot lead to better natural resource governance.

While there are case studies from Asia, Africa and Latin America, only two specifically reflect the African and Latin American experience and there is a very strong focus on Nepal. Latin America has a long history of Participatory Action Research (PAR) and participatory learning approaches. Although the authors site this work, one or two additional cases studies from Latin America and the relevant experiences in this region, in particular, would have surely served to further illustrate the fundamental issues related to ACAs and natural resource governance. A richer geographic scope would have served to strengthen its arguments and purpose. The limitations in the geographic scope of this volume, including case studies form a small number of countries, may undermine its overall audience as well.

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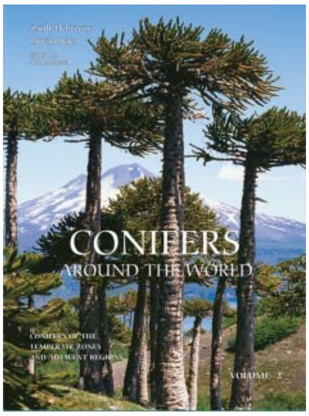
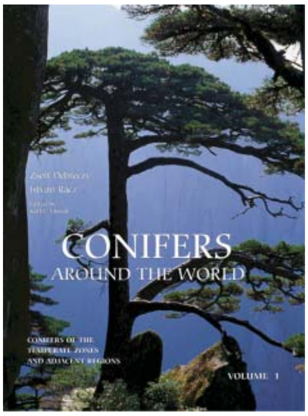
Conifers around the world: conifers of the temperate zones

Zsolt Debreczy and Istvan Racz (edited by Kathy Musial)

DendroPress Ltd., Budapest, Hungary. 2 volumes, 1089 + xxi pages. $250





This wonderful book is the first English translation of a book originally published in Hungarian in 2000 under the title of ‘Conifers around the Earth’. This text is a revised and extended version of that original work and is richly illustrated with over 3700 colour photographs, and extensive range maps and illustrations. The book is the fruit of a labour of love spanning several decades, during which the authors sought out and recorded conifer species in their natural habitats, involving more than 2000 days of field work. The focus is on the conifers of the boreal and temperate zones, including some temperate genera that occur in the subtropics. However, genera that are confined to the tropics and subtropics are excluded. Thus, there is no place for the kauri (*Agathis australis*) of the north island of New Zealand. 541 conifer species are covered in the book. Only taxa that occur in the wild are considered and no mention is made of ornamental cultivars of different conifers.

After some introductory pages, the work opens with about 130 pages covering the history of conifers, their identification and classification and various features of their morphology. The distribution of conifers in relation to climate is also discussed based on the ten climate zones proposed by Walter and Lieth in the 1960s. This is followed by an overview of the various conifer genera illustrated by fine botanical drawings. Then the main body of the publication occurs, presenting conifers on a regional basis separated into 11 regions, eight in the northern and three in the southern hemisphere. This presentation takes up the last two-thirds of the first volume and the opening two-thirds of the second volume. The regions that are distinguished are: Europe and adjacent areas: continental Asia including China; Japan and adjacent islands; Taiwan; western North America; eastern North America; Mexico and central America; West Indies and Bermuda; Chile and Argentina; Australia; and New Zealand. Each regional account starts with a presentation of the region, its history, the climate zones found within it, and the floristics of the region. This is followed by a set of range maps for each species present in the region and series of photographs illustrating the main conifer habitats. Lastly, each individual conifer species found in the region is presented on a single page with a brief text giving the taxonomy and distribution of the species and the main identification features. The description is supported by a main photograph of typical tree or stand, plus smaller photographs showing cones and typical foliage. After the last regional account, there follows nearly one hundred pages of photographs of the bark of every conifer species discussed. Finally there is an Appendix with a short presentation of a number of species and varieties where the taxonomy is uncertain, and lastly there is a glossary, several pages of references, a list of conifer scientific and common names and a quick finder allowing the reader to identify the main text describing a particular species.

The knowledge presented in this book cannot fail to impress the reader, whether that person wishes to gain knowledge about the species of a particular region or to learn more about a few individual species. The realisation that 355 species of conifer are listed as being ‘endangered’ in the wild will come as a sobering thought to many readers and emphasise the need for careful and dedicated programmes of genetic conservation. While most readers will know something about the towering conifers of the Pacific North-West of America, the detailed presentations of conifers in Mexico and China will be new to many, and may be of great interest as foresters consider the potential role of novel species in increasing the resilience of commercial forests to projected climate change. The existence of trees of Kashmir cypress (*Cupressus cashmeriana*) over 90 m tall was not something I was aware of before reading this book. This kind of information will make this book a valuable reference for many years to come.

In a book of this magnitude and importance, there are bound to be some errors and some points that could be improved. Some of the taxonomy may be open to question, for instance the separate account of a race of *Pinus nigra* subsp. *nigra* in the southern Carpathians (p. 211) seems rather odd and might have been better placed in the Appendix. There appear to be some words missing in the discussion of Caledonian pine woods (p. 221) while the text describing *Taxus baccata* (p. 223) suggests that it is the only shade tolerant conifer in the European region, which ignores the shade tolerance shown by a number of European silver firs such as

Abies alba and *A. bornmuelleriana*. On p. 654 the term 'the Pilgrims' is used to describe the Pilgrim Fathers, while the discussion of *Pinus strobus* (p. 691)makes no mention of the serious damage caused by white-pine blister rust. The presentation of the individual species might have been better if the range maps and the bark photographs had been combined with the text and other photographs on a single page. I found it irritating to be shifting from page to page to check information on a particular species. There is little mention of the extent to which some species are used in commercial forestry, for example the distribution maps for Atlas cedar (p. 149) and Scots pine (p. 152) do not show the extensive planting outside the natural range. If a revised edition was ever produced, then an appendix summarising the use of different conifer species in forestry might be helpful. However, these are minor blemishes that do little to lessen the high quality of this book.

It was a pleasure to review this book and the wonderful pictures reminded me of places I have been fortunate to visit and introduced me to places I would like to go and species I would like to see. On page 9 of the book, the authors state that:

> *'One of our goals in creating this book is to awaken a sense of awe and wonder and to serve witness to what has been lost and highlight the remarkable diversity [of nature] that remains'.*

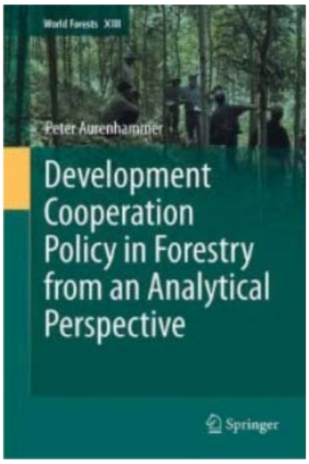
Both the authors and the publishers are to be congratulated on producing a book which meets these aspirations.

W.L. (Bill) Mason
Senior Silviculturist
Forest Research
Scotland

Development Cooperation Policy in Forestry from an Analytical Perspective

Peter K. Aurenhammer

Springer Dordrecht, Heidelberg, London, New York, 2013, 322 pp., ISBN 978-94-007-4956-6. £135.00



This book is about aid to forestry. The foreword warns the reader that "Aurenhammer's thinking and the book are too complex to be grasped overall and all at once." The theories and methods used are indeed complex and may be unfamiliar to many from a forestry background. However, it is the tortured syntax which drains the energy of the reader, hinders understanding and will limit the book's appeal among the readers to which the World Forests series is directed. Books on forestry aid are few and far between and it is a pity that this one escaped the gaze of Springer's English language editors.

The book is the publication of the doctoral thesis of the author and is based on a study funded by the Austrian Ministry of Forestry into bilateral forestry aid policy. The aim of the study was to understand better the political processes behind forestry aid and the role of various organisations in creating or preventing change. The study is confined to bilateral aid. It touches only in passing on aid provided through multilateral institutions and on the role that non-governmental organisations play. It examines the forest development policies of Austria, Finland, Germany and Sweden and analyses information on 24 aid projects, supported by field research on eight projects in seven countries (Bhutan, Nepal, Honduras, Nicaragua, Kenya, Tanzania and Uganda).

The research places forest development policy within the context of wider development policy and theories, foreign policy and theories of power. It links power to organisational and system theory and applies quantitative network analysis to investigate the influence different actors (organisations rather than individuals in this study) have on aid to forestry.

This work, together with the overview of methods and definitions in Chapter 1, takes up the first four chapters and about half the length of the book. Chapter 5 is based on the author's field research and examines whether forestry aid leads to changes in the income of rural communities. Chapter 6 presents a discussion about capacity construction and destruction. The book concludes with a short Chapter 7 on discussion and conclusions and a four page résumé where the author summarises his thoughts on what development cooperation *should* be about.

A series of 14 hypotheses is introduced as the book unfolds. Confusingly they are not introduced in numerical order and are hard to keep track of. It would have helped readers to navigate the text if the hypotheses had been presented in one place in Chapter 1 together with an explicit statement of the purpose of the study on which the book is based. Although some of the hypotheses are expressed in a manner that makes it difficult to discern if the evidence presented supports them or not, it is the analysis and discussion around these hypotheses that provide the substance of the book. Acknowledging that 'development' can only be defined in normative and ideological terms and not objectively, the analysis seeks to explain what forestry aid is for, what it is meant to achieve. Is it to contribute to wider development efforts to reduce poverty and promote economic development in less developed countries? Is it to reduce deforestation and conserve forests for the global as well as local environmental benefits this brings? Who decides what the priorities will be, how objectives might be sequenced over time, and to which countries assistance will be provided? How do the capacities and motivations of the organisations involved, and the way they are organised and relate to each other, help effect change?

The evidence from expenditure by the four donor countries (in 78 recipient countries over a 10-year period) confirms that wider political factors have a greater influence on aid to forestry than objective problem assessments. Contrary to what would have been expected if decisions about aid were based solely on the importance of the problems to be dealt with, only 18% of total aid to forestry went to countries with a low Human Development Index while 60% went to countries with a medium or high HDI. Only 21% went to the 15 countries with the highest absolute loss in forest cover. The reasons for this (strategic political interests, trade, historical inertia, presence of embassies or availability of staff etc.) are well rehearsed in the wider development literature and are by no means confined to these four donor countries. The author's work perhaps came too early to capture more fully the changes in sources of influence over forestry aid that climate change, and REDD+ in particular, have brought. These changes to the cast of influential actors and bargaining networks that are introduced in chapters 3 and 4 have been profound in many countries (and international organisations too).

Network analysis suggests that government officials, in both donor and recipient countries, have most influence over decisions about forestry aid – largely, if not only, because they control the money. The observation that forestry advisers have relatively little influence within development agencies rings true. This is in part because forestry aid is a very small percentage of total aid but it is also a consequence of historical and cultural factors that vary from one agency to another. In the four donor countries studied non-governmental organisations rarely reach what the author defines as a medium level of overall influence. This reviewer would be surprised if government officials in those countries shared that conclusion and doubts very much if officials in, say, Norway and the UK, would.

This author ranks the organisations concerned with development in the four donor countries in terms of their potential to effect change. FORMIN (Finnish Ministry of Foreign Affairs) and BMZ (German Ministry of Economic Development and Cooperation) have a high potential; GTZ (now GIZ – German Agency for International Cooperation), KfW (German Development Bank) and SIDA (Swedish International Development Cooperation Agency) have medium potential, and; BMaA (Austrian Ministry of Foreign Affairs) and ADA (Austrian Development Agency) have low potential. The reasons for this relate largely to independence of action (particularly budget autonomy) and the ability to draw on the skills and experience of other organisations to complement internal capacity. The author cites the number of staff in FORMIN who have field experience and the Ministry's ability to draw on a strong pool of consultants, and the close links between BMZ and GIZ with the latter's more than one hundred forestry experts. One of the main reasons the Austrian organisations have low potential is because the two organisations have been negotiating their respective responsibilities for six years without reaching a conclusion. Such rivalries have been dealt with more ruthlessly in other countries or bubble under the surface less noticeably.

The field research concludes that aid had little impact on income and poverty reduction in the projects studied. Only four out of 10 interventions yielded higher average annual household incomes and in most cases net income, after expenses and opportunity costs, was negative. As the author puts it, forests and trees are providing more secure livelihoods rather than a miraculous route out of poverty.

The results of the field research support the hypothesis that the income of communities and households from forests and trees is independent of the form of tenure. However, the sample size was small, seven interventions on government land and three on private or community land. While the evidence on tenure and income may be inconclusive the author is surely right in suggesting that the capacity to realise rights in the face of competing interests is just as important as the form of tenure.

The chapter on capacity building and the ownership of development is an unusual mixture of theory, illustrative stories drawn from the literature and the author's personal observations. It does not derive from the research and analysis presented earlier. It highlights the inequalities in the relationships between donors and recipients and within the societies of recipient countries and argues for forms of development that encourage local innovation and self-reliance and help maintain local social structures and values.

John Hudson
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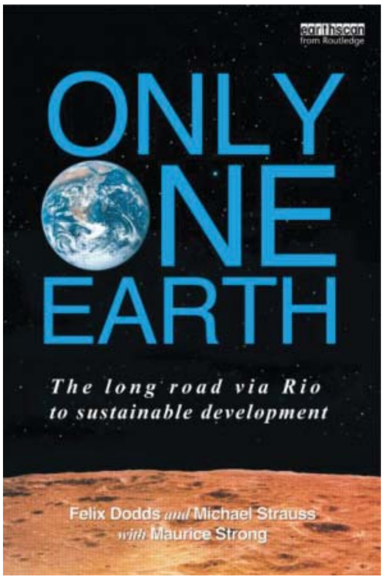
Only one earth: the long road via Rio to sustainable development.

Felix Dodds and Michael Strauss with Maurice Strong.

Earthscan from Routledge. 2012. ISBN 13: 9780415540254
ISBN 10: 0415540259 £24.99



The title of this book "Only one earth" comes from the original report by Barbara Ward and Rene Dubos, which was prepared for the World Conference on the Human Environment, held in Stockholm forty years ago. The title became the slogan of Stockholm, and this book aims to recapture the public enthusiasm and the political will of that time by reminding us of the progress – or sometimes, lack of it – since then, alerting us to the environmental threats still hanging over us, and identifying some possible directions in which we might now go.

The book is divided into two parts: I The journey from Stockholm, an account starting with preparations for the Stockholm Conference in 1972 and going up to preparations for the World Conference on Sustainable Development in 2012 (Rio+20). Unfortunately the book went to press in May 2012, before Rio+20; presumably the intention was for it to be presented there. Part II looks ahead, The Challenges of the Future, which because of its early publication can only offer pointers to the issues and outcomes of the 2012 Conference.

One of the outcomes of Rio in 1992 was Agenda 21, the non-binding, voluntarily implemented action plan for sustainable development for the first part of the twenty-first century, whose various chapters offered a practical approach to the application of policies related to sustainable development at the national or local levels – or in the case of Chapter 11 (*Combating deforestation*) realistic advice to the forest manager. I was responsible for preparing the reports on Chapter 11 in the late 1990s and have been disappointed to note that since then Agenda 21 and Chapter 11 have apparently been dropped from reports to recent international meetings on development. Certainly there was little mention of Agenda 21 in the report of Rio+20, bar the reaffirmation of nations to implement it.

The book has a valuable chapter which evaluates the outcomes of Agenda 21, using a "traffic light rating system" using inputs from two assessors. Sadly Agenda 21 Chapter 11 rates "Limited progress/far from target"; both assessors recognise that overall rates of deforestation have decreased, thanks to increased planting, but the loss of primary forest is still too high, largely as a result of countries' failure to prevent clearing for shifting cultivation, poor governance and weak institutions in developing countries. This chapter includes too a section on some of the shortcomings of Agenda 21, notably its sectoral approach which discouraged integrated and cross-sectoral solutions.

Two other forest-related chapters, namely 12 (*Managing fragile ecosystems: combating desertification and drought*) and 13 (*Managing fragile ecosystems:sustainable mountain development*) also score "Limited progress/far from target", and again while progress is acknowledged weak capacity is believed to be holding growth back. Of the forty chapters of Agenda 21 evaluated by this publication, only five have a final rating of better than "Limited progress". They are: Chapters 27 (Major groups – NGOs), 28 (Major groups – local authorities), 35 (Science for sustainable development), 38 (International institutional arrangements) and 39 (International legal instruments and mechanisms), all of which score 2 or "good progress/on target". But Chapters 7 (Promoting sustainable human settlement development) and 9 (Protection of the atmosphere), score 0, or "no progress or regression". Part of the reason may be lack of funding – overseas development aid (ODA) fell from $US62.4 billion in 1992 to $US48.7 billion in 1997 and it was not until 2002 that global ODA would again be more than $US60 billion. The authors also point out that the Millennium Development Goals (MDG) from the eponymous summit in Johannesburg in 2000 may have *taken the focus off the larger sustainable development agenda and focused on a much narrower seat of goals....The MDGs were adopted as* the *reference framework by the development community, leading to the aim of alleviating poverty without properly addressing underlying causes.*

I was also closely involved in the meetings of the Intergovernmental Forum on Forests, which was established in 1997, and later in the UN Forum on Forests (UNFF), both of which are briefly mentioned, but there is no recognition of the Collaborative Partnership on Forests (CPF) the important initiative set up in 2001 to coordinate the activities of the main international bodies involved in forestry.

The authors make no secret of their political beliefs, with the "occupy" movement being described as "One of the welcome major political developments of 2011). Would it had been as coherent as the authors suggest! But they are no Luddites, and while stating that *our* [present] *growth path is not sustainable* they also recognise that *Today the principal goal of our economy must be to improve the lives of all of the world's people.....The challenge will be ..to accomplish that without compromising the resources of the planet itself*. This is the eternal challenge, to square the circle of economic growth with sustainable development. The text includes quite some discussion on sustainable consumption and production and on ways in which economic growth can be de-linked from environmental degradation as well as describing some of the possible policies that might change patterns of consumption and production which are eminently sensible. They are also refreshingly scathing of many western politicians, especially those in the USA, quoting the notorious 1992 statement of George Bush (snr.) *The American Way of Life is non-negotiable* and many negative examples from the way of life in the USA.

The final chapter lists 21 actions to help save the planet; it is not clear if they are given in order of priority. The collection goes from (first) *Adopt the 1992 Earth Charter* (from Rio) to (last) *Restructure credit-rating agencies to include sustainable development criteria*. They range, in my view, from the admirable, such as the second *Agree a new global climate agreement*, and the sixteenth *Decide that all subsidies that undermine sustainable development should be eliminated*, to the hopefully attainable like the tenth *Improve international cooperation and development aid*, to the frankly impossible *Approve a* [apparently legally-binding] *Convention on corporate social responsibility and accountability* or *Impose a global financial transaction tax*. Maybe I'm as out of touch as the chairman of IBM was in 1943 when he foresaw a world market for at most five computers, but I will be most surprised if more than a few of the twenty one wish-list is ever achieved!

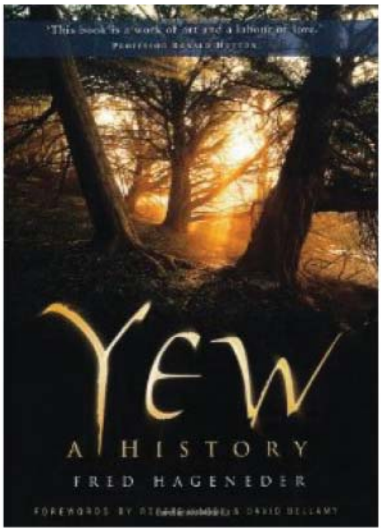
In sum, I recommend this book as an excellent account of the developments leading up to Rio+20, and also as a good summary of the challenges that face us who live on this one earth. All forestry libraries should have it, and, since it appears to be available free of charge, all those interested in the international dialogue that lead to Rio and beynd.

Jim Ball
President, CFA

Yew: a history

Fred Hageneder

The History Press. 2nd edition 2011. 320 pages. ISBN 978-0-7524-5945-5 £20.



This is a highly readable, comprehensive and scholarly book on *Taxus*, a genus with a global distribution which has humankind from an early stage in our development as settled people. The author is an ethnobotanist (as well as musician, and artist) which explains the division of the book into two sections – *Nature*, covering autecology and utilisation, and *Culture* (by far the longer) with chapters entitled, for example, *Poetry*, *The Great Passage* (dealing with the passing of humans from life to death), *Mountain Mothers* which refers to yews growing at high altitudes, religious activities and deities associated with them, and the human attributes related to the deities, and *The Tree of Life* (Paradise and the afterlife but also the interdependence of all forms of life).

The book is very well illustrated with excellent photographs (although I might carp that it is not always easy to judge the scale of some of them in the absence of human figures). There are good diagrams and boxes, some of the latter being by specialists in particular fields – the box on the dendrochronology of yew by Andy Moir being (to me) especially interesting. There are extensive lists of sources and endnotes, useful appendices and an enlightening glossary, plus good descriptions of technical subjects in the text.

Species of yew are found in the New World (Canada, the U.S.A. and Mexico), Europe, and Asia including India, China and Russia. We Europeans tend to think of yew trees as isolated specimens or perhaps clusters, but in fact it occurs in pure natural stands and it was an important component of undisturbed natural communities. We also imagine it as a characteristic tree of European churchyards but in fact it is conserved in Buddhist and Shinto shrines in Asia too.

I did a mental double-take on noting that the author uses girth and not diameter in tree measurement, but on reflection he is justified in the case of this genus because of its growth habit in old age. And I was going to query his justification for defining breast height as 5 foot above ground (150 cm) whereas I have always believed that the international standard is 1.3 m (or 4 foot 3 inches for the unreconstructed). Fortunately, however, I checked first with Wikipedia and learned that several countries, among them the USA, New Zealand, India, Malaysia, and South Africa, measure breast height at 1.4 m while ornamental trees are usually measured at 1.5 m above ground.

All parts of yew trees, except of the Himalayan yew (*T. wallichiana*), are poisonous, bar the bright red aril, and although in 1998 there were over eleven thousand cases of human poisoning from yew worldwide, nearly all in children, none of them were fatal. Yet the figures quoted for the amounts of yew leaves that are considered fatal for humans are relatively small – between 50 and 100 grams – so it is perhaps surprising that there are not more accidental deaths. The arils are an important food for several birds which disperse the seed – although some other birds eat them.

There has been a steep decline in natural yew populations in many European and Asian countries, historically because of grazing and over-exploitation among other reasons. The latter occurred during medieval times when yew was the preferred species for longbows and when its use as a weapon was superseded it was destroyed to reduce the risk of poisoning to grazing animals. More recently deforestation in general has led to the loss of yew habitats, but since 1966 the discovery of taxanes, alkaloids derived from yew bark, used for chemotherapy in the treatment of cancer, have led to widespread destruction. I recall visiting the foothills of the Indian Himalayas in the 1990s and seeing many of the yew stripped of leaves. Fortunately the drugs derived from the taxanes are now partially synthesized and the pressure on trees growing in forest has been reduced with the development of plantations in the USA and several Asian countries.

The chapter on the longbow describes how this weapon, of importance for hunting as well as war, was developed; so old is the longbow that even "Otze", the 5,000 year-old Neolithic man found in the ice in the Tyrolean Alps in Italy in 1991, was carrying one – albeit he was evidently still working on his unfinished bow. I had not appreciated that from medieval times the longbow was laminated, with heartwood (which compresses) on the archer's side of the bow and a thin layer of elastic sapwood on the other side. Yew long bows recovered from the wreck of the Mary Rose (1545) may have weighed up to 80 kg and have been effective at 240 m. The English army, with its Welsh archers, may well have dominated medieval battlefields but in fact much of the wood was imported and an informative map shows the routes along which yew staves moved in the early 16th century from Bavaria and Austria by river, land and sea to reach Britain and other European countries. Such was the shortage of yew staves in England that during the reign of Queen Elizabeth I her army replaced its bows with guns, despite the guns remaining inferior in fire power for the next 200 years, with the bow capable of firing 6 arrows to the gun's one bullet with greater range and accuracy.

The belief that yew trees were grown in churchyards as a source of bow staves is briskly debunked: the supply from consecrated ground would likely not have met even one fiftieth of the army's needs; indeed the absence of any evidence for the objections of Christians to the use of yew grown on holy ground suggests that churchyards were definitely not a source of bow staves. Indeed, pre-ecclesiastical yews may not have had any association with pagan religious sites either and the evergreen yews planted in churchyards may owe their existence as much to their symbolism of continuity.

The author is a scholarly debunker; he briskly dismisses *The Golden Bough* by Sir James Frazer, a book that was highly regarded in its day (the first edition was published in 1889). It dealt with the religions of classical antiquity and influenced not only authors such as W.B. Yeats, T.S. Eliot, D.H. Lawrence and James Joyce but also helped lay the foundations for studies in the emerging twentieth century sciences of anthropology, sociology and related fields. The author claims that Frazer was predisposed to believe that oak was the sacred tree of the ancients, with its associated parasite mistletoe, and selected his sources to support his theory. But Hageneder presents evidence – convincing to me at least – that the sacred tree was in fact the yew.

One of the strangest stories related is of the moving of a yew tree in 1907 in Frankfurt, Germany where a 12m high yew weighing over 40 tonnes and over 200 years of age was moved from the old Botanic Garden to the new one. The distance was 3.5 km and there is a splendid photo of the gigantic tree making its stately seventeen-day journey across the city, pulled by two steam rollers! Another interesting tale is of the first Christmas trees, which were introduced in Germany, were yew. Thus the Christmas tree introduced to Britain by Prince Albert in the 1840s was also a yew – although it is likely that the idea of a tree at Christmas had been introduced, at least to the Hanoverian Royal Family, shortly before that.

I did not find the Index straightforward; concerning two of the yews I know, the Fortingall yew of Scotland and the Irish yew, a fastigiate form first discovered at Florence Court in Co. Fermanagh, I found the former under Yew sites, Scotland, Fortingall, the latter under Yew(s), Irish. While scanning the index I noted entries for Wiltshire and was immediately interested for that is where I live now, but on looking in the text I found that the reference is to two photos of pure yew woodland on private land in the county – but no information on its location. While I would have liked to have visited it I appreciate that the owner may have requested privacy from the merely interested such as me, surely there could have been some explanation in the text of its significance?

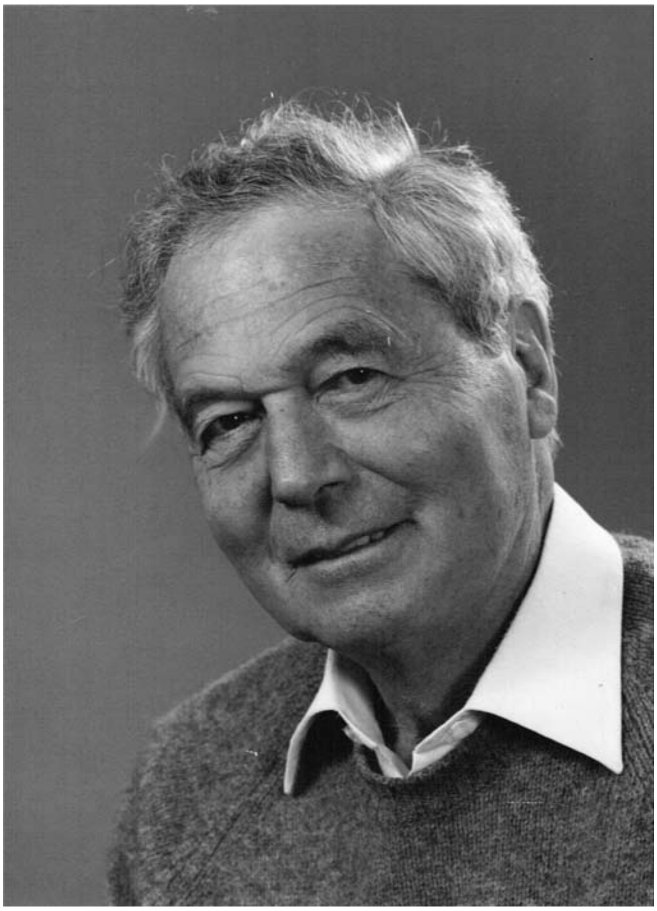
It is really hard to find other faults, but here are a couple of niggles, which I am surprised have not been rectified in this second edition:

- Some of the words or phrases are not explained – on p. 47, what is "10-DAB content"? On p. 66, what does the symbol Ω signify?
- The author betrays a slightly blinkered view of forest administrations – on p. 66 he refers to a forestry "commission", but so far as I know the only national forestry commission is that of Great Britain. Again on p. 89 he refers to "the" forest service, when in fact he is referring to the U.S. Forest Service.

But these are flyspecks when set against the magnificent achievement of this book in describing all aspect of the silviculture and utilisation of this major tree and its enormous influence on human language, customs and culture. Every forestry library where yew is found should have a copy, and foresters whose nearest and dearest may lack ideas for a Christmas present could well start dropping hints that this book would be a most acceptable surprise under the tree on Christmas morning – a yew tree of course.

Jim Ball
President, CFA

Dr. FREDERICK CORNELIUS HUMMEL
1915–2012



My friend and former boss, Fred Hummel, died aged 97 on 21 October 2012 at his Guildford home. Fred, as he was known in the forestry world, had an unusual start in life. He was born in Switzerland. His father, a member of the Colonial forest service serving in British Honduras (now Belize), and his mother were German, both became naturalized British citizens in 1914. They were on home leave when war broke out. Due to his father's awkward situation (German family but now a British national working for the British Colonial Service) the Foreign Office told him that as the war would be over within 3 months he should wait in neutral Switzerland for the duration.

In due course Fred's parents decided he should go to an English prep school, but after a none too happy period there he was moved to a German school from which he took his university entrance examination (Abitur). So well did he do in this that when he decided to go to Oxford his college of choice, Wadham, accepted the Augsburg university's marking and he entered to read forestry. After graduation, a short stint in the Colonial forest service in Uganda (at Budongo) was cut short by the war. This led to service in East Africa as a subaltern in the King's African Rifles until 1946.

In 1948 he joined the Forestry Commission at Alice Holt Lodge, Farnham, Surrey as the mensuration officer. His mathematical abilities led to his acquiring a D Phil; the practical application of this work produced the now familiar method of measuring standing trees, the tariff method, in use ever since. He developed volume tables and new provisional yield tables. He led the way in showing that, except in the most exposed conditions, total volume production was largely independent of thinning intensity.

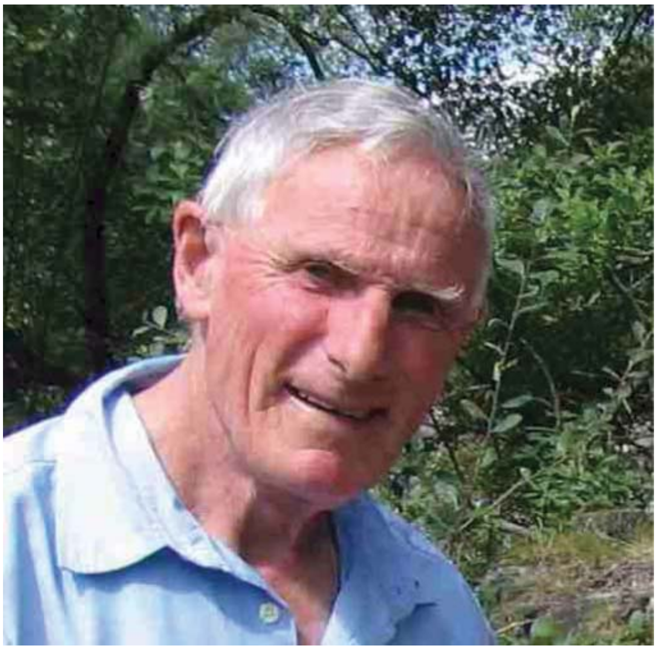
He oversaw the use of modern tools in statistics, economics and forest inventory. The last field was central to his work for the Food and Agriculture Organisation on a study of Mexican forests' potential: this led him from survey and forest planning further into policy questions. On his return to the Commission from 5 years working in Mexico he was promoted to run a group termed management services covering planning and economics, work study, and organisation and methods A dramatic professional change of course came a few years later when a promotion made him a full-time Commissioner of the Forestry Commission. Some would have regarded this the pinnacle of their career, but Fred accepted a further challenge when offered the post of Head of the Forestry Division of the European Commission. Here his diplomatic skills were exercised to the full. Though he did not enjoy the bureaucratic methods of the EC, Fred showed his many talents in initiating new approaches and promoting the cause of forestry in a Cinderella division limited by the exclusion of forestry from the Treaty of Rome. One result of this limitation was that all the work on forests had to be inserted as part of something else, and in Fred's efforts to build forestry up much of what he found himself having to do was to undertake such humdrum activities as addressing passing out ceremonies at forest ranger colleges in various EC countries.

His work in the Forestry Commission and in Brussels made him a known expert on planning and policy questions and especially after his retirement in 1980 he continued to find his advice being sought by national forest services as well as international institutions worldwide. His wide experience of forest planning and organisation, his knowledge of leading personalities combined with his proficiency in several languages made him a formidable operator. Fred was a rare combination of outstanding intellect, with a seemingly inexhaustible energy and relentlessness in pursuing solutions to problems. To cap it all he was a modest man with a warm and generous personality which made him instantly likeable. In every aspect, the array of consultations, studies, lectures and publications that he has left is quite astonishing. His career has to be unique for its extraordinary range and variety and as a result his influence on events in the field of forest policy was enormous.

He is survived by his son Antony (by his first wife Nancy), his second wife Floriana, and their three daughters, Anna, Silvia and Julia.

Arnold Grayson

Dr (DAVID) NEIL PATERSON
1929–2012



David Neil Paterson was a celebrated forester, tree breeder, saw-miller, furniture producer and social entrepreneur. Son of Robert Thomas Paterson, and Grace Kirkpatrick, David Neil Paterson was the original 'wild swimmer' and almost born in the sea. His mother had taken the family swimming in Ayr in October 1929 while 8 months pregnant and the shock had started contractions, and Neil was born in Kilmarnock.

His father was an agricultural academic breeding cotton and building irrigation schemes in Sudan who also, translated Arabic and local languages for General Wingate while fighting with the Sudanese camel corps in Ethiopia. He returned to Scotland playing a leading role in the establishment of the West of Scotland Agricultural School.

Pre-school trips to the Sudan during the 30s inspired Neil to a sense of adventure and were to define much of his career. He spoke fondly of the times he and his brother disappeared on their donkeys into the Sudanese desert as the sun went down without the knowledge of their poor petrified parents.

He was educated at Strathallan School in Perthshire and Edinburgh University, turning up to Edinburgh University on the wrong day for the entrance exams for his intended career choice – Dentistry. He looked to see what other exams were on that day and tried his hand at forestry bumbling into a wonderfully fulfilling career to which he was ideally suited and very successful. He graduated from Edinburgh in 1952.

Building on his undergraduate success as a prize winning student he was made an Associate of the Institute of Wood Science, given an honorary diploma from British Columbia. In 1967 he was also one of the first to receive a PHD from the University of East Africa in Nairobi in forestry genetics, catapulting him onto the international conference stage. Latterly he had spent time at Keble College, Oxford University, where he had a long association.

It was while he was in Edinburgh that the Stone of Scone disappeared from Westminster Abbey and was transported by a series of Morris Minors back to Scotland. Neil alluded to involvement in this campaign, but had taken a vow of secrecy and the exact knowledge of whereabouts of that historic stone has gone to the grave with him.

After a two year stint in national service (the Air Force put his ability to good use peeling potatoes), Neil headed off to see the world arriving on the east coast of Canada in 1954 with little other than his saddle with the intention of buying a horse and riding across the nation to find work. He found work in British Columbia where he surveyed a huge area of forest wilderness in the remote Yukon. He was flown in on ski boats, and lived with a gang of men for months on end living off porridge and elk. Here he learned over the long winter nights to play the mouth organ, a source of entertainment for years to come.

From Canada to Kenya in 1959, where as a British Government employee Neil served as District and then Regional Forest Officer for the Aberdare and Kinnangop regions. A fluent Swahili and Kikuyu speaker, Neil over saw thousands of acres of forest, protecting species for the people of Kenya and breeding bigger and better building materials for them (the subject of his PHD). He managed over a thousand men and was responsible for hundreds of thousands of villagers. He also encountered the end of the Mau Mau uprising and had horrific tales to tell. However he embraced the idea of decolonization, unlike many of his former colonial administration colleagues, wearing the tie of the newly independent country with pride and doing his best to build the capacity of his young African colleagues.

In 1969 he moved from Kenya to Malawi where he ran a research station in forestry genetics and was in charge of the forest workers training school, but the call to Scotland was too strong. Neil decided he wanted his family to belong to Thornhill in Dumfriesshire and turned down positions in South Africa Rhodesia and Oxford University to return to the place where his heart resided.

By the age of 40 Neil had achieved more than most people do in a life time.. but in the absence of a forestry research station or university in Thornhill, Neil set about creating his own employment. He quite literally built a little sawmill from wood, with the help and expertise of his foreman, Jimmy Sutherland. Along with a 1950s bandmill from Belgium and at one point, Dobin the Clydesdale horse, Neil built a little business into the leading hardwood sawmill in Scotland, exporting to the USA and Holland.

In part as an outlet for his wood he developed Queensbury furniture, reproducing Rennie Macintosh furniture, the plans for which he sketched when the museum guards weren't looking at Glasgow's Kelvin Hall Museum or Hunterian gallery. To house the business, and save the building from ruin, he bought and renovated the Queensbury Rooms (the old family factory canteen) in Thornhill which he then sold back to the village as the community centre. Similarly he renovated the historic Thornhill Parish Hall. This was unsuitable for his needs in many ways, but he wanted to renovate buildings as going concerns and that building is now once again central to the village social life again as an art gallery, coffee shop and retail outlet.

It was for Thornhill that he became a real social entrepreneur. There was always a project on the go. He founded the Thornhill squash club, converting a small church into a vibrant one court club where he played until his late 70s. He founded the Abbeyfield home in Thorhnill society and campaigned for its building, as chairman of the community council he organised clean ups of the woods and built paths through them.

Perhaps the most ambitious of his social entrepreneurship projects was the founding of the Crichton University with a number of other retired academics.

For Neil everything was possible – "can't afford bricks and a builder? build the sawmill from wood.", "can't afford a tractor? – use an old horse", "don't want a building to go to ruin? Find some money, do it up and pass it on". "Need more academic study in SW Scotland? – get some people together and build a university" Neil often said– 'you can do anything if you put your mind to it' and it was certainly true for him.

Neil founded the British Hardwoods Project to replenish our indigenous deciduous stocks. To that end, he outlined a plan at Oxford University to garner the necessary support of significant land owners but afforded no genuflection to the privileged.

When one prominent Lord made the journey from his estate in Northern England to Neil's house in Thornhill he sat in the same seat in Neil's study as his sawmillers who'd drop round for their wage packet one a week. The saw dust was flicked to the floor and he stayed for soup at the kitchen table. Neil valued home brew with the boys at the mill every bit as much as whisky with the Duke discussing planting oak trees.

What motivates social entrepreneurs varies, for Neil it was his love of people. At Christmas, he always wanted to have to dinner the lonely and the infirm.

(David) Neil Paterson was the last generation of cravat wearers, he was a real gentleman with a big heart. He died after a typically valiant fight following a ruptured oesophagus in Edinburgh Royal Infirmary aged 82. He is survived by his wife Judy and sons Rob and Dirk.

Rob Paterson