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

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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

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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:

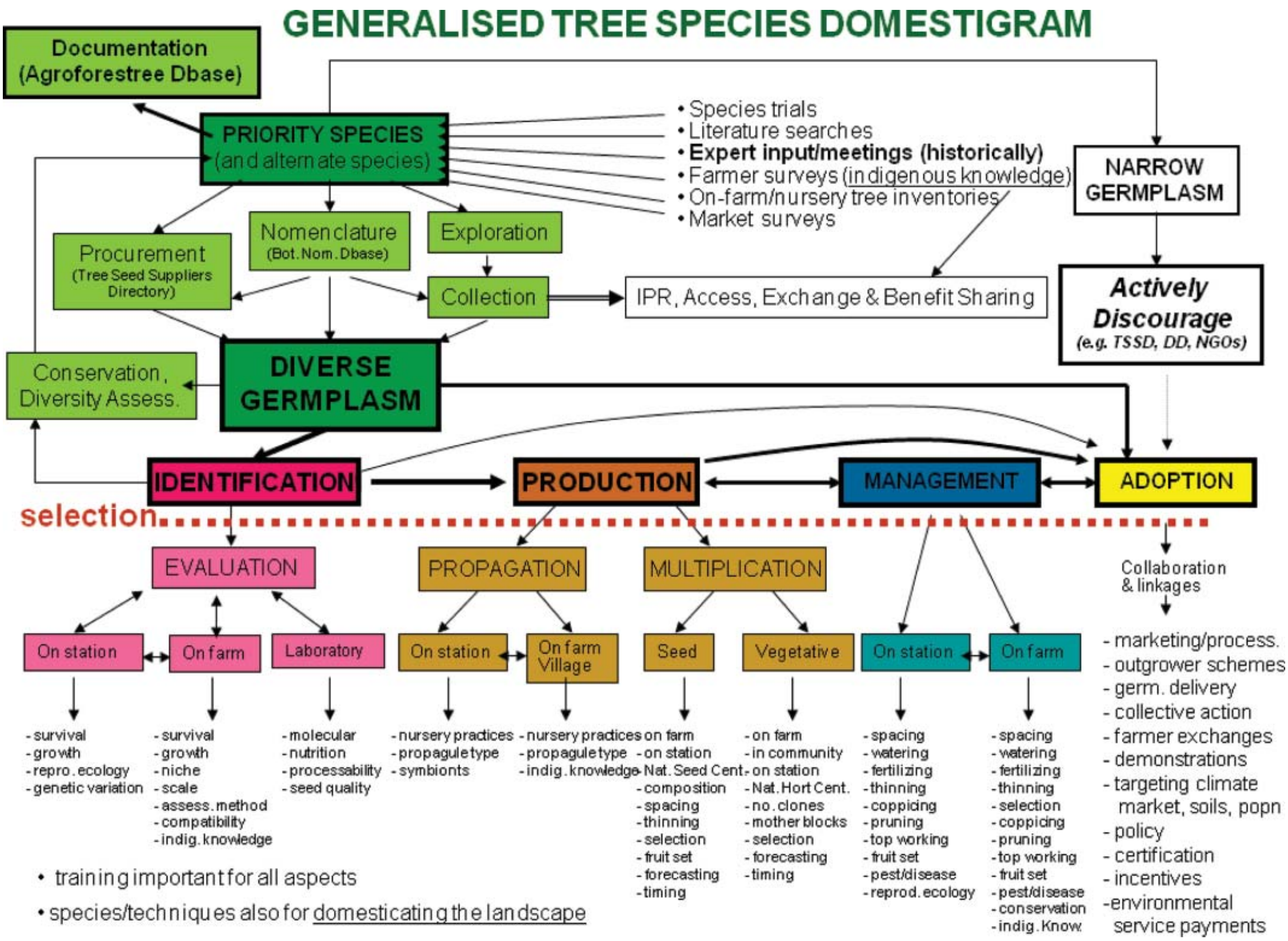
1. Reasons for domestication (home use, market, conservation of the species, agroecosystem diversification, improved livelihood strategies)
2. Tree uses required (products and services)
3. History and scale of cultivation (as native and exotic)
4. Natural distribution, intraspecific variation and ecogeographic 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.

ACKNOWLEDGEMENTS

This work was supported by ACIAR project FST/2005/089 Improved silvicultural management of *Endospermum medullosum* (whitewood) for enhanced plantation forestry outcomes in Vanuatu. Drs Roger Leakey, Lex Thomson, and two anonymous referees offered many helpful suggestions.

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