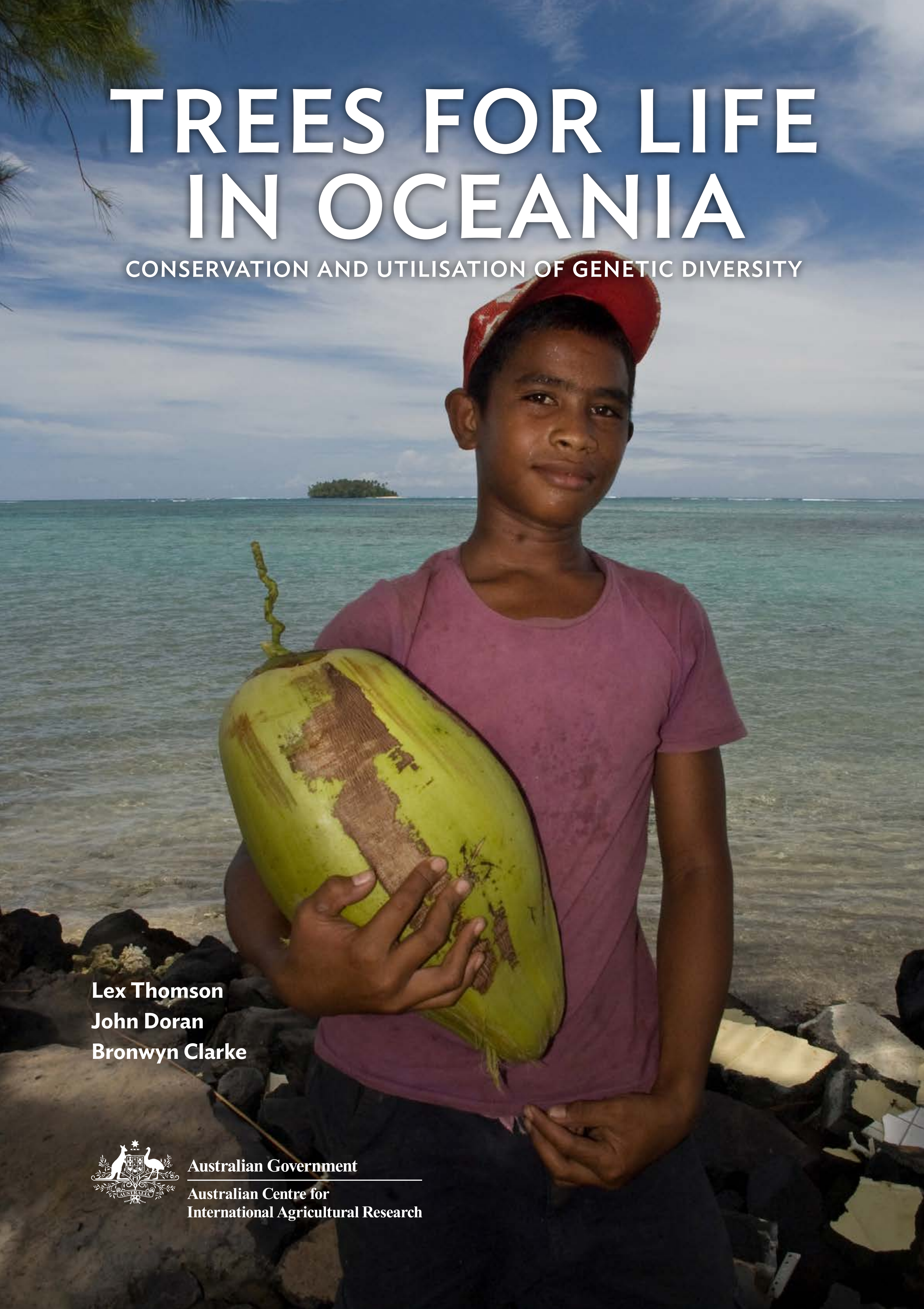

TREES FOR LIFE IN OCEANIA

CONSERVATION AND UTILISATION OF GENETIC DIVERSITY

Lex Thomson
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Australian Government
Australian Centre for International Agricultural Research

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CONSERVATION AND UTILISATION OF GENETIC DIVERSITY

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Front cover: 'Nui Afa'—a traditional variety of coconut (*Cocos nucifera*) selected for production of fibre or coir in Samoa (Photo: Roland Bourdeix, (1) CIRAD, UMR AGAP, F-34398 Montpellier, France; (2) AGAP, Univ Montpellier, CIRAD, INRA, Montpellier SupAgro, Montpellier, France)

Back cover: Fast-growing *Eucalyptus deglupta* which has a range of uses, including timber, stream-bank stabilisation, shade and honey production—planted specimen, Kolombangara, Solomon Islands (Photo: Bronwyn Clarke, CSIRO Australian Tree Seed Centre)

Foreword

Forests and trees play a vital role in the economic, social, environmental and cultural lives of the peoples of Oceania. However, both biodiversity and the genetic diversity of individual species are under threat or already suffering from impacts of habitat loss, overharvesting and competition from invasive weeds. In addition, the islands of the south-western Pacific are considered among the most vulnerable regions of the world to climate change. Accordingly, enhancing the diversity, health and the extent of forests, agroforests and trees in Oceania is of paramount importance in ameliorating and mitigating the effects of climate change.

The Australian Centre for International Agricultural Research (ACIAR) has been supporting research in South-East Asia and the Pacific Islands on the growing, management, processing and marketing of indigenous and exotic tree species since the early 1990s. Especially important are those tree crops that are well adapted to the local, diverse conditions; are amenable to production by smallholders as well as larger operators; provide a range of services to local communities; and afford possibilities for high-value local processing.

This book, prepared with inputs from 85 specialists in the nominated subject areas, including many Pacific Island foresters and horticulturists, aims to provide information on a selection of important Oceanian species. It highlights their valuable genetic diversity and provides recommendations for conserving and making best use of this diversity. This unique publication will guide sustainable utilisation of those species that are vital to the Pacific Islands and elsewhere in the developing tropics. As a forester, I am proud that ACIAR has made this information widely available in such an attractive form. This book should be invaluable for those planning and funding research on tree species in the Asia–Pacific region. It will also help smallholders and larger landowners involved in reforestation and agroforestry, and government agencies and other organisations involved in conservation and domestication of tree and shrub species in Oceania.

Andrew Campbell
Chief Executive Officer
ACIAR

This book is dedicated to the memory of the late Mr Doug Boland, SPRIG 1 Project Director, who passed away on 31 May 2001. Doug was a respected and well-liked forester, botanist and social scientist in Australia, throughout the Pacific Islands region and beyond. He played a major role in surveying the forest and tree genetic resources of Pacific Island village communities during SPRIG Phase 1. Doug's favourite and specialist professional areas of interest included the fields of floral biology and traditional ethnobotanical knowledge. He worked in CSIRO's Division of Forestry and Forest Products as an experimental scientist and was well known in CGIAR working as a forest scientist at ICRAF (World Agroforestry Centre) in Nairobi from 1991 to 1994, where he received ICRAF's Certificate of Merit for Research Achievement. During his professional career, Doug authored numerous scientific papers and books on botany and forestry. Doug Boland is remembered as a warm and generous man, and a consummate and widely respected professional.

Folau ā, Doug, and mālō ʻaupito.

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Preface

Information on the importance of forests and trees to communities in Oceania, proper utilisation of genetic diversity in domesticating a tree species along with advice on where to access germplasm for planting programs is provided in the introductory chapters to this book. The core of the book, however, is the species accounts. These provide background biological information, including species-specific knowledge of genetic diversity and conserving genetic resources, on around 60 high-priority, mainly indigenous tree and shrub species in Oceania, as well as a small number of widely planted exotic species. The species covered include those of importance culturally as well as for timber and non-timber products and services, such as fruit, nuts, essential oils, medicines, flowers/ornamental, soil and coastal protection, land rehabilitation, carbon sequestration and in mixed traditional and modern agroforestry systems.

The primary purpose of the book is to highlight the paramount importance to the success of tree planting in countries in Oceania of selecting the most appropriate germplasm to represent a species of interest, and the associated need to protect and maintain genetic diversity of these species. Use of carefully selected germplasm will better ensure optimum growth and suitability for proposed end use(s), whether it is for timber production or non-wood purposes.

The origins of this book go back to 2006 when one of us (Lex Thomson) was based at Bioversity International in Rome. Authors were contacted and about 20 responded with species drafts. For various reasons, the book was not completed at that time. In 2016, there was still a clear need for such information to promote the appropriate and sustainable utilisation of diverse forest and agroforest genetic resources, particularly in countries and territories of Oceania. With this scope, a new editorial team of Lex Thomson, John Doran and Bronwyn Clarke approached the Australian Centre for International Agricultural Research (ACIAR) which fully supported its publication.

A modest updating of the species coverage and authorship of species' accounts and introductory chapters followed, based on our current knowledge of: (1) priority species of present economic and environmental importance in Oceania or potential for future broadscale use; and (2) genetic diversity of the nominated species, ways of making best use of this diversity; and germplasm handling and supply. Regrettably, many important tree species had to be overlooked because of space and time limitations.

Many authors (85) have contributed to one or more chapters or species accounts and we wish to acknowledge their expert inputs. Without these, this book would not have been possible. Included are many Pacific Island foresters who have been critical to the success of forestry and agroforestry research and development projects over the past two decades. These projects have often been undertaken in partnership with scientists and colleagues from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Australian universities and with the support of ACIAR and the Australian Agency for International Development (AusAID; now the Department of Foreign Affairs and Trade) through the South Pacific Regional Initiative on Forest Genetic Resources (SPRIG) project.

We envisage that this book will provide a key resource document, not only for current and future donor-funded forestry projects in countries and territories in Oceania, but also for the broader tree-planting community throughout the region. Smallholders and larger landowners involved in reforestation and agroforestry who are looking to sustainably increase their yields by better use of genetic resources, and scientists involved in domestication of tree and shrub species in Oceania, will benefit from the information provided.

Lex Thomson, John Doran and Bronwyn Clarke

May 2018

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Many of the photographs used in the 'Species accounts' were made available by the authors and editors of the book. Thanks are due to the numerous other people who have contributed photographs; they are named in the 'Photograph credits' below.

The authors of the *Araucaria cunninghamii* account would like to convey special thanks to Ian Bevege for searching the Australian Virtual Herbarium records, inspecting many Queensland islands via Google Earth (and the Queensland Globe version of Google Earth) for the presence of native hoop pine, and advising the results. They would also like to thank Keith Gould, Les Hawkes, Peter Kanowski Sr, Peter Lear and Peter Stanton for contributing information on Queensland islands with or without native hoop pine.

Photograph credits

Many thanks to the photographers and organisations who have graciously allowed us to use their images to illustrate the species accounts. Photograph captions include abbreviated names which are listed here alphabetically in full. Photographers who are also contributing authors (marked 'A') have their full contact details included in Appendix 1.

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Abbreviations

ACIAR	Australian Centre for International Agricultural Research
ANBG	Australian National Botanic Gardens
AusAID	Australian Agency for International Development (to November 2013; now the Australian Government Department of Foreign Affairs and Trade)
CANBR	Centre for Australian National Biodiversity Research
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CSIRO	Commonwealth Scientific and Industrial Research Organisation
dbh	diameter at breast height (1.3 m)
FAO	Food and Agriculture Organization of the United Nations
FSM	Federated States of Micronesia
ha	hectare
IUCN	International Union for Conservation of Nature
m asl	metres above sea level
MAI	mean annual increment (wood volume)
MAR	mean annual rainfall
MAT	mean annual temperature
PICTs	Pacific island countries and territories
PITSC	Pacific Islands Tree Seed Centre
PNG	Papua New Guinea
SPC	Pacific Community (previously Secretariat of the Pacific Community)
SPRIG	South Pacific Regional Initiative on Forest Genetic Resources (project)
USA	United States of America
USDA	United States Department of Agriculture

Introduction

Forests and trees play central roles in the economic, social and environmental lives of the peoples of Oceania. We have here defined Oceania very broadly, as encompassing the islands of the central and southern Pacific, including Micronesia, Melanesia and Polynesia, as well as Australia, New Zealand, the island of New Guinea and the Malay Archipelago, in recognition of the human and floristic connections linking this region. Whether found as montane or lowland rainforests and dry forests, mangrove or riparian forests, coastal forests or agroforests, they all provide income, food, timber, fuel, medicines and countless other culturally important products and a wide range of critical ecosystem services, such as soil protection and enrichment, water catchment, animal and plant habitat, coastal protection, climate regulation, pollution control and carbon sequestration. First and foremost, however, is that forests harbour the greatest biodiversity and levels of endemism of all terrestrial ecosystems. Thus, maintaining and enhancing the diversity, health and the extent of forests and trees in Oceania is a first line of defence against climate change, natural disaster, poverty and environmental breakdown.

Challenges facing forests in Oceania

Sadly, there has been significant loss of all types of forest area, forest biodiversity and forest-related ecosystem services throughout Oceania due mainly to destructive and unsustainable practices, such as agricultural and other land clearance, invasive alien species, unsustainable harvesting, mining and other human developments. This is especially true in the Pacific Islands, which make up a large part of Oceania and are clearly among the most vulnerable regions on Earth to climate change, extreme weather and tidal events, and land degradation. Trees and healthy forest biodiversity offer a level of protection against the increasingly negative impacts of the drivers of biodiversity loss and food and livelihood insecurity; and Oceanian islands historically have the highest rates of extinction of terrestrial and freshwater species on Earth. This is often as a direct or indirect result of deforestation, forest degradation or agrodeforestation. The sustainable management of forests, agroforests and trees is thus a priority if these dangerous trends are to be addressed so that forests and trees will remain a foundation for climate, environmental, food, health, energy and livelihood security in Oceania.

While most of the larger high island Pacific countries and territories have good overall forest and tree cover (commonly over 50%), forest quality and extent are quite variable. In fact, many of these forests are now degraded to varying degrees and probably have limited capacity to act as a buffer against climate, environmental, economic and social change and to continue to provide the biodiversity and ecosystem services of healthy forests.

History of regional efforts to safeguard tree resources

In recognition of the loss of forest cover and the importance of trees, the Food and Agriculture Organization of the United Nations (FAO) championed a campaign to promote the protecting of trees in its 'Trees outside Forests' program in the late 1990s. Subsequently, with the support of the Australian Government, a regional action plan was developed in 1999 to identify practical actions that could be taken at the international, regional, national and local levels to curb the loss of forest and tree genetic resources in the Pacific Island countries and territories (PICTs). This Pacific Sub-regional Action Plan for Conservation, Management and Sustainable Use of Forest and Tree Genetic Resources involved the support of 18 PICTs, the FAO Forestry Department, the Pacific Community (SPC: previously the Secretariat of the Pacific Community), the joint Australian Agency for International Development (AusAID; now the Australian Government Department of Foreign Affairs and Trade) and Commonwealth Scientific and Industrial Research Organisation (CSIRO) South Pacific Regional Initiative on Forest Genetic Resources (SPRIG) project and the Secretariat of the Pacific Regional Environment Programme (SPREP), and was adopted the following year by the Pacific Islands Heads of Forestry (Pouru 2000). This document was reviewed and updated in 2007.

In 2008, the resulting new regional action plan—Forest and Tree Genetic Resource Conservation, Management and Sustainable Use in Pacific Island Countries and Territories: Priorities, Strategies and Actions, 2007–2015—was formally endorsed by the Pacific Islands Heads of Agriculture and Forestry Services and approved by the Ministers of Agriculture and Forestry in their regional meetings held in Apia, Samoa. This action plan was a significant document, serving as a framework for planning and implementing the conservation, management and sustainable use of forest and tree genetic resources within the PICTs. It set out priorities for implementation over the period, building on previous work and incorporating new knowledge and changes in priorities. It guided PICTs in developing and implementing relevant activities and policies within their own regional, national and local policies and action plans; thus, contributing to the security and development of their forest genetic resources for the present and future generations. The document is currently undergoing a review.

An important strategy under this action plan was the 2012 establishment, by SPC through its Land Resources Division, of the Pacific Islands Tree Seed Centre (PITSC), as part of the Centre for Pacific Crops and Trees (CePaCT), to facilitate the efficient and safe exchange and supply of tree seed in the Pacific region. This recognised that the loss of forestry biodiversity is a major contributing factor to a deterioration of Pacific peoples' wellbeing, and that PICTs, individual islands and island communities often have insufficient and vulnerable forest genetic resources, making it difficult for them to sustain their forests and trees into the future based solely on the genetic resources found within their borders. Recent examples are the incursions in 2010 on Tuvalu's northern atoll Nanumea of the kou leafworm (*Ethmia nigroapicella*) that devastated all of the beach cordia (*Cordia subcordata*) trees—a main coastal protection tree, seabird rookery species and culturally important tree for woodcarving; and the erythrina gall wasp (*Quadrastichus erythrinae*) to Fiji, which by the same period had virtually killed all of the *Erythrina* trees—a critical multipurpose, nitrogen-fixing, coastal protection and agroforestry genus in Fiji. Both cases will require reintroduction of more-resistant genetic strains of these species from other countries. Another earlier example was the reintroduction of *Terminalia richii* from Samoa to Niue under the SPRIG project as the species had been locally extirpated on Niue.

Compiling knowledge to facilitate progress—the aims of this book

Despite the above efforts, challenges continue to exist, including the availability of adequate information on Pacific tree species that will enable individuals and communities to make informed decisions on which species and varieties to select, propagate and promote in particular locations. This includes the preservation of local knowledge about their own tree species which, in the face of rapid modernisation and modern education, is being rapidly lost from Pacific oral cultures that traditionally preserved and transmitted information by 'word of mouth' or doing—a rich heritage that is disappearing with the passing away of the older generation and with rural people migrating to urban areas. This loss of traditional knowledge of the names, characteristics and use of trees and plants is resulting in many of our people, especially our younger generation, losing their connection to forests and trees, and therefore their ability to protect and conserve these important resources.

Consequently, in many PICTs, the list of species for reforestation and agroforestry projects is quite limited, and usually the majority of species on the list are exotics. Exotic species can be easier to deploy because of the existing knowledge base and pathways to obtain improved germplasm and propagate sufficient numbers compared with local tree species. In order to change this situation, it is of utmost importance to collect and properly document more information, including identifying research needs and threats regarding indigenous Pacific Island tree species. More and better information will create renewed interest in local species, enabling successful propagation and domestication. This will contribute to the sustainable management of the remaining native forests, agroforests and species richness outside forests in villages and towns where the planting of useful trees is a critical foundation of food and livelihood security and an important basis for propagating and conserving this knowledge among the younger, increasingly urban generation of Pacific Islanders. Furthermore, even basic first steps in domesticating appropriate Pacific Island tree species—such as range-wide seed collections, propagation research and provenance trials—have yet to be undertaken. These activities are urgently required for the improvement and wider planting of local species using diverse and superior germplasm.

This publication, which has been prepared by specialists in the nominated subject areas, is aimed at contributing to the needs outlined above. Utilisation of genetic diversity in domesticating a species, along with advice on where to access germplasm for planting programs, is provided in the next two chapters. Following these are the 'Species accounts' which highlight around 60 high-priority tree or shrub species, native, naturalised or exotic to countries in Oceania. These species are individually recorded with information on nomenclature, botanical description, distribution, uses and, most importantly, genetic diversity and progress, if any, in making the best use of this diversity in utilisation of that species. Each account concludes with a section describing threats and needs (e.g. more research) in conserving genetic diversity.

Because there are presently very few formal systematic conservation efforts for Pacific Island tree species and their genetic diversity, such programs need to be accorded a much higher focus by Pacific Island governments and donors to ensure this diversity remains available to future generations of Pacific Islanders. This will provide vital safeguard against climate change, sea-level rise, increasingly destructive extreme weather and tidal events, food and livelihood dependence, increasing poverty and the Pacific Island–wide pandemic of nutrition-related non-communicable diseases and premature mortality. Much of these health problems can be attributed to the abandonment of diets based around the inter- and intraspecific diversity of multipurpose food trees and associated agroforestry species that were the foundation of traditional 'organic' diets.

Authors: Sairusi Bulai and Randolph R. Thaman

Conserving and making efficient use of forest genetic resources

Introduction

Oceania is rich in tree species, including many endemics with narrow geographical ranges, while others, especially coastal species, extend throughout much of Oceania. The more cosmopolitan of these species may extend throughout tropical Asia and beyond. Humans have strongly influenced the spread and, in more recent times, the fate of many of Oceania's tree species. There are now many hundreds of exotic tree species present on Pacific Islands, including both modern and ancient Polynesian introductions, some of which have become naturalised. A small number of environmentally damaging, invasive woody weed species, notably African tulip tree (*Spathodea campanulata*) and *Leucaena leucocephala*, are capable of transforming entire ecosystems and threaten the region's forest biodiversity and genetic resources.

The peoples of the Pacific are strongly dependent on forest and tree-crop products for their material needs and livelihoods: trees provide fuel, building materials, shelter, food, medicines and other cultural products. The traditional ocean-going vehicles of the Pacific Islanders are canoes fashioned or crafted from a variety of tree products, including bark, hollowed-out logs, carved wood or timbers lashed together with lianas or rope made from coconut and other fibres. The value of various tree and other woody perennial species for particular uses is well recognised by the local peoples of Oceania, and this has led to informal domestication within some species: for example, the selection of 'noble' cultivars of kava (*Piper methysticum*) in Vanuatu; improved and seedless varieties of breadfruit (*Artocarpus* spp.) in Polynesia; low-oxalate fruit varieties of *Pandanus tectorius* in Micronesia; superior nut morphotypes of *Barringtonia*, *Canarium* and *Terminalia* species; and diverse ornamental foliage forms of *Acalypha*, *Cordyline*, *Croton* and *Polyscias* species in Melanesia.

Many Pacific peoples have been highly mobile for thousands of years, and colonising settlers have often brought important plant species and varieties with them during migration (Whistler 2009). Consequently, for certain tree species, it can be difficult to ascertain whether they are currently occupying their historical natural range, or whether they have become naturalised following ancient human introductions. The use of highly conserved genetic molecular markers can yield insights into human-mediated plant movement. For example, based on chloroplast DNA evidence, the occurrence of *Santalum yasi* in Tonga is thought to have been an introduction from Fiji (Harbaugh and Baldwin 2007), while the origin of Indian sandalwood (*Santalum album*) is thought to have been in Indonesia, with ancient introductions to India and elsewhere. Another useful tool is the analysis of pollen records—these often indicate the introduction of species with human settlement as well as the cultivation of exotic or naturally occurring species. Fall (2010), for example, found that *Casuarina equisetifolia* and *Pandanus tectorius* likely came under cultivation in Tonga post-colonisation by the Lapita people, as evidenced by increased pollen frequency of these species measured in marshland soil samples from Lotofoa Swamp on Foa island.

Conservation, key threats and domestication status of Oceanian tree species

The conservation and domestication status of important Oceanian forestry, agroforestry and horticultural species is given in Table 1. Of concern is the number of species that have been listed as Vulnerable or Endangered in the IUCN (International Union for Conservation of Nature) Red List of Threatened Species; <www.iucnredlist.org>. However, we have noted that, in some cases, IUCN Red List status may overstate the level of threat (e.g. *Acacia crassicarpa*), a problem that has been also noted in other contexts (e.g. Webb 2008). Of greater concern is the number of important tree species that are yet to be assessed for their conservation status. We have made our own assessment of each species which indicates that the overall conservation status of Oceania's tree species requires urgent attention, with some IUCN non-listed species assessed as Critically Endangered by us. Table 1 also outlines the actions that are being taken to conserve the remaining diversity of the listed species and, where applicable, actions that have been taken to domesticate and genetically improve the species.

Although domestication and genetic improvement do involve selection and narrowing of the gene pool, well-designed programs will ensure that a genetically diverse breeding population is also maintained. For many of the listed species, the commercial imperative to produce and plant genetically improved trees will be key to their conservation, as it is only through the breeding programs that the funds and expertise to carry out conservation works will be made available. This gives cause for optimism that many species that are currently listed as threatened in Table 1 might be preserved through tree breeding efforts associated with agroforestry and other plantations. Examples are the genebanks and other genetically diverse plantings that have already been established for some species. However, it is also important to consider the myriad non-commercial species that are less well studied but are potentially also threatened. In situ conservation of intact forests and forest fragments throughout Oceania remains the key to maintenance of genetic diversity for these species. This includes improved sustainable management of native forests (Thomson 2001), the establishment and maintenance of protected forest areas (Thomson and Theilade 2001) and greater interconnectivity of forest fragments, agroforests and trees in the landscape (Lindenmayer and Franklin 2002; Dawson et al. 2013).

The key threats in Oceania to forest biodiversity and tree species and their genetic diversity are considered to be habitat loss, fragmentation and conversion; climate change; overharvesting; and alien invasive species.

Habitat loss and fragmentation

Habitat loss, especially from frequent wildfire, and conversion of forests to other land uses, principally agriculture, have been the main causes of loss of forests and their constituent species in Oceania. Fragmentation of remnant populations also threatens species and genetic diversity through increased likelihood of loss of small populations, with reduced prospects of recolonisation, and reduced gene flows leading to increased inbreeding.

Climate change

The effects of human-induced climate change on Oceanian tree species are likely to be manifold as documented by Thomson and Thaman (2016). The impacts range from factors directly affecting growth, related to altered temperature, rainfall and rainfall seasonality, to indirect factors such as disease incidence, through to the impacts of cyclones (typhoons). Recent years have seen the rise of the so-called 'super-typhoons'—highly damaging tropical storm systems that have caused widespread devastation in places such as Australia, Fiji, Niue, the Philippines, Samoa and Vanuatu. Another particular challenge for Oceania is the impact of rapidly rising sea levels on many of the low-elevation coastal forests and atolls. Lowland forests are often a rich source of important biodiversity, and are very commonly interspersed with human settlement and farming land. Their loss to rising sea levels is a major concern to the communities which depend upon them. Upland forests are not immune from climate change either: rising temperatures pose a distinct threat to sensitive high-altitude forest communities.

Overharvesting

In a number of cases, human exploitation of certain high-value tree species, including sandalwoods and other highly prized timbers, has led to their extinction—such as the sandalwood species *Santalum fernandezianum*, in Juan Fernández Islands; and others to the brink of extinction, such *S. boninensis* in Ogasawara Islands, Japan; or is an ongoing threatening factor in the examples of *S. yasi* in Fiji and Tonga, *Gyrinops* spp. in Papua New Guinea (PNG) and *Intsia bijuga* throughout the Pacific Islands. Extinctions of potentially important subpopulations of some species continue—for example, Doran et al. (2012) found that in less than 10 years, 9 out of 15 subpopulations of *Endospermum medullosum* (Vanuatu whitewood) that had been included in genetic conservation and domestication plantings had become extinct in the places from which they had been collected. Table 1 exemplifies that exploitation of tree species for their forest products is a problem that is compounded by clearing of forests for cultivation of agricultural crops or for human settlement. For example, many subpopulations of *Eucalyptus urophylla* in Indonesia have been heavily impacted and are likely to be lost in the future (Pepe et al. 2004).

Alien invasive species

Introduced woody invasive species pose serious and continuing risks to island forest ecosystems. Of particular concern are those species that have been shown to be capable of completely transforming existing forest ecosystems: these include *Spathodea campanulata* in Fiji (and elsewhere), *Leucaena leucocephala* in New Caledonia, Vanuatu and Samoa, and *Miconia calvescens* in Tahiti and Hawai'i. The Pacific Island Ecosystems at Risk website, <www.hear.org/pier/index.html>, is an invaluable repository of information on woody weeds and provides listings and descriptions of plant species that threaten ecosystems of the Pacific Islands.

Conservation strategies and mechanisms for Oceania

In situ, ex situ and circa situm approaches

The three broad types of conservation strategy for forest genetic resources are referred to as in situ, circa situm and ex situ (FAO et al. 2001, 2004a, b; Young et al. 2004). In situ conservation, including dynamic conservation, involves the conservation of ecosystems and natural habitats, ecological processes, and the maintenance and recovery of viable populations of species in their natural surroundings. It is highly appropriate to the hundreds of Oceanian tree species that are often widely used but not yet domesticated. It is likely that a combination of species-oriented and site-oriented strategies will be most satisfactory for dynamic conservation approaches, as has been found in Europe (Lefèvre et al. 2013). Ex situ conservation involves the conservation of species outside of their native habitats and is especially appropriate for economically important species, but also as a complementary approach for those species for which in situ conservation is uncertain or problematic.

While formal conservation measures such as in situ conservation of forests and remnants, genebank plantings and trials (ex situ) are a key part of the overall conservation effort, the role of other ex situ and circa situm conservation plantings is equally important. Circa situm conservation entails conservation within altered agricultural landscapes (e.g. agroforestry systems, home gardens) outside natural habitats but within a species' native geographical range (Boshier et al. 2004). It is highly appropriate for a large number of socioeconomically important Oceanian trees that have been partially domesticated and which are often protected during farming and other development activities. These plantings include commercial as well as those made by smallholders.

A key activity associated with any conservation program is the production of genetically diverse seed and its distribution to growers. Seedlots that are derived from a sufficiently broad genetic base provide an important repository of species' genetic diversity. If planted outside the species' natural range, these plantings effectively form part of the ex situ conservation effort (e.g. *Swietenia macrophylla* plantings in Fiji). If seedlots of appropriate genetic diversity and derived from suitable populations are planted on sites that are close enough to the natural stands for gene flow from the planted stands to the natural to occur, then these plantings are effectively a circa situm conservation planting.

Circa situm plantings in smallholder farms have been identified as a critically important source (or potential source) of genetic diversity for numerous tree crops in various parts of the world (Boshier et al. 2004; Dawson et al. 2013). The role of circa situm conservation of Oceanian species through garden and village plantings is probably critical for many species and could be taken advantage of more frequently in conservation and breeding strategies. The problem of 'genetic pollution' from plantings of exotic species that can cross-pollinate with native species and give rise to potentially undesirable hybrids and dilution of the native species' gene pool may also occasionally be a problem—the widespread introduction of *Santalum album* within the native range of *S. yasi* is a salient example of this (Bush et al. 2016).

The need for conservation strategies in Oceania is great and there is considerable scope and a major opportunity to secure the genetic diversity of many of the key, economically important species before they disappear due to climate change and other human-induced threats. Conservation efforts will need to engage both government agencies and communities, with assistance from non-government organisations.

Seed collections and genebanks

Much of the work required for conservation will also underpin domestication and breeding activities: the two objectives are highly complementary and ought to be planned and undertaken together. An initial step is to rapidly undertake surveys of natural populations and sampling of seed and/or vegetative material. Sampled germplasm should then be either (1) stored (as seed) and/or (2) planted out into genebanks, trials or other long-term, appropriately managed and documented plantings. This has already been done for a number of species; for example, *Acacia koa*, *Cocos nucifera* and *Endospermum medullosum* (see notes in Table 1 and relevant species accounts). For some species, the initial effort has been made, but maintenance of genebanks and other conservation efforts has lapsed (e.g. *Artocarpus altilis* and *Eucalyptus deglupta*). Ongoing care and maintenance is required to ensure that conservation measures taken are effective in the long term. The Pacific Islands Tree Seed Centre (PITSC) in Fiji and other government tree seed centres must play a major role in storage and all-important documentation. The major challenge with genebank plantings is finding an appropriate number of planting sites with long-term security, and a reliable long-term collaborator who will ensure the ongoing maintenance associated with the conservation program. Complementary to these practical actions is assessing the genetic diversity within species—this is important as it guides the amount of sampling and appropriate conservation effort required.

Coordinated conservation efforts

As detailed in the previous chapter, there were two significant regional action plans that served as a framework for planning and implementing the conservation, management and sustainable use of forest and tree genetic resources within the PICTs between 1999 and 2015, but a replacement is still under review. The main achievement under the 2007–2015 plan was the establishment of the SPC PITSC in Narere, Fiji, along with training in seed collection and handling and safe movement of germplasm, including support from the Australian Government/CSIRO and the United Kingdom's Millennium Seed Bank Partnership. Currently there is limited external donor or other support for forest genetic resources research and development in the Pacific Islands, aside from projects supported by the Australian Centre for International Agricultural Research (ACIAR) Forestry Research Program.

Given the scale of threats to the Pacific Island forest genetic resources, including from climate change, and their importance in underpinning sustainable rural development, there is an urgent need for a renewed coordinating mechanism for conservation and management of the region's unique forest genetic resources that links with the FAO Commission on Genetic Resources for Food and Agriculture's Global Plan of Action for the Conservation, Sustainable Use and Development of Forest Genetic Resources (GPA-FGR, adopted by the FAO Conference in 2013) (CGRFA 2014a). The global plan was based on the findings of *The state of the world's forest genetic resources* (CGRFA 2014b) and recommendations of the Intergovernmental Technical Working Group on Forest Genetic Resources. The global plan identifies four priority areas for action: (1) improving the availability of, and access to, information regarding forest genetic resources (FGR); (2) conservation of FGR (in situ and ex situ); (3) sustainable use, development and management of FGR; and (4) policies, institutions and capacity building. Under these priority areas, the plan includes a total of 27 strategic priorities for action at the national, regional and international levels. The implementation of the GPA-FGR strengthens sustainable management of forests and contributes towards the Convention on Biological Diversity's Aichi Biodiversity Targets and the United Nations' Sustainable Development Goals.

Domestication and breeding strategies

The fundamental principles of domestication and breeding of Oceanian forest trees are essentially the same as those of other forest and horticultural tree species: genetic improvement in traits of interest can be achieved through recurrent selection and mating and through activities such as selection and vegetative propagation of superior individuals. In both activities, individual trees with favourable characteristics—usually combinations of traits such as growth rate, stem straightness, fruit yield, disease resistance and other attributes of interest—are selected from a breeding base population. These selections are mated and the process is repeated using the new generation of genetic material. Assuming the traits of interest are heritable (i.e. they have some component of genetic control that can therefore be transmitted to the next generation), the result is improvement of the key traits in each generation, but also a narrowing of the genetic diversity of the breeding population. Readers are directed to Eldridge et al. (1993) and Harwood et al. (2001) for discussion of the key elements of breeding strategies and breeding plans for tree species.

Leakey and Akinnifesi (2007) point out that many forest tree breeding programs have focused on seed-based seedling production, while horticulturalists have tended to favour vegetative propagation of fruit and nut trees. The former method has the advantage of potentially being able to produce large quantities of genetically diverse planting stock at a low cost, while the latter has the advantage of being able to target specific traits that are rare, or co-occur rarely and/or have low narrow-sense heritability. Moreover, many tropical tree species are not easily propagated by seed due to being 'shy seeders' and/or having recalcitrant seed (i.e. seed that does not survive well or at all in storage). However, a strategy based on vegetative propagation alone does not provide generational improvement of traits, rather it gives rise to 'varieties' of trees that have fixed properties. When only a few such varieties are widely planted, to the exclusion of sexually produced planting stock, low genetic diversity is the result. As already discussed, breeding programs and breeding base populations play a critical genetic conservation role for many Oceanian tree species, a function that is better served by seed-based populations that contain a wider sample of the underlying population's genes. Narrow, clonally based deployment populations may also leave growers exposed to widespread loss through disease and a lack of capacity for adaptation to climate change.

Assembly of breeding and/or conservation populations of tropical tree species is notoriously difficult in many cases. For the numerous species that have recalcitrant seed and/or for orthodox species where it is difficult to adequately sample populations within a single season, it may be necessary to accumulate selections in a mixed-age genebank planting. Clonally propagated selections could also be added to seedling-based plantings. Though it has been rarely attempted for Oceanian species, it may be possible to stimulate and/or boost flowering and seed production in such a planting through the application of plant growth regulators and silvicultural management. It is desirable to obtain a synchronously produced seed crop from as many genotypes as possible so that testing of traits using even-aged material can be undertaken as a core domestication and breeding activity.

Concluding remarks

Oceania is rich in tree species, many of which have important commercial and cultural uses. It is a growing concern that many of the species have been overexploited or are in decline from other human-induced causes. Furthermore, the rising threats posed by climate change will negatively impact on the genetic diversity of both socioeconomically important tree species and lesser known species. The domestication and breeding of commercially important species present a major opportunity to undertake conservation of their diversity, and the two activities ought to be complementary. It is well appreciated that domestication and tree breeding result in breeds with improved traits and greater commercial profitability. However, plantations of improved trees from well-designed and genetically diverse breeding populations also help to secure conservation of intraspecific diversity. Plantings within species' natural ranges offer the opportunity for circa situm conservation, whereby pollen flow from plantings can augment the often low genetic diversity within natural forest fragments. Plantings outside species' natural ranges can serve as important ex situ conservation measures. However, the role of in situ conservation will remain vital for the diverse Oceanian forest ecosystems and their component species. This is especially the case for the numerous species that are not candidates for domestication and breeding programs, and for which dedicated conservation programs are unlikely to be supported.

Table 1. Key tree species for cultivation in Oceania included in this book, with description of conservation status (IUCN 2016), an estimate of the status made by the authors, a description of threats to the species, and a summary of progress in domestication and breeding. International Union for Conservation of Nature (IUCN) and author-estimated classifications include LC (Least Concern), VU (Vulnerable), EN (Endangered) and CR (Critically Endangered). Many of the species are not yet classified (NC) by IUCN.

Species	**Conservation status**			**Conservation/domestication/breeding program**
	IUCN	**Est.**	**Comment**	
Acacia auriculiformis	LC	LC	Not considered under threat	Breeding programs, including hybrid breeding, underway in India, Thailand and Vietnam. Wide dispersal of genetic material effectively forms ex situ conservation population
Acacia colei	LC	LC	Not considered under threat	Domestication underway in West Africa for seed-based food and fodder
Acacia crassicarpa	VU	LC	Species is thought to be secure in much of its range in Papua New Guinea (PNG) and northern Australia	Breeding and domestication underway in Indonesia, Australia, China, Vietnam, Philippines and Thailand
Acacia koa and *A. koaia*	LC VU	LC VU	Clearing of natural populations and threats from diseases, especially of *A. koaia*	Breeding programs underway for *A. koa* with emphasis on disease resistance and adaptation to various ecotypes
Acacia mangium	NC	LC	Potential threat from fungal pathogens and inbreeding in populations outside of the core distribution	Later-generation breeding programs underway; most important commercial acacia in Asia
Acacia torulosa	LC	LC	Not considered under threat	Various forms have been developed for multipurpose use in Africa
Acacia tumida	LC	LC	Not considered under threat	Formal domestication not yet commenced
Agathis macrophylla	EN	EN	Local population extinctions and ongoing threats from logging and seed predation, including from feral rats	Has suffered population decline from logging but still common within its natural range. A conservation plan needs to be implemented

Species			Conservation status	Conservation/domestication/breeding program
	IUCN	Est.	Comment	
Araucaria cunninghamii	LC	LC	Not considered under threat	Breeding program in Australia focused on sawn-timber production; the program also serves an ex situ conservation function
Artocarpus altilis	NC	LC	Loss of cultivars and associated knowledge is a threat	Genebanks and conservation measures taken in the 1960s and 1970s have been abandoned and there is a need for genebanking of important cultivars
Barringtonia edulis and *B. procera*	NC	LC–CR	Certain *Barringtonia* species (cutnuts) and populations are likely extinct in the wild, though still frequently found in cultivation	Formal domestication has not commenced
Calophyllum inophyllum	LC	LC	Generally well conserved, but possible overharvesting in places such as Tuvalu and Kiribati	Formal domestication has not commenced
Canarium indicum	NC	LC	Not considered under threat	Improvement programs in PNG, Solomon Islands and Vanuatu building on traditional domestication and selection of superior nut morphotypes
Casuarina equisetifolia	NC	LC	Generally secure, but some unprotected forests in parts of the wide range being lost to coastal development	Relatively sophisticated domestication and breeding programs underway in Thailand, India and elsewhere
Cocos nucifera	NC	LC	Generally safe, but loss of some traditional varieties has occurred due to widespread planting for copra	Conservation and breeding of this global staple crop is coordinated by COGENT, the Coconut Genetic Resources Network
Corymbia citriodora	NC	LC	Not considered under threat	Breeding from a broad genetic base underway in Australia
Endospermum medullosum	NC	VU	Under threat from logging; some Vanuatu subpopulations recently extinct	Conservation and domestication program underway in Vanuatu, but securing genetic in situ resources there and in other parts of natural range a priority
Eucalyptus camaldulensis	NC	LC	Not considered under threat, though altered river flows in some parts of range a potential threat	Later-generation breeding programs for tropical subspecies underway in numerous countries worldwide, including pure-species and hybrid breeding
Eucalyptus cloeziana	NC	LC	Not considered under threat	Domestication and breeding underway in Australia
Eucalyptus deglupta	NC	EN	Loss of wild stands throughout natural range an ongoing threat; the South Sulawesi population may have gone extinct	Testing and domestication has commenced, though previously assembled populations and genebanks may have been neglected
Eucalyptus pellita	NC	LC	Not considered under threat	Domestication and pure-species and hybrid breeding advanced in Australia, Indonesia, Brazil, China and Vietnam
Eucalyptus urophylla	NC	VU–CR	IUCN survey indicates >50% of populations Vulnerable to Critically Endangered	Breeding underway in several countries, but hybridisation with other eucalypts lowers utility of these populations for ex situ conservation
Falcataria moluccana	NC	LC	Not considered under threat	Domestication and breeding underway in Indonesia and Malaysia
Flueggea flexuosa	NC	LC	Not considered under threat	Formal domestication has not commenced
Garcinia sessilis	NC	LC	Not considered under threat	Conservation and management underway in Tonga (outside natural range)
Gliricidia sepium	NC	LC	Not considered under threat	Provenance testing indicates large variation among provenances that could be captured, though breeding not commenced
Grevillea robusta	NC	LC	Not considered under threat	Breeding programs and ex situ conservation populations established in Australia and Africa

Species	Conservation status			Conservation/domestication/breeding program
	IUCN	Est.	Comment	
Gyrinops ledermanii and *G. caudata*	NC	CR	All species within *Gyrinops* are listed in CITES Appendix II*. Many populations at extreme risk	Conservation and domestication to alleviate wild harvesting urgently required
Hibiscus storckii, including three undescribed Fijian *Hibiscus* spp.	NC	VU–CR	Very few individuals remaining in wild and at severe risk from global warming and extreme climatic events	Hybrid breeding for floral attributes
Inocarpus fagifer	NC	LC	Not considered under threat	Farmer-selected cultivars recognised in Samoa, Tonga and Vanuatu
Intsia bijuga	VU	VU	Threat from intensive exploitation of native stands for timber. In some places, such as Vava'u, Tonga, only a few individuals remain	Conservation and domestication not underway but a high priority
Macadamia integrifolia and *M. tetraphylla*	NC	VU	Clearing and population fragmentation are the main threats	Breeding programs and cultivar development underway; increased conservation efforts warranted
Mangifera foetida	LC	EN	Many crop wild relatives of *M. indica*, including *M. foetida*, are endangered from cutting for timber and land use changes	Species is crop wild relative of commercial mango *M. indica*. Locally recognised fruit forms and cultivars
Melaleuca cajuputi	NC	LC	Some parts of distribution in Vietnam threatened by clearing, potential susceptibility *to Puccinia psidii* (myrtle rust)	Breeding underway in Indonesia
Melaleuca quinquenervia	NC	LC	High susceptibility and emerging threat from *Puccinia psidii* (myrtle rust) in Australian part of range	Breeding underway in Vietnam
Meterosideros excelsa	NC	EN	Threatened by clearing, stock and feral animal browsing, with 95% of natural forests lost	40 cultivars have been developed
Meterosideros polymorpha	NC	LC	Potential susceptibility to *Puccinia psidii* (myrtle rust). Major new concerns for the species' future since discovery in 2014 of two species of the pathogenic fungus *Ceratocystis* causing serious disease and mortality on Hawai'i Island	Conservation works underway focused on disease resistance
Musa troglodytarum (fe'i)	NC	EN–CR	*Fe'i* banana seeded populations and cultivars are insecure. Some cultivars have been lost and others reduced to one clump and at extreme risk	Some genebanking and ex situ conservation underway and conservation framework formally developed
Ochroma pyramidale	NC	LC	Not considered under threat—a pioneer species with excellent regeneration capacity	Breeding program has been formulated and initiated in PNG (East New Britain province)
Pandanus tectorius	NC	LC	Not considered under threat	Many traditionally selected varieties and clones have been selected. A field genebank of traditional *P. tectorius* varieties has been established in Kiribati
Piper methysticum	NC	LC	Not considered under threat	Many traditional clones and varieties recognised but no formal breeding
Pometia pinnata	NC	LC	Loss of valuable cultivars through agrodeforestation and lack of replanting	Numerous traditional clones and varieties recognised but no formal breeding
Pterocarpus indicus	VU	VU	Overexploitation due to logging, with reduction in genetic diversity	No conservation plan in place
Santalum album	VU	VU	Overexploitation in the wild due to sandalwood trade	Breeding programs underway in India, Australia, Indonesia and China. Potential 'genetic pollutant' in parts of the Pacific region
Santalum austro-caledonicum	NC	VU	Overexploitation in the wild due to sandalwood trade	Conservation strategy developed and breeding program being actively pursued by the Vanuatu Department of Forests

Species	Conservation status			Conservation/domestication/breeding program
	IUCN	Est.	Comment	
Santalum insulare	NC	EN–CR	Overexploitation in the wild due to sandalwood trade; seed predation by feral rats. The species is essentially dependent on human management to control rat predation and undertake replanting	Conservation and planting program underway
Santalum yasi	NC	EN	Overexploitation in the wild due to sandalwood trade, genetic pollution from *S. album*	Conservation and domestication programs underway in Fiji and Tonga
Swietenia macrophylla	VU	VU	CITES II listed*. Overexploitation due to mahogany timber logging	Not native to Oceania, but potential regional role for ex situ conservation. Genetic diversity likely to be lacking in Oceanian populations
Syzygium malaccense	NC	LC	At risk of loss of genetic diversity and threatened at local population level	Improved fruit selections have been produced in South-East Asia, including in Malaysia and Thailand
Tectona grandis	NC	VU	Logging and land use changes are threats in much of natural range	Teak improvement programs underway in India, Indonesia, PNG, Solomon Islands, Thailand and several African countries
Terminalia catappa	NC	LC	Currently secure but most populations are near sea level and at risk from rising sea levels and storm surges	No formal domestication plan
Terminalia richii	NC	EN	Naturally uncommon and genetic resources depleted by harvesting and clearing for agriculture with regeneration supressed by vines	Conservation strategy devised by the South Pacific Regional Initiative on Forest Genetic Resources (SPRIG) but not yet implemented
Xanthostemon melanoxylon	NC	CR	Critically endangered due to mining and illegal harvesting	Seed collection and ex situ conservation recommended

* Species listed in the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) Appendix II are defined as 'not necessarily threatened with extinction, but in which trade must be controlled in order to avoid utilisation incompatible with their survivial' (cf. species listed in Appendix I are threatened with extinction; trade in specimens of these species is permitted only in exceptional circumstances) (CITES 2018).

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Germplasm availability and propagation requirements

The importance of diversity has been discussed in previous chapters, but it is those managing forests and plantings, and establishing new plants, who are in a position to have the most impact on the continuing diversity of these forests and agroforests. This chapter considers sources of high-quality germplasm, and the propagation requirements of the species covered by this book.

Planting material

Seed

Whether collecting seed yourself or obtaining it from somewhere else, it is important to be using seed of good quality. There are two aspects of 'good quality' seed to consider and they are genetic quality and physiological quality.

Briefly, good genetic quality seed is seed that has been authenticated as to the species and has well-documented details of its collection. It should have a broad genetic base (i.e. be collected from 10 or more well-spaced trees) and, if for research purposes, it is preferable to be collected from just one population or geographical area; that is, constituting a provenance collection. For general and commercial plantings, good genetic quality may entail germplasm that has been selected and/or genetically improved in line with the main purposes for which the trees are being grown.

Physiological quality is influenced by: (1) timing seed collection to coincide with peak maturity; (2) hygienic collection practices which exclude extraneous material, and careful handling during processing to avoid damage; and (3) appropriate storage practices—that is, a minimum of dry, cool conditions, depending on species, and stable temperatures. Some seed ('orthodox') will maintain viability for months or even years if kept in a sealed container in a cool place, while some species with 'recalcitrant' seed cannot withstand cold storage and must be sown immediately or stored briefly at ambient temperatures. Another type of seed is 'intermediate' in storage requirements between these two extremes and might require cold storage to maintain viability for any length of time.

A manual of operating procedures for seed collection, documentation, seed testing, treatment and storage of priority species in Oceania (Young et al. 2014) is available in hard copy from the SPC PITSC in Narere, Fiji, or the manual is available as a digital download from the SPC Digital Library on the SPC website; <https://lrd.spc.int>. There are many accounts available on nursery practices for tropical trees. A selection of these (see Carter 1987; Quayle and Gunn 1998; Gunn et al. 2004) can be accessed through the CSIRO Research Publications Repository; <https://publications.csiro.au/rpr/home>. These cover important aspects that are often overlooked in the procedures applied in forest nurseries throughout Oceania, such as the need for soil sterilisation, protection of seed from heavy rains during germination and use of fungicides to control diseases.

Appendix 2 provides known requirements for the germination, seed storage and vegetative propagation of the species covered in this book.

Vegetative material

Vegetatively propagated plants are genetically identical to the mother plant. In comparison, plants grown from seed contain genes from both a mother and a father plant, with the father plant often being unknown (Schmidt 1993).

Vegetative propagation of trees is used in tree breeding and plantation establishment but also has value as an alternative propagation method where seed is difficult to store, to germinate or is not available.

Reproducing plants vegetatively enables the capture of valuable characteristics exhibited by individual plants, such as desirable essential oil composition and yield, flower colour and size, nut size and taste, ease of removing nut shell, growth traits, wood quality, uniformity of a characteristic and so forth. This is why clonal plantations have been utilised in many industries, from wood pulp to essential oils.

For many tropical tree species, methods of vegetative propagation have already been developed, particularly for major food genera such as *Artocarpus*, and commercial timber genera like *Eucalyptus*. For each species treated in this book, Appendix 2 indicates whether it has been successfully propagated vegetatively or is considered a candidate for vegetative propagation.

Macropropagation (cuttings, grafting, marcotting)

Propagation by cuttings is the most convenient and affordable of these methods and is used where possible. Marcotting is a variation of propagation by stem cuttings where root formation is initiated before the plant part is separated from the mother tree. Grafting involves a shoot (scion) of the desired tree being joined to a rootstock of a different genetic origin (Schmidt 1993).

The rooting of stem cuttings is best for mass propagation of trees but requires the establishment of managed stock to provide a supply of juvenile cutting material (Mbile et al. 2004). Marcotting can be successful in situations where rooted cuttings are not, but this method is more time-consuming and not good for producing large numbers of plants (Mbile et al. 2004). Grafting is a useful tool for combining a strong root system and main stem, often hardy to local conditions, with a scion that has desirable characteristics, such as fruit with good flavour (Quayle and Gunn 1998).

Methods of vegetative propagation by stem cuttings, grafting, budding, marcotting and division are described in detail in Quayle and Gunn (1998). Other specialist references on vegetative propagation of forest trees include Gunn et al. (2004), Longman (1993) and Schmidt (1993). All of these are available online (see the 'Selected bibliography' for details).

Micropropagation (tissue culture)

In vitro propagation (tissue culture) offers an alternative to using seed. Propagation of woody trees through tissue culture has several advantages, including fast multiplication of elite genotypes, quick release of improved cultivars, production of disease-free plants and season-independent production of plants (Phulwaria et al. 2012).

However, establishing a tissue culture propagation method for a tropical tree species is not without its challenges. The first stage of initiating cultures from mature forest trees can be difficult because of high levels of contamination and/or high secretion of polyphenols and tannins. Problems with culture contamination and phenolic exudation as well as in vitro recalcitrance are more common with cultures derived from mature tissues, yet at the same time, being able to establish tissue cultures from mature trees is ideal as stock trees can be selected for desired traits. Cultures initiated from explants derived from juvenile sources are generally easier to establish in vitro than adult plants of the same genotype. The use of juvenile tissue has been successful with a number of species; for example, *Acacia auriculiformis*, *A. mangium*, *Aqualaria malaccensis*, *Azadirachta excelsa*, *Calamus manan*, *Dyera costulata* and *Tectona grandis* (Krishnapillay 2000).

The rejuvenation of mature tissues can be achieved in a number of ways: for example, serial subculture of shoot tips (von Aderkas and Bonga 2000); ex vitro grafting of mature tree twigs onto juvenile trees (Huang et al. 1992; Peña-Ramírez et al. 2010); and pruning/lopping of selected trees to encourage the growth of rejuvenated shoots (Vibha et al. 2014).

Multiplication and rooting of established in vitro shoot culture systems for tree species can be demanding, with very specific requirements depending on the species and often the variety. Because of the importance of a good rooting system for effective establishment in the field/plantation, ex vitro rooting seems to be a more appropriate method compared with in vitro rooting, especially for plantation establishment (Benmahioul et al. 2016). The ex vitro technique is comparatively less time-consuming and more cost-effective, and requires less labour, chemicals and equipment compared with in vitro rooting because plantlets rooted ex vitro do not need any additional acclimatisation before transplanting into field conditions. Further, plantlets developed through ex vitro rooting have lateral roots, just like a natural root system, and higher root length, resulting in higher transplant survival rates than plantlets with roots generated in vitro (Yan et al. 2010).

A review of the literature conducted by Pijut et al. (2012) outlines the in vitro techniques used in the propagation of tropical hardwood species, and provides details of the methodology for some key species, such as *Santalum album* (sandalwood), *Swietenia macrophylla* (mahogany) and *Eucalyptus grandis* (flooded gum). The review notes that some research on tropical tree technologies has been undertaken by private companies and, therefore, the data are confidential, patented or often only partially shared as scientific publications.

Using tissue-cultured plants to establish new plantings

Whether tissue culture plantlets have been imported or locally produced, they must be of the highest quality and, in particular, have a very good root system. Documentation should be provided so that the recipient of the germplasm knows the origin of the stock. Phytosanitary certification should also be provided if available. Acclimatisation and hardening are very important aspects for tissue-cultured tree species and often different types of greenhouses are required to facilitate hardening. Facilities that provide good shading and misting/fogging might also be necessary to ensure effective hardening of the planting material, thereby minimising losses in the field planting.

Germplasm availability and Oceanian germplasm supply networks

There are several germplasm suppliers and supply networks operating in the Oceanian region, as outlined below. All details were current as of February 2018.

SPC has established a regional seed centre known as the Pacific Islands Tree Seed Centre (PITSC) which is based in Narere, Fiji. The role of this centre is to act as a regional focal point for coordination and implementation of priority germplasm collection, storage, distribution, research and training. It is a good first point of contact to assist with either providing seed or organising the required collections to be undertaken. PITSC has developed a seed-collecting manual (Young et al. 2014) which includes protocols for ensuring that collections are of both high genetic and physiological quality. This centre also maintains contacts throughout the region and may be able to identify alternative seed sources if they do not have seed in stock:

Pacific Islands Tree Seed Centre
Forest and Trees Program
Pacific Community
CePaCT Building, Narere Complex, Narere, Suva, Fiji
Email: elinay@spc.int
Ph: +679 3370 73

Other sources of tree seed in the region include:

Australian Tree Seed Centre
CSIRO National Collections and Marine Infrastructure
GPO Box 1700, Canberra, ACT 2601, Australia
Email: atsc@csiro.au
Website: <www.csiro.au/atsc>
Note: this centre supplies source-identified seed of mainly Australian native species and advice on alternative suppliers, propagation requirements and other aspects of utilising a particular species.

The Principal Silviculturist
Silviculture Research Division, Forestry Department
Ministry of Fisheries and Forests
PO Box 2218, Government Buildings, Suva, Fiji
Ph: +679 3322 311
Fax: +679 3320 380
Website: <www.mff.gov.fj>

Daniel K. Inouye US Pacific Basin Agricultural Research Center
Tropical Plant Genetic Resources and Disease Research
PO Box 4459, Hilo, Hawai'i 96720, USA
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Fax: +1 808 959 3539
Website: <https://www.ars.usda.gov/pacific-west-area/hilo-hi/daniel-k-inouye-us-pacific-basin-agricultural-research-center>

World Agroforestry Centre (ICRAF), Tree Seed Suppliers Directory
Website: <www.worldagroforestry.org/output/tree-seed-suppliers-directory>
Note: at present, it is not possible to search for a particular taxon in order to find out which suppliers may stock it. You can only search for suppliers in a particular country and then you need to check with individual suppliers regarding the species they stock.

Vegetative material

There are no specific suppliers of tissue cultures of tropical tree species in the Oceanian region. However, tissue culture laboratories exist in some countries and therefore there is always the possibility that an agreement could be negotiated for such a laboratory to supply specified germplasm. Any negotiation and endeavour focusing on the supply of tissue cultures of tropical tree species must take into account the problems that can be encountered when tissue culturing tropical tree species.

Care in choosing suppliers is vitally important and suppliers should not be selected until discussions have been undertaken with the biosecurity staff of the importing country.

The main supplier of tissue-cultured trees in Oceania is:
Arakai Pty Ltd T/A Yuruga Nursery
PO Box 926, Mareeba, Queensland 4880, Australia
Email: nursery@yuruga.com.au
Note: Yuruga Nursery currently supplies *Corymbia* hybrids and 'Saltgrow' and 'Summer Series' eucalypts. Yuruga Nursery uses a biodegradable paper pot (Quickpot), engineered for planting directly into the ground without the need to remove a pot or container which eliminates root disturbance and enhances plant establishment.

Tissue culture laboratories in India are also a source of tropical tree species. For example, Ambica Agro, <www.ambicaagro.net/forestry-plants.html>, supplies tissue cultures of teak, eucalyptus, sandalwood, mahogany, Malabar neem and poplar. AGbioteck Laboratories (India) Ltd, <www.agbiotek.com/Timber.

php>, supplies tissue cultures of *Tectona grandis*, *Acacia mangium* and *Gmelina arborea*.

Quarantine constraints in importing germplasm

The majority of countries in Oceania are contracting parties to the International Plant Protection Convention (IPPC). PICTs are represented at the IPPC by a regional body, Pacific Plant Protection Organisation (PPPO), and each contracting country has a National Plant Protection Organisation (NPPO) which implements the required actions identified by the IPPC in order to protect their own and other countries from pests and diseases.

In order to determine whether to allow a new species into a country, the NPPO will normally undertake a risk assessment. For some species, a risk assessment will have already been done and a set of conditions determined for safe importation of the species. For unassessed species, a risk assessment can be a lengthy and costly process, particularly if details of the species in the country of origin or elsewhere are unknown, so it is advisable to have plenty of lead time when trying to import new germplasm for a particular project. You may also find that the species of interest is not allowed to be imported into your country. This can be for a variety of reasons usually to do with possible associated pests and diseases or its weed potential.

To import seed or plant material, you will need to find out the requirements of your country's NPPO which is usually the national government agriculture department. Generally, you are required to obtain an import permit which sets out the conditions of importation. The exporting country usually needs to supply a phytosanitary certificate stating that the germplasm has been inspected and meets the conditions of importation of the importing country, as set out on the import permit. These conditions may include treatment of the seed or plant material, such as dusting with a fungicide and/or insecticide. The phytosanitary certificate, along with a copy of the import permit, is sent with the germplasm.

The importing conditions for tissue culture plantlets are the same as those for seed. Before any importation, consultation with the biosecurity or quarantine authority of the importing country is vitally important. The NPPO will issue the import permit and the exporting country must adhere to the conditions stated on the import permit. It is essential, therefore, that the exporting country is also consulted to ensure they can meet the required conditions; for example, can access chemicals that may be required for treatment of the shipment.

Authors: Bronwyn Clarke and Mary Taylor

Species accounts

The information on each species is arranged under the following headings.

Nomenclature (family, botanical and common names)

In preparing these digests, the latest, most widely accepted botanical names have been used—and mostly as given in *The plant list*, <www.theplantlist.org>. The place of publication of the accepted name of each species is given. The derivations of genus and specific and infraspecific epithets are included, as far as can be ascertained. Synonyms are occasionally provided where species names have been recently changed or earlier names are still in common use. Some wide-ranging species have many common names applied to them both within and between countries. A selection of the more generally used common names by country of occurrence are indicated in the accounts.

Summary of attributes and why diversity matters

A short synopsis is provided of the species' main attributes and uses, our current knowledge of its genetic diversity and how this is of economic and environmental importance, and the work needed to capture, conserve and make better use of this diversity.

Description

A summary of the main morphological characteristics of a species is given. For more detailed botanical descriptions, readers should refer to the relevant publications in the relevant species' list in the 'Selected bibliography'.

Distribution

The geographical distribution of each taxon is given for the species' natural range and a map provided. The point data upon which the distribution maps are based were sourced largely from the Global Biodiversity Information Facility (which accesses over 1,000 databases across the world), the CSIRO Australian Tree Seed Centre database and various reports. These data were vetted and only natural occurrences included, apart from some species such as *Musa troglodytarum* and *Syzygium malaccense* where the native range is unclear due to ancient human introductions. Additional points were added when the data did not reflect the known distribution, particularly when there were no records for a country or island where the species occurs. In the case of species in which infraspecific taxa are recognised, the distribution given is for the species as a whole unless stated otherwise.

The relevant countries where a taxon is planted outside its natural range and may have become naturalised are given. This section concludes with a listing of key climatic and edaphic requirements for the successful establishment of the taxon in question.

Uses

The principal wood and non-wood uses of each species are given.

Diversity and its importance

Knowledge of a species' genetic diversity is highlighted along with progress in domestication and improvement. In some cases (e.g. *Santalum austrocaledonicum* and *Tectona grandis*), individual species are well down the pathway to optimum use of genetic resources, including active breeding programs providing improved seed. However, this is more the exception than a general rule for the species highlighted in this book. In many cases, and despite a species' importance as a source of food, medicine, wood, ornament and/or environmental restoration, there has been no detailed examination of genetic diversity. The studies needed to determine the extent of genetic variation in these species and domestication and improvement strategies are highlighted.

Conservation of genetic resources (including threats and needs)

Conservation issues threatening the viability of a species and its component subspecies and populations are documented, including threats from climate change, overharvesting, invasive species, pests and diseases. Ways of addressing these problems by complementary in situ, ex situ and circa situm conservation strategies are proposed as appropriate.

Other information relating to each species account includes:

- ***References***—key literature on each species, with a focus on genetic diversity, and from which these species treatments have often been substantially derived, is given in the 'Selected bibliography'.
- ***Contact details for authors***—these are provided in Appendix 1 in alphabetical order by surname, each with position held, affiliation and postal and email addresses.
- ***Germination, seed storage and vegetative propagation information***—details known for each species are compiled in Appendix 2.
- ***Images***—many of the photographs used in the accounts were provided by the authors of the individual accounts. Where other individuals or organisations have provided photographs, their generous cooperation and assistance is acknowledged in the photo captions, with full names given in the 'Photograph credits' within the Acknowledgments.

Acacia auriculiformis

Family: Mimosaceae
Botanical name: *Acacia auriculiformis* A.Cunn. ex Benth. In Hooker's *London J. Bot.* 1: 377 (1842). The genus name is believed to have been derived from the Greek *akazo*, I sharpen, alluding to the spiny stipules of many African and Asiatic species. The specific epithet comes from the Latin *auricula*, external ear of animals, and *forma*, form, figure or shape, in reference to the shape of the legume.
Common names: standard local name in Australia is northern black wattle, but it is also known as ear-pod wattle, Darwin black wattle and tan wattle. Other common names include *da ye xiang si* (China); Australian babul (India); *kasia* (Indonesia); Japanese acacia (Philippines); *ngarari*, *unar* (PNG); *krathin narong* (Thailand); and *keo la tram* (Vietnam).

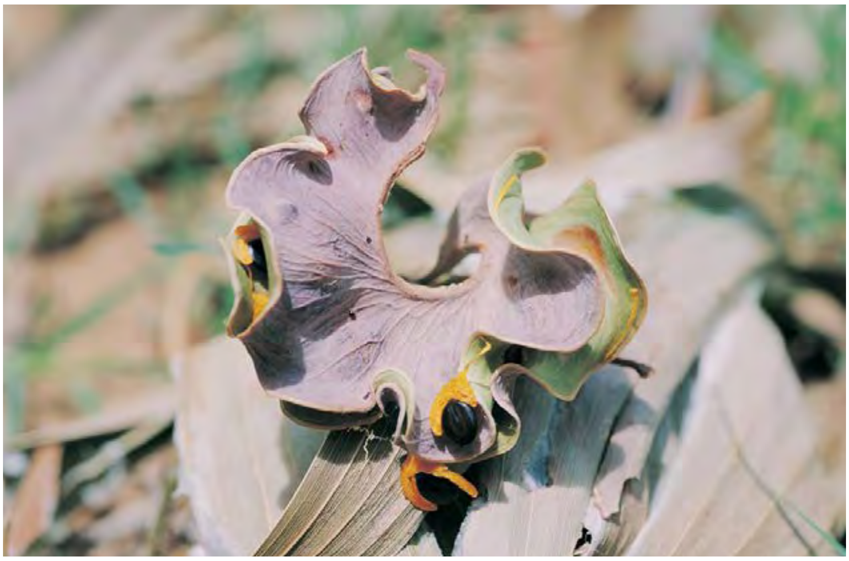
Summary of attributes and why diversity matters

Acacia auriculiformis occurs in diverse habitats and is one of the best adapted species for growth on harsh sites in the tropics. Its rapid early growth rate, ability to fix nitrogen and tolerance of infertile, acid, alkaline, saline or seasonally waterlogged soils and moderate dry seasons make it a very useful species for the rehabilitation of degraded lands. It has been widely planted for wood and fuelwood production, erosion control, ornament or shade, mainly in Asia but also in Africa and South America.

There is considerable diversity among regions of natural occurrence in morphology and stem form of *A. auriculiformis*. Such variation offers great opportunities for selection for fast growth and straight stems in breeding programs, providing outstanding prospects for industrial plantations and production of timber products. Hybridisation with *A. mangium* has substantially improved its growth rate and, in many cases, also resulted in improved stem form.

Description

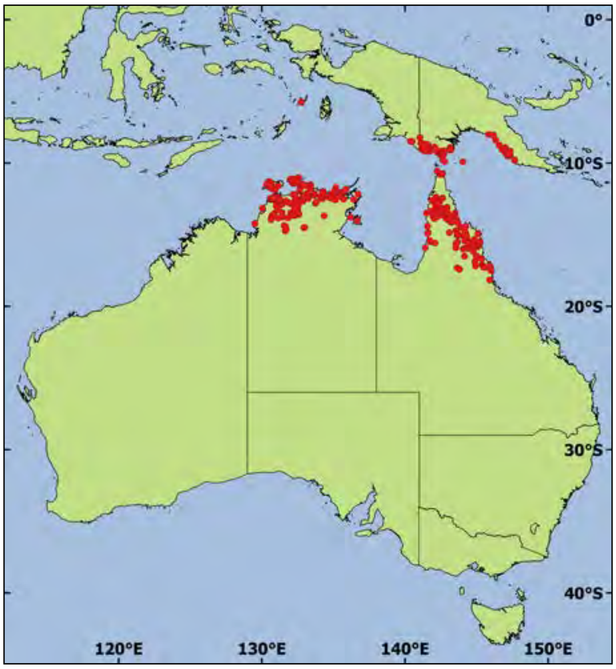
Habit medium to large tree to 35 m tall with a long straight bole under favourable conditions in its natural habitat; more commonly it is a small tree of 8–10 m with a short, heavily branched bole. ***Bark*** young trees have smooth grey-coloured bark, becoming rough and longitudinally fissured with age. ***Leaves/phyllodes*** newly germinated seedlings produce bipinnate leaves but soon develop phyllodes, generally at leaf node number 3 or 4; adult phyllodes straight or falcate, 8–20 cm long, 1.1–4.2 cm wide; longitudinal nerves parallel and numerous, 3–5(–6) more pronounced than the rest, free to base, not confluent with lower margin; distinct gland at the base of the phyllode. ***Inflorescences*** spikes to 8 cm long, arranged in pairs in the upper axils. ***Flowers*** bright yellow. ***Pods*** flat, flexible but hard, rather woody, glaucous, transversely veined with undulated margins, 1.5 cm wide, 6.5 cm long; initially straight or curved, but becoming twisted and irregularly coiled on maturity. ***Seed*** held transversely in the pod, blackish, broadly ovate to elliptic, 4–6 mm long, 3–4 mm wide, encircled by a yellow, orange or red funicle-aril; at maturity,



Above: Pods and seed (Photo: M. McDonald)
Left: Flower spikes and phyllodes (Photo: CSIRO)

Top: Crooked stem form; Cobourg Peninsula, Northern Territory, Australia (Photo: CSIRO)

Bottom: Excellent bole form; Bensbach River, Western Province, PNG (Photo: L. Thomson)



pods dehisce along a single margin, often leaving seed dangling from the pod by the aril while still on the tree.

Distribution

Acacia auriculiformis has a disjunct distribution in Australia, PNG and Indonesia, between latitudes 9–16°S and longitudes 130–145°E. In Australia, it occurs on Cape York Peninsula and Torres Strait, Queensland, and in the northern part of the Northern Territory, including several offshore islands. In PNG, it occurs in Central Province and Western Province and extends into Papua province and the Kai Islands of Indonesia.

Owing to its ease of establishment and adaptability, *A. auriculiformis* has been widely planted throughout tropical Asia, and also in tropical regions of the Pacific Islands, Africa and South America.

Acacia auriculiformis occurs naturally in hot humid and hot subhumid climatic zones. The mean maximum temperature of the hottest month (November–December) is in the range of 32–34 °C, and the mean minimum temperature of the coolest month (May–September) is 17–22 °C within its natural range. Outside the natural distribution, the species adapts to a wider range of temperatures. Mean annual rainfall (MAR) ranges from 760 to 3,400 mm with a summer monsoonal pattern and a dry-season range of 0–7 months. Altitudinal range of plantings is 0–1,000 metres above sea level (m asl). Most natural occurrences are on lowland sites along rivers, but it also occurs on the edges of sand dunes, behind mangrove swamps and along river levees and flood plains. The soils are frequently yellow earths, but vary from dune sands and sandy loams to alluvials with a high clay and humus content. The pH range is usually 4.5–6.5, but *A. auriculiformis* has proven tolerant of highly alkaline (pH 8–9) and acid (pH 3) soils. It can also tolerate saline soils.

Uses

Acacia auriculiformis is a fast-growing, multipurpose species, and is grown for a wide range of purposes from fuelwood to soil improvement, erosion control and ornament. It is a common street tree in many countries.

Wood—the heartwood is light brown to dark red and the sapwood is cream to yellow. The basic density is 500–650 kg/m^3. The timber is fine grained, often decoratively figured and finishes well. The wood makes attractive furniture and is also suitable for construction work, wood turning and carving. Its high basic density and calorific value of 19.7–20.5 MJ/kg make it ideal for firewood and charcoal.

Plantation-grown trees are suitable for the production of unbleached kraft pulp and high-quality neutral sulfite semichemical pulp. Plantations have been established in Karnataka, India, and Vietnam for the production of paper pulp.

Wood panelling using *A. auriculiformis*; Thailand (Photo: CSIRO)

Non-wood—the bark has sufficient tannins (about 13%) for possible commercial exploitation. Bark extract is used as a natural dye in the batik textile industry in Indonesia. Lac insect culture using *A. auriculiformis* as the host plant is possible.

The species has a spreading, densely matted root system which helps stabilise eroding land. It has been used widely in revegetation of degraded land and rehabilitation of grassland in India, Indonesia and Vietnam. Other common uses include providing shade and for ornamental purposes.

Diversity and its importance

Variation in the growth and tree form among provenances of *A. auriculiformis* has been well documented. In general, provenances from the Northern Territory grow slowly and produce multistemmed trees. PNG provenances are most vigorous but many sources from Queensland also grow fast and produce trees of good stem form. In particular, Queensland provenances from Kings Plains, Coen River and Morehead River all grow well with outstanding stem form. The separation into three distinct groups corresponding to the three main geographical distributions of the species in Queensland, the Northern Territory and PNG was also evident in a seedling morphology study and isozyme analysis.

Acacia auriculiformis seed orchard/agroforestry planting with understorey of cardamom, with Vuniani Kuruwali; Laulau, Naitasiri, Fiji (Photo: L. Thomson)

Provenance trial—contrasting bushy form of an Asian landrace (foreground) with Kings Plains, northern Queensland provenance (background); Terai region, Nepal (Photo: L. Thomson)

Breeding programs have successfully capitalised on these variations, and improved the utilisation of the species. Excellent progress in genetic improvement programs of this species has been made in India, Thailand, Vietnam and Fiji. In Vietnam, hybridisation with *A. mangium* has substantially improved growth rates and, in many cases, also resulted in improved stem form.

Conservation of genetic resources (including threats and needs)

The species is not considered under threat and, to date, there have been no specific attempts to conserve the genetic resources of *A. auriculiformis* in situ. The wide planting and extensive provenance and progeny trials established in many countries serve ex situ conservation purposes very well.

There are several diseases and insect pests of *A. auriculiformis*, but none are limiting to establishment on appropriate sites at present.

Authors: Khongsak Pinyopusarerk, Stephen Midgley and Lex Thomson

Acacia colei

Family: Mimosaceae
Botanical name: *Acacia colei* B.R.Maslin & L.A.J.Thomson. In *Aust. Syst. Bot.* 5: 737 (1992).

The specific epithet honours former CSIRO senior technical officer Eric George Cole (1927–) who participated in major seed and botanical collections of this species in the 1980s.

Two varieties of *A. colei* are recognised, distinguished mainly by their pods (see below): var. *colei* and var. *ileocarpa*.

Common names: Cole's wattle, kalkardi

Summary of attributes and why diversity matters

Acacia colei is a fast-growing, nitrogen-fixing shrub or small tree suitable for cultivation on a wide range of sites in the semi-arid tropics. Its importance is enhanced by its many beneficial attributes when cultivated on adverse sites, including: impact on annual crop yields through production of large quantities of biomass for use as mulch and organic matter; protection of crops from strong winds; production of excellent firewood and charcoal; and production of seed as a source of nutritious food suitable for consumption by livestock and humans, especially when staple annual crops fail.

Despite the wide natural range of *A. colei*, field trials in different locations have generally shown limited variation in provenance or seedlot performance. There also appears to be limited difference in the growth performance of the two varieties. Economically important intraspecific variation in *A. colei* arises from the different utilisation potentials for human food of the two varieties. The seed of var. *ileocarpa* is held more firmly in the coiled pods than that of var. *colei* and so the mature pods can be left on the tree longer without seed loss. Knowledge of the use of *A. colei* seed for human consumption is still in its infancy in Africa but it is expected that breeding may enhance the human food potential of this species.

Description

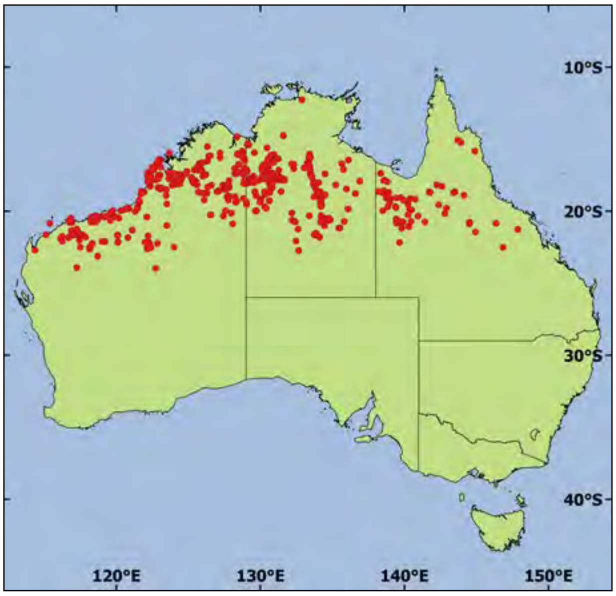
Habit spreading shrub or small tree to 2–5 m tall, 4–6 m wide, with a compact crown and ascending branching; basal bole diameter rarely exceeds 25 cm as this is a relatively short-lived species (typically <10–15 years); crowded plants are tall and slender, while widely spaced plants have short boles and spreading crowns. ***Bark*** grey and smooth on main trunks but reddish-brown towards the ends of the branches. ***Phyllodes*** silvery green or grey-green appearance due to a covering of dense, minute silver hairs; adult phyllodes broadly elliptic, 7.5–22.5 cm long, 1.0–5.5 cm wide, slightly recurved at tip; var. *ileocarpa* has slightly narrower adult phyllodes than var. *colei*. ***Inflorescences*** cylindrical spikes ≤6.5 cm long, in pairs in the upper axils. ***Flowers*** hermaphroditic, bright yellow. ***Pods*** 4–5 mm wide, thin textured, constricted and raised over the seeds; varieties distinguished mainly by their pods—var. *colei* has curved pods while var. *ileocarpa* has tightly coiled pods. ***Seed*** hard-coated, glossy black, 4–5 mm long, 2.5 mm wide, with a bright yellow, oily aril.

Top: Buds and flowers (Photo: CSIRO)
Bottom: Habit of mature specimen (Photo: CSIRO)

Distribution

Both varieties of *A. colei* are endemic to the semi-arid tropics of northern Australia but var. *colei* is more common and widespread. It extends from the Pilbara and southern Kimberley regions in Western Australia, across central Northern Territory to the Mount Isa region in western Queensland. In contrast, var. *ileocarpa* has sporadic occurrences in the southern Kimberley and

Pilbara regions of Western Australia to western Northern Territory. No introgression between the two varieties has been observed even in localities in the southern Kimberley region where the two varieties grow together in intimate mixtures.



Acacia colei has been established successfully in dry tropical Africa, including Burkina Faso, Cape Verde, Nigeria, Niger, Senegal and Zimbabwe, and tropical Asia, including India (Tamil Nadu, West Bengal), Indonesia (West Timor), Nepal and Thailand.

Acacia colei is a species of the hot semi-arid tropics. Within its natural range, MAR is 270–690 mm, with a strong summer maximum, but rainfall is highly erratic between years. The dry season typically lasts for 8–9 months. Altitudinal range is 0–450 m asl. The area is mostly frost free but 1–2 light frosts may occur annually in elevated inland localities. *Acacia colei* favours disturbed sites. It is most often found in proximity to drainage lines and flood plains on well-drained sands or red loamy clays These are mostly mildly acidic (pH 5.5–6.5) but it is also found on some alkaline soils (pH 8.5).

Uses

Acacia colei is a fast-growing, nitrogen-fixing shrub or small tree suitable for cultivation on a wide range of sites in the semi-arid tropics. It is grown for a range of purposes.

Wood—it produces a good fuelwood which can be converted into an excellent charcoal. The heartwood is hard, dense (870 kg/m^3), dark brown and has a high calorific value. This species has proved very useful for fuelwood production on adverse or degraded sites in West Africa.

Non-wood—in West Africa, *A. colei* is also grown as a windbreak and as an amenity plant. Additionally, in this region, the seed of *A. colei,* which is usually produced precociously and in large quantities, is increasingly valued as an alternative source of human food. In drought years when yields from staple crops fail, villagers modify local millet- and sorghum-based recipes to produce meals that incorporate *A. colei* seed processed as flour. The seed of var. *ileocarpa* is held in the pods for a longer period after ripening and the compact clusters are easier to harvest compared with var. *colei*. *Acacia colei* seed has been shown to be nutritious, containing 23% crude protein, 11% fat and 53% carbohydrate, and assessed as safe for incorporation into human diets by up to 25% of the total diet based on seed weight.

Two acacia-based agroforestry systems currently being developed in Niger prominently feature *A. colei*. The Sahelian Eco-Farm (SEF) and the Farmer Managed Agroforestry System (FMAFS) are attempts to address the main constraints to Africa's rainfed agriculture; namely, soil erosion, low soil fertility, low water use efficiency, drought, shortages of animal fodder, low income and an inefficient distribution of the labour force throughout the year. *Acacia colei* produced in these systems provides seed for human or livestock consumption, wood for household consumption or sale and environmental services (windbreak, mulch, organic matter, nitrogen fixation) which contribute to increased annual crop yields. Its high tolerance to drought and lack of susceptibility to most insects and diseases attacking annual crops make it an excellent backstop for adverse years when annual crops fail. It is estimated that the combined profit per hectare from all the SEF components is 10 times higher than the profit derived from a millet field.

Dry zones of some PICTs (e.g. Fiji) are becoming so degraded, with a total loss of top soil down to bedrock, that *A. colei* is being considered as a candidate species for revegetation of these harsh environments for tree growth.

Diversity and its importance

Acacia colei was previously included under *A. holosericea*. During the mid-1980s, observations of trials of tropical dry-zone Australian acacias in Sub-Saharan Africa suggested *A. holosericea* might include several taxa. Genetic and morphological studies showed *A. holosericea* sensu lato comprised three superficially similar entities with different ploidy levels; namely, *A. colei* (hexaploid), *A. holosericea* sensu stricto (tetraploid) and a reinstated species, *A. neurocarpa* (diploid). *Acacia colei* appears to have evolved as an allopolyploid following a hybridisation event(s) between *A. neurocarpa* (diploid) and *A. elachantha* (tetraploid).

Above left: Charcoal produced from *A. colei* wood; Senegal (Photo: L. Thomson)

Above right: Firewood from *A. colei*; Maradi, Niger (Photo: T. Rinaudo)

Left: Villager processing *A. colei* seed; Maradi, Niger (Photo: T. Rinaudo)

Despite the wide natural range of *A. colei*, field trials in different locations have generally shown limited variation in provenance or seedlot performance. There also appears to be limited difference in the growth performance of the two varieties. These apparently low levels of adaptive variation across populations most likely reflect genomic uniformity, and possibly the species consists of a limited number of related clones that reproduce through apomixis. However, apomixis could not be confirmed in a pilot study in which emasculated flowers failed to produce pods while bagged flower spikes produced pods at relatively low frequency. Adaptive traits in *A. colei* may be largely 'fixed' for a few related genotypes that are capable of reliable fast growth on adverse sites and which are capable of producing prodigious quantities of seed from a young age. Breeding may enhance the human food potential of *A. colei*. There is, therefore, a fundamental need to understand its reproductive biology and breeding system.

With the seed of var. *ileocarpa* more tightly retained in the pods than that of var. *colei*, the former variety is more amenable for use as a food plant as the mature pods can be left on the tree longer without seed loss. Pickers can wait for a high proportion of the pods to ripen before harvesting and spend less time on repeat harvests. Even though the pods hold seed longer, once fully dry, a light

Acacia colei seed on Koori grinding stone; Australia (Photo: CSIRO)

Pods of var. *ileocarpa*; Kimberley region, Western Australia (Photo: L. Thomson)

Pods of var. *colei* (Photo: CSIRO)

beating with a stick will separate seed from pods. In West Africa, pods of var. *colei* ripen unevenly, and exposed seeds dangle by the aril for a brief period often dropping within 1–2 days of ripening. Pickers must return daily to harvest newly ripened pods. Australian seed collectors quickly and easily extract seed from var. *colei* using simple hand-threshing techniques.

The three species in the *A. holosericea* complex are closely allied to a group of tropical species some of which have similar domestication potential to *A. colei*. This group includes *A. cowleana*, *A. elachantha*, *A. grandifolia*, *A. nesophila*, *A. pellita*, *A. sericoflora* and *A. thomsonii*. The commercially important industrial timber plantation species *A. mangium* also has close affinities with this group.

Conservation of genetic resources (including threats and needs)

Acacia colei is relatively common throughout its wide natural distribution and there are few threats to its genetic resources. Many populations occur in relatively remote regions where the main land use is rangeland cattle stations. It is also a naturally resilient species and populations usually thrive following site disturbance, including catastrophic, periodic wildfires. The main risk may come from a new pest or disease, given its apparently low level of genetic diversity.

Authors: Maurice McDonald, Lex Thomson and Tony Rinaudo

Acacia crassicarpa

Family: Mimosaceae
Botanical name: *Acacia crassicarpa* A.Cunn. ex Benth. In Hooker's *London J. Bot.* 1: 379 (1842).

The specific epithet is from the Latin *crassus*, thick, and *carpus*, fruit, and refers to the thick pod.
Common names: northern wattle, thick-pod salwood (Australia); carpa (as plantations in Indonesia)

Summary of attributes and why diversity matters

Over the past 30 years, *Acacia crassicarpa* has changed from a virtually unknown tree to a significant commercial plantation species for the pulp and paper industries of South-East Asia. Its natural occurrence in the humid tropics and proven performance on poorly drained, acidic sites suggest it will find an expanded place in tropical plantation forestry.

The habit and stem form of *A. crassicarpa* vary considerably across its natural range, with trees from PNG and Indonesia being generally larger with greater apical dominance than those in Australia. Considerable diversity has been recorded in survival and growth as planted trees and wood properties such as shrinkage and strength and yields of chemical pulp. Commercial breeding programs are now capitalising on this diversity through selection for fast growth, good form and uniform wood density, improved resistance to pests and diseases and resistance to cold. However, the sustainability of *A. crassicarpa* plantations is being challenged by pathogens, including root rot (*Ganoderma*) and wilt disease (*Ceratocystis*). Maintenance of genetic diversity in breeding populations will likely play a key role in addressing these current and different future challenges.

Description

Habit tree to 20 m tall, but occasionally reaching 30 m, attaining its best development as a straight-boled tree in Western Province, PNG, and in southern Papua, Indonesia; in Queensland, trees rarely exceed 15 m tall; typical form is bushy with heavy crown, but single-stemmed trees with a long straight or somewhat sinuous bole can be found. ***Bark*** dark or grey-brown, hard, with deep vertical furrows; inner bark red and fibrous. ***Phyllodes*** smooth, grey-green, curved, 11–22 cm long, 1–4 cm wide; nerves numerous, longitudinal, 3 prominent and 4 subprominent; phyllodes borne on angular, lined, scurfy branchlets. ***Inflorescences*** spikes 4–7 cm long on thick stalks clustered in groups of 2–6 in the axils. ***Flowers*** bright yellow. ***Pods*** dull brown, oblong, woody, flat or twisted, 5–8 cm long, 2–4 cm wide, veins oblique. ***Seed*** black, 6 × 3 mm, arranged transversely, with the pale creamy-yellow funicle folded and thickened, forming a long aril. ***Reproductive phenology*** in native forests, the main flowering period is May–June,

Even-aged pure stand of *A. crassicarpa*; Western Province, PNG (Photo: L. Thomson)

Multistemmed form; Lizard Island, Queensland, Australia (Photo: M. McDonald)

Flower spikes and phyllodes (Photo: B. Maslin)

Cluster of pods (Photo: CSIRO)

but light flowering may occur as late as September; the peak fruiting season is October–November.

Distribution

The species has a disjunct distribution at latitudes 8–20°S in north-eastern Queensland, Australia, south-western PNG and Papua, Indonesia, mainly at altitudes from near

sea level to 150 m asl but up to 700 m asl on the Atherton Tableland in Queensland.

The significant attraction of *A. crassicarpa* as a plantation species is its demonstrated capacity to grow in a variety of difficult soil types, from highly organic low pH soils in Sumatra (Indonesia) to infertile inland sands in central Vietnam which are seasonally waterlogged and suffer extended dry-season drought. As a result, *A. crassicarpa* has been widely planted throughout tropical Asia, and in tropical regions of Africa and South America.

Acacia crassicarpa is found in the humid and subhumid lowland tropics where average summer-dominated annual rainfall is in the order of 1,000–3,500 mm with a 3–6-month dry season. The entire range is frost free. It occurs in open forests and woodlands on sites with impeded drainage or sometimes at the margins of closed rainforests. In Australia, it is commonly found behind coastal foredunes and on coastal plains and foothills on a variety of soil types, including calcareous beach sands, yellow earths derived from granite, red earths on basic volcanics, red-yellow podzolics over schists, and alluvial and colluvial soils.

Uses

Acacia crassicarpa has become a significant commercial plantation species for pulp and paper in South-East Asia and has found use in wooden furniture manufacture. In 2006, there were over 200,000 hectares (ha) of commercial plantations of *A. crassicarpa* established in South-East Asia, primarily on the island of Sumatra where it is used as feedstock for bleached hardwood kraft pulp. Basic density for typical plantation-grown trees is 490–530 kg/m^3 with pulp yields typically 51–52%. Its success as a plantation species is due to its vigorous growth, with plantation yields of over 30 m^3/ha/year on good sites, ease of establishment and capacity to tolerate a wide range of soil types. Its excellent performance and adaptability could lead to wider use in tropical plantation forestry.

Wood—the heartwood is deep reddish-brown, attractively marked, hard and moderately heavy with basic densities varying from 480 to 640 kg/m^3. It is suitable for a wide range of sawn-timber end uses, such as boatbuilding, flooring and veneer. Its pleasing colour and straight form in plantations have led to pilot commercial use of the timber for furniture and other solid wood applications. The narrow sapwood is creamy yellow, susceptible to rapid fungal decay in moist environments and attack by *Lyctus* borers. In Tabora, Tanzania, it is being grown as a source of fuelwood for curing tobacco.

Non-wood—it finds use in revegetation and fixation of coastal sand dunes and for shelterbelts.

Acacia crassicarpa interplanted with *Casuarina equisetifolia* for coastal stabilisation; Hainan, China (Photo: K. Pinyopusarerk)

Diversity and its importance

Significant provenance variation has been recorded in field trials in Thailand, Indonesia, Malaysia, China and elsewhere, clearly establishing the outstanding growth potential of PNG provenances of *A. crassicarpa*, with early height growth rates of 5 m/year being recorded. However, there is a strong genotype × environment interaction and not all PNG provenances grow well on all sites. Queensland provenances appear to be more resistant to cyclone damage than the faster growing PNG provenances. In China, significant differences in cold resistance among half-sibling families were recorded. Levels of genetic diversity in *A. crassicarpa* are generally lower than in either conifers or eucalypts, and the degree of population differentiation higher. The species has high levels of outcrossing with little variation in the outcrossing rates between populations.

Considerable diversity has been recorded in economically important wood properties, such as shrinkage and strength and yields of chemical pulp. Commercial breeding programs are now capitalising on this diversity through selection for fast growth, good form and uniform wood density plus resistance to pests and diseases.

Acacia crassicarpa has been affected by *Ganoderma* root rot and *Ceratocystis* stem wilt in Indonesia and Malaysia. Field observations suggest genetic resistance and/or tolerance exists; however, evidence is currently limited. Since clonal deployment of resistant genotypes is the quickest and most effective way of delivering resistant planting material, ongoing research to develop clonal forestry for *A. crassicarpa* is warranted.

Acacia crassicarpa may infrequently form natural hybrids with *A. peregrina*.

Conservation of genetic resources (including threats and needs)

Despite many native populations of *A. crassicarpa* remaining intact throughout its native range, the species appears in the IUCN Red List as Vulnerable based on a 1998 assessment. Field observations based on extensive sampling in PNG by CSIRO teams at that time do not support this classification and a revised classification of Least Concern is recommended. The first seed collections of *A. crassicarpa* were made in northern Queensland in 1981 and comprehensive collections began in Australia and PNG in 1982. Several further collections were made with international cooperation and support, including the first collections in Indonesia in 1990. Thorough, broad-based collections now form the basis for seed orchards and comprehensive commercial breeding programs at several sites in Indonesia, Australia, China, Vietnam, the Philippines and Thailand.

Insect pests such as the stemborer beetle (*Platypus* sp.) and the stem girdling beetle (*Sinoxylon* sp.) have been reported on *A. crassicarpa*; however, damage by pests has generally been localised and of minor significance. *Acacia crassicarpa* is susceptible to some foliar diseases and root rots but has not yet been damaged by heart rot, at least not to the extent observed in *A. mangium*. The identification of a damaging leaf blight pathogen, *Passalora perplexa*, suggests that this might become a constraint to expanded plantation development.

Under the right conditions, *A. crassicarpa* can readily shade out competing vegetation. This, together with the capacity to produce over 150 kg seed/ha, indicate potential to become a weed in some circumstances.

The broad genetic diversity available through both *A. crassicarpa*'s natural and managed breeding populations will be a vital tool for breeders to successfully address challenges currently posed by *Ganoderma*, *Ceratocystis* and other fungal problems that may emerge in the future.

Authors: Stephen Midgley and Lex Thomson

Left: Four-year-old, second-generation *A. crassicarpa* seedling seed orchard showing good bole form; Dong Ha, central Vietnam (Photo: C. Harwood)

Below left: Single bole form (PNG provenance); Mangaia Island, Cook Islands (Photo: L. Thomson)

Below right: Multistemmed form (Queensland provenance); Mangaia Island, Cook Islands (Photo: L. Thomson)

Acacia koa (including *A. koaia*)

Family: Mimosaceae
Botanical name: *Acacia koa* A.Gray. In *U.S. Explor. Exped*. 15: 480 (1854).

The specific epithet comes from the Hawaiian language name for the tree, which also means 'warrior'.

Acacia koa is a tetraploid species with $2n = 52$. It probably evolved from Australian ancestors, possibly *A. melanoxylon*. *Acacia koa* was originally classified as *A. heterophylla* var. *latifolia* Benth. in 1842 but was elevated to species rank in 1854. Past classifications, no longer recognised, have at different times divided *A. koa* into varieties *hawaiiensis*, *weimeae*, *latifolia*, *kauaiensis* and *waianaeensis*, based on morphology and geography, or put Kauaʻi island acacias into the species *A. kauaiensis*.

Current taxonomy places the native acacias in Hawaiʻi into two species: *Acacia koa* and the related *A. koaia* Hillebr. (common name *koaiʻa*). The latter is a shorter statured tree of dry open woodlands, with generally wider spreading crowns, shorter narrower phyllodes, darker yellow–coloured flowers, and harder wood. Although it occurs on all the main Hawaiian Islands, *A. koaia* is much less common than *A. koa* and is listed as Vulnerable by IUCN. An intermediate form also exists on the island of Kauaʻi.
Common name: koa

Summary of attributes and why diversity matters

Acacia koa is the most important native timber tree of Hawaiʻi, United States of America (USA). It is fast-growing, nitrogen-fixing and can reach 30 m in height and 2 m in diameter under ideal growth conditions. In its native range in the Hawaiian Islands, the tree is more important today for providing habitat for native forest birds and watershed protection than it is for its highly valued timber.

A major impediment to reforestation with *A. koa* is the lack of planting stock adapted to the many different site conditions across Hawaiʻi and lack of resistance to common non-native pests and diseases. While wood colour and figure vary greatly among individuals and populations—from plain, light-coloured wood to the much more valuable, highly figured and coloured wood—little is known about inheritance of wood quality in this species. Development of superior lines with good survival on harsh sites, good growth rates and form, resistance to pests and diseases and good-quality wood is needed to stimulate reforestation with this useful tree species.

Description

Habit tree to 25 m tall and 1.5 m diameter at breast height (dbh), with the largest trees reaching heights of over 30 m and >2 m dbh (on optimal sites with deep soil and adequate rainfall); forest specimens regenerate in gaps in the canopy and develop long, straight boles ≤10 m, while open-grown specimens in pastures are broader than they are tall, fork within a few metres of the ground, and have thick, fluted boles. ***Bark*** smooth grey on young trees of <20 years, often with a rusty orange colour caused by epiphytic algae; rough and flaky on older trees. ***Phyllodes*** sickle-shaped developing from flattened leaf stems, 7.5–26.0 cm long, 0.5–2.5 cm wide; young phyllodes have a blue-green bloom on the surfaces which fades to green as the phyllode matures. ***Inflorescences*** borne axially or in terminal panicles. ***Flowers*** white to cream, about 2 mm long, borne in round heads about 8 mm in diameter, with 1–3 heads borne on common peduncle c. 1 cm long. ***Pods*** flat, brown and papery, 8–25 cm long, 0.8–1.5 cm wide, containing 5–8 seeds. ***Seed*** flattened and ellipsoid, 6–12 mm long, 4–7 mm wide; the long axis of the seed is perpendicular to the long axis of the pod.

Globular flower heads (Photo: J.B. Friday)

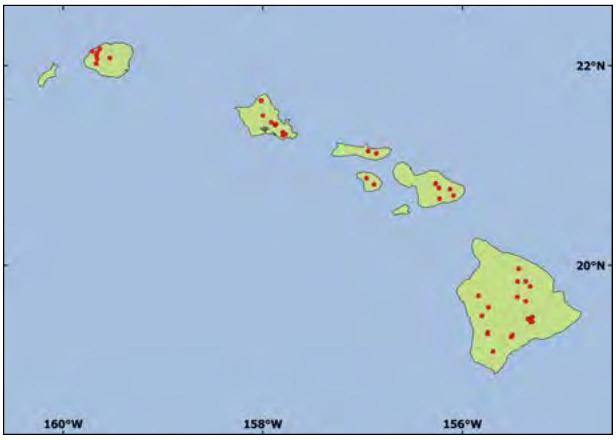
Pods and seed (Photo: J.B. Friday)

Even-aged pure stand of *A. koa* (Photo: J.B. Friday)

Typical open-grown habit with canopy wider than height (Photo: J.B. Friday)

Distribution

Acacia koa is endemic to the six main Hawaiian Islands of Kaua‘i, O‘ahu, Maui, Moloka‘i, Lana‘i and Hawai‘i (22°13′N 159°42′W to 19°2′N 155°7′W). No large plantations exist outside of the Hawaiian Islands.



Most *A. koa* forests grow between 300 m and 2,200 m asl in mesic to wet environments. Mean annual rainfall is 850–5,000 mm with a variable distribution and a dry season that can extend to 4 months. Range in mean annual temperature (MAT) is 9–21 °C with an absolute minimum temperature of –4 °C. *Acacia koa* is tolerant of shallow, infertile soils but intolerant of waterlogging. It prefers loams, sandy clay loams, clays, clay loams and sandy clays of acid to neutral pH (range 4.0–7.4).

Uses

Under suitable conditions, *A. koa* is a fast-growing, nitrogen-fixing species with good self-pruning ability. It requires full sun and tolerates fire and frost when mature. *Acacia koa* is the most important native timber tree of Hawai‘i and is of wide utility.

Wood—this species is primarily valued for its wood, which is made into furniture, guitars and ukuleles, interior panelling, flooring, picture frames and turned bowls. Wood colour ranges from pale straw yellow to reddish-brown to dark chocolate brown. The most highly prized wood is highly figured with tight curls that give the finished wood a three-dimensional appearance. Wood is easily worked, has medium hardness and takes a fine polish. An important cultural use of *A. koa* is the construction of traditional canoes, which are carved out of a single log. Logs large enough to make six-person racing canoes (15 m) are rare and highly prized. In ancient times, Hawaiians built seagoing canoes out of *A. koa* logs that were large enough to carry crews thousands of kilometres across the open sea. Trees of *A. koa* large enough to create such canoes no longer exist today.

Non-wood—the most important economic value of *A. koa* forests comes from watershed protection. *Acacia koa* and *‘ōhi‘a* (*Metrosideros polymorpha*) forests cover the high rainfall areas in the upper slopes of most Hawaiian watersheds and promote even streamflow and recharge of island aquifers. *Acacia koa* forests are also critical habitat for native Hawaiian forest birds, such as the *‘akiapōlā‘au* (*Hemignathus wilsoni*), along with many endangered plant species. The largest *A. koa* reforestation project in Hawai‘i is not a timber plantation but

Cabinet made from *A. koa* wood showing fiddleback grain (Photo: J.B. Friday) a restoration of forest at the Hakalau Forest National Wildlife Refuge, where over 1,000 ha of *A. koa* and other native tree species have been replanted to create habitat for endangered birds and plants.

Diversity and its importance

Acacia koa is diverse genetically and phenotypically, with variation among populations in leaf size and shape, bole straightness and seed size. Common garden experiments have shown that there is genetic variability in growth rates and water use efficiency, although research has not yet discovered evidence for genetic variability in cold tolerance. Anecdotal evidence from harvesters supports differences among populations in wood colour and figure, although it is unknown how much these differences are due to environmental rather than genetic factors. Some half-sibling families of *A. koa* show good resistance to the koa wilt disease caused by the vascular wilt fungus *Fusarium oxysporum* f. sp. *koae*, which causes high levels of mortality in plantations at lower elevations (below about 600 m asl). Greenhouse studies have shown that survival of seedlings inoculated with the pathogen can vary from 3% to 92%. Breeding programs are underway to create seed orchards of resistant families for different ecological zones within the Hawaiian Islands. Low success in rooting cuttings impedes the development of seed orchards from selected genotypes, and studies have shown a strong genetic component to rooting ability.

Modern analysis of microsatellite markers shows that Kaua'i populations of *A. koa* are genetically more diverse as well as being distinct from O'ahu, Maui and Hawai'i populations. A phylogenetic analysis of *A. koa*, *A. koaia* and intermediate forms, also using microsatellite markers, showed that there are genetic differences among the three groups but suggested that these differences are insufficient to warrant classifying them into different species. A more recent phylogenetic study found that the morphologically similar species *A. heterophylla*, which is endemic to Réunion Island in the Indian Ocean, nests entirely within the *A. koa* complex, demonstrating that the ancestral *Acacia* species somehow colonised Réunion

Typical broad phyllodes of *A. koa* trees from the island of Hawai'i (Big Island); USA (Photo: J.B. Friday)

Narrow sickle-shaped phyllodes of *A. koa* trees in O'ahu and Kaua'i populations; Hawaiian Islands, USA (Photo: J.B. Friday)

from Hawai'i, rather than both having evolved from a common Australian ancestor.

Conservation of genetic resources (including threats and needs)

Over half of the original *A. koa* forests of Hawai'i have been lost, mainly due to clearing for cattle and sheep grazing, but also through unsustainable harvesting, clearing for agriculture, wildfire and competition by invasive plant species. Most of the remaining *A. koa* forests are in public and private reserves where they are protected from harvesting and land conversion but still susceptible to degradation by invasive plants and animals, insect pests and diseases. Non-native woody plant species, such as *Psidium cattleianum* and *Fraxinus uhdei*, comprise the understorey of many native forests and prevent regeneration of native species. Feral cattle, sheep and goats browse natural *A. koa* regeneration and strip bark from the stems of sapling and pole-size trees. The acacia psyllid, *Acizzia uncatoides*, first established in the Hawaiian Islands in 1966, attacks the terminal leader of young *A. koa* seedlings, causing multiple stems to grow at heights between 1 and 2 m above the ground. Trees deformed in this manner are still valuable for wildlife habitat but not for timber.

Work is needed on pollination, phenology, reproductive biology and vegetative propagation of *A. koa*. Good initial progress has already been made in developing trees resistant to koa wilt disease, but more work is needed to develop lines appropriate for different ecological sites on different islands. Another need is for cold-tolerant stock to enable reforestation of degraded lands at higher elevations (>2,000 m asl) where frost mortality is common. To date, there has been little work on selection for bole straightness, wood colour or wood figure. Development of lines of straight-stemmed *A. koa* with superior wood properties would do much to promote reforestation of this native species on private lands across Hawai'i.

Author: James B. Friday

Acacia mangium

Family: Mimosaceae
Botanical name: *Acacia mangium* Willd. was originally described in *Herb. Amboin*. 3: 123 (1750) as *Mangium montanum*.

The combination *Acacia mangium* was made by C.L. Willdenow in *Sp. Plant*. 4: 1053 (1806). The specific epithet alludes to the phyllodes resembling leaves of *mange*, mangroves, in Indonesia.
Common names: brown salwood, mangium, black wattle, hickory wattle (English); *tange hutan*, *mangge hutan* (Indonesia); Sabah salwood (Malaysia); *biar* (PNG). In Sarawak, the trade name 'Borneo teak' has been adopted by some *A. mangium* timber and veneer producers.

Summary of attributes and why diversity matters

Acacia mangium has become a major commercial plantation species in the humid lowland tropics, primarily for production of pulpwood; well-managed plantations in such environments can reach productivities exceeding 40 m^3/ha/year at 2.5 years of age. However, the sustainability of such plantation resources is now being seriously challenged by pathogens, including a root rot and a shoot canker and wilt disease. Maintenance, and even enhancement, of genetic diversity in breeding populations will likely play a key role in addressing these current and different future challenges.

Molecular genetic studies of *A. mangium* have revealed moderately high genetic diversity in the species overall and considerable variation in outcrossing rates between populations. These studies have also shown the genetic differentiation between populations to be consistent with geographical discontinuities in the species' natural distribution, and that populations closer to the centre of its natural range in PNG have both the highest levels of genetic diversity and the highest outcrossing rates. Field trials have found that provenances with higher outcrossing rates and genetic diversity generally rank higher in growth parameters.

Description

Habit large tree to 30 m tall with a straight bole extending up to more than half the total tree height, with diameter up to about 50 cm; on adverse sites, it occurs as a small tree or large shrub of 7–10 m; lower bole is sometimes fluted in older trees. ***Bark*** lower bark rough, furrowed longitudinally, varying in colour from pale grey-brown to brown. ***Phyllodes*** dark green, glabrous, borne on very acutely angled, glabrous and stout branchlets, large, normally 11–27 cm long, 3–10 cm wide; characterised by (3–)4(–5) main longitudinal nerves, basally confluent but distinct from the lower margin, with minor nerves strongly anastomosing to form a prominent reticulum. ***Inflorescences*** elongated spikes 5–12 cm long. ***Flowers*** whitish (or cream), borne on peduncles 0.6–1.0 cm long, singly or in pairs in the upper axils. ***Pods*** linear, tightly coiled when ripe, slightly woody, 7–8 cm long, 0.3–0.5 cm wide. ***Seed*** shiny black, longitudinal in pod, ovate to oblong, 3–5 × 2–3 mm with a yellow or bright orange (rarely red) funicle folded to form an oily, fleshy aril beneath the seed.

Pods and seed (Photo: M. McDonald)

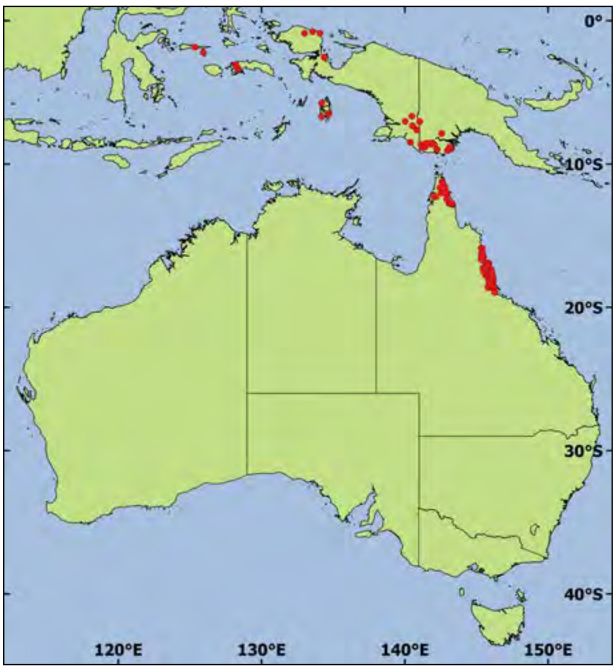
Flower spike and phyllodes (Photo: M. McDonald)

Multistemmed shrub form (East Kalimantan landrace); Pulau Laut, South Kalimantan, Indonesia (Photo: L. Thomson)

Even-aged stand; Dimisisi, Western Province, PNG (Photo: M. McDonald)

Distribution

In Australia, *A. mangium* occurs in two relatively small areas of tropical lowlands of Queensland; from Jardine River (11°20′S) to Claudie River (12°44′S) at the tip of Cape York Peninsula and from Ayton (15°54′S) to south of Ingham (18°30′S) on the eastern coast. Further north, it extends through the Western Province of PNG into



the Indonesian provinces of Papua (Merauke area), West Papua (Vogelkop Peninsula) and Maluku (Sula, Seram and Aru Islands).

Acacia mangium has become a major exotic plantation species for pulpwood production in the humid tropical lowlands of Asia. Worldwide, the area planted with *A. mangium* was estimated to exceed 1.4 million ha in 2011, with the largest plantation areas in Indonesia, Malaysia and Vietnam. In addition, there were estimated to be around 230,000 ha planted with hybrids of *A. mangium* × *A. auriculiformis*. *Acacia mangium* was also, until recently, seen to have good potential in parts of Africa and Central and South America. However, the emergence of serious pathogen problems in many plantation areas may severely limit its future potential as a commercial species.

Most natural occurrences are in the coastal, tropical lowlands with an altitudinal range of 0–800 m asl and 1,200–3,600 mm MAR with a summer maximum. Soils are typically acidic and range from sandy or loamy alluviums to red-brown loamy clays.

Uses

Acacia mangium's success in humid lowland tropical plantations from the late 1980s until the present has been due to its: wood properties that make it acceptable for a wide range of end uses; vigorous growth—mean annual increment (MAI) >30 m^3/ha on favourable sites with good management; tolerance of acidic and low-nutrient soils; ability to grow reasonably well where weed competition is severe, such as on *Imperata* grasslands; ease of seed storage and propagation; ease of establishment; and, until recent times at least, relative freedom from serious disease issues.

Wood—plantation-grown wood is well suited for production of both kraft pulp and high-quality neutral sulfite semichemical pulp, with screened kraft pulp yields in the range of 47–57%. Acceptable pulp yields have also been obtained with chemo-thermo-mechanical pump (CTMP) and mechanical pulping processes.

Timber of *A. mangium* is also suited to a range of other uses, including fuelwood, charcoal, building and furniture timber, manufactured flooring, veneer and manufacture of particleboard. The heartwood is hard with a pale yellow-brown colour while the sapwood is light coloured. It has a basic density of around 420–480 kg/m^3, air-dry density of around 500–600 kg/m^3 and is classed as a light hardwood with low to moderate strength properties. The timber has a close grain, is relatively stable, kiln-dries well without serious defects and it is relatively easy to saw, polish, drill and turn. The heartwood is moderately durable when exposed to weather, but not in contact with the ground, and is moderately resistant to preservative treatment.

Non-wood—use is relatively limited. *Acacia mangium* phyllodes can serve as forage for livestock and are very good for soil mulching. Its flowers can be used by bees for honey production.

Right: *Acacia mangium* (including hybrid) logs being sawn to produce furniture components; central Vietnam (Photo: C. Harwood)

Below left: Production of rotary veneer from *A. mangium*; Sarawak, Malaysia (Photo: R. Arnold)

Below right: Manufacture of furniture from *A. mangium*; Sabah, Malaysia (Photo: D. Boden)

Diversity and its importance

Molecular genetic studies have found moderately high genetic diversity in *A. mangium* overall, with the genetic differentiation between populations being consistent with geographical discontinuities in the species distribution. There is considerable variation in genetic diversity and outcrossing rates between populations, with those closer to the centre of the natural distribution in PNG having both the highest levels of genetic diversity and the highest outcrossing rates, with those at the southern and western extremes of the distribution the lowest. Provenances with higher inherent diversity and outcrossing rates rank best for growth traits in field trials.

Large differences between provenances of *A. mangium* have also been observed for growth rate, stem straightness and frequency of multiple leaders. PNG provenances have consistently been the best performers for growth, closely followed by the Claudie River provenance from Far North Queensland. The slowest growing provenances have been those from Maluku and southerly parts of its distribution in Queensland.

Acacia mangium is known to form natural hybrids with *A. aulacocarpa*, *A. auriculiformis* and *A. polystachya*. Selected *A. mangium* × *A. auriculiformis* hybrid individuals have shown considerable commercial success due to their fast growth, fine branching and straight boles in some environments, and are now used extensively in plantation establishment programs in Indonesia, Malaysia and Vietnam. While these hybrids are intermediate between the two parents in morphology and wood properties, they tend to inherit the better stem straightness of *A. mangium* and the self-pruning ability and better stem roundness of *A. auriculiformis*. Clones

Well-formed specimen; Sarawak, Malaysia (Photo: CSIRO)

Variation in bole form; Naitasiri, Fiji (Photo: L. Thomson)

of selected F1 (first-generation) hybrids can average twice the wood volume of *A. mangium* at 4.5 years on some sites, especially those too dry for *A. mangium* in Vietnam.

Substantial resources have been invested in genetic improvement programs for the species, particularly over the past 30 years by commercial forest plantation enterprises in Australia, China, Indonesia, Malaysia and Vietnam. Early genetic gains in volume from such improvement programs in Indonesia were reportedly in the order of 50–70% compared with local selections.

Conservation of genetic resources (including threats and needs)

Acacia mangium is a species with strong competitive ability that, under the right conditions, can readily shade out competing vegetation. In some circumstances it has potential to become a weed. Consequently, it shows rapid regeneration when its natural stands are disturbed and is still abundant within its native distribution. In addition, the maintenance of broad genetic diversity in breeding populations provides a dynamic form of ex situ genetic conservation for this species. The importance of this genetic diversity has been given even greater weight in recent years owing to a number of severe pathogen problems being faced by commercial plantations of *A. mangium*.

The sustainability of current *A. mangium* plantation areas and the species' future commercial potential is being challenged in Malaysia and Indonesia by root rot caused by *Ganoderma philippii* (also known as red root rot). This pathogen can cause crown dieback, reduced growth and tree death, with over 25% of trees affected in some plantation areas. Cost-effective management tools based on biological and chemical treatments of soil and stumps have yet to be developed for controlling this pathogen in *A. mangium* plantations. Evidence of genetic resistance and/or tolerance in *A. mangium* to *G. philippii* root rot is currently limited, though there have been numerous anecdotal accounts and suggestions of variation among provenances. Given the potential economic impact of the disease in this and possibly other commercially important plantation species, more work in this area seems well warranted.

Since around 2010, an even more serious pathogen threat has emerged on *A. mangium* in the form of a new shoot canker and wilt disease. The causal species, *Ceratocystis acaciivora*, was described for the first time in April 2011. Already it has caused more serious economic losses than *G. philippii* root rot in *A. mangium* plantation areas in at least Indonesia and Malaysia, where thousands of hectares of *A. mangium* plantation are being replaced with other species. *Ceratocystis acaciivora* is particularly aggressive. It infects *A. mangium* through pruning and other stem wounds, such as made by animals or resulting from silvicultural operations in young plantations. The pathogen causes lesions that extend substantially beyond the physical damage associated with the wound, and can rapidly lead to stem wilting, dieback and even tree death.

Recent research in Malaysia found heritability estimates were close to zero for traits associated with *C. acaciivora* resistance and tolerance. Nevertheless, the same study found significant differences among both regions and seed sources within regions for many of the traits used to assess damage by this pathogen. The latter suggests that modest genetic improvement might be realised through selection among populations and sources for resistance and tolerance, though a lack of additive genetic variation will make the development of *A. mangium* genotypes resistant and/or tolerant to *C. acaciivora* challenging.

Even in the absence of the two foregoing major pathogens, *A. mangium*'s yields of logs suitable for solid wood end uses can be limited by the occurrence of fungal heart rot in the central core of the stem from early ages. While such defects have relatively minor impact on pulp yields if trees are harvested early, as is standard practice in most of the larger industrial plantations of *A. mangium*, heart rot can significantly and markedly reduce recoveries of sawn wood and veneer from older logs in some, but not all, environments.

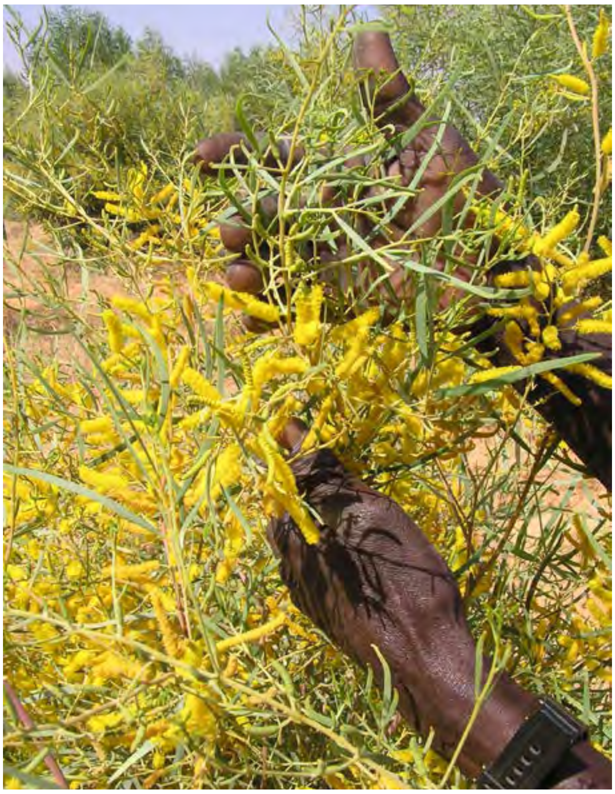
The broad genetic diversity available through both *A. mangium*'s natural and managed breeding populations will likely be fundamental to enabling breeders to successfully mitigate challenges currently posed by *G. philippii*, *C. acaciivora*, heart rots and possible other pathogen problems that may emerge in the future. If breeding and silviculture cannot manage to surmount susceptibility to these pathogens, they will seriously threaten the future of *A. mangium* as a commercial plantations species in many environments worldwide.

Author: Roger Arnold

Acacia torulosa

Family: Mimosaceae
Botanical name: *Acacia torulosa* Benth. In *J. Proc. Linn. Soc. Bot.* 3: 139 (1859).

The specific epithet is derived from the Latin *torulus*, a little bulge, and *osus*, abounding in, referring to the abundant pods, which are strongly constricted between the seeds.
Common names: torulosa wattle, deep gold wattle, thancoupie (English); torulosa (Niger)



Flower spikes and phyllodes (Photo: P. Cunningham)

Summary of attributes and why diversity matters

Acacia torulosa is a fast-growing shrub or small tree adapted to a wide range of well-drained sites in tropical hot subhumid and hot semi-arid climatic zones. It is drought tolerant, nitrogen-fixing and noted for prolific biomass production. This makes it useful for agroforestry farming systems as a windbreak and a source of fuelwood, edible seed for human and animal food, mulch production, small roundwood (posts and poles) and building timber. It is also useful for land reclamation and ornamental purposes.

Provenance variation in growth and survival of *A. torulosa* indicates that a range of provenances should be screened when testing the species. For example, provenance selections in Niger have produced two tree types that have been domesticated for commercial use in the Sahelian zone of West Africa. A branched seed-producing type is being developed for use in agroforestry farming systems while a tall-growing type is better suited for roundwood and timber production.

Description

Habit small spreading shrub or tree of 2–8 m but may reach 15 m with a wide crown; new shoots resinous, angular and yellowish. ***Bark*** rough, grey, fibrous, flaky when old. ***Phyllodes*** hairless, straight or curved, 5–20 cm long, 4–18 mm wide, yellowish green; nerves longitudinal, numerous, very close together (8–14/mm) with 1–3 nerves more prominent than the rest. ***Inflorescences*** cylindrical spikes 1–4 cm long, in axillary pairs. ***Flowers*** dull yellow, peduncles 1–9 mm long. ***Pods*** moniliform, 8.5–20.0 cm long, 5–7 mm wide, longitudinally wrinkled and yellow-brown. ***Seed*** longitudinal in the pod, 4.5–7.7 mm long, 3–5 mm wide, shiny dark brown with pale cream aril.

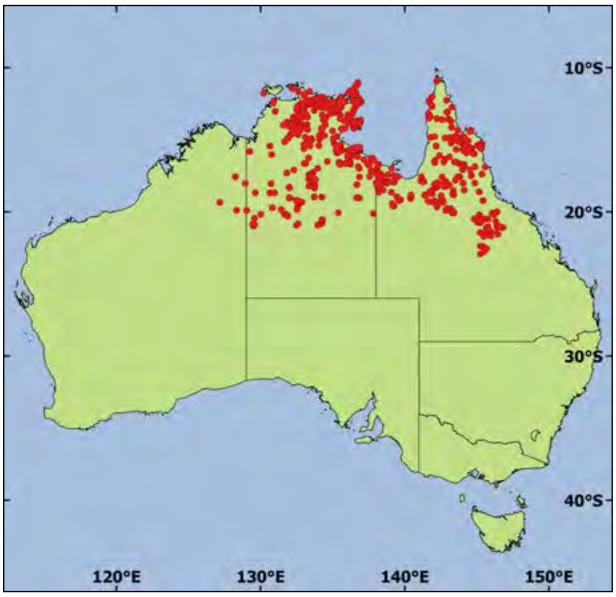
Pods and seed (Photo: P. Cunningham)

Distribution

Acacia torulosa is a naturally occurring tree species of northern Australia where the main distribution is in the lowlands of the north of the Northern Territory and Cape York Peninsula, Queensland. There are also isolated occurrences in the Kimberley region of Western Australia.

This species has been very widely trialled outside Australia, including in countries in Asia, Africa, the Americas and Oceania.

Although mostly distributed in the hot humid zone (700–1,150 mm MAR), there are large areas in hot semi-arid zones where it can be found in locations with 225–275 mm MAR and an 8-month dry season.



Rainfall occurs mainly in summer. Altitudinal range is 0–350 m asl. The area is mostly frost free but 1–2 light frosts may occur annually in elevated inland localities. *Acacia torulosa* is recorded from plains, stony hills, ridges of steep slopes, beach dunes and stream banks. Soils are usually well drained and include deep sands, rocky skeletals, silts and loams. They are typically acidic and of low fertility, but may be alkaline (e.g. the species has performed well on raised coral terrace soils of pH 7.5 in Indonesia) or slightly saline in some places.

Uses

Acacia torulosa is a fast-growing, nitrogen-fixing shrub or small tree suitable for cultivation on a wide range of sites in tropical, hot subhumid and hot semi-arid climatic zones. In Niger, two distinct types of *A. torulosa* have been domesticated for commercial use in the Sahelian zone of West Africa: a tall-growing form and a highly branched and well-adapted spreading form.

Wood—dark brown, tough and strong with an air-dry density of 720 kg/m³. Indigenous Australians used the species to make spears, spearheads and pegs for spear-throwers. The tall-growing form can reach a height of 6 m with a stem diameter of ≤15 cm at 1 m above ground level after 4 years of growth at Maradi, Niger. In the Upper East region of Ghana (850 mm MAR), trees of this type have reached 6 m in 2 years. The tall-growing form can also be used in agroforestry farming systems but may be better suited to plantation production for building timber, fence posts, poles and farm tool handles.

Non-wood—*A. torulosa* has been recommended as an ornamental for gardens and amenity areas and for mine-site rehabilitation in northern Australia and its seed was used as food by Indigenous Australians during famine. The gum was also eaten.

In Niger, the highly branched spreading form has been developed for multipurpose use in agroforestry farming systems with alley cropping. This type provides good windbreaks and produces good-quality fuelwood and edible seed for human and animal consumption. Trees can be pruned to 1.0–1.3 m every second year to provide firewood and reduce competition with annual crops. The coppicing regrowth also enhances seed production and produces large quantities of mulch, which, together with nitrogen fixation, stabilise the soil and enhance fertility. Local Fulani herders have used one highly branched *A. torulosa* type for arrow shafts.

Three-year-old *A. torulosa* trees have produced 2–12 kg seed/tree in Maradi (450 mm MAR). The nutritious seed has high value as human food and has been treated in the same way as *A. colei* seed for this purpose. *Acacia torulosa* flour has been incorporated into local diets as a 25% mix with local grains such as millet, sorghum and wheat. The seed also has high potential for export to the international gourmet food market for use in a range of foods, including a syrup for ice-cream.

Compared with *A. colei*, which has been used in Maradi as a protein supplement in local foods for over a decade, *A. torulosa* has less bran and yields 64% flour compared with 67% for *A. colei*. The lighter coloured *A. torulosa* flour does not have the beany flavour that often affects *A. colei* flour, is easier to work as the bran sifts more readily and, in general, has a better texture for cooking. *Acacia torulosa* seed has a higher amino acid content (20.8%) than *A. colei* (14.6%), but both are low

Single bole form used for timber; Danja, Niger (Photo: P. Cunningham)

Food dishes from *A. torulosa* seed; Niger (Photo: P. Cunningham)

Multistemmed shrub form; Niger (Photo: P. Cunningham)

in methionine. Seed harvest, thrashing and cleaning are more rapid and easier for the larger seeded *A. torulosa* compared with *A. colei*.

Diversity and its importance

There have been 37 provenances of *A. torulosa* collected from their natural distribution in northern Australia by CSIRO's Australian Tree Seed Centre. The Maradi Integrated Development Project managed by Serving In Mission (SIM) International from 1998 to 2010 tested 15 of these diverse provenances and identified five main classes of tree types, including two types with high potential for production of different end products in different climatic zones.

Type 1 trees—tall growing, few stems, low seed production, >6 m at 4 years of age—have been domesticated for pole production in the 450–500 mm MAR regions of the Sahel with lateritic and sandy loam soils. This type is also under development in the Upper East region of Ghana. Type 2 trees—medium growing, multistemmed, high wood/seed production, 4–5 m tall at 4 years—have been developed for multipurpose use in agroforestry farming systems and are adapted to 350–550 mm MAR regions in the Sahel. The Type 2 trees (provenances from Elliot, Newcastle Waters and the Tanami Desert in the Northern Territory) are proving to have the greatest potential with good adaptability. They also flower and give good seed production at Maradi from the second year and longevity under good management and pruning has exceeded 12 years.

Tree form; Cadell River, Northern Territory, Australia (Photo: CSIRO)

Further research to determine the flowering biology, seed production and suitability for human food is needed to support the domestication of adapted *A. torulosa* provenances and selections. Further field trials need to be established to determine the adaptability and suitability of Type 2 *A. torulosa* selections and provenances in agroforestry farming systems in wider areas of the Sahel, including those in the 250–300 mm MAR belt.

Conservation of genetic resources (including threats and needs)

Acacia torulosa, like *A. colei*, is relatively common throughout its wide natural distribution and there are few threats to its genetic resources. Many populations occur in relatively remote regions where the main land use is rangeland cattle stations. It is also a naturally resilient species and populations usually thrive following site disturbance. Ex situ conservation measures are also implicit in the testing and selection work that is being carried out in the Sahelian zone of West Africa based on the extensive *A. torulosa* seed collections safely stored and documented at CSIRO's Australian Tree Seed Centre in Canberra, Australia.

Authors: Peter Cunningham and Salifou Yaou

Acacia tumida

Family: Mimosaceae
Botanical name: *Acacia tumida* F.Muell ex Benth. In *Flora Aust*. 2: 409 (1864).

The specific epithet is from the Latin *tumidus*, swollen, thickened, referring to the pod. Four varieties (see descriptions below) are recognised in this species: var. *tumida*, var. *extenta*, var. *kulparn* and var. *pilbarensis*.
Common names: pindan wattle, spear wattle, wongai

Summary of attributes and why diversity matters

Acacia tumida is a fast-growing, nitrogen-fixing small shrub or tree with the potential to ameliorate adverse sites in the arid to semi-arid, seasonally dry tropics. It provides a valuable source of fuelwood and produces prodigious quantities of seed on these sites that can be used as a source of food for livestock and humans, especially when annual staple crops fail.

A feature of *A. tumida* is its diversity in habit and morphology over a gradient of contrasting environmental conditions, across several natural bioregions in north-western Australia. Four varieties of *A. tumida* are recognised reflecting this diversity, each characterised by contrasting utilisation potentials. Diversity in *A. tumida* is further exemplified by considerable provenance variation, particularly in var. *tumida*.

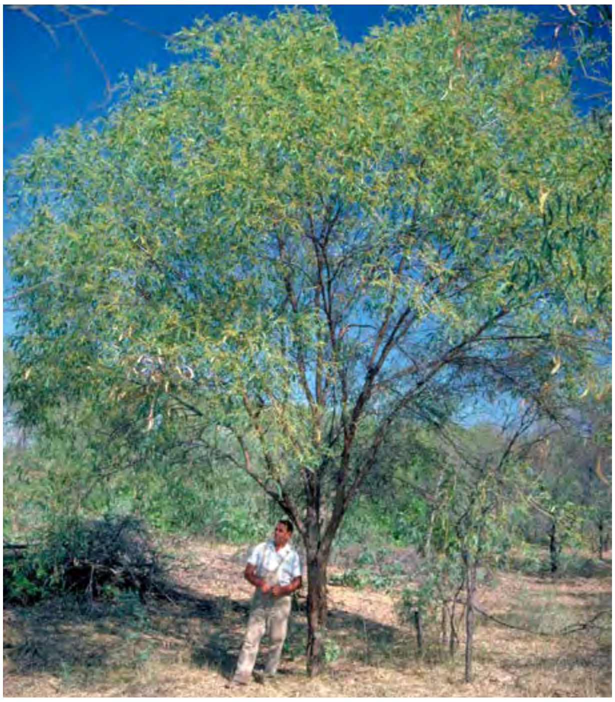
Description

Habit multistemmed bushy shrub or single-stemmed tree with glabrous and pruinose branchlets: var. *tumida* usually a single-stemmed tree, 12–15 m tall, with a well-developed trunk and a dense crown; var. *extenta* slender, wispy tree; var. *kulparn* multistemmed shrub, to 2 m tall, with 4–6 stems arising from ground level; var. *pilbarensis* small tree to 6 m tall. ***Bark*** lower bark hard, longitudinally fissured, grey; upper bark smooth. ***Phyllodes*** relatively large, often pruinose: var. *tumida* dense crown of large, falcate adult phyllodes, 10–20 cm long, 2.5–6.0 cm wide; var. *extenta* adult phyllodes 17–25 cm long, 0.7–1.2 cm wide; var. *kulparn* short, dimidiate phyllodes, 6–12 cm long, 2.5–3.5 cm wide; var. *pilbarensis* usually strongly falcate phyllodes, 10–15 cm long, 0.8–2.2 cm wide. ***Inflorescences*** cylindrical spikes: var. *tumida* spikes to 7 cm long; other varieties 2.0–4.5 cm long. ***Flowers*** small, hermaphroditic, golden. ***Pods*** ≤16 cm long, 3–10 mm wide, sub-woody, straight to slightly curved, more or less wrinkled longitudinally. ***Seed*** hard-coated, shiny, dark brown-black, 5–8 mm long, 3–4 mm wide, with a prominent cream aril.

Flower spikes and phyllodes of var. *kulparn* (Photo: M. McDonald)

Pods of var. *tumida* (Photo: M. McDonald)

Young trial specimen of var. *kulparn* fruiting heavily; Dosso, Niger (Photo: L. Thomson)



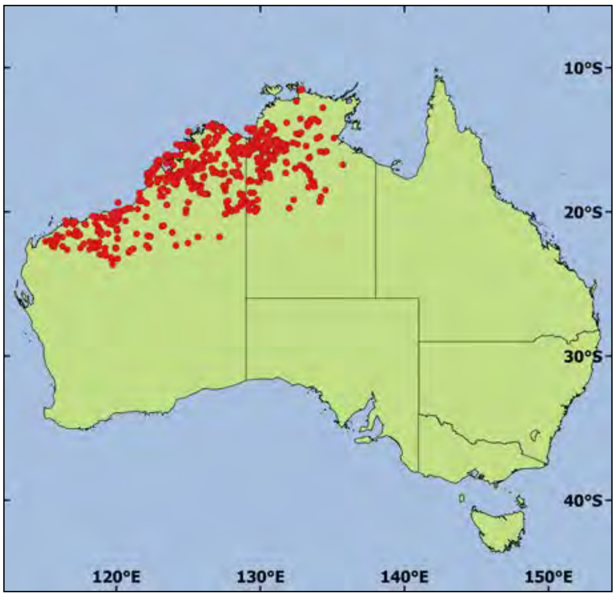
Var. *tumida*, Kalumburu; Kimberley region, Western Australia (Photo: M. McDonald)

Var. *pilbarensis*; Spear Hill, Pilbara, Western Australia (Photo: M. McDonald)

Distribution

All varieties of *A. tumida* are endemic to north-western Australia: var. *tumida* occurs in the Kimberley region of Western Australia and adjacent areas of the Northern Territory; var. *kulparn* in the Tanami Desert – Great Sandy Desert – Eighty Mile Beach regions; var. *pilbarensis* is restricted to the Pilbara region; and var. *extenta* is only known from one population near Mt Trafalgar in the far north-west of the Kimberley region.

As an exotic, there is potential for formal domestication of *A. tumida* in Senegal, southern Vietnam and Tamil Nadu in India. It has also been cultivated in a wide range of countries, including Africa and the Middle East (e.g. Angola, Burkina Faso, Cameroon, Chad, Egypt, Ethiopia, Gambia, Ghana, Kenya, Malawi, Mali, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Somalia and Sudan, Syria and Yemen), China, Pakistan, the Philippines and Sri Lanka. *Acacia tumida*, like *A. colei* and *A. torulosa*, has high potential for revegetation of degraded sites in the dry zones of some Pacific Island nations (e.g. Fiji).



This species occurs in the arid to semi-arid, hot and subhumid seasonally dry tropics (450–1,000 mm MAR, summer maximum, dry season of 5–9 months, altitudinal range 0–500 m asl). It is found naturally on a wide range of depositional landforms on a diverse range of acidic soils from sands through to clay loams.

Uses

Acacia tumida is a species capable of relatively fast growth on adverse sites. It is particularly useful for its ability to remediate degraded soils, including the stabilisation of wind-blown sands. For example, it has been successfully cultivated on deep, wind-blown sands in Vietnam, on degraded sandy soils in Senegal and on sand dunes in Yemen. Once successfully established, *A. tumida* can ameliorate the growth of annual crop yields by providing a source of mulch and organic matter. It can fix atmospheric nitrogen, helping it to colonise infertile sites and improve soil organic matter and nitrogen levels.

Wood—of the four varieties, var. *tumida* has the most potential as a fast-growing source of biomass, fuelwood, timber for light construction and possibly pulpwood. The wood is hard and dense with dark brown heartwood and, while tests have not been conducted, it is likely to have favourable calorific values for the production of charcoal. The ability of this variety to produce a source of fast-growing biomass during the early stages of its growth reduces the need for villagers to harvest slower growing species from native vegetation.

Non-wood—seed of *A. tumida* was consumed traditionally by Indigenous Australians, particularly the shrub form, var. *kulparn*. This variety is reproductively precocious and produces prodigious seed crops, often in <2 years under cultivation. The seed is nutritious, containing 18% crude protein, 6% fat and 9% available carbohydrate. The superior coppicing ability of var. *kulparn* also prolongs its potential to supply a renewable source of light firewood and seed crops. Coppicing trials with var. *kulparn* have demonstrated a favourable response to various pollarding treatments, while, in contrast, the coppicing response of var. *pilbarensis* was absent or very poor. Var. *kulparn* clearly has the most potential as a supplementary source of human food or for stockfeed, but the other varieties can also be useful, particularly in times of drought when staple annual crops fail.

Although reportedly a shelterbelt and agroforestry species, its shady crown and shallow, spreading root system compete with annual crops and usually limit its potential use in these roles.

Diversity and its importance

The three most widely distributed varieties of *A. tumida* are represented by a diverse range of populations with potential for inclusion in domestication programs. The differences in adaptive and morphological traits exhibited by these three varieties are genetically based, and this has been confirmed by their performance in field trials. These differences have significant implications for their successful domestication, particularly in relation to climate matching and targeting the most appropriate end use. For example, field trials show that var. *tumida* is usually single-stemmed with a well-developed trunk when cultivated and would be suitable for the production of poles and fuelwood, but would grow best in areas that receive 700–1,000 mm MAR; var. *kulparn* is a low, coppicing, multistemmed shrub, best suited for the production of light firewood and seed for human or stock food and is adapted to areas that receive 300–400 mm MAR; while var. *pilbarensis* is a dense shrub, branching from near ground level, suited for light firewood production, adapted to extremely hot areas that receive ≥300 mm MAR, and, based on field observations from natural stands, is better adapted to alkaline soils. Additionally, *A. tumida* has close affinities and sometimes hybridises with 11 other arborescent acacias that also have their centre of diversity in north-western Australia.

Conservation of genetic resources (including threats and needs)

Acacia tumida is a common species across its natural range, with limited threats likely to affect the conservation of its genetic resources. Most of its populations occur in relatively remote regions where land use is mainly rangeland cattle stations. Like the majority of *Acacia* species in this region, it is a naturally resilient species and following site disturbance, such as seasonal wildfires, populations regenerate rapidly either via seedlings or, in the case of var. *kulparn*, both coppice regrowth and seedlings.

There is a need to understand the reproductive biology and breeding system of *A. tumida*. This is fundamental for the implementation of successful breeding programs that aim to enhance seed production or improve its potential for timber production. Broadscale, representative seed collections from natural populations should be targeted to assess variation in these attributes and potentially to form the basis of any future breeding programs.

Authors: Maurice McDonald and Lex Thomson

Glaucous and green phyllode forms of var. *kulparn*; Fitzroy Crossing, Western Australia (Photo: M. McDonald)

Agathis macrophylla

Family: Araucariaceae
Botanical name: *Agathis macrophylla* (Lindl.) Mast. In *J. Roy. Hort. Soc.* 14: 197 (1892).

The genus name is from the Greek *agathis*, a ball of thread, an allusion to the globose female cone. The specific epithet comes from the Greek *macros*, large, and *phyllon*, leaf, referring to the large leaves. Whitmore (1980) amalgamated *A. vitiensis* (from Fiji) and *A. obtusa* (from Vanuatu) under *A. macrophylla*. This taxonomic change has been largely supported by ribulose-bisphosphate carboxylase (rbcL) gene sequences, chemical analysis of diterpene acids and leaf micromorphology.
Common names: Pacific kauri (English); *dakua*, *dakua makadre*, *makadre* (Fiji); *duro*, *marabete* (Solomon Islands); *kaori*, *nendu*, *nejev*, *khoe* (Vanuatu)

Summary of attributes and why diversity matters

Agathis macrophylla is one of the largest trees in the Pacific region, reaching about 40 m in height and 3 m dbh. It is an important timber species and preferential logging has reduced mature stands of the species to protected and difficult-to-access areas. *Agathis macrophylla* occurs at a considerable range of altitudes (0–1,150 m asl) and rainfall regimes (1,600–6,000 mm MAR) throughout eastern Melanesia.

The range of climatic and edaphic influences experienced by the species results in considerable variation in height and stature. Morphological variation also exists between trees from populations of the three archipelagos in which the species naturally occurs; namely, Santa Cruz (easternmost Solomon Islands), Vanuatu and Fiji. Populations from these archipelagos were once considered to constitute three separate species. Some of this variation among different provenances has important implications for silviculture.

Description

Habit majestic tree to 25–30 m tall (to 40 m on Erromango, Vanuatu), with spreading horizontal branches that may form a massive (to 36 [width] × 24 [depth] m) rounded crown; trunk generally straight, with a bole to 20 m long and 1.5–3.0 m dbh. ***Bark*** green-brown and smooth when young, becoming grey, thick and peeling in rough patches; scales leave shallow depressions on the bark. ***Slash*** reddish to dark sandy brown outer and inner bark, over white to cream wood; injured bark exudes a clear to whitish resin with a strong resinous smell, soon hardening white or light yellow. ***Leaves*** opposite to subopposite, decussate, kept in 1 plane by twisting stems; simple, leathery, elliptic to lanceolate, c. 7–18 cm long, 2–5 cm wide; mature leaves deep dark green and shiny above, often glaucous below, margin entire and recurved, apex acute, base rounded; venation fine, parallel and often inconspicuous; young leaves bright green, sometimes reddish, when emerging; petioles to 5 mm long. ***Cones*** *male cones* cylindrical at anthesis, green, 8–12 × 20–25 mm, drying light brown; microsporophylls are strongly imbricate at anthesis, margin thin, entire or irregularly toothed with a rounded head to 2 × 2 mm, and a thick centre thinning gradually to a narrow margin, each with 6–14 pollen sacs; peduncles stout, to 7 mm long; basal bracts form a loose basal cupule, wider than cone base; pollen grains

Leaves; Vanuatu (Photo: L. Thomson)

Mature tree; Macuatu, Vanua Levu, Fiji (Photo: L. Thomson)

Trees refoliating after Tropical Cyclone Winston; Nadarivatu, Viti Levu, Fiji (Photo: L. Thomson)

30–60 µm in diameter; *female cones* ellipsoid or globose, to 13 cm wide, slightly glaucous, green, maturing brown, with a peduncle to 2 cm long. ***Seed*** small, ovoid to globose, flattened and winged, attached to a triangular cone scale c. 2.5 cm across.

Distribution

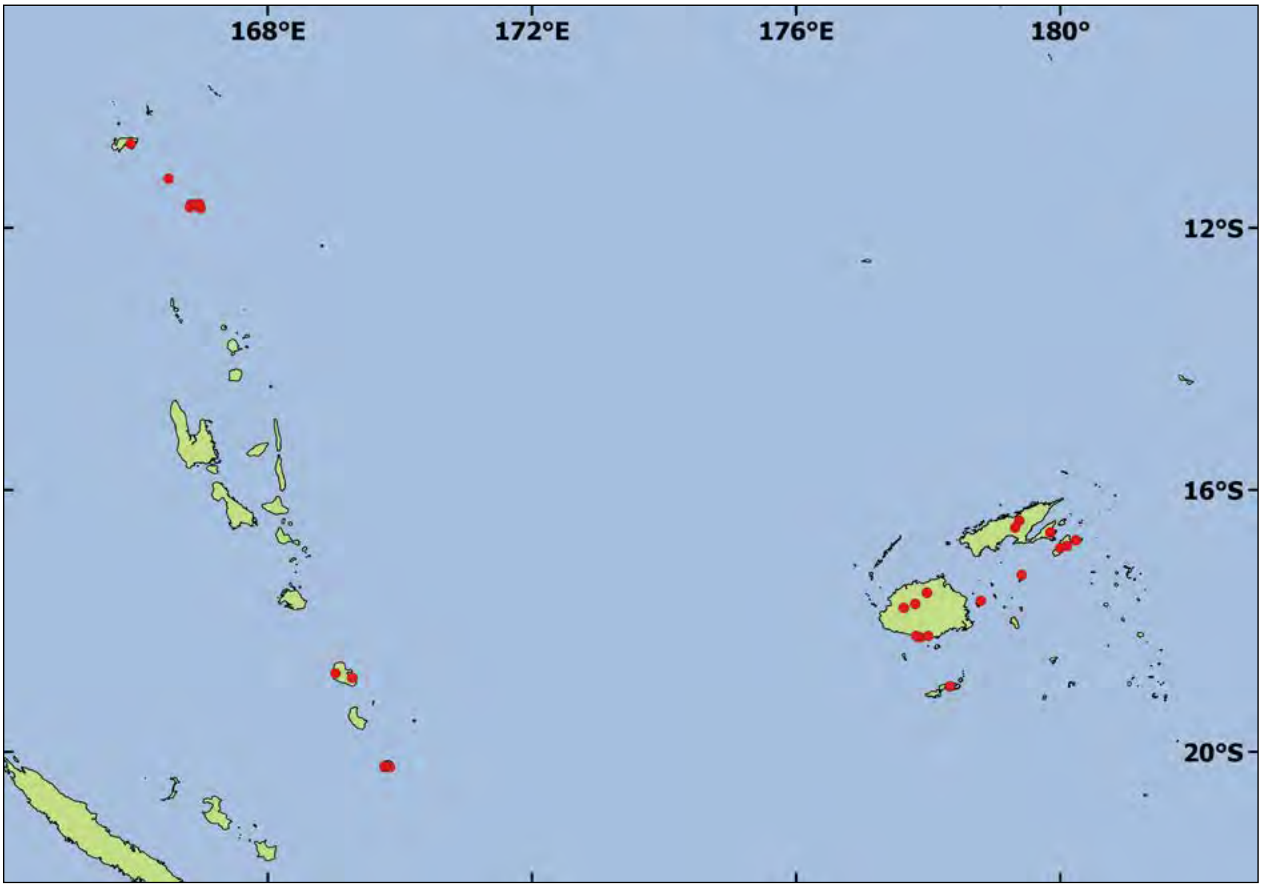
Agathis macrophylla is the most easterly occurring species of the genus, occurring on the islands of Nendo, Vanikoro (and adjacent Te Anu) and Utupua in the Santa Cruz Group of Solomon Islands, on Aneityum and Erromango in Vanuatu, and Viti Levu (and adjacent Ovalau and Koro), Vanua Levu (and adjacent Taveuni, Qamea and Rabi) and Kadavu in Fiji.

Agathis macrophylla is found from near sea level to 1,150 m asl in lowland and montane forest. Rainfall varies throughout the distribution, ranging from 1,600 to 6,000 mm MAR, and is likely to be an important environmental variable promoting variation in the species. It generally prefers basalt-derived clay loams and clays with a well-developed upper humus layer. It has also been reported on coral limestone terraces and bordering mangrove vegetation. Tree growth is poor on compacted and waterlogged soils and the species is most commonly found on well-structured, friable and freely drained soils. In several locations, *A. macrophylla* is a dominant component of the forest either in the upper canopy or emergent above the canopy. The species is most abundant on ridges and upper slopes, sometimes forming almost pure groves that consist of trees of different ages. However, it also occurs frequently as scattered individuals in mixed-species tropical rainforest.

Uses

Agathis macrophylla displays good potential for plantation forestry and enrichment plantings: the species grows moderately fast in full sunlight; has low susceptibility to pests and diseases; and displays good self-pruning ability in semi-shaded areas. However, this potential has not been realised because of concerns over economic viability, associated with long rotation periods and the need for extensive weed control during early years in high-light environments.

Traditional—*A. macrophylla* is of great importance to local people throughout its natural range in Melanesia,



primarily for its timber. Traditional uses are similar throughout its range. The timber is utilised for house and other construction, furniture, canoe-making and carving, while its resin is used for glazing pots, lighting fires, as canoe caulk, glue and in torches. The smoke of the resin was once used as a dye for hair, tattoos and to paint clothes black. In some areas, *A. macrophylla* may also have spiritual significance. For example, in Fiji, it is the totem tree of several family clans, villages and districts.

Wood—*A. macrophylla* is a highly valued commercial timber species, often generating valuable cash income for local communities through logging royalties. It produces a finely textured, straight-grained, pale and uniform timber that is easily worked and glued and has excellent physical, mechanical, working and veneering properties. The timber is valued for handicrafts, furniture, veneer, boatbuilding, light construction and panelling.

Non-wood—commercial export of the resin was practised in Fiji, but was prohibited in 1941 as no method for tapping an economic yield of gum could be found that did not also result in tree mortality.

Kava bowl crafted from A. *macrophylla*
(Photo: L. Thomson)

Diversity and its importance

Despite now being considered a single species, the populations of *A. macrophylla* from the Santa Cruz Islands, Vanuatu and Fiji exhibit considerable morphological differences in bole form, bark and foliage. For example, leaves of trees from Santa Cruz are typically larger and broader than those from drier and cooler parts of its range in Fiji. Even within one region, different morphotypes have been reported. On the basis of differences in leaf characters and stem form, the presence of at least two morphologically distinct types on Erromango and another one on Aneityum have been recognised. At Anelghowat village on Aneityum, local villagers recognise three variants based on bark and timber characteristics. Similarly, in Fiji, two different forms have been reported; one taller and with less frequent side branches, referred to as *dakua balavu*, and the other, *dakua leka*, being shorter and more branched.

The differences among different forms have important silviculture implications, with plants from Vanikoro being the fastest growing provenance sources, while plants from southern Vanuatu have the most favourable silvicultural characteristics, exhibiting good health, vigour, form, branching characteristics and self-pruning. Genetic studies on the variously recognised morphological and folklore varieties are needed to verify their status and ascertain their significance.

Conservation of genetic resources (including threats and needs)

Agathis macrophylla remains reasonably common throughout its natural range. However, few pristine stands of *A. macrophylla* remain due to a history of intensive logging and the species was assessed as Endangered by IUCN in 2013. When Europeans arrived in the South Pacific, they soon became aware of the timber potential of *A. macrophylla*, and many stands on Kadavu and Ovalau in Fiji had already been exhausted by the middle of the 19th century. Major milling companies continue to shift operations into areas where the species is locally abundant. Reports that it is almost extinct on Utupua in Solomon Islands are of great concern, and the present status of these populations needs to be confirmed.

Several stands of *A. macrophylla* are in protected areas. In Vanuatu, the Erromango Kauri Reserve was established in 1995, including some 3,257 ha of forest that is rich in *A. macrophylla*. In Fiji, *A. macrophylla* occurs in several protected areas, including the Wabu Catchment Nature Reserve, Mt Evans National Park, Vunivia Forest Park and the Waisali Forest Reserve. However, all these areas are on leased land that is traditionally owned, meaning continuous engagement with, and support of, landowners is required for ongoing protection.

One major obstacle in the conservation of *A. macrophylla* is its inability to invade habitats degraded by fire, cultivation or erosion. Another threat to the species may be introduced rats, which have been observed to destroy most seedlings in Santa Cruz. Until proper conservation measures for the species have been put into place, logging operations must retain large seed trees to provide seed for regeneration after logging, proceed into the prevailing wind direction to allow natural re-seeding of the logged area, and keep logging roads and skidding tracks to a minimum.

Agathis macrophylla is resistant to strong winds and cyclones. It is also relatively resistant to diseases, pests and environmental threats. The species has low susceptibility to termite attack and beetle larvae, but old trees are sometimes affected.

Authors: Gunnar Keppel, Lex Thomson and Eliki Senivasa

Araucaria cunninghamii

Family: Araucariaceae
Botanical name: *Araucaria cunninghamii* Mudie. In Mudie R. *The Picture of Australia* London: Whittaker, Treacher and co. (1829) pp. 133, 148.

The genus is named after the Spanish exonym *Araucano* ('from Arauco') applied to the Mapuches of central Chile and south-western Argentina, whose territory incorporates natural stands of this genus. The specific epithet honours Allan Cunningham (1791–1839), botanist and explorer. Two varieties are recognised: *A. cunninghamii* Mudie var. *cunninghamii* and *A. cunninghamii* var. *papuana* Lauterb. (see features below).
Common names: hoop pine, colonial pine, Richmond River pine, Moreton Bay pine, Dorrigo pine (Australia)

Summary of attributes and why diversity matters

Notable features of *A. cunninghamii* are its very wide latitudinal range, from around 1°S to 31°S, and its wide altitudinal range, from sea level to 3,355 m asl. Its natural habitats encompass a range of contrasting edaphic and other environmental conditions, from soils of volcanic and granitic origins through metamorphics to deep insular and coastal sands, and tropical and subtropical moist rainforests to dry vine forests. Of all conifers native to Australia, *A. cunninghamii* is the only one to become a commercially successful plantation species. It has proven well adapted to a range of ex-rainforest sites and capable of growth rates of up to 20 m^3/ha/year, and somewhat higher with genetically improved stock on better sites. Amenity plantings of the species can succeed on non-rainforest sites. With good management, it can provide premium-grade timber sought after by sawmillers and veneer and ply producers.

The successful *A. cunninghamii* plantation forestry in Queensland has been bolstered by genetic improvement and is built on a solid foundation of the broad genetic diversity that exists within the species. The history of plantation establishment and genetic improvement of *A. cunninghamii* provides an excellent example of the dual economic and conservation benefits that can be obtained through the integration of gene conservation and genetic improvement with commercial plantation development.

Description

Habit tall tree to 60 m tall and ≤2 m dbh with long straight boles of little taper and free of branches for up to two-thirds of tree height in some of its natural forests; on many islands off the Queensland coast, it also occurs as a large branched, glaucous-foliaged shorter tree over dry vine forests or forming virtual mono-specific stands on fractured massive granites; typically, the species has an open crown consisting of dark green foliage that is clumped towards the ends of branches; some trees have long internodes (to 5 m). ***Bark*** reddish-brown to coppery on young trees; dark brown or black, hard and rough with horizontal cracks forming hoops on older trees. ***Leaves*** adult leaves small, scale-like, narrow-triangular, 0.7–2.0 cm long, spirally arranged, sharply pointed, slightly curved and loosely imbricate; var. *cunninghamii* juvenile leaves usually 6–20 mm long, 0.8–2.0 mm wide; its microsporophylls are usually rhombic, smooth; apex acute; var. *papuana* juvenile leaves usually 6–20 mm long, 1.0–2.3 mm wide; its microsporophylls usually have a rounded upper margin and rugose surface. ***Cones*** the species is monoecious (cones of both sexes occur on the 1 tree), unisexual (female and male cones are separate) and predominantly outcrossing; *male cones* terminal, cylindrical, 4.0–7.5 cm long, borne at ends of twigs and formed of numerous tightly packed scales each bearing 5–8 pollen cells; *female cones* globular or ovoid, borne at ends of short shoots and made up of numerous bracts, each with an ovule-bearing scale fused on its upper surface; trees tend to produce female cones in the upper part of the crown from about 10 years of age and male cones in the central part of the crown only after about 25 years—thought to be an adaptation to minimise self-pollination; as a consequence, differential flowering patterns occur in grafted stock made with scions taken from these different positions within the crown, allowing seed orchards of mixed-source grafts to be established that produce viable seed within just a few years of planting. ***Fertilised female cones*** terminal, almost globular, ≤10 cm in diameter and composed of

Male cones (Photo: S. & A. Pearson)

Above left: Female cones (Photo: © CANBR)

Above right: Open-grown specimen; near Cambridge Plateau, New South Wales, Australia (Photo: © M. Fagg, ANBG)

Left: Bark of young tree (Photo: © M. Fagg, ANBG)

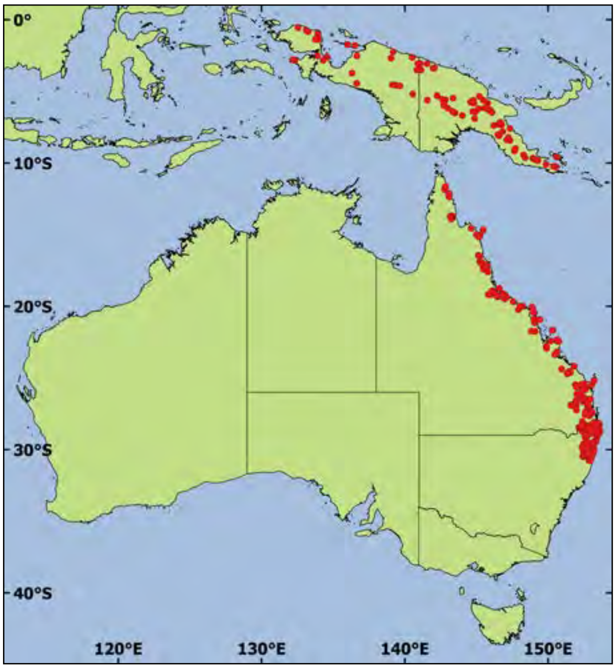
flattened, wedge-shaped woody scales with lateral wings. ***Seed*** single seed embedded in each winged cone scale. ***Tropism*** *A. cunninghamii* has fixed shoot systems; thus, a shoot, once differentiated as a lateral shoot, always remains as a branch or branchlet (of plagiotropic habit); however, under certain circumstances, shoots emanating from leaf axils between branch whorls on the main stem take on and retain an upright, tree-like habit (i.e. orthotropic habit).

Distribution

Araucaria cunninghamii has a highly discontinuous natural distribution in Australia, PNG and Indonesia. Var. *papuana* extends from around 1°S on the Vogelkop Peninsula (West Papua province, Indonesia) to around 10°30′S in the Owen Stanley Range (PNG); it is especially abundant in PNG's central highlands. It also occurs on Fergusson and Yapen Islands (PNG and West Papua, respectively). This variety most commonly occurs in montane forests at altitudes between 1,000 and 2,500 m asl, though its range extends from 500 m up to 3,355 m asl.

Var. *cunninghamii* extends southwards along the eastern fringes of Queensland, Australia, from around 11°40′S on Shelburne Bay and inland Cape York to the Dorrigo Plateau and Hastings River in northern New South Wales at around 31°S, with an altitudinal range from sea level to around 1,000 m asl. This variety mostly occurs on the mainland within 150 km of the coast, but it is also found on many islands off the Queensland coast between 14°40′S (Lizard Island) and around 26°S (Fraser Island). The form from the McIlwraith Range (at the southern end around 14°S, 300–400 m asl), but not from lowlands further north and south, resembles var.

papuana, at least in foliage and bark, and in fast growth rate in a trial in the tropics near Kuranda, Queensland. Before European settlement of Australia, most of the great natural stands of *A. cunninghamii* were in southern Queensland and northern New South Wales within 350 km north and south of where Brisbane is today.



The biggest areas of commercial *A. cunninghamii* plantations that currently exist are in Queensland, which have over 40,000 ha. Much smaller areas exist in New South Wales, PNG and West Papua. Trial plantings of this species have been undertaken in several other countries, including South Africa, Malaysia and China, but none of these has led to large-scale commercial plantings.

Araucaria cunninghamii has a very wide latitudinal range, from around 1°S to 31°S, and altitudinal range of 0–3,355 m asl. Mean annual rainfall varies from 750 to 4,500 mm with a summer maximum. Incidence of frost is low to moderate (upland sites). Soils are generally free draining, of light to heavy texture and are of acidic to neutral pH.

Uses

A well-established market exists for Queensland plantation *A. cunninghamii* timber, with demand from both domestic and international buyers. High-grade sawn and veneered *A. cunninghamii* serves the upper end of the domestic market, taking advantage of long lengths of clear wood, and exports include sawn wood, veneer and woodchips. In times past, very substantial quantities of timber were also exploited from *A. cunninghamii*'s accessible natural stands in Australia, PNG and Indonesia.

Wood—*A. cunninghamii* plantations provide premium-grade, uniform-quality tropical softwood that is finely textured and, from pruned and long-internode trees, largely knot-free. It is valued for its uniform density and texture, which contribute to a very fine grain that is excellent for working, painting and staining. High-grade sawn-wood products include joinery, furniture and clear mouldings. Shorter lengths are used for finger-jointed furniture and other applications. Lower grade wood is marketed as structural material and treated wood is used for applications such as fencing. Untreated, lower grade

Utilisation of *A. cunninghamii* timber in boards, furniture and decorative items (Photos: G. Nikles)

Logs thinned from an *A. cunninghamii* plantation being loaded for transport; south-eastern Queensland, Australia (Photo: G. Nikles) wood is suitable for bins and pallets. Speciality uses include colonial-style architecture, such as French doors, balustrades and decorative finishes, and, on account of its non-tainting quality, in confectionery as sticks, especially in ice-cream-based sweets.

Non-wood—*A. cunninghamii* continues to be planted in Australia and internationally for amenity purposes.

Diversity and its importance

Since 1929, numerous provenance trials of *A. cunninghamii* have been undertaken in Queensland and some in New South Wales and PNG. The most comprehensive trials were established in Queensland and New South Wales between 1971 and 1973 with 400 families from 40 provenances. These and other trials have demonstrated substantial genetic variation at the levels of taxonomic variety, provenance, family and individual trees. The most promising provenances for growth and stem straightness in south-eastern Queensland have included Jimna, Emu Vale, Gallangowan, Goodnight Scrub, Miva and Yarraman. These and other south-eastern Queensland provenances are represented in several clonal seed orchards delivering seed of different improved breeds. However, to develop a breeding population better adapted to tropical northern Queensland (cf. subtropical southern Queensland), a separate 'northern provenances population' was initiated in 1990 followed by establishment of a clonal seed orchard in northern Queensland comprising genotypes selected in local plantations originating primarily from PNG and Far North Queensland provenances.

Genetic variation in internode length; Brisbane, Queensland, Australia (Photo: G. Nikles)

Wise exploitation of the species' genetic diversity in the Queensland breeding program has provided substantial genetic gains for growers. This has primarily been delivered to operational plantations through seed from clonal seed orchards. Improved material comprising control-pollinated families averaged over 30% greater volume and 40% higher stem straightness scores compared with a routine control source in one report.

Renewed interest in exploring the potential of *A. cunninghamii* as an alternative to short-rotation, pulpwood and lower value species has recently emerged in at least China and Malaysia. For success in such plantation environments that differ markedly from that of the key *A. cunninghamii* plantation areas in southern Queensland, it is likely that a different mix of genotypes and provenances will provide optimal base populations for ongoing breeding than those in the breeding program in Queensland. Even so, in any new program, it would be wise to test improved material via seedlots from a range of Queensland and PNG clonal seed orchards.

Conservation of genetic resources (including threats and needs)

In the past, substantial quantities of *Araucaria* timbers, obtained from both *A. cunninghamii* and the closely related bunya pine, *A. bidwillii*, were harvested from natural stands. For example, during 1940–1941, around 439,000 m^3 were harvested from Crown lands in Queensland. But long before this period, it had been recognised that rates of cutting of *Araucaria* species from Queensland's natural forests would not be sustainable. This led the Queensland Government to deliberately reduce harvests from natural stands while simultaneously developing an *A. cunninghamii* plantation program; together, these policy moves led to preservation of large areas of natural *Araucaria* forests in Queensland. The success of the move into plantations is evidenced by the fact that the log harvest volumes from the sustainably managed *A. cunninghamii* plantations in Queensland have exceeded the highest annual removals from native forests, which were recorded during the 1940s.

Even though considerable areas of *A. cunninghamii* habitat, including subtropical and tropical rainforests, have been cleared for agriculture and other land uses since European settlement of Australia, substantial areas of the species' natural habitats are now protected in perpetuity within national parks, forest reserves and state forests. Outside Australia, while much of the accessible native *A. cunninghamii* in the Bulolo and Wau valleys in PNG has been harvested, this is not the case for most of the species' numerous occurrences elsewhere in PNG and Indonesia. While few of the *A. cunninghamii* populations existing today in PNG and Indonesia have any formal protection, most are remote and inaccessible, occurring at higher elevations and/or on steep terrain, and thus to date have not been exploited for timber.

Araucaria cunninghamii—including both varieties—is considered sufficiently widespread and abundant to be categorised as a species of Least Concern on the IUCN Red List. IUCN estimates the current overall extent of *A. cunninghamii*'s occurrence is >20,000 km^2 with an area of occupancy of >2,000 km^2. However, the formal conservation status of *A. cunninghamii* in PNG and Indonesia is uncertain, given the intense historical exploitation and climate change.

To complement the in situ conservation provided by natural stands, Queensland's *A. cunninghamii* breeding and plantation program currently constitutes an excellent ex situ conservation program for the species. The breeding populations developed in Queensland have included 876 first-generation plus-tree genotypes drawn from many provenances, including a number from PNG. These genotypes are contained in grafted clone banks and/or clonal seed orchards with progeny of many included in several field trials. However, continued effective long-term maintenance of these ex situ genetic resources, now dominated by commercial imperatives, presents a challenge such that the in situ conservation of this species mentioned above seems likely to be of fundamental importance in the long term.

Araucaria cunninghamii is susceptible to a number of pests and diseases. A pine bark weevil, *Aesiotes notabilis*, can attack the stem, though this is usually associated with damage from pruning done outside the recommended season. Hoop-pine borer, *Pachycotes australis*, which is usually associated with logging debris and slash, can infect and damage stands of *A. cunninghamii*, while hoop-pine stitch beetle, *Hyleops glabratus*, can cause damage to needles. A root disease fungus, *Phellinus noxius*, is a potential problem in young, second-rotation plantations. However, all of these can be managed with a combination of high-quality silviculture, integrated pest management and superior genetic stock.

Authors: Garth Nikles and Roger Arnold

Artocarpus altilis (with reference to *A. camansi* and *A. mariannensis*)

Family: Moraceae
Botanical name: *Artocarpus altilis* (Parkinson) Fosberg. In *J. Wash. Acad. Sci.* 31: 95 (1941).

The genus name is derived from the Greek *artos*, bread, and *karpos*, fruit, an allusion to the fruit's starchy texture and fragrance when cooked that is reminiscent of freshly baked bread. The specific epithet is from the Latin for fat or fattened and presumably refers to the shape of the fruit, as the fat content of its fruit is very low (0.2%). The breadfruit complex includes *A. altilis* and *A. mariannensis* Trécul, as well as natural hybrids between these two species. *Artocarpus altilis* is derived from wild-seeded *A. camansi* Blanco which is native to PNG. Vegetative propagation coupled with human selection in Melanesia and Polynesia and introgressive hybridisation in Micronesia were involved in the origins of breadfruit.

Common names: breadfruit (English); *kuru* (Cook Islands); *mei*, *mai* (Federated States of Micronesia [FSM]); Kiribati; Marshall Islands; Marquesas Islands, French Polynesia; Tonga; Tuvalu); *buco*, *uto* (Fiji); *lemae*, *lemai* (Guam; Northern Mariana Islands); *'ulu* (Hawai'i, USA; Rotuma, Fiji; Samoa; Tuvalu); *mos* (Kosrae, FSM); *meduu* (Palau); *kapiak* (PNG); *'uru* (Society Islands, French Polynesia); *bia*, *bulo*, *nimbalu* (Solomon Islands); *beta* (Vanuatu)—as well as hundreds of cultivar names

Summary of attributes and why diversity matters

Breadfruit has been cultivated as a traditional starch crop throughout Oceania for close to three millennia. Breadfruit trees are an important component of home gardens and traditional agroforestry systems. They produce nutritious starchy fruit, varying in nutritional composition, taste, texture, cooking and storage qualities, as well as edible seed. Other useful products include: timber for buildings, canoes and carving; fibre for cordage and fabric; latex; medicines; windbreak; shade; and ornament.

Hundreds of cultivars have been selected and named and are perpetuated clonally by vegetative propagation. Some cultivars have a wide distribution while others are localised to specific islands. Hybrid cultivars are typically better suited to atoll environments than *A. altilis*. Production of fruit over a 9–12-month period is feasible in many areas by selecting and planting a wide range of cultivars.

Description

Habit evergreen tree ≤21 m tall, typically 12–15 m tall, ≤2.5 m dbh; trunk often develops extensive buttresses, especially *A. mariannensis* and hybrid cultivars; roots spreading and grow on or slightly below the surface; white, milky sap is present in all parts of the plant. ***Bark*** smooth. ***Leaves of A. altilis*** alternate, broadly obovate to broadly ovate, 12–61 cm long, 10–47 cm wide; dissection ranges from almost entire with only slight lobing to deeply pinnately lobed with ≤13 lobes cut from two-thirds to four-fifths of the distance from margin to midrib; blade generally glossy, glabrous, dark green with few to many white to reddish-white hairs on the midrib and veins, especially on the upper surface. ***Leaves of A. mariannensis*** generally smaller than *A. altilis* (10–31 cm long, 5–20 cm wide), broadly obovate to broadly elliptic; often entire or have 1–6 lobes cut less than halfway to the midrib in the distal third or half of the leaf; upper surface glossy and glabrous while petiole, upper midrib and veins densely pubescent with reddish-brown appressed hairs. ***Inflorescences*** trees are monoecious with the club-shaped male inflorescences (12–45 cm long, 2–5 cm wide) appearing first; most diploid forms produce abundant, fertile pollen while triploids and hybrid diploids are generally sterile; female inflorescences consist of 1,500–2,000 reduced flowers surrounding a spongy core; the perianth parts fuse together and develop into the fleshy, edible portion of the fruit; trees are cross-pollinated but pollination is not required for the fruit to form. ***Fruit of A. altilis*** variable in shape, size, texture, colour and seediness; usually round, oval or oblong, 10–30 cm long, 9–20 cm wide, weighing 0.3–6.0 kg; skin pale green, yellow-green or brownish-yellow (often stained with dried latex exudations) at maturity; skin texture varies from smooth to slightly bumpy to spiny; flesh creamy white or pale to deep yellow; fruit typically mature and ready to harvest as a starchy staple in 15–19 weeks, at which time it is firm to the touch and must be cooked before eating; ripe fruit soft with sweet, creamy flesh that can be consumed raw or cooked; trees begin fruiting in 3–5 years and are productive for many decades; seedless cultivars typically have numerous minute withered ovules surrounding the core while seeded forms contain from 1 to many viable seeds. ***Fruit of A. mariannensis*** cylindrical or asymmetrical and generally weigh <500 g; skin dark green with a pebbly texture; flesh dark yellow containing few to many large dark brown seeds. ***Seed*** little or no endosperm, no period of dormancy, germinate immediately and unable to withstand desiccation; rarely used to propagate *A. altilis* or hybrid cultivars, although *A. camansi* and

Above: Breadfruit is a major Polynesian food staple; Upolu, Samoa (Photo: L. Thomson)

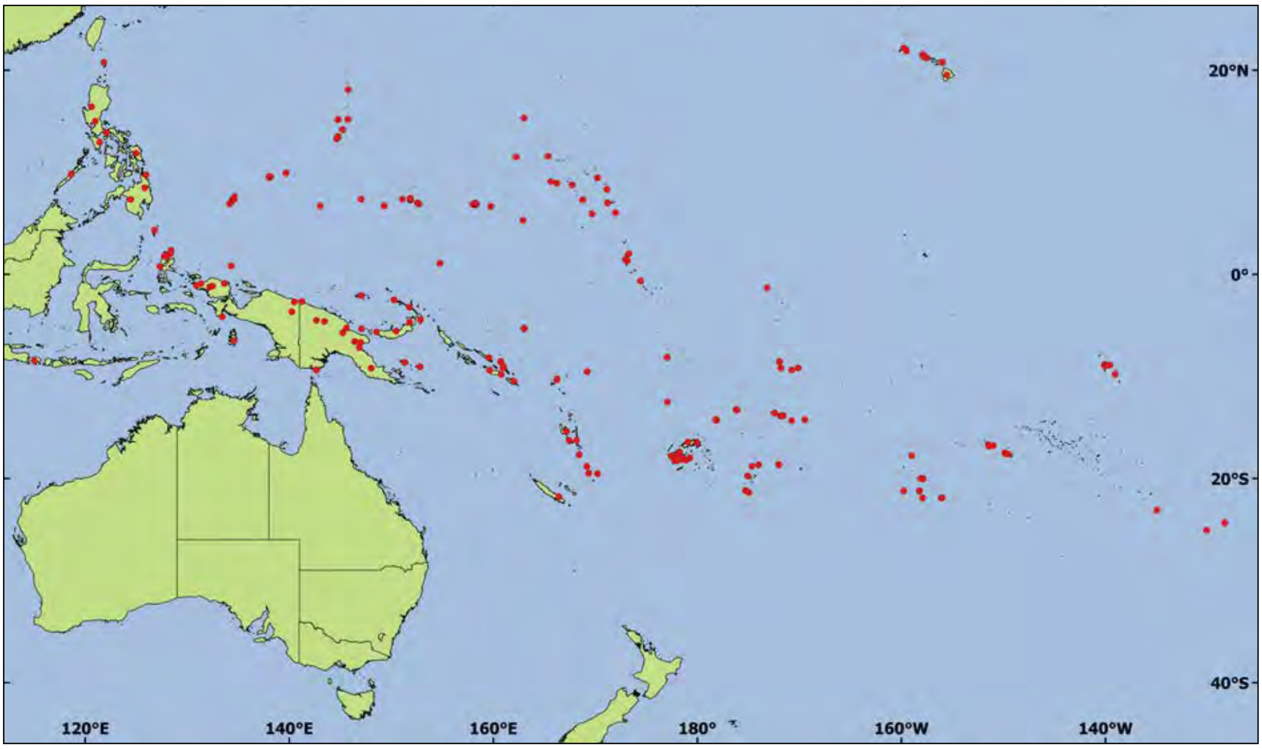
Left: Seven-year-old breadfruit tree; Maui, Hawai'i, USA (Photo: D. Ragone)

A. mariannensis must be grown from seed since the trees do not produce the root suckers typically used for vegetative propagation.

Hybrid cultivars exhibit characteristics of both parent species. Common characters contributed by *A. altilis* include deeply dissected leaves, white hairs, dense fruit, decreased fertility and smooth skin. *Artocarpus mariannensis* characters include entire to shallowly lobed leaves, reddish-brown hairs, spongy-fleshed fruit due to minimal fusion of adjacent perianth parts, bumpy fruit surface and deep yellow flesh. Hybrid cultivars can be seedless or contain few to many seeds.

Distribution

Artocarpus altilis, the most widely distributed species of breadfruit, is an ancient Polynesian introduction throughout the Pacific Islands where it is cultivated in home gardens and mixed agroforestry systems. Since the late 1790s, a few Polynesian cultivars have been planted in the Caribbean, Central and South America, Africa, South-East Asia, India, Sri Lanka, Madagascar, the Maldives, the Seychelles, northern Australia and southern Florida, USA. Since 2009, introductions of new



Pacific-origin cultivars have been made to 36 countries in Oceania, the Caribbean, Central America, Africa and Asia.

Artocarpus camansi (breadnut, *kamansi*, *kapiak*), the wild ancestral form of breadfruit, is native to the island of New Guinea and possibly the Maluku Islands, Indonesia. It may be naturalised in the Philippines and is a recent introduction from there to a few Pacific locales. While uncommon in the Pacific Islands, *A. camansi* is cultivated in the Caribbean, Central and South America, South-East Asia and West Africa.

Artocarpus mariannensis (*chebiei*, *dugdug*) is native to Palau and the Mariana Islands where it is typically associated with raised coral or elevated limestone ridges. This species, and the many hybrid cultivars of *A. altilis* × *A. mariannensis*, are cultivated throughout Micronesia, especially on atoll islands, and have been distributed as far south as Tuvalu and Tokelau while a few trees are found in Hawai'i. With the exception of several trees on Rabi (Fiji) brought from Banaba Island (Kiribati) and Hawai'i, neither *A. mariannensis* nor hybrid cultivars are grown elsewhere in the Pacific or in other tropical regions.

Breadfruit trees typically grow in the hot humid lowlands, although they are occasionally found in the highlands. Altitudinal range is 0–1,500 m asl and MAR is 1,000–5,000 mm with a short dry season of 0–3 months. Trees grow best in deep, well-drained, humus-rich alluvial soils of acidic pH, but will tolerate coralline soils of atolls and seasonal inundation on flood plains. Cultivars differ greatly in their tolerance of adverse conditions, with a few being able to tolerate shallow calcareous soils, brackish water and salt spray.

Uses

These multipurpose trees are primarily grown for their nutritious fruit, but they also provide a range of other non-wood products (see below) as well as timber. Breadfruit is grown in home gardens and small orchards and is an important component of traditional agroforestry systems.

Wood—breadfruit timber is used for buildings, canoes and carving.

Non-wood—the fruit is typically consumed as a starchy staple when firm and mature. It is a gluten-free, energy-rich food and a good source of complex carbohydrates, fibre and minerals such as potassium, calcium, copper, iron, magnesium, phosphorus, manganese and zinc. This nutritious fruit also provides B vitamins (niacin and thiamine) and vitamin C. Some cultivars have high levels of pro-vitamin A carotenoids. The protein contains all the essential amino acids and is especially rich in phenylalanine, leucine, isoleucine and valine. Breadfruit provides a higher quality protein than staples such as maize, wheat, rice, soybean and potato. Cooked seed is a good source of protein (17–20% for breadnut; 8% for breadfruit) and minerals.

Yields are extremely variable, ranging from <100 to >700 fruit/tree, depending on the cultivar, size, age and condition of tree. Average yields are 150–200 fruit/tree. Based on a planting density of 50 trees/ha, breadfruit has an average projected yield of 5.23 tonnes/ha after 7 years. This compares favourably with the average global yields of rice, wheat and maize (4.1, 2.6 and 4.0 tonnes/ha, respectively).

Although an important staple throughout Oceania, breadfruit is considered an underutilised crop due to the seasonal nature of production and fruit perishability. Most fruit are produced for subsistence purposes with increasing quantities of fresh fruit and prepared products available for sale in village and town markets. Interest in drying and grinding the mature fruit into meal or flour has significantly increased in the past 5 years throughout the Pacific region. Expanding use of breadfruit can be accomplished by selecting cultivars that extend the fruiting season, improving postharvest handling and storage, and developing simple, economical means to

Breadfruit ready for cooking in *uhmw* (traditional oven using hot stones); Pohnpei, FSM (Photo: D. Ragone)

Breadfruit slices in solar dryer; Suva, Fiji (Photo: J. Bennett) process the fruit into delicious food products, as well as marketing and promotion.

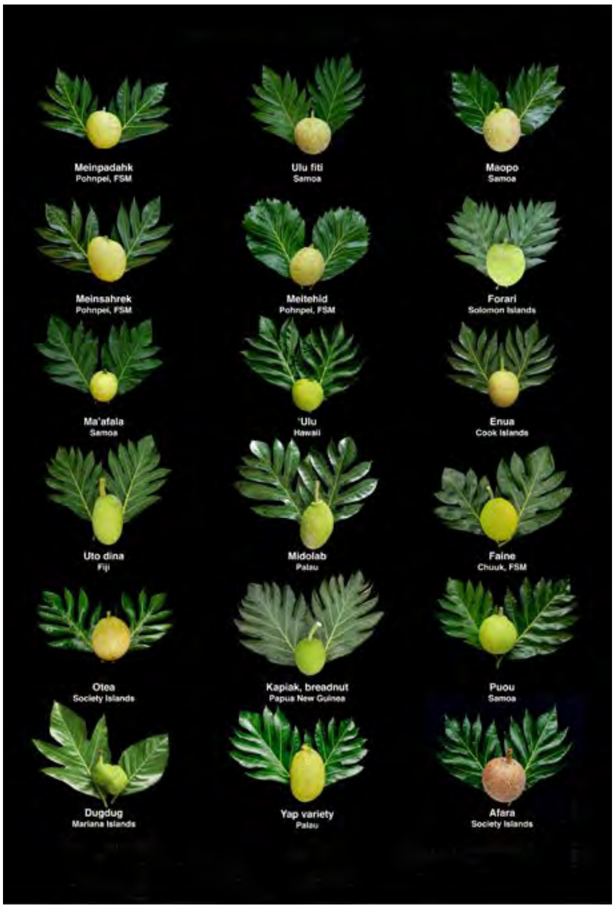
Breadfruit also provides medicine, adhesives, animal feed, shade, mulch and other environmental benefits. The trees also provide shelter and food for important plant pollinators and seed dispersers, such as honeybees, birds and fruit bats.

Diversity and its importance

Thousands of years of cultivation and selection of breadfruit have led to a wealth of genetic diversity and unique breadfruit cultivars suited to different purposes and environments. Molecular, cytological, morphological, archaeological, linguistic and ethnographic studies provide information about the origins and distribution of breadfruit.

Most Melanesian and Polynesian breadfruit cultivars are derived from *A. camansi*. Vegetative propagation increased the chances of few-seeded or seedless cultivars originating (due to accumulated somatic mutations and meiotic defects) and persisting (due to human selection). The prominence of seedless cultivars increases from the island of New Guinea eastward through Melanesia (where seeded cultivars are common) into western Polynesia (where few-seeded and seedless cultivars are prevalent) and into eastern Polynesia (where virtually all cultivars are seedless triploids). Seeded cultivars are diploid ($2n = 2x = 56$) while seedless cultivars are generally triploid ($2n = 3x = \sim 84$).

Domesticated breadfruit in Micronesia includes hybrid cultivars between *A. altilis* and *A. mariannensis*



Variation in breadfruit foliage and fruit (Photo: D. Ragone)

Fruit of Maopo variety; Upolu, Samoa (Photo: L. Thomson)

Fruit of Puou variety; Upolu, Samoa (Photo: L. Thomson) as well as 'Polynesian triploid' cultivars. Micronesian hybrids include fertile and sterile diploids and sterile triploids. Northward migration from the south-eastern Solomon Islands – Vanuatu region into central-eastern Micronesia, followed by subsequent human migrations and trading within Micronesia, would have brought diploid *A. altilis* into contact with *A. mariannensis*, allowing the two species to hybridise. Subsequently, varying degrees of introgression and human selection led to the diversity of cultivars unique to Micronesia. The productivity of traditional agroforestry systems on Pohnpei and Chuuk (FSM) and the almost year-round availability of fruit is largely due to this wide diversity of cultivars.

The natural ranges of *A. camansi* and *A. mariannensis* do not overlap, so direct hybridisation between these two species in the past is unlikely. Now that *A. camansi* has been introduced from the Philippines to Palau, Pohnpei and other Micronesian islands where *A. mariannensis* occurs, hybridisation between these species is likely.

Breadfruit is propagated clonally using root suckers, with seedless and seeded cultivars propagated this way. Cross-pollination readily occurs when fertile diploid species or cultivars are planted together, and diploid, and even triploid, cultivars will produce viable seed. Seedling selection would capture greater genetic diversity available in the breadfruit complex and facilitate development of new cultivars.

Conservation of genetic resources (including threats and needs)

Ethnobotanical studies of breadfruit diversity have documented 131 cultivar names in Pohnpei, 132 in Vanuatu, 46 in Samoa and >50 for the Marquesas Islands. However, many of these cultivars could not be located and farmers are concerned that the trend towards fewer cultivars will continue. In many Pacific Islands, breadfruit diversity continues to decline because of cultural and economic change, loss of traditional knowledge, limited replanting of cultivars, environmental factors (cyclones, drought), pests and diseases. The number of trees has decreased and cultivars have disappeared or are becoming rare. Wild populations of *A. mariannensis* in Guam and Rota (Northern Mariana Islands) have seriously declined due to cyclone damage, the disappearance of its important natural disperser, flying foxes, and foraging of seedlings by introduced deer. Numerous trees and cultivars could disappear throughout the northern Pacific Islands as a result of record-breaking droughts in 2016.

To help conserve and study breadfruit, several germplasm collections were assembled in the Pacific Islands in the 1960s and 1970s, including an extensive regional collection in Samoa, and plantings of local cultivars in Pohnpei, Kosrae and Solomon Islands. All of these have been neglected or abandoned since the 1980s.

A field genebank of breadfruit species and cultivars was established in the mid-1970s at the National Tropical Botanical Garden (NTBG) in Hawai'i. More than 300 accessions and approximately 130 cultivars from 34 Pacific Islands, Indonesia, the Philippines, the Seychelles and Honduras are conserved and studied by the NTBG's Breadfruit Institute. Fifteen cultivars are maintained as in vitro plants. Thirty-two accessions of *A. altilis* are maintained in the United States (US) National Plant Germplasm System at the Pacific Basin Tropical Plant Genetic Resources Management Unit in Hilo, Hawai'i.

Recognising breadfruit's importance locally, regionally and internationally for food security and building climate-resilient food systems, several countries are accelerating their breadfruit conservation and research programs. SPC's Centre for Pacific Crops and Trees in Narere, Fiji, began maintaining local and regional germplasm as in vitro plants in the early 2000s. Vanuatu is an important centre for breadfruit diversity and 123 accessions from 8 islands were planted in the country's first breadfruit genebank at the Vanuatu Agricultural Research and Technical Centre in 2005.

An integrated conservation strategy must address in situ and ex situ conservation of this important Pacific crop; and preserve and perpetuate traditional knowledge as well as breadfruit cultivars and genetic diversity.

Author: Diane Ragone

Barrington ia edulis and *B. procera*

Family: Lecythidaceae
Botanical names: *Barringtonia edulis* Seem. In *Flora Vitiensis* 1: 82 (1866); *B. procera* (Miers) R.Knuth. In *Das Pflanzenreich* IV, 219: 25 (1939).

The genus is named after Daines Barrington (1727–1800), English jurist, antiquary, botanist and naturalist. The specific epithets are after the Latin *edulis*, edible, in reference to the edible kernel; and *procerus*, long, in reference to the long pendulous inflorescence. A close relative, *B. novae-hiberniae* Laut. (bush cutnut), from PNG, Solomon Islands and Vanuatu, also has edible fruit.
Common names: cutnut (English); *B. edulis* generally known as *vutu*, *kutuvala*, *vala*, *vutu kana* (Fiji); *B. edulis* and *B. procera* known as *pao* (PNG), *katnat* (Solomon Islands) and *navele* (Vanuatu). Both species have many vernacular names in local dialects.

Summary of attributes and why diversity matters

Cutnuts are small- to medium-size tropical nut trees. They are adaptable, multipurpose and are part of traditional agroforestry practices throughout Melanesian countries. They are renowned for their edible kernels and, among other uses, make useful mid-canopy companion trees to other crop plants.

Cutnuts have been utilised locally since ancient times and are more frequent in cultivation than in native forest. They exhibit extensive intraspecific variation in size and inflorescence and fruit characteristics. Intensive selection for desirable fruit and tree characteristics at the village level has resulted in cultivation of many different morphotypes. There is great scope for implementation of range-wide varietal screening and breeding programs to improve commercial traits in cutnuts, especially kernel size. Research is needed into reproductive biology and vegetative reproduction of cutnuts in support of breeding activities.

Description

Barringtonia edulis*—*Habit small tree, 6–24 m tall, 30–40 cm dbh, narrow to broad crown. ***Bark*** almost smooth, thick, greyish brown. ***Slash*** light brown, exposing white wood. ***Leaves*** simple, obovate-oblong, joined in rosettes at the end of the branches, very glossy on both sides, chartaceous, large, 20–71 cm long, 7–25 cm wide, margin entire, apex acuminate, base cuneate, petiole 0.5–1.5 cm. ***Inflorescences*** ramiflorous and terminal racemes, pendulous, 50–100 cm, densely flowered (40 fls); flowerbuds greenish, hairy with apical pore 2–4 mm in diameter; rachis ± fissured, yellowish grey-green, pulverulent. ***Flowers*** not scented; petals 4,

Planted tree of *B. edulis*, with Prof. Konai Helu Thaman; Fiji (Photo: R.R. Thaman)

Raceme of *B. edulis* (Photo: R.R. Thaman)

Above left: Raceme and fruit of *B. procera*; Vanuatu (Photo: L. Thomson)

Above right: Bunch of hanging *B. procera* fruit; Kolombangara, Solomon Islands (Photo: L. Thomson)

Left: Flowering trees, *B. procera*; Espiritu Santo, Vanuatu (Photo: L. Thomson)

cream or rose coloured; stamens conspicuously long, white, tinged pink at the tips. ***Fruit*** light green ripening dark green to purple-green, fleshy, firm, ellipsoid, 6–10 × 4–7 cm, truncate, tapering towards base, tomentose, crowned with persistent calyx, sessile or pedunculate. ***Seed*** ovoid, white, small, 2.5 × 1.5–3.0 cm.

Barringtonia procera—Habit small, slender, sparsely branched tree, 7–12(–24) m tall, ≤45 cm dbh. ***Bark*** smooth when young becoming fissured with large lenticels present. ***Leaves*** dark green, crowded towards ends of thick branchlets marked with prominent leaf-scars, obovate-oblong, chartaceous, glabrous, 22–66 cm long, 8–24 cm wide, very glossy on both sides, serrate-crenulate towards the apex, acuminate (tip recurved), base cuneate, subsessile with petiole ≤0.6 cm long. ***Inflorescences*** spikes terminal, pendulous, 30–100 cm, densely populated with green to white or red flowerbuds (≤150 fls); rachis c. 0.5 cm, slightly fissured, yellowish grey-green, pulverulent. ***Flowers*** bisexual, not scented, opening buds 10–15 mm; calyx red and closed in bud, rupturing into 2(–4) lobes; petals 4, cream or white, revolute; stamens red, cream or yellow. ***Fruit*** crowded, cylindrical, ± 8-sided endocarp, hooked near the base on alternate ribs, 6.0–8.5 cm long, truncate at both ends (≤6 cm at base, ≤4 cm at apex); colour variable from greyish green to dark purple. ***Seed*** ovoid, slightly fissured, 3–3.5 × 1–2 cm.

While herbarium specimens of *B. edulis* and *B. procera* resemble one another, they differ in the following characters: *B. edulis* has petioled leaves, pedicelled flowers and an ovoid fruit (green when fresh), while *B. procera* has (sub)sessile leaves and flowers and typically purplish fruit.

Distribution

Barringtonia edulis occurs naturally in Fiji, Vanuatu and Solomon Islands and is widely planted throughout these island archipelagos. Present occurrences of the species in north-eastern PNG are thought likely to originate from Polynesian introductions in ancient times. In Fiji, *B. edulis* is widespread in forest, woodland, and pasture, from sea level up to c. 400 m asl. It is recorded from Viti Levu, Vanua Levu, Kadavu, Ovalau, Beqa, Matuku, Vanuabalavu and Lakeba. In Vanuatu, it occurs on all islands up to an elevation of 600 m asl, while in Solomon Islands, it is widespread in cultivation, but rarely recorded from the wild.

Barringtonia procera occurs in Solomon Islands, Vanuatu and PNG (Bougainville). Elsewhere in PNG (e.g. Augusta River, Huon Peninsula, Tami Island, New Britain and New Ireland), it is regarded as an ancient introduction. It is no longer found anywhere in the wild in PNG. In Solomon Islands, it is common in secondary rainforest, sago swamps and village gardens at low elevation. It is found on Treasury and Shortland Islands, New Georgia, Hobupeka, Vangunu, Guadalcanal and Makira. In Vanuatu, the species is found mainly in a cultivated state in villages, gardens and along tracks, at low altitudes. It is more frequent from the Torres Islands to Pentecost and Malekula, but is still well represented as far as Efate. It is likewise present in Futuna but has not been recorded from Tanna or Erromango.

Both species have not been widely cultivated outside their native range.

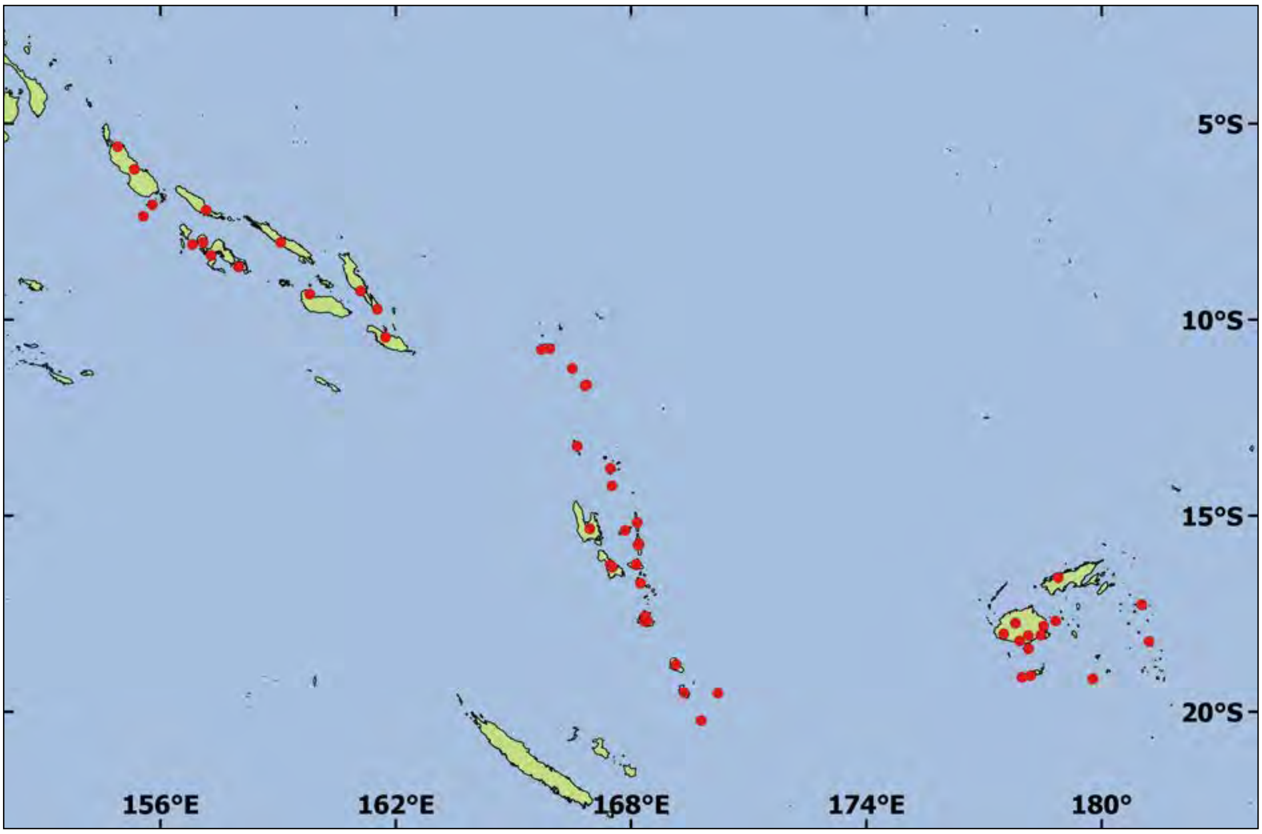
Cutnuts typically inhabit lowlands of the humid tropics with warm temperatures throughout the year and high MAR (1,500–4,300 mm). Elevation range is from near sea level to 600 m asl. Cutnuts grow well in free-draining, light to heavy soils, including coralline soils near the coast. Range in pH is 5.1–8.5. They are tolerant of cyclones and shallow, saline and infertile soils but not waterlogged soils.

Uses

Cutnuts are part of traditional agroforestry in their regions of occurrence. They are often used to demarcate boundaries or planted around villages and in secondary forests. Often interplanted with other crop plants, they serve as an excellent mid-canopy companion tree to species such as canarium, breadfruit and sago palm. Traditionally, almost every part of a cutnut plant was put to some useful purpose.

Wood—of poor quality with wide cream sapwood and soft cream-brown heartwood. It is not durable and only suitable for temporary light construction. The wood is sometimes used as casing timber in Fiji and making paddles in the Reef Islands, Solomon Islands. Fallen branches or felled trees are used as firewood.

Non-wood—seasonally, the kernels are a highly nutritious food. They are eaten raw, grilled or boiled. In Vanuatu, they may occasionally be crumbled into *lap-lap*. Partially dried kernels are sometimes threaded on the



midrib of a coconut palm leaf and sold in markets to raise income. In northern Vanuatu, cutnuts are peeled, bound up in *Hibiscus* bark, then smoked and stored for several months above the hearth (to reduce spoilage from pests and high humidity). Unsmoked, the kernels last at most for 1–2 weeks. In western Solomon Islands, kernels are roasted and baked into puddings together with edible hibiscus and coconut cream.

In traditional medicine, the leaves are used for treating inflammation of the ear, the sap extracted from the bark for treating ciguatera poisoning, coughs and urinary tract infections, and the form with red leaves is used for abortions or as a contraceptive. Cutnuts provide good bee forage and make for a useful and decorative park or street tree.

Cut fruit of *B. procera* showing edible nut; Espiritu Santo, Vanuatu (Photo: L. Thomson)

Honey bees collecting *B. procera* pollen (Photo: L. Thomson)

Diversity and its importance

Cutnuts are extremely variable in many morphological traits. They vary in size; for example, dwarf trees of *B. procera*, where height growth does not exceed 2 m, occur infrequently in most islands of Vanuatu and are increasingly cultivated in Fiji gardens. They offer the potential for breeding short, easy-to-harvest trees if their present poor productivity can be improved.

There is extensive intraspecific variation in foliage colour (e.g. rare red forms of *B. edulis* occur in Vanuatu), size and colour of inflorescence and fruit characteristics such as colour, shape, rigidity of shell and size, including kernel weight. Numerous morphotypes with different nut-in-shell and fruit characteristics have developed over time because of extensive and intensive selection for desirable fruit and tree characteristics by local people. Each community possesses its own collection of cutnut trees, and each morphotype has its own particular name.

Research is needed on the reproductive biology of cutnuts, their vegetative propagation and varietal screening as prerequisites to implementing formal tree improvement activities on these very important trees.

Green and purple fruit morphotypes of *B. procera* (Photo: B. French)

Conservation of genetic resources (including threats and needs)

Although no longer common in the wild, cutnuts are still reasonably well represented on disturbed habitats throughout much of their native ranges, although some populations have been greatly reduced or extirpated.

Authors: Lex Thomson and Chanel Sam

Calophyllum inophyllum

Family: Clusiaceae
Botanical name: *Calophyllum inophyllum* L. In *Sp. Pl.* 1: 513 (1753).

The genus name comes from two Greek words *kalos*, beautiful, and *phyllon*, a leaf, referring to beautiful leaves; the specific epithet again from two Greek words, *inodes*, fibrous, and *phyllon*, a leaf, referring to the fibrous leaves of this species.
Common names: beach mahogany, beach calophyllum, Alexandrian laurel, Borneo mahogany, beauty leaf (English); *ponyal* (Bangladesh); *tamanu* (Cook Islands; Society Islands and Marquesas Islands, French Polynesia); *dilo* (Fiji); *daog*, *daok* (Guam; Northern Mariana Islands); *kamani*, *kamanu* (Hawai'i, USA); *njamplung*, *dingkaran* (Indonesia); *polanga*, *pinnai* (India); *te itai* (Kiribati); *lueg* (Marshall Islands); *bintangor laut*, *penaga laut*, *penaga* (Malaysia); *ponnyet*, *poan* (Myanmar); *btaches* (Palau); *palo maria*, *bitaog* (Philippines); *isou* (Pohnpei, FSM); *hefau* (Rotuma, Fiji); *fetau* (Samoa); *takamaka* (Seychelles); *krathing*, *saraphee naea*, *naowakan* (Thailand); *feta'u* (Tonga); *nabangura* (Vanuatu); *c[aa]y m[uf]u* (Vietnam); *biyuch* (Yap, FSM); and many more

Summary of attributes and why diversity matters

Calophyllum inophyllum has a wide distribution in coastal locations in the Pacific and Indian oceans, from Madagascar, South Asia and Malesia to northern Australia and Oceania. It grows relatively fast in these locations where it must withstand strong winds, including intense tropical cyclones, and salt spray. Few tree species are better adapted to cope with gradual climate change and extreme events and protecting rocky coastlines and inland areas from erosion, wind damage and salt spray. The tree has an exceptionally broad climatic range as indicated by wide amplitude in key bioclimatic factors. It is planted for a wide range of wood (e.g. construction timbers, flooring and furniture) and non-wood (e.g. seed oil, latex and bark have medicinal properties) products and is often planted as an ornamental, avenue or shade tree, or for dune stabilisation.

This species shows substantial variation in economic traits, including growth rate, wood quality, reproductive phenology, size of fruit, yield of seed oil and tolerance of growth-limiting conditions, throughout its broad geographical range. A recent medical study has shown differences in the antibacterial and cytotoxic properties of nut oils from different geographical sources (Fiji, Indonesia, New Caledonia and Tahiti). Collection of a wide range of germplasm, establishment in provenance/progeny trials and selection of faster growing, better adapted genotypes for specific end uses (e.g. coastal reclamation or timber combined with seed oil production) should lead to better outcomes from planting this species.

Description

Habit medium-size tree ≤25(–35) m tall, usually with crooked, leaning bole and large horizontal branches, ≤2 m dbh, without buttresses, broad spreading crown. ***Bark*** rough, grey to light brown with deep fissures alternating with flat ridges. ***Slash*** cut bark reddish-brown on white hardwood, exuding white or pale-yellow latex when cut. ***Leaves*** opposite, decussate, simple and entire, without stipules, petiolate; blade elliptic, ovate, obovate or oblong, 8–20 cm long, 6–9 cm wide; leaf base and tip rounded, leathery, shiny dark green, glabrous, with closely parallel secondary venation at right angles to the midrib alternating with latex canals. ***Inflorescences***

Open-grown specimen; Hilo, Hawai'i, USA (Photo: J.B. Friday)

Flowers (Photo: J. Bennett)

Above: Beach specimen; Rotuma, Fiji (Photo: L. Thomson)

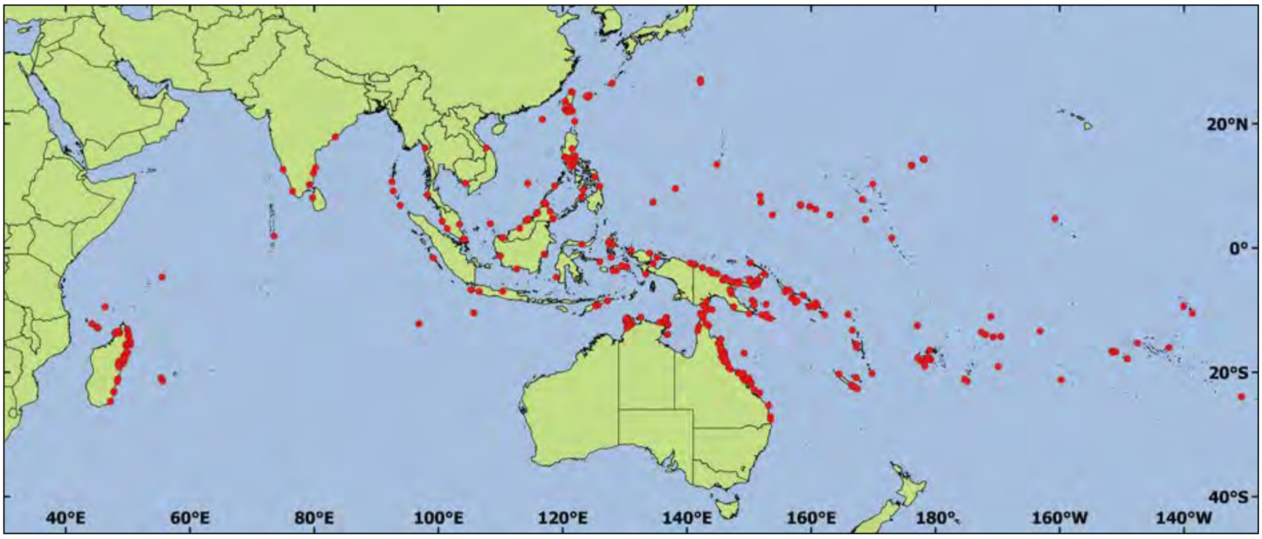
Left: Fruit and foliage; Lifuka, Ha'apai, Tonga (Photo: L. Thomson)

axillary false racemes, sturdy, 7–15 cm long, sometimes branched, 5–15(–30) flowered. ***Flowers*** bisexual, fragrant, 2.0–2.5 cm diameter; tepals 8(–13), obovate, 1 cm long, white; stamens numerous, in 4 bundles, anthers conspicuous, orange-yellow; ovary superior, globose, 1-celled; style long and slender, stigma peltate. ***Fruit*** globose to obovoid drupe, somewhat poisonous, thin-fleshed, 2.5–5.0 cm diameter, on pendulous stalks to 5 cm long, yellowish brown and wrinkled when ripe, containing a single seed. ***Seed*** globose to ovoid, 2–4 cm diameter, brown, hard-shelled, very oily. ***Reproductive phenology*** trees may flower all year round but typically there is a peak season depending on location. In northern Australia, the peak is in the summer rainy season with mature fruit available during the following winter period.

Distribution

The distribution of *C. inophyllum* extends from Madagascar, through Indian Ocean islands, tropical Asia as far east as Japan's Ryukyu Archipelago, northern Australia and Pacific Islands to as far east as French Polynesia (approximate limits north to south: 30°N to 25°S). Although this is thought to be the natural range of the species, it is unclear if some populations have become naturalised following earlier cultivation. It is planted within its natural range and also as an exotic in such places as the Caribbean, Hawai'i, Central America and West Africa.

Calophyllum inophyllum prefers tropical climates with 18–33 °C MAT and 1,000–5,000 mm MAR, variably distributed. It will tolerate a dry season of ≤5 months duration. Altitudinal range is 0–200(–800) m asl. The species is found in coastal forests and flourishes on free-draining, sandy or xeric soils, although it will tolerate seasonally waterlogged and saline soils. It also tolerates salt winds and spray typical of exposed coastal positions. *Calophyllum inophyllum* trees survive up to



Category 3 cyclones with minimal damage, but at higher categories, trees may lose small and large branches. They may also be uprooted on beaches through sand removal and extreme storm surge generated by the most intense cyclones, but are less prone to uprooting than coconuts in such situations, and even bare-rooted *C. inophyllum* trees with broken limbs and stripped of bark recover rapidly. It is also sometimes found in riparian forests further inland. The species has a slow to moderate growth rate and is reasonably fire resistant once the bark thickens. It has been reported to be a dependable coppicing species.

Uses

Wood—traditional uses include making canoes, boatbuilding and craftwood. The highly prized wood is occasionally also used for construction, carpentry, flooring, stairs, furniture and cabinetwork, gunstocks, cartwheel hubs, vessels and musical instruments. It is suitable for sulfate pulping.

The sapwood is pale yellow or pinkish-brown, sharply demarcated from the cedar-brown or red-brown heartwood. Grain is strongly interlocked and texture moderately coarse. The wood of *C. inophyllum* is moderately dense, 560–800 kg/m^3 at 15% moisture content, and moderately hard. Sawn surfaces can be woolly, the wood difficult to plane because of the interlocking grain and slow-drying, leading to defects such as twisting and warping. Production of short lumber lengths of ≤3 m is recommended as a result.

Non-wood—numerous uses in traditional medicine have been recorded from throughout the species' natural range based on the latex or decoctions from the bark, leaves, roots and seed. It is the green, strongly scented seed oil, containing 50–60(–73)% fixed fatty oils and a resinous fraction, that appears to have the widest efficacy and utility. This oil has skin-healing properties and is used to treat burns and skin diseases as well as for cosmetic applications. Recent medical trials have confirmed the pharmacological effects of the seed oil as a wound-healing and antimicrobial agent, and demonstrated that the concentration of oil needed to exhibit therapeutic effects is lower than concentrations exhibiting cytotoxic effects in vitro. The oil also has anti-inflammatory, antifungal, antibacterial, ultraviolet (UV) absorption and insecticidal properties, as well as having potential as a feedstock for biodiesel production. Recent studies showed extracts from the leaves and seed of *C. inophyllum* had efficacy against conditions including the human immunodeficiency virus (HIV), cancer, leukaemia and intracellular parasites.

Calophyllum inophyllum is an excellent tree for soil stabilisation and windbreaks in coastal areas as it tolerates salt spray and high winds of cyclonic intensity

Drying kernels prior to oil extraction; Suva, Fiji (Photo: J. Bennett)

and has a dense canopy that shelters more sensitive plants. It is grown as part of mixed garden agroforestry systems, as boundary markers and is a favourite large-tree ornamental in many Pacific Islands.

Diversity and its importance

Calophyllum inophyllum shows substantial diversity in tree size and habit, wood quality, reproductive phenology, size of fruit, yield of seed oil and tolerance of growth-limiting conditions throughout its broad geographical range. Collection and screening of suitable, faster growing, better adapted provenances for particular end uses should lead to better outcomes and is highly recommended. For example, in the case of seed oil, a study of provenance variation in seed morphometric characters and oil content in Australia and Sri Lanka showed significant provenance variation in seed characteristics and oil content. Seed from Anuradhapura, Sri Lanka, and seed from Cardwell, Australia, recorded the highest (c. 57%) and the lowest (c. 31%) oil content,

Variation in nut and kernel size (Photo: J. Bennett) respectively. Selection and breeding for higher yields of seed oil could well become economically viable, as *C. inophyllum* seed oil is likely to become even more important in the future because of its medicinal properties.

Provenance variation in sapwood density, bark thickness and reproductive phenology has also been demonstrated. As many of these economic traits are likely to be heritable, in the presence of useful levels of additive genetic variation there is great scope for capturing genetic gains through selection and breeding among the most desirable provenances. Despite this, we do not know of any organisations pursuing the genetic improvement of this species at this time.

Natural hybridisation may occur with other *Calophyllum* species of which there are about 190 in total.

Conservation of genetic resources (including threats and needs)

Calophyllum inophyllum has a wide geographical range and is locally abundant in many areas. Considered broadly, it does not appear to be in danger of genetic erosion. However, in places where it is infrequent, there may be local concerns. For example, in some Pacific Islands, such as Kiribati and Tuvalu, its overuse, removal in land clearing and absence of replanting over the past century have made it increasingly scarce. In these cases, the remaining trees need to be protected and replanting programs initiated, both as part of coastal reforestation programs and in urban areas, where it is a very effective and attractive shade and roadside tree.

The species is susceptible to an array of insect pests and fungal diseases throughout its range but typically trees recover quickly from such attacks. One exception is in the Seychelles where many *C. inophyllum* trees are affected by a vascular wilt disease (caused by the fungus *Leptographium calophylli*) which causes severe dieback and ultimately tree mortality. The suspected vector is the beetle *Cryphalus trypanus*. The wood is reported to be resistant to termites in Hawai‘i.

Authors: Lex Thomson, John Bennett and John Doran

Canarium indicum

Family: Burseraceae
Botanical name: *Canarium indicum* L. In *Amoen. Acad.*, Linnaeus 4th edn: 143 (1759).

The genus name is derived from the Indonesian word *kanari* or *kenari*, which is the local name for the species, while the specific epithet refers to its origin from the East Indies.

Common names: canarium, canarium nut (English); galip nut (PNG); *ngali*, ngali nut (Solomon Islands); *nangai* (Vanuatu)

Bunch of mature fruit (Photo: USC)

Summary of attributes and why diversity matters

Canarium indicum is a fast-growing, multipurpose tree of the humid tropics, providing an important seasonal food (nuts), timber, shade and kernel oil which is a substitute for coconut oil and has potential in skincare products. It is suited for inclusion in agroforestry and home garden systems and has been very successful in mixed cropping systems with cocoa and coconut. Prospects for commercial development of the edible nuts of *C. indicum* are considered excellent because of their potential as a high-value export crop for confectionery or oil extraction.

There is high variability from tree to tree in morphotype, nut and kernel size and nutritional components as well as phenolic and oil contents of nuts. This variability provides opportunities for domestication of *C. indicum* by selecting elite trees and developing improved cultivars. Successful domestication depends on genetic diversity both in the wild population and in cultivated trees. An understanding of this diversity is imperative to development of *C. indicum* as a large-scale crop and to conserve and manage the species in wild populations.

Branchlet showing distinctive large stipules; Espiritu Santo, Vanuatu (Photo: L. Thomson)

Description

Habit large tree to 40 m tall, 30 m crown diameter and 1.0–1.5 m dbh, although most mature trees are 20–30 m high and 15–20 m across with 0.5–1.0 m dbh; bole commonly buttressed, normally to about half the tree height. ***Bark*** smooth to scaly and dimpled, grey or brownish grey to yellow-brown; inner bark laminated, reddish-brown to pinkish-brown, exuding a milky resin. ***Leaves*** dark green with 6–8 pairs of leaflets on a rachis to 30 cm long; large stipule at the junction of the branchlet and petiole; individual oblong leaflets 7–28 cm long, 3.5–11.0 cm wide. ***Inflorescences*** terminal panicles, 15–40 cm long. ***Flowers*** small, white; mostly dioecious with male and female flowers on separate trees—however, some trees produce hermaphroditic

Sapling in agroforestry planting; Espiritu Santo, Vanuatu (Photo: L. Thomson)

Above left: Green fruit, ripe fruit, immature endocarp in green pericarp, mature endocarp in ripe pericarp (L to R) (Photo: USC)

Above right: Bunch of near-mature fruit; Espiritu Santo, Vanuatu (Photo: L. Thomson)

Left: Planted specimen showing large buttresses, with John Bennett; Suva, Fiji (Photo: L. Thomson)

flowers. ***Fruit*** ovoid drupe, around 3–6 cm long, 2–4 cm wide, borne on slightly drooping stems; green when immature, turning to black and abscising from the tree when mature. ***Seed*** nut-in-shell is obtained by removing the fleshy pericarp (exocarp and mesocarp) of the fruit; kernel contained within an extremely hard shell (endocarp); endocarp very variable in size and weight, range 28–62 mm long, 20–35 mm wide and 8–20 g in weight; in transverse section, nuts triangular with 3 locules that may develop and contain 1–3 seeds although 1 is most common; kernel enclosed in a tough brown testa, ease of removing testa depends on age and moisture content of nut—testa can be removed easily from dried kernels after soaking in hot water for 90 seconds; kernels from mature fruit have significantly higher oil content and weight than from immature fruit. ***Reproductive phenology*** flowering is initiated by changes in day length with the start of flowering dependent on the latitude; fruiting is dependent on local conditions with the season—in PNG April–May and September–November, in Solomon Islands August–October, in Vanuatu October–January; in areas with non-seasonal rainfall, there may be almost continuous fruiting throughout the year; fruiting commences about 7 years after planting.

Distribution

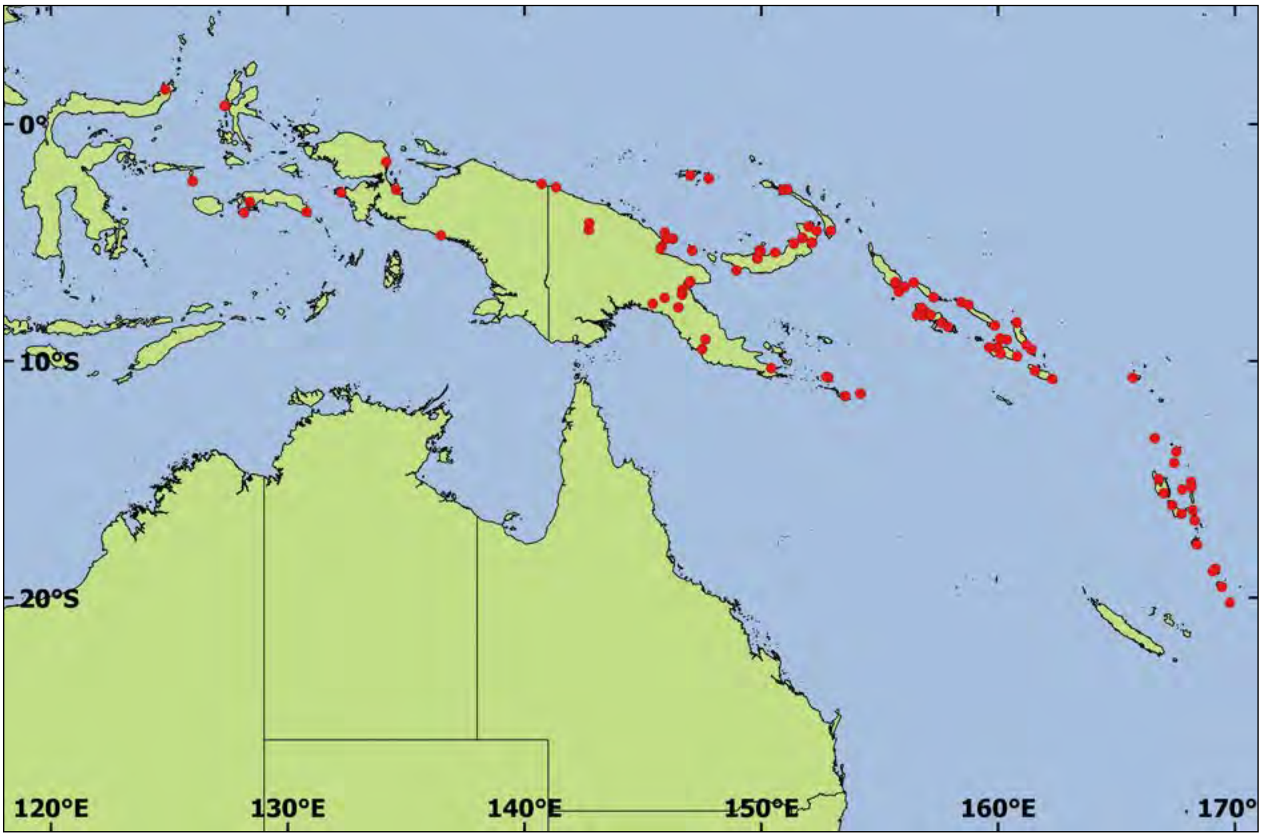
Canarium indicum is indigenous to lowlands (0–600 m asl) in eastern Indonesia, PNG, Solomon Islands and Vanuatu. It is widespread and common in Solomon Islands and Vanuatu. The main resource exists in native forests although plantings are increasing, particularly in PNG.

It has been introduced to Fiji and cultivated for the edible nuts. Some small plantings have been made in Far North Queensland using seed from PNG.

This species grows in lowland, subhumid to humid climates with 1,800–4,000 mm MAR, summer maximum or uniformly distributed and a short dry season of 0–3 months. Altitudinal range is 0–600 m asl. *Canarium indicum* grows best on medium- to heavy-textured soils of moderate to high fertility. It does not tolerate shallow, infertile or saline soils.

Uses

Traditionally, *C. indicum* has been valued as a timber species and, for thousands of years, a very important food tree as well as having cultural significance. *Canarium indicum* is fast growing and suited for inclusion in agroforestry and home garden systems. Currently, *C. indicum* is grown mostly in smallholder blocks or harvested from the wild. Some plantation trials



have shown that *C. indicum* trees are very successful in mixed cropping systems with cocoa and coconut.

Wood—fine-textured, pink-brown, medium density (basic density 430–560 kg/m³), non-durable and suitable for light construction, mouldings, veneer and numerous interior uses. Traditional wood uses in Solomon Islands and Vanuatu include house building, canoes, custom bowls and fuel.

Non-wood—*C. indicum* trees have potential to replace *Gliricidia*, a legume tree used to shade cocoa in mixed agroforestry systems. The edible kernels have a pleasant subtle flavour and are highly marketable products which are mostly traded fresh in roadside and village markets, either as nut-in-shell or as dried kernels. Commercialisation of *C. indicum* has begun with a pilot factory at the National Agricultural Research Institute at Kerevat, East New Britain province, PNG. Kernels are highly nutritious with a protein content of 8–14% and are relatively rich in potassium, magnesium and iron. They contain 67–75% oil, which is liquid above 35 °C and semisolid below 24 °C and includes oleic acids (monosaturated fat) 30–40%, palmitic acid (saturated fat) 28–38%, linoleic acid (polyunsaturated fat) 12–22% and stearic acid (saturated fat) 10–20%. The quality of stored nuts depends on moisture content, maturity of nuts at harvest and the conditions of storage. For prolonged storage, kernels need to be dried to water activity 0.2–0.3 (a_w) or a moisture content of 1.5%, equating to nut moisture content of approximately 6%. The kernel has good shelf life in-shell when dried to a stable moisture content, enabling safe transport and handling. There is huge potential for value adding (such as roasting), expanding the domestic markets in PICTs and creating export markets. A strong industry would improve the livelihoods of rural households in PNG, Solomon Island and Vanuatu.

The shell is historically used for fuel and has potential for greater use for electricity generation and the production of biochar and charcoal. Some parts of the tree (bark, resin and oil) are used for their medicinal properties. *Canarium indicum* oil is also valued in the

Training in processing nuts; East New Britain, PNG (Photo: USC) cosmetic industry and is an important source of cooking oil in the region.

Diversity and its importance

The genus *Canarium* comprises about 78 species of medium to large trees (>40 m tall) from low to middle elevation regions of the subtropics and tropics. Several of these species are valuable as a food resource. *Canarium odontophyllum* (*dabai* or Sarawak olive) is consumed mainly for its olive-like fruit. *Canarium ovatum* is the basis of a nut industry in the Philippines while *C. harveyi* is cultivated for its edible nuts on a small scale in Solomon Islands.

Canarium indicum var. *indicum* (canarium) has been valued for its edible nuts for thousands of years at a village level in Melanesia, with many local varieties developed through informal selection. The *C. indicum* resource at present is widely scattered, and poorly understood and documented. There is high variability in nut size and morphotype, kernel size, carbohydrate and protein content, and oil composition. There is also high tree-to-tree variability in nutritional components and phenolic content of nuts. This variability provides opportunities for domestication of *C. indicum* by selecting elite trees and developing improved cultivars. Successful domestication depends on genetic diversity both in the wild population and in cultivated trees. An understanding of this diversity is imperative to development of *C. indicum* as a large-scale crop and to conserve and manage the species in wild populations.

Variation in kernel size (Photo: USC)

Conservation of genetic resources (including threats and needs)

Suggested conservation measures are: (1) maintain natural stands of the species; (2) propagate elite trees with both sexual and asexual techniques to increase the germplasm collection; and (3) capture a greater range of traits, such as growth, yield and disease resistance. Seed from *C. indicum* is recalcitrant, becoming non-viable when stored for short periods and prone to germinate at maturity. Asexual propagation techniques, such as tissue culture, cuttings and/or grafting, are desirable to produce trees that avoid the variability of seedlings and produce uniform cultivars that maintain the required characteristics.

Authors: Bruce Randall, David Walton, Tio Nevenimo, Matthew Poienou, John Moxon, Godfrey Hannet and Helen Wallace

Casuarina equisetifolia

Family: Casuarinaceae
Botanical name: *Casuarina equisetifolia* L.Johnson. Two subspecies are recognised: subsp. *equisetifolia* in *Amoen. Acad*. 4: 143 (1759); and subsp. *incana* (Benth.) L.A.S.Johnson in *J. Adelaide Bot. Gard*. 6: 79 (1982).

The genus name is derived from the Malay *kasuari*, and alludes to the similarity between the drooping foliage of the genus and the plumage of the cassowary bird. The specific epithet is derived from the Latin *equinus*, pertaining to horses, and *folium*, a leaf, alluding to the similarity of the cladodes to horse hair; also the Latin *incanus*, hoary or white, in reference to the hairy new shoots.
Common names: *Casuarina equisetifolia* is known by many common names which reflect the wide distribution and planting of the species: coast sheoak (Australia); *pau-ferro* (Brazil); *mumahuang* (China); *mvinje*/sea pine/whistling pine (East Africa); *nokonoko* (Fiji); casuarina (India); *cemara/tjemara* (Indonesia); *mokumao/ogasawara-matsu* (Japan); *ru/ru laut* (Malaysia); *tin-yu* (Myanmar); *agoho* (Philippines); *yar* (PNG); *filao* (Senegal; Mauritius); horse-tail sheoak (South Africa); *kasa ghas*, swamp sheoak (Sri Lanka); *son thale* (Thailand); *toa* (Tonga); Australian pine (USA); and *philao* (Vietnam).

Summary of attributes and why diversity matters

Casuarina equisetifolia is a nitrogen-fixing tree of considerable social, economic and environmental importance in many tropical areas of the world. It is widely planted for reclamation of unstable coastal ecosystems in the tropics and subtropics. It is salt tolerant and can grow on sands, so is especially useful for erosion control and windbreaks along coastlines and estuaries. The wood has many uses but is renowned as a fuel. It is a truly multipurpose species, providing a range of products and services for industrial and local end uses.

International provenance trials have revealed considerable genetic diversity in *C. equisetifolia* from different regions including in morphology, stem form and age to first flowering. Screening of a wide range of provenances and selection of those best suited to the site and proposed end use is recommended. For industrial applications, selection of particular provenances for fast growth, straight stems and pest and disease resistance is feasible.

Description

Habit subsp. *equisetifolia* small to large tree, 8–35 m tall and ≤1 m dbh; subsp. *incana* typically a large shrub or small tree 6–10 m tall; crowns finely branched; form in wild populations highly variable, from crooked low-branching trees on exposed seashores to straight-stemmed forest trees in more sheltered situations. ***Bark*** light grey-brown, smooth on small trunks, becoming

Young tree; Denis Island, the Seychelles (Photo: L. Thomson)

Female flowers and needle-like foliage (cladodes) (Photo: G. Carr)

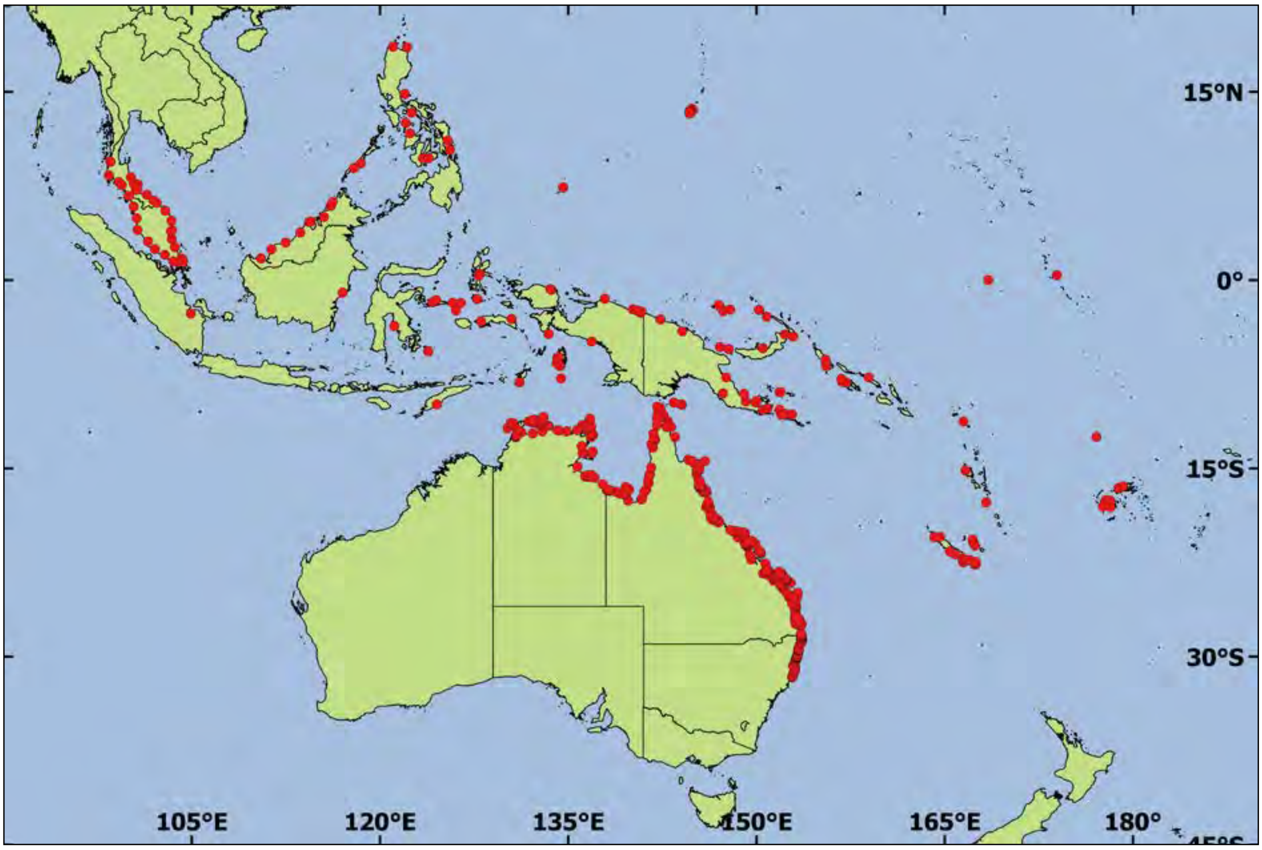
Fruit and male flowers (pale green catkins); 'Eua, Tonga (Photo: D. Bush)

rough and thickly furrowed on older trees; inner bark reddish and astringent. ***Cladodes*** drooping, needle-like, furrowed, 1 mm diameter, 20–38 cm long, angular to rounded in cross-section, glabrous or pubescent. ***Leaves*** reduced, minute, teeth-like, borne in whorls of 5–9/node. ***Inflorescences*** *male flowers* occur on simple terminal, elongated spikes, 7–40 mm long, and are arranged in whorls with 7–11.5 whorls/cm spike; *female flowers* are borne on lateral woody branches. ***Cones*** globose, 10–24 mm long, 9–13 mm wide, with acute bracteoles ± protruding from the surface of the cone; sparsely hairy (subsp. *equisetifolia*) or covered in fine, white or rusty hairs (subsp. *incana*). ***Seed*** cream to dull-brown winged samara, 6–8 mm long. ***Reproductive biology*** wind-pollinated, predominantly dioecious species, and considered outbreeding; however, monoecy does occur in this species from <10% to as high as 80% as observed on Guam.

Distribution

Casuarina equisetifolia subsp. *equisetifolia* occurs in beach or strandline forest from southern Thailand and Peninsular Malaysia, and eastwards to Sabah and Sarawak in Malaysia, the Philippines, Indonesia, northern Australia, Melanesia and Polynesia. In Australia, subsp. *incana* intergrades with subsp. *equisetifolia* on the Queensland coast between Sarina and Mackay, and extends southwards to near Port Macquarie, New South Wales. Subsp. *incana* also occurs in Vanuatu and New Caledonia.

Casuarina equisetifolia is the most widely introduced *Casuarina* species, including to >90 countries outside the species' natural range, and is now a common feature in the coastal landscape of most tropical countries, where



it is often naturalised. These include the Caribbean, Mexico, Central and South America, West and East Africa and elsewhere in Asia. Extensive plantations have been established in China, Cuba, India, Puerto Rico, Thailand, Vietnam, Kenya and many other countries in Africa.

Casuarina equisetifolia grows in hot humid to hot subhumid climates with 350–3,500 mm MAR and a dry season of 0–6 months. It is commonly confined to a narrow strip adjacent to sandy shores, rarely extending inland to lower hills (e.g. in Fiji). Soils are typically well drained and rather coarse textured, principally sands, ≥2 m in depth, often covering a more moisture-retentive layer of sandy loam. The species tolerates both calcareous and slightly alkaline soils (pH 5.0–9.5), salt spray and temporary inundation with sea water; however, it is intolerant of prolonged waterlogging. It has been successfully grown in dune sands, tin-mine spoils and sterile pumice.

Uses

Casuarina equisetifolia is a fast-growing, multipurpose species that is used in many products and other applications.

Wood—hard and heavy with an air-dry density of 900–1,000 kg/m^3. Rays are prominent on the radial surfaces of sawn timber. It is used for boatbuilding (e.g. in southern China) but is difficult to use for fine carpentry. Poles are popular as masts for fishing boats, piles, posts and tool handles. The wood is increasingly used to produce paper pulp, especially in India. It is highly regarded as a fuel and produces high-quality charcoal. The calorific value of the wood is 20.9 MJ/kg and that of charcoal exceeds 29.3 MJ/kg.

In India, fast-grown smallholder plantations of *C. equisetifolia*, managed on 4-year rotations, provide a valuable resource base for production of kraft pulp. For the Andhra Pradesh Paper Mills alone, some 80,000 ha of smallholder plantations are managed by >30,000 families. Grown in such conditions, the wood has a basic density of 550–570 kg/m^3 and some 3.8 green tonnes debarked wood will produce 1 tonne of kraft pulp.

Non-wood—the most common uses of *C. equisetifolia* are for environmental protection, such as sand-dune stabilisation, shelterbelts, land reclamation and erosion control. Thousands of kilometres in China, India and Vietnam have been planted with subsp. *equisetifolia* to stabilise the shifting sands. In Sarawak, the species is protected because of its importance in controlling coastal erosion. Many areas of natural occurrence are prone to tropical cyclones and the species' general tolerance to strong winds has encouraged its use in protective plantings. The 2004 tsunami that occurred on the southern coast of Thailand devastated large patches of coastal vegetation but *C. equisetifolia* trees growing on the beachfront withstood and survived the devastating waves. This protective function, along with high productivity and soil fertility–enhancing properties, has resulted in *C. equisetifolia* becoming a popular agroforestry species in coastal Vietnam and India.

Root extracts from *C. equisetifolia* are used for medical treatment of dysentery, diarrhoea and stomachache. The bark is widely harvested for traditional

Right: Beach protection and shelterbelt planting; southern China (Photo: CSIRO)

Below left: Windbreak protecting crops from salt spray; Houma, Tongatapu, Tonga (Photo: R.R. Thaman)

Below right: Firewood from *C. equisetifolia*; Tamil, Nadu, India (Photo: K. Pinyopusarerk)

Harvesting of bark for traditional medicines; Tongatapu, Tonga (Photo: L. Thomson)

medicinal uses throughout the South Pacific Islands. In Peninsular Malaysia, a decoction of the twigs is used for treating swelling and the powdered bark is used for treating pimples on the face. *Casuarina equisetifolia* bark contains 6–18% tannin and has been used extensively in Madagascar for tanning purposes.

Diversity and its importance

Results of extensive international provenance trials have been reported, which detailed substantial genetic variation among provenances and landraces, and evidence of a provenance × site (i.e. genotype × environment) interaction. This interaction, however, was not as great as might have been expected from the large number of diverse seed sources included in the trials. In general, much of the variation between provenances could be better explained by country- or region-of-provenance effects. This hypothesis was supported by the results of multivariate analyses of morphological characteristics of seedlings and adult material which showed a separation between natural provenances from South-East Asia and Australasia and the Pacific Islands.

In the international provenance trials, trees from natural provenances from South-East Asia and landraces from Asia were generally faster growing than those from Australasia and the Pacific Islands. There were differences in the branching habit among seed sources but, in general, individual trees produced many horizontally formed branches. This species' characteristic branching habit, together with fine needle-like branchlets, underscore its suitability for planting as windbreaks in coastal areas. Populations introduced to Asia and Africa appear to flower more intensively than those in the natural distribution range.

Variation in form in 1-year-old *C. equisetifolia* provenance trial—PNG provenance (L) and Thailand provenance (R); Coimbatore, Tamil Nadu, India (Photo: A. Nicodemus)

Conservation of genetic resources (including threats and needs)

There appears to be no specific conservation and management strategy developed for *C. equisetifolia*. Some of the locations in South-East Asia and elsewhere, where better performing provenance/seed sources occur, are continually threatened with agricultural and economic development. Without active conservation measures, many of these valuable genetic resources are being progressively lost. Breeding populations consisting of >100 individual families from a large subset of provenances and landraces used in international provenance trials have been established in China and India. These serve as ex situ reserves of genetic material, as does the large collection of >300 individual family seedlots that is safely stored at the CSIRO Australian Tree Seed Centre in Canberra, Australia.

Of a range of serious recorded diseases, the most important threat to *C. equisetifolia* is blister bark disease, which is caused by a hyphomycete fungus (*Subramanianospora vesiculosa*). Infected trees die rapidly after exhibiting symptoms of foliar wilt and cracking of the bark where blisters develop, enclosing a black powdery mass of spores. The disease was first reported in Orissa State, India, and is now throughout the country. It has also been reported in Indonesia, Mauritius, Sri Lanka, Thailand and Vietnam. Over 50 species of insects are known to feed on *C. equisetifolia*, but serious pest problems have not occurred. Prominent among the disadvantages of the species are that it: is fire sensitive; does not compete well with weeds; has poor coppicing ability; and has the potential to become a weed under certain conditions.

Authors: Khongsak Pinyopusarerk and Stephen Midgley

Cocos nucifera (with a focus on Oceania)

Family: Arecaceae
Botanical name: *Cocos nucifera* L. In *Species Plantarum* p. 1188 (1753).

The genus name is from the Portuguese word *macaco*, monkey, alluding to the three small holes on the coconut shell that 16th century Portuguese sailors thought resembled a monkey's face. The specific epithet is from the Latin *nux/nucis*, nut, and *fero*, I bare.

Cocos nucifera is diploid with 32 chromosomes ($2n = 32$) and is the sole species of the genus *Cocos*. Being monotypic, hybrid cultivars are generally a product of intraspecific crosses.

Common names: coconut, coconut palm (English); *cocotier* (French); *nu* (Cook Islands); *niu* (Fiji; PNG; Polynesia); *niyog* (Guam; Philippines); *nizok* (Mariana Islands); *ni* (Marshall Islands); *ha'ari* (Society Islands, French Polynesia)

Summary of attributes and why diversity matters

Coconut palms play a crucial role in the culture, environment, agriculture and tourism of the tropical Pacific Islands. The critical commercial and subsistence importance of the coconut palm means there is a great need to replant coconuts and to rehabilitate existing plantations that have deteriorated due to the decline in the copra trade.

Coconut varieties that have been passed down from generation to generation of Pacific Islanders are under threat from the globalisation of trade, cultural levelling, diseases and climate change. Due to fragility of insular ecosystems, the Pacific region is likely to be the location where losses are the most substantial and of the most socioeconomic importance due to the use of various coconut varieties as sources of food, fuel and other materials for low-income families.

Description

Habit erect tree-like palm ranging from dwarf forms to tall forms ≤30 m tall (see descriptions of different main types below). ***Bark*** smooth with prominent rings, greyish. ***Leaves*** pinnate fronds, typically ≤4 m in length, 1.2–1.8 m wide, bright green, clustered at top of trunk. ***Inflorescences*** bracts 45–90 cm long. ***Flowers*** monoecious, subsessile, in large axillary clusters, cream coloured. ***Fruit*** green, yellow or bronzy red when immature, brown when mature, large (to 30 cm long), subglobose to ellipsoid, with a thick fibrous husk surrounding a hard nut (endocarp) filled with a hard, white oily edible 'meat' or copra and, when young, with sweet water. ***Seed*** coherent with the endocarp; the female flower takes 10–12 months after pollination to mature as a viable seednut.

Traditional coconut varieties are classified in four main types:

Tall types represent 90–95% of all existing coconut palms. They are often simply called 'Talls'. They generally

Coconut plantation for production of copra; Shark Bay, Santo, Vanuatu (Photo: L. Thomson)

Coconut grove; Hawai'i, USA (Photo: J.B. Friday)

Fiji Tall variety; Suva, Fiji (Photo: L. Thomson)

Above left: The 'seven in one' coconut palms in Rarotonga, Cook Islands. One the most famous coconut palms in the South Pacific, with all seven palms reputed to have come from the same seednut planted in 1898 (Photo: R. Bourdeix)
Top right: Coconut plantation ('Fiji Tall' variety); Coral Coast, Viti Levu, Fiji (Photo: L. Thomson)
Bottom right: Coconut plantation; Hawai'i, USA (Photo: F. & K. Starr)

form quite heterogeneous cross-pollinating populations. Talls can grow at a rate of >50 cm annually when young and flower at 6–10 years with an economic life span of 60–70 years.

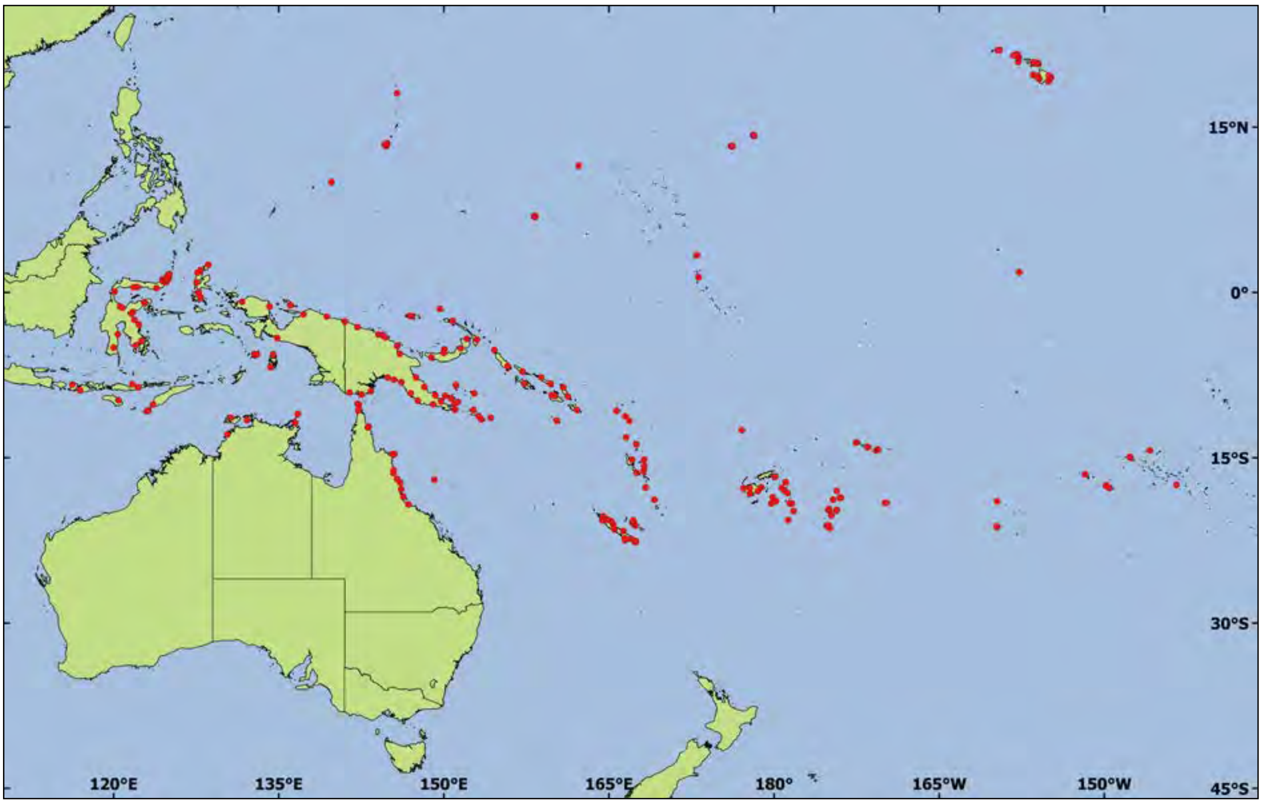
Preferentially Self-pollinating Dwarf types are often called 'Dwarfs', 'Fragile Dwarfs' or 'Malayan-type Dwarfs' (because the Malayan Red and Yellow Dwarfs are the most widely known cultivars of this type). They grow at a rate of 15–30 cm annually, have a productive life span of 30–40 years and usually start flowering 12–30 months after field planting. Apart from their usually short height, these varieties show a combination of common characteristics: autogamic preference, small size of organs, precocity and rapid emission of inflorescences. Because of the last two characteristics, they play an important role in genetic improvement programs.

Preferentially Cross-pollinating Compact Dwarf types are generally called simply 'Compact Dwarfs' or 'Niu Leka–type Dwarfs' (because the 'Niu Leka' Dwarf from Fiji is the most widely known cultivar of this type). This type of dwarf coconut is much rarer and mainly found in the Pacific region. Because of its very slow vertical growth and its thick stem being tolerant to cyclones, this form could play a crucial role in the future of coconut agriculture.

Semi-tall types include a few forms intermediate between Dwarfs and Talls, with variable reproduction modes. The most famous is the 'King Coconut' cultivar from Sri Lanka.

Distribution

The local names for coconut (*niu* in Polynesia and Melanesia, *niyog* in the Philippines and Guam) are derived from the Malay word *nyiur* or *nyior*. This is often cited as proof that the species originated in the Malay–Indonesian region. The coconut appears to have moved eastward towards the Pacific region and then further into the Americas. Towards the west, it moved to India and Madagascar. Evidence suggests that coconuts were spread by sea currents to many island groups. In addition, voyagers used to carry coconuts for food and drink; this enhanced the introduction of the crop to other destinations. By taking seednuts from one isolated island to another, early Pacific Islanders were able to reproduce and breed their own varieties in an empirical but stable manner.



Commercial production of coconuts occurs mainly on tropical coastal lowlands. However, the species can be cultivated up to an elevation of 1,200 m asl near the equator or ≤900 m at higher latitudes. Mean annual rainfall varies from (700–)1,200 to 2,300(–5,000) mm with a uniform or bimodal distribution and a dry season that can extend to 4 months. Growth and fruit production are reduced at the extremes. It prefers deep, fertile and well-drained soils of pH 5.5–6.5. It is self-pruning, highly resistant to wind damage and may tolerate some salinity but is intolerant of shade (as shade greatly diminishes or stops flowering/fruiting).

In the Pacific Islands, the coconut palm grows even in marginal coastal conditions, tolerating drought and poor soils. It is highly resilient, able to withstand severe tropical cyclones and flooding (of short duration). Small coral islets often continue to exist mainly because the palms' fibrous root systems prevent coastal erosion.

Uses

The coconut is popularly known as the 'Tree of Life' and all plant parts are useful. Coconut is an important livelihood and food security crop for >10 million farmers most of whom are smallholders, cultivating coconut palms worldwide on around 12 million ha. In 2014, FAO estimated the global production at 61.5 million tonnes, which equates to about 123 billion nuts/year, but this is thought to be a conservative figure.

Raising coconut seedlings in the nursery takes at least 6–12 months. The fruit has no dormancy, preventing storage of seednuts. The large size of the seednuts and the seedlings makes their transportation expensive, both for farmers (from seed gardens to their fields) and for genebanks (international movements of germplasm). Only about 65% of seednuts are generally selected as seedlings for field transfer. Planting densities generally

Roadside stall selling green coconuts for drinking; Tongatapu, Tonga (Photo: R.R. Thaman)

Above: Thatched coconut fronds being used for roofing insulation; Mangaia, Cook Islands (Photo: L. Thomson)

Right: Bottle of virgin coconut oil; Suva, Fiji (Photo: L. Thomson)

range between 80 and 300 trees/ha, depending on variety and cultural practices.

Wood—the trunk is used in house construction, fencing, animal pens, for other articles such as food containers, tools, walking sticks and, recently, for sawn timber cut in both portable and permanent timber mills.

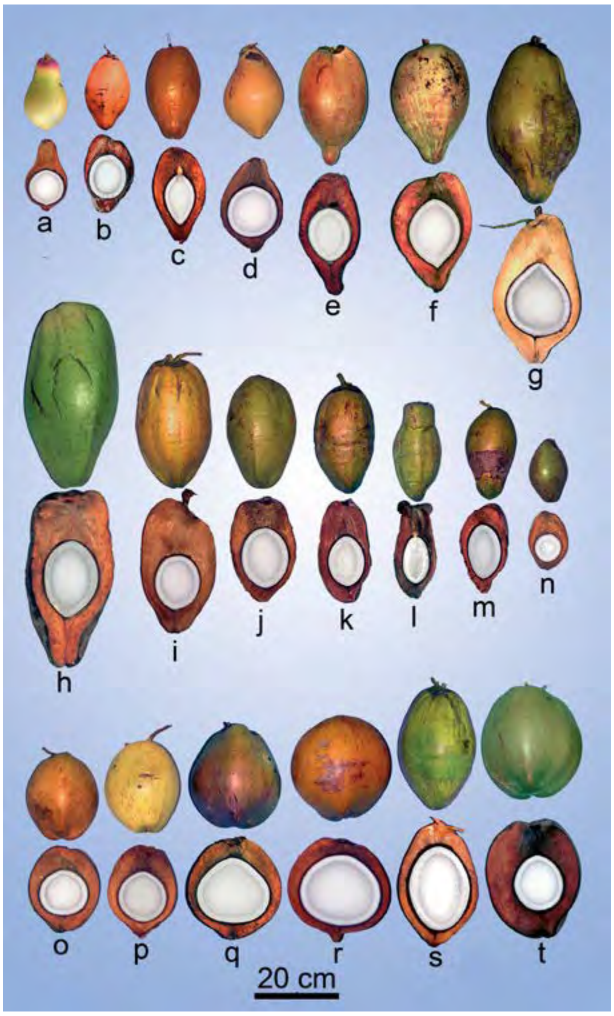
Non-wood—the leaves are used for thatched roofing and handicrafts; the sap from the spathe is processed into vinegar, wine and sugar; the husk is a source of fibre/coir for various uses; coconut shells can be burned into activated charcoal or carved as handicrafts and containers; the kernel is a source of oil, cream and desiccated coconut powder; and the water inside the nut used for beverage, wine and vinegar.

The market for coconut water is presently exploding. In 2016, coconut water had an annual turnover of about US$2 billion, but it is expected to reach US$4 billion within 5 years. In many countries, farmers are now cultivating dwarf-type coconut varieties for mass production of coconut water.

Diversity and its importance

Over millennia, humans have slowly selected and maintained numerous coconut varieties used for many purposes. It has resulted in an extraordinary morphological diversity which is expressed firstly by the range of colours, shapes and sizes of the fruit. Although the sequencing of coconut genome is now under investigation, the genetic structure of coconut germplasm is yet to be fully understood, which limits the exploitation of its diversity for genetic improvement.

In the Pacific region, coconut palms were first widely cultivated in the mid-1800s following an upsurge in European demand for oil and coir. From 1830 to 1930,



Variability in coconut fruit shape, colour and proportion of husk (Photo: R. Bourdeix)

Great phenotypic variation existing even in the very small atoll of Tetiaroa (only 12.8 km^2) in French Polynesia: (1 to 6) long-shaped fruit of traditional varieties selected for the use of husk/coir (or a varietal mix including these varieties); (7, 8, 9 and 11) fruit with thin husk and a nipple at the distal end; (10) small wider fruit; (12) young fruit said to be of the 'Oviri' variety (medicinal coconut); (13, 14) big rounded fruit without nipple; (15) fruit with nipple and a very thin husk; (16) horned coconut from Onetahi Motu (Photo: R. Bourdeix)

'Nui Afa' traditional variety—a very large, long nut selected for production of fibre or coir; Samoa (Photo: R. Bourdeix)

following the development of the international market for copra (dried kernel), the number of palms planted in the Pacific region increased by 80–100%. The varieties that had been carefully selected over thousands of years by Pacific Islanders have been diluted by the mass of coconut palms that were planted solely for copra production.

Conservation of genetic resources (including threats and needs)

Coconut germplasm is conserved and used daily by millions of small farmers. Initiatives have been launched to recognise this prominent role, and to sustain it by promoting new multifunctional landscape management approaches, such as the Polymotu concept.[1] For instance, in a project led by SPC and funded the Global Crop Diversity Trust, two small Samoan islands have been replanted for both conservation and ecotourism purposes with the famous traditional 'Niu Afa' variety, which produces the largest coconut fruit in the world. Factors impacting coconut in situ conservation include: constraints and advantages related to coconut biology; climate change; pests and diseases; links with ex situ conservation in institutional field genebanks; farmers' knowledge regarding the reproductive biology of their crop; socioeconomic dynamics; and legislative and policy measures. Despite the upturn in the global market, many coconut farmers remain insufficiently organised and poor and investments in coconut research remain scarce. Pests and diseases, such as the recent Guam biotype of the coconut rhinoceros beetle and lethal yellowing caused by phytoplasmas, are killing millions of coconut palms, ruining many farmers' livelihoods and eroding the precious genetic diversity of coconut varieties.

Authors: Roland Bourdeix and Pons Batugal

1 The Polymotu (many islands) concept uses the geographical isolation of special sites for conservation and reproduction of individual varieties of plants and animals, and dervives from previous initiatives in the conservation of coconut varieties by ancient Polynesians.

Corymbia citriodora

Family: Myrtaceae
Botanical name: *Corymbia citriodora* (Hook.) K.D.Hill and L.A.S.Johnson. In *Telopea* 6: 185–504 (1995), formerly known as *Eucalyptus citriodora*.

The genus name *Corymbia* is from the Latin *corymbium*, a corymb, referring to floral clusters where all flowers branch from the stem at different levels but ultimately terminate at about the same level. Two subspecies are recognised: *Corymbia citriodora* subsp. *citriodora*—Latin *citron* (lemon), *odorus* (having a smell); and *C. citriodora* subsp. *variegata*—Latin *variegatus* (variegated, referring to the bark). An additional subspecies is proposed: *C. citriodora* subsp. *henryi*, currently known as *C. henryi* (Blake) K.D.Hill and L.A.S.Johnson; the name honours Neil Henry, a forester who first recognised the species. Subsp. *henryi* is considered to be a 'genic' species with subsp. *variegata* based on nuclear microsatellite loci, where segregation of genes with large effects or selection might be the source of their phenotypic differences without a corresponding genomic differentiation.
Common names: subsp. *citriodora*—lemon-scented gum, lemon-scented iron gum; subsp. *variegata*—spotted gum, spotted iron gum; subsp. *henryi*—large-leaved spotted gum

Summary of attributes and why diversity matters

Corymbia citriodora occurs naturally in northern Australia from the seasonally dry tropics to subtropical areas. It is a widely adaptable, drought-tolerant species capable of reasonable growth rates in both summer and winter rainfall areas. It produces strong, hard and moderately durable wood suitable for fuelwood, charcoal, posts and poles, pulpwood, tool handles, sawn timber and general construction materials. It is also a useful source of non-wood products such as essential oil and honey. It is often planted along roadsides or in parks as an ornamental tree providing shade and shelter.

Provenance/family trials in Australia and elsewhere have reported provenance and individual family variation in growth rate, form, disease resistance and essential oil characteristics. Controlled crossings with a closely related species (*C. torelliana*) have produced hybrids that are vastly superior to the parental species in growth rates, disease resistance, insect and frost tolerance and ease of vegetative reproduction. Selection and breeding, therefore, can play important roles in the successful domestication of the species.

Description

Habit medium to large tree, 25–35 m tall but occasionally reaching 60 m tall and ≤1.2 m dbh, usually with straight trunks and of handsome appearance. ***Bark*** smooth to ground level, cream, pink or coppery, spotted in the south of its range grading to plain in the north. ***Leaves*** adult leaves (subsp. *citriodora* and subsp. *variegata*) concolorous, 8–16 cm long, 0.5–1.8 cm wide, with leaves of subsp. *citriodora* from the northern part of its distribution usually narrower than from southern areas; at all growth stages, subsp. *citriodora* leaves

Flowers (Photo: D. Kleinig)

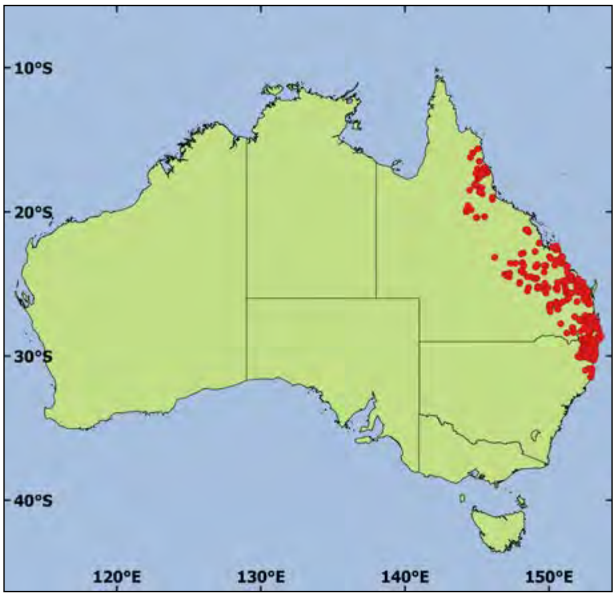
Sculptural trees in urban landscape; Carlton, Victoria, Australia (Photo: L. Thomson)

Bark (Photo: D. Lee)

have a citronellal (lemon) odour when crushed; adult leaves of subsp. *henryi* are larger, 11–28 × 2.2–4.5 cm. ***Inflorescences*** corymb, compound structures originating from the axils of the upper leaves. ***Buds and flowers*** opercula hemispherical-apiculate; subsp. *citriodora* buds 1.0 × 0.6 cm and flowers, seen June–November, creamy white; subsp. *variegata* buds 1.1 × 0.7 cm and flowers, seen March–November, white; subsp. *henryi* buds larger and creamy coloured, 1.3 × 0.8 cm and flowers, seen June and October–January, white. ***Fruit*** pedicellate, ovoid or urceolate, often warty, woody, 0.7–1.5 × 0.7–1.1 cm. ***Seed*** of all three taxa boat-shaped, non-winged and coloured reddish black.

Distribution

Together the three subspecies of *C. citriodora* cover a natural range in Australia from Cooktown in Queensland (latitude 15°30′S) to near Taree in New South Wales (31°46′S), a distance of about 2,000 km (north–south). Subsp. *citriodora* has a disjunct distribution in the northern part of its range (Cooktown to Mackay). In the southern half of its range, it has a fairly continuous distribution from Rockhampton to Maryborough and extends out past Springsure (400 km inland). Subsp. *variegata* overlaps with subsp. *citriodora* at the northern end of its distribution and mixed stands occur along the boundary between the two subspecies. It occurs from Maryborough west to Carnarvon Range



(400 km inland) down to near Taree in New South Wales. The distribution of subsp. *henryi* overlaps that of subsp. *variegata*, ranging from Brisbane, Queensland, to the Grafton region in New South Wales.

Corymbia citriodora has been extensively planted as an ornamental within and outside its natural range in Australia and in many other regions of the world. Places where it has been planted for commercial purposes include Africa, Asia (e.g. China, India and Sri Lanka), Oceania (e.g. Fiji) and South America (especially Brazil, where 6 million trees were planted).

The three subspecies occur across a large gradient of environmental conditions, from the dry tropics with 600 mm MAR and up to 6–8 months dry (<40 mm rainfall/month) through to 2,000 mm MAR in the subtropics with only 3–4 months dry. The species generally occurs on upper slopes of hills on skeletal soils (shallow, drought-prone soils that are nutrient poor), but also occurs on soils derived from basalt or metamorphic rock. It performs poorly in cold and frosty conditions.

Uses

Corymbia citriodora is a useful multipurpose, coppicing tree species producing wood and non-wood products like essential oil. Although not a species of outstanding growth rate, it gives acceptable growth on a wide variety of sites. It is moderately drought tolerant, resistant to fire damage, moderately resistant to cyclonic winds and generally not badly impacted by pests and diseases. Throughout its native range, it is an important timber species. In Queensland, over 80% of the timber processed in hardwood sawmills is known as spotted gum (= *C. citriodora*).

Wood—the heartwood is dark brown, hard, strong, easily worked, air-dry density c. 950–1,010 kg/m^3; the sapwood is white, susceptible to *Lyctus* borer attack. The

Above: Sawlogs of *C. citrodora* (Photo: J. Huth)

Left: Felling *C. citriodora* for timber production (Photo: J. Huth)

timber of *C. citriodora* in Australia is used for heavy construction, house framing, flooring and tool handles, while logs, following preservative treatment, are used as power poles. Plantations of subsp. *variegata* and hybrids with *C. torelliana* are grown for the same suite of solid wood products. In southern Africa, subsp. *henryi* is grown as a pulpwood species in areas too hot and dry for the current suite of commercial *Eucalyptus grandis* × *E. urophylla* hybrids, particularly in the northern KwaZulu Natal coast of South Africa and in Mozambique. In Brazil, hybrids between *C. torelliana* and subsp. *citriodora* are grown in Minas Gerais state for charcoal production for the steel industry.

Non-wood—subsp. *citriodora* is an important source of citronellal-rich (lemon-scented) essential oil, with China, India and Brazil being the main producers and where it can be grown profitably by smallholders. Other uses include honey production, shade and shelter, and as an ornamental tree along roadsides or in parks.

Diversity and its importance

In Australia, unimproved pure *C. citriodora* (all three subspecies) are slow starters with productivity in the order of 0.3–5.0 m^3/ha/year at 3 years of age. Growth accelerates as plantations mature, with MAIs at age 10 in the order of 2–15 m^3/ha (depending on site). The better *Corymbia* hybrid families are up to 200% more productive than *C. citriodora* on the same sites and capture the site more quickly, due to the denser, wider juvenile crown, thus reducing the need for additional weed control.

Domestication of *C. citriodora* is well underway, with the largest Australian program based in Queensland including all three subspecies (Australian Government Department of Agriculture and Water Resources and the University of the Sunshine Coast), with smaller domestication and breeding programs running in New South Wales (Forest Corporation of NSW). There are also domestication and breeding programs in Brazil (primarily subsp. *citriodora*), New Caledonia (subsp. *citriodora* only), South Africa (primarily subsp. *henryi*) and India (subsp. *citriodora*). In the Queensland program, moderate heritability for growth has been observed (narrow-sense open-pollinated heritability [h^2op] = 0.22) and moderate to high heritability (h^2op = 0.44–0.58) observed for resistance to *Quambalaria piterika*, a fungal disease challenging the species in Australia.

The pleasant, lemon-smelling foliar essential oil of subsp. *citriodora* is widely used in less expensive perfumes, soaps and disinfectants; it has antibacterial, antifungal and insecticidal activity. Oils are assessed on their odour characteristics and total aldehyde (citronellal) content, with a minimum of 70% aldehydes as a market requirement. At least four chemical forms of subsp. *citriodora* with citronellal contents ranging from 1–91% are recognised in the natural stands in Australia. The natural diversity of these chemotypes may, in part, account for the substantial variation in citronellal contents between oil batches from different regions of cultivation. In addition to provenance and family variation in citronellal content, there is substantial

Variation in leaves and fruit (Photo: D. Lee)

variation (0.5–5.0%, w/w, fresh weight) in oil concentration in leaves. These traits have been found to be highly heritable in other oil-producing species. There appears to be considerable scope for improving oil production in subsp. *citriodora* through selection and breeding for growth and oil characteristics.

In Queensland, a range of factors limiting development of *C. citriodora*—lack of mass flowering in seed orchards, susceptibility to *Quambalaria* shoot blight caused by *Q. piterika* and low amenability to vegetative propagation—have led to the testing and development of *Corymbia* hybrids (*C. torrelliana* [♀] × *C. citriodora* [♂]). Many hybrid families have significant advantages in terms of growth, disease, insect and frost tolerance, and can be vegetatively propagated. The *Corymbia* hybrids also exhibit broad environmental plasticity, allowing the best families and clones to be planted across a wider range of sites than *C. citriodora*, and resulting in more land being suitable for hardwood plantation development.

Conservation of genetic resources (including threats and needs)

Corymbia citriodora is a common species across its natural range and regular long-distance gene flow occurs. Around Brisbane and the Gold Coast, Queensland, some provenances of the species (subsp. *variegata* and subsp. *henryi*) are under threat from urban development. Across the rest of its range, it readily regenerates by seedling growth and coppice from lignotubers.

The broad genetic base in the domestication and breeding populations established in Queensland and New South Wales are at risk due to the current downturn in the hardwood plantation sector and subsequent refocusing of hardwood forestry on harvesting timber from native forests. There is a need to ensure ongoing investment in these genetic resources to facilitate development of the species both domestically and internationally.

Author: David Lee

Endospermum medullosum

Family: Euphorbiaceae
Botanical name: *Endospermum medullosum* L.S.Smith. In *Proc. Roy. Soc. Queensland* 58: 53 (1947).

The genus name is derived from 'endosperm' which is the seed tissue that surrounds the embryo and nourishes it during germination. The specific epithet derives from the Latin *medulla*, pith, and refers to the branchlets having pith.
Common names: whitewood (English); *siamena*, *jumkejuk*, *jurasan* (Indonesia); basswood (PNG); *a'asa*, *kakadikana* (Solomon Islands); *whitewud* (Vanuatu)

Summary of attributes and why diversity matters

Endospermum medullosum is a fast-growing, mid-density timber species with excellent forestry plantation and agroforestry potential in the South Pacific region. The timber is particularly useful for mouldings and the pale colour of the wood lends itself to a variety of coloured stains. The species occurs mainly in lowland, humid tropical climates of high rainfall and no pronounced dry season and is adapted to a wide range of soils.

In Vanuatu, the transition from harvesting endangered wild resources of *E. medullosum* to more sustainable plantations and woodlots is underway supported by a tree improvement program established in 1998 under the AusAID/CSIRO SPRIG project. First-generation trials subsequently converted to a seedling seed orchard showed significant provenance and individual family variation in growth, form and wood density traits among indigenous seedlots and useful levels of heritable variation in these traits. This seedling seed orchard is now the preferred seed source for plantation and woodlot establishment in Vanuatu and plays an important role in the ex situ conservation of the species. Second-generation progeny trials are now underway with the potential to produce even more highly improved seed in the future.

Description

Habit large tree (20–)30–40(–60) m tall with long, clear bole, sometimes with steep buttress, diameter (above buttress) typically 50–80 cm; distinctive crown, shallow, flat-topped with large horizontal branches in tiers. ***Bark*** light brownish grey, often appearing whitish from a distance, scaly at base and smooth above. ***Leaves*** simple/entire, large, 8–25(–33) cm long, 5.5–20(–25) cm wide, cordate or peltate, mid-dark green, subshiny with fine soft hairs above, light silvery green and densely hairy below, spirally arranged and bunched in clusters at branch ends; petiole thick, 3–12(–23) cm long, usually with 2 glands at the base. ***Inflorescences*** in axillary panicles, 10–19 cm long, with racemose branches to 4 cm long, covered in stellate hairs; bracts and bracteoles 1.5–2.0 mm long, triangular. ***Flowers*** dioecious (male and female flowers are borne on different trees); bisexual flowers are rarely present; flowers small and arranged in axillary spikes, greenish white behind the leaves, calyx indistinctly 4-lobed, petals absent; *male flowers* calyx c. 1.5 mm long, 5–7 stamens spirally arranged on an androphore c. 1.7 mm long, anthers 4-valved, fragrant; *female flowers* pedicels 3–4 mm long, calyx c. 1 mm long, ovary tomentose, 1-locular, stigma sessile, discoid, lobed, c. 1 mm wide. ***Fruit*** borne on the panicles, each a small, firm to fleshy, ovoid drupe, 8–9 mm long and 5–6(–7) mm wide; light greyish green, ripening light yellowish green and covered in fine hairs. ***Seed*** fruit does not split and encases a single black seed c. 6 × 4 mm.

Female flowers (Photo: J. Doran)

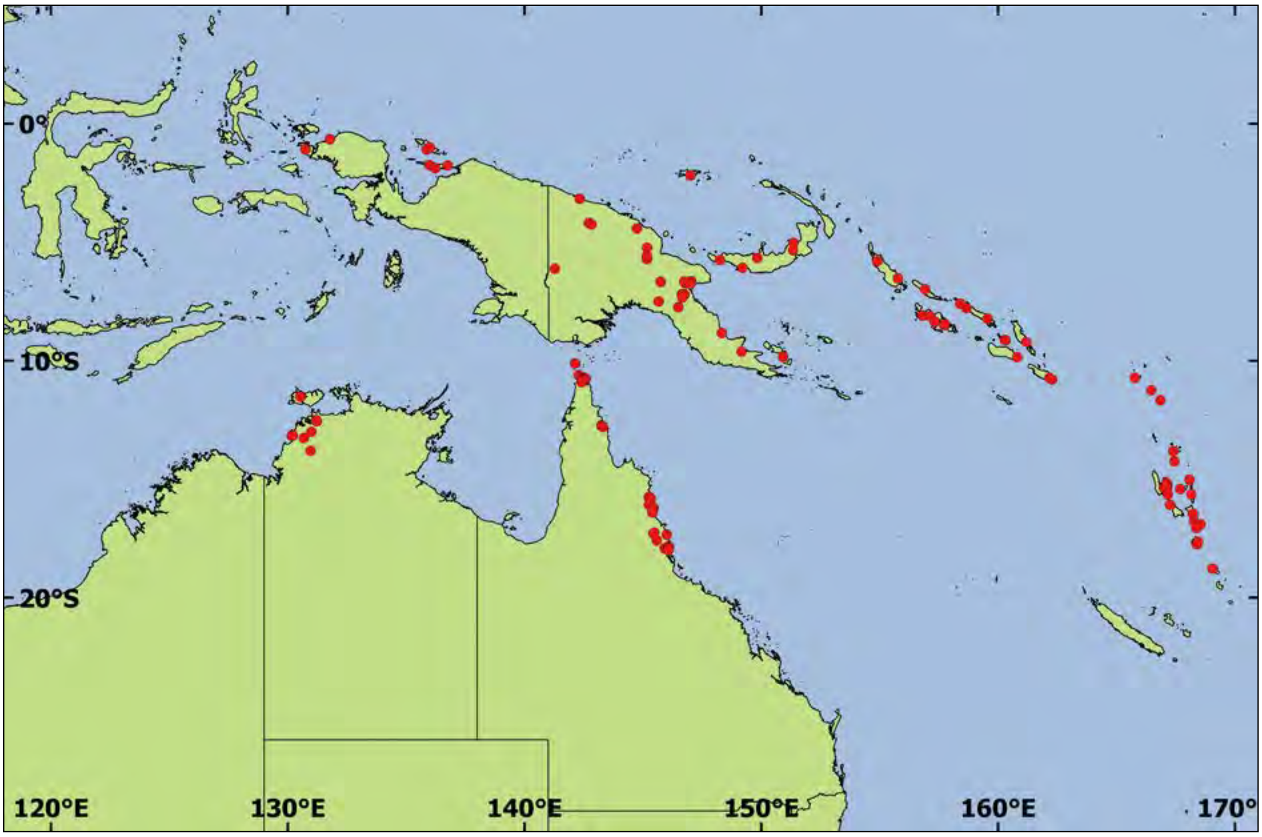

Fruit (Photo: J. Doran)

Mature tree; Sara, Espiritu Santo, Vanuatu (Photo: L. Thomson)

Distribution

Endospermum medullosum is distributed from the island of New Guinea (Indonesia and PNG), through Solomon Islands, including Santa Cruz Islands, to Vanuatu. In Indonesia, it is recorded from several islands on the northern-western coast of New Guinea, namely Salawati, Biak and Yapen islands and adjacent mainland. The species is widespread in PNG, including the Momase Region (West and East Sepik, Madang and Morobe provinces), Papua Region (Gulf, Northern and Milne Bay provinces), Bismark Archipelago (Manus and New Britain provinces) and Bougainville. The species is widespread in Solomon Islands. In Vanuatu, *E. medullosum* extends from the Banks Islands (Vanua Lava and Gaua) in the north throughout the archipelago, including Espiritu Santo, Malo, Malekula, Maewo, Pentecost, Ambrym, Ambae and Efate, south to Erromango. The species has a scattered, sparse distribution in northern Australia, from near the tip of Cape York and Iron Range (Claudie River) to Tully in northern Queensland and in the western portion of the Top End of the Northern Territory. The species has been infrequently planted in Fiji and Samoa.

This species is predominantly a pioneer species of lowland sites (near sea level to 350 m asl) in humid tropical climates of high rainfall (typically 2,500–4,500 mm MAR) with no pronounced dry season. It grows on a very wide range of soil types, including clays, gravelly alluvials, sandy clays, grey sandy loams of considerable depth and seasonally inundated soils. On



Espiritu Santo, the species grows on ferralitic cambisols comprising soils of good fertility formed over raised limestone.

Uses

Endospermum medullosum is a fast-growing, high-value native timber tree in parts of Melanesia. In Vanuatu, for example, where its silviculture, utilisation and genetic improvement are being intensively studied, it is highly suited to planting by farmers in small woodlots or agroforestry systems. A significant advantage offered by the species is resistance to windthrow during cyclones which is a frequent risk to successful plantation production in Vanuatu. The primary commercial product from *E. medullosum* is timber. It is capable of producing roundwood fence posts and building poles in 7 years, small sawlogs in 15 years and large veneer and saw logs in 25 years, under agroforestry and more broadscale plantation programs. Under suitable management, the species can produce useful products throughout the production cycle.

Wood—a light, low-strength, straw-white hardwood with an air-dry density of 400–450 kg/m^3 (12% moisture content). The timber is non-durable in ground but readily treatable with preservatives to prevent blue stain and attack from pinhole (ambrosia) borers. Its sapwood is susceptible to *Lyctus* borers and should be given an appropriate anti-*Lyctus* treatment before being sold. Recent research has shown that the heartwood can be penetrated with preservative using vacuum and pressure processes, enabling utilisation outdoors both in- and above-ground. The timber is easy to work and finishes well. It is used in Vanuatu for light construction, furniture, interior joinery works and has potential for veneer and plywood production. Defect-free (clear) boards have a ready market locally and for export (e.g. to Japan). In PNG, it is considered suitable for many purposes, including moulding, veneer, wide boards, lining, joinery, interior finish, match splints, matchboxes, shuttering, turnery, dowels, pattern-making, packing cases, furniture, cabinetwork, weatherboards, shingles and drawing boards. In Solomon Islands, the species is used for light construction, weatherboards and boom-logs. Community uses include firewood, canoe-making and carving. Young sawlogs (e.g. 15 years of age) taken as thinned stems exhibit growth stresses as bow in sawn cants. Control of blue stain by spray treatment with an appropriate antifungal compound is compulsory to prevent early staining of board surfaces, and kiln drying is recommended to prevent the same defect occurring within thick boards (e.g. 50 mm).

Non-wood—the bark and sap are used in PNG and Vanuatu for traditional medicines, including treatment

Sawn boards of *E. medullosum;* Espiritu Santo, Vanuatu (Photo: J. Doran)

of rheumatism and stomach-ache. The sap has a high starch content and has, therefore, potential to be used with wood waste to produce ethanol.

Diversity and its importance

In Vanuatu, transitioning from harvesting wild resources of *E. medullosum* to more sustainable plantations and woodlots is crucial for ensuring an ongoing supply of forest products. With the aims of increasing the economic value of the industry and thus increasing planting rates and conserving genetic resources, the Vanuatu Department of Forests (with support from the SPRIG project) commenced a tree improvement program for *E. medullosum* in 1998. The program started with the establishment of the first extensive provenance/progeny trials (seed from 110 (female) trees from 6 islands) on the eastern coast of Espiritu Santo. The results at 11.4 years (c. half rotation age) demonstrated considerable island- and family-level variation in dbh and form. Trees with the fastest growth and best form were from Espiritu Santo provenances. The results were broadly encouraging for capturing genetic gains from a recurrent selection and breeding program: growth, form and wood density narrow-sense heritability estimates were low to moderate, with useful amounts of phenotypic variation and no adverse genetic correlations. These trials have now been thinned on superior growth traits to form a contiguous, first-generation seedling seed orchard. This source is now preferred for plantation and woodlot establishment in Vanuatu and is highly recommended for wider use in the South Pacific. Second-generation seedling seed orchards have been established on Espiritu Santo that promise even greater genetic gains in the future.

The reproductive phenology and seed longevity in *E. medullosum* are biological factors that influence its breeding and rate of improvement. Flowering and seed set are highly influenced by climatic factors leading to sporadic seeding (with several consecutive seasons

Above: Provenance/progeny trial of *E. medullosum;* Shark Bay, Espiritu Santo, Vanuatu (Photo: J. Doran)

Left: Superior half-sibling progeny from Ambae individual in provenance/progeny trial, with Mesek Sethy; Shark Bay, Espiritu Santo, Vanuatu (Photo: L. Thomson)

potentially aborted due to cyclones) and its seed appears recalcitrant or short-lived orthodox with limited storage potential beyond a few weeks under controlled conditions (but seed may be longer lived in the field).

Conservation of genetic resources (including threats and needs)

Among other considerations, the conservation of genetic resources is vital for the ongoing genetic improvement of the species. In Vanuatu, *E. medullosum* is the most important native timber tree, but it has been exploited to the point of extinction of numerous native subpopulations for its valuable timber and conversion to other end uses, despite a formal conservation strategy being drafted over 10 years ago. It is imperative, therefore, that the remaining viable native populations be sustainably managed (in situ conservation), that steps be taken to bolster genetic diversity in threatened populations (e.g. through circa situm conservation plantings) and ex situ conservation strategies be implemented in addition to those taking place as part of the Vanuatu Department of Forests improvement program for *E. medullosum*.

One serious threat to the ability to propagate the species is the wasp larvae (*Syceurytoma* sp., family Eurytomidae) that causes substantial damage to developing seed crops. Seed crops need to be collected as soon as they are mature and cleaned of infected fruit by flotation immediately on collection. The species is also susceptible to a range of defoliators, leaf skeletonisers and fungal pathogens but the damage is generally not serious. Advantageous characteristics include the species' high resistance to brown root rot caused by *Phellinus noxius*, and its wind firmness and the ability of its crown to recover quickly after major cyclones that can remove leaves, lateral branches and even break tops, depending on severity.

Authors: Lex Thomson, Graeme Palmer, John Doran and Rexon Viranamangga

Eucalyptus camaldulensis

Family: Myrtaceae
Botanical name: *Eucalyptus camaldulensis* Dehnh. was originally described and published by F. Dehnhardt in *Cat. Plant. Hort. Camald.* 2nd edn (1832), based on a cultivated tree grown in a private botanical garden near Naples, Italy (L'Hortus Camalduli di Napoli/Type: Hortus Camaldulensis, Italy) and after which the species was named.

The genus name, *Eucalyptus*, is derived from two Greek words, *eu*, well, and *kalyptos*, covered, referring to the cap (operculum) that protects the flower before it opens. A taxonomic revision of *E. camaldulensis* by McDonald et al. (2009) divided the species into seven subspecies: subsp. *acuta* (Latin *acutus*, sharpened, referring to shape of the bud cap); subsp. *arida* (Latin *aridus*, arid, referring to its arid occurrence); subsp. *camaldulensis*; subsp. *minima* (Latin *minimus*, small, referring to the size of buds and fruit); subsp. *obtusa* (Latin *obtusus*, obtuse, referring to the blunt end of the bud cap); subsp. *refulgens* (Latin *refulgens*, reflecting light, referring to the shiny leaves); and subsp. *simulata* (Latin *simulatus*, resembling, referring to the buds which are indistinguishable from *E. tereticornis*). Each of these subspecies is clearly identifiable by both molecular genetics and key morphological features, including operculum shape, the arrangement of stamens in the bud and the reticulation density of adult leaves.

Common names: river red gum, Murray red gum (south-eastern Australia), river gum (Western Australia). Lesser used names include flooded gum, creek gum, forest gum and blue gum. Timber from natural stands is often referred to simply as red gum.

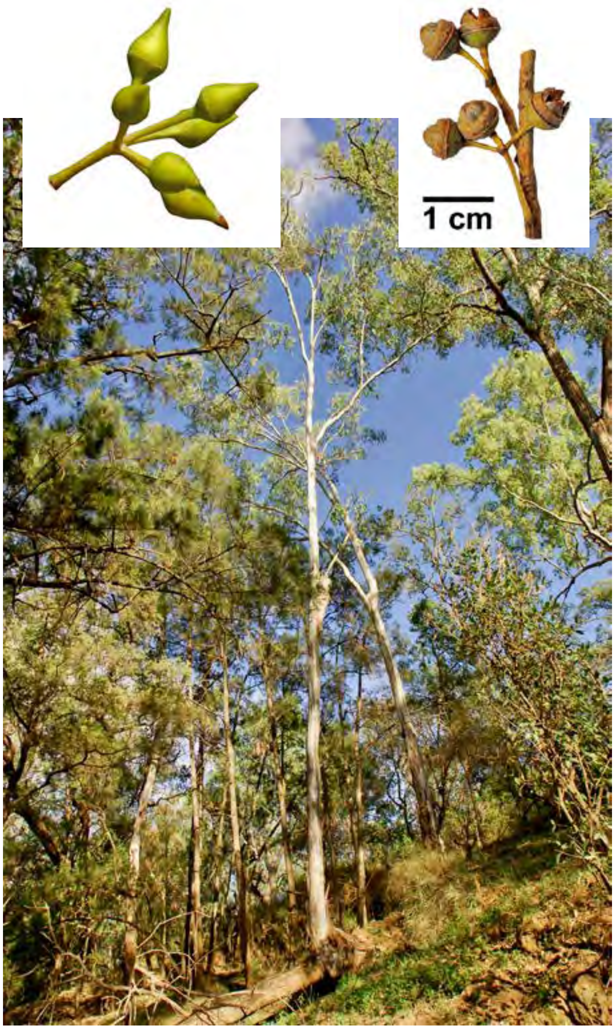
Summary of attributes and why diversity matters

Eucalyptus camaldulensis has the widest geographical range of any eucalypt in Australia; across its range, it encompasses substantial phenotypic and genetic variation with seven subspecies now recognised. It is one of the most widely cultivated eucalypts across a range of arid, temperate and tropical countries, with southern provenances generally better suited to temperate, Mediterranean-type climates and more northern provenances to subtropical and tropical climates.

Selection of both the most appropriate subspecies and the right provenance(s) within subspecies is of critical importance for success of the species in exotic planting environments. Selected subspecies and provenances can tolerate extreme drought, high temperatures, low temperatures and heavy frosts (down to –8 °C or so), saline soils and groundwater, and/or sodic soils. These tolerances combined with potential for rapid growth (≤45 m^3/ha/year or more in well-managed plantations), good coppicing ability and versatile wood and non-wood properties has led to wide success of selected subspecies and provenances, in pure form and/or as hybrid parents, in commercial and/or environmental plantings.

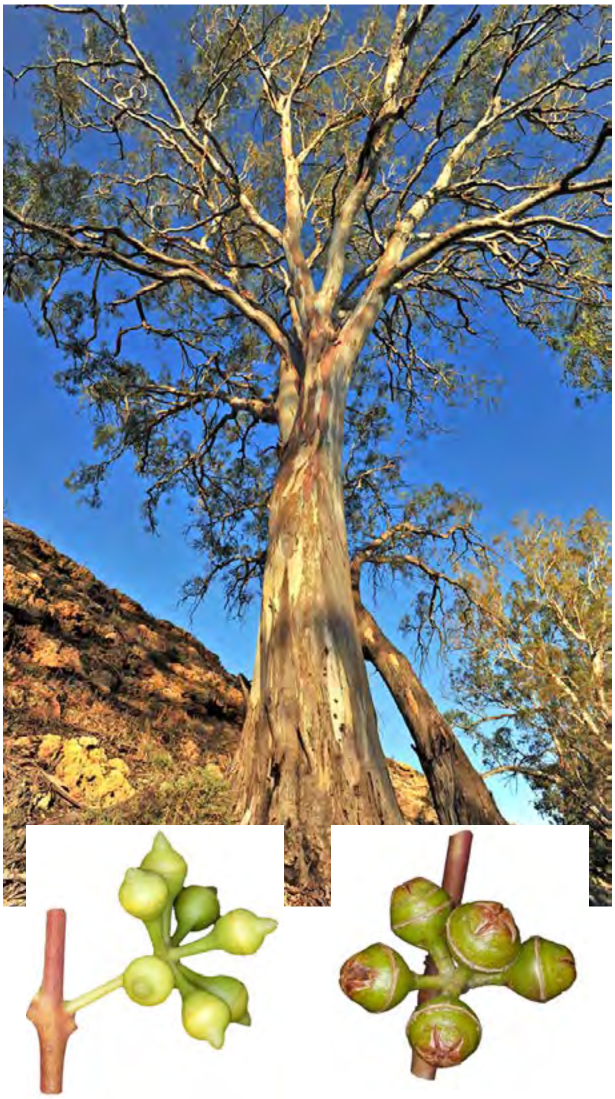
Description

Habit one of the most morphologically variable eucalypts across its range; habit varies from single-stemmed, 30–40 m tall forest trees to low spreading trees of ≤10 m tall in drier inland areas of Australia. Stem diameter (dbh) can reach ≥1–2 m. ***Bark*** smooth white, grey, yellow-green, grey-green or pinkish-grey, shedding in strips or irregular flakes; mature trees may sometimes

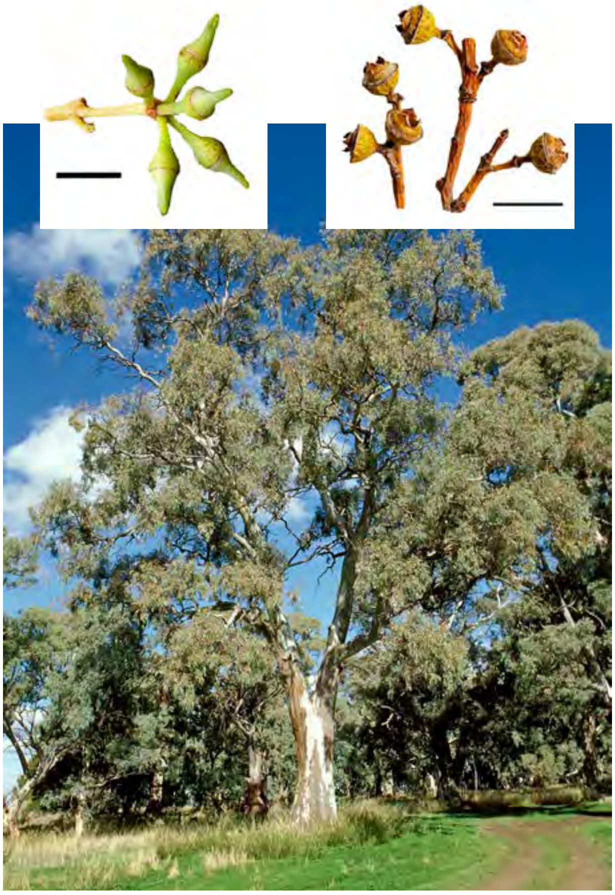


Subsp. *acuta*: mature tree—Deep Glen, northern Queensland, Australia; buds; fruit (Photos: M. McDonald)

Subsp. *arida*: mature tree—Gum Vale Gorge, north-western New South Wales, Australia; buds; fruit (Photos: M. McDonald)



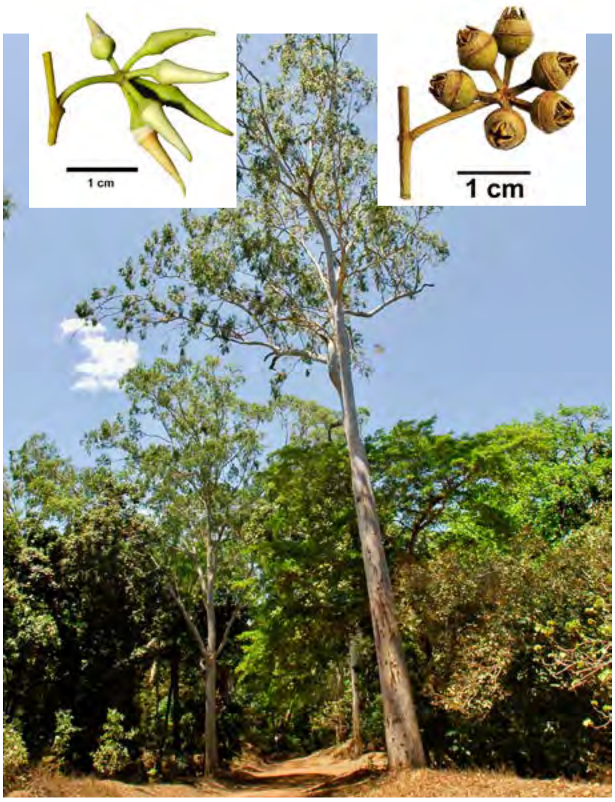
Subsp. *camaldulensis*: mature tree—Murray River, near Renmark, South Australia; buds; fruit (Photos: M. McDonald)



Subsp. *minima*: mature tree—Willochra Creek, South Australia; buds; fruit (Photos: M. McDonald)

have a rough, persistent stocking (1–2 m) of bark. ***Leaves*** adult leaves lanceolate to narrowly lanceolate, acuminate, lamina 8–30 cm long, 0.7–4.2 cm wide, green or grey-green, concolorous; petioles terete or channelled, 1.2–1.5 cm long. ***Inflorescences*** simple, axillary, 7–11(–13) flowered. ***Buds*** pedicellate; hypanthium hemispherical, 2–3 mm long, 3–6 mm wide; operculum globular-rostrate (typical), ovoid-conical (subsp. *obtusa*) or, in subsp. *simulata*, horn-shaped, 4–6(–13) mm long, 3–6 mm wide. ***Flowers*** white; peduncles slender, terete or quadrangular, 6–15 mm long; pedicels slender, 5–12 mm long. ***Fruit*** hemispherical or ovoid, 5–8 mm long and wide; disc broad, ascending; 3–5 exserted valves. ***Seed*** cuboid, yellow-brown (typical, double coated), with some sources mixed with black seed (single seed coat).

Subsp. *obtusa*: mature tree—Leichhardt River East, near Mt Isa, Queensland, Australia; buds; fruit (Photos: M. McDonald)



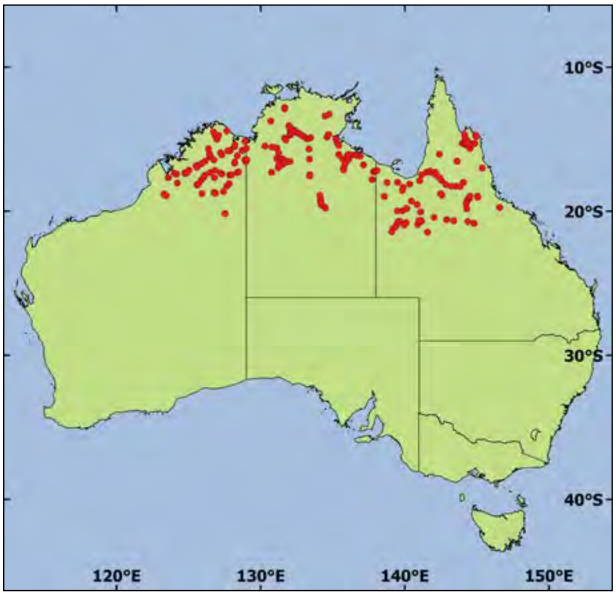
Subsp. *simulata*: mature tree—Normanby River, northern Queensland, Australia; buds; fruit (Photos: M. McDonald)

Subsp. *refulgens*: mature tree—Meeberri Station, Murchison district, central Western Australia; buds and fruit (Photos: M. McDonald)

Distribution

Eucalyptus camaldulensis is the most widely distributed Australian eucalypt species, occurring in all mainland states across an area of around 5 million km^2: subsp. *acuta* is widespread, extending from the Morehead River on Queensland's Cape York Peninsula south to northern-central New South Wales; subsp. *arida* has a large, highly fragmented range across the inland of Australia from central-western Queensland and north-western New South Wales, across central Northern Territory, northern South Australia and the central deserts of Western Australia to as far south-west as the Murchison region; subsp. *camaldulensis* occurs on most tributaries of the Murray–Darling River system through Victoria and New South Wales to the Condamine River in south-eastern Queensland. It is also common in the south-east of South Australia, with outliers on Yorke Peninsula, Kangaroo Island and Eyre Peninsula; subsp. *minima* is endemic to

South Australia, occurring in the Flinders Ranges and adjacent areas; subsp. *obtusa* occurs across the northern part of Australia from the Kimberley region of Western Australia, across tropical Northern Territory to the Gulf and Einasleigh regions of north-western Queensland; subsp. *refulgens* is endemic to Western Australia and occurs along rivers and creeks in the Pilbara, Gascoyne and Murchison regions; subsp. *simulata* is endemic to northern Queensland with sporadic occurrences in central Cape York Peninsula and two disjunct populations further south in northern Queensland.



Note: this map shows only the natural distribution of *E. camaldulensis* subsp. *obtusa* and subsp. *simulata*

The distributions of subspecies are not mutually exclusive—there are areas were subspecies co-occur and/or intergrade. Where subspecies intergrade, trees can have highly variable bud shapes, ranging from those of both putative parents as well a range of intermediate types. Reported co-occurrences include: subsp. *arida* with subsp. *minima* on Yunta Creek, north-east of Peterborough in South Australia; subsp. *minima* with subsp. *camaldulensis* on the Broughton River, South Australia; subsp. *arida* with subsp. *camaldulensis* in western New South Wales and also to the south and south-east of Charleville, Queensland; subsp. *acuta* with subsp. *simulata* on Cape York Peninsula, Queensland; subsp. *acuta* and subsp. *camaldulensis* intergradation near Morven, Queensland; and subsp. *acuta* and subsp. *obtusa* intergradation in northern Queensland.

Some *E. camaldulensis* subspecies are also known to intergrade with and into other species. Extensive intergradation between subsp. *arida* and *E. rudis* occurs in Western Australia, extending from the Moore River near Mogumber to the Irwin River, near Dongara. Other natural putative hybrids involving *E. camaldulensis* that have been recorded include subsp. *obtusa* with *E. alba*, *E. bigalerita* and *E. tintinnans* in northern Australia, and subsp. *camaldulensis* with *E. blakelyi*, *E. chloroclada*, *E. dealbata*, *E. largiflorens*, *E. melliodora*, *E. ovata*, *E. porosa, E. rubida, E. tereticornis* and *E. viminalis* in southern Australia.

Globally, *E. camaldulensis* is one of the most widely used tree species for planting in arid and semi-arid lands. Extensive commercial plantations have also been established in somewhat higher rainfall tropical regions, mainly in South-East Asia, China, India, Mexico and Brazil. In at least China, India and Thailand, the species is of major economic importance to commercial eucalypt growers as both a pure species and as a parent of hybrid taxa.

Over its range, climatic parameters vary substantially: climatic indicators for northern provenances (latitude 24°S or lower) are MAR 400–2,500 mm, summer incidence, dry season of 2–8 months, MAT 18–29 °C; climatic indicators for southern provenances (>24°S) are MAR 400–2,000 mm, winter/uniform incidence, dry season of 0–7 months, MAT 10–25 °C. Despite its extensive natural distribution, *E. camaldulensis* generally occupies a relatively narrow ecological niche, being mainly confined to watercourses and flood plains. In limited locations, it extends to slopes at higher elevations, such as in the Mt Lofty Ranges near Adelaide, South Australia, and away from watercourses in south-western Victoria. Its altitudinal range is 20–700 m asl. It occurs mainly on sandy and alluvial soils (northern provenances) or heavy clays (southern provenances) and most subspecies and provenances are not well adapted to calcareous soils. This species is moderately salt tolerant, and tolerant of mild frosts and waterlogging, but levels of tolerance vary widely between provenances.

Uses

Eucalyptus camaldulensis is a fast-growing (producing up to 45 m^3 wood/ha/year or more in well-managed plantations), coppicing hardwood species with versatile wood and non-wood properties. This has led to wide success of selected subspecies and provenances in pure form and/or as hybrid parents in commercial and/or environmental plantings across a range of arid, temperate and tropical countries.

Wood—the heartwood can have an attractive red colour and figure, with a fine texture and often interlocked wavy grain. Slow-grown timber from natural stands is hard, dense (c. 700 kg/m^3 basic density), durable, resistant to termites, and has many uses. Correctly handled, such timber is useful for speciality and outdoor furniture, construction timber, roundwood, veneers, fuelwood and more.

Wood densities of plantation-grown *E. camaldulensis* are somewhat lower (c. 530–700 kg/m^3 basic density) and vary with age, subspecies and provenance of origin, and plantation environment but do not appear to be closely associated with rate of growth. Plantation-grown wood from pure *E. camaldulensis* and/or hybrids of the species is used for poles, posts, firewood, charcoal, pulp production, fibreboard, sawn timber and production of veneers for use in utility-grade plywood. Plantation-grown timber generally requires preservation treatment for durability in the ground.

Non-wood—*E. camaldulensis* is also widely planted for shade, shelter and amenity purposes. Owing to its tolerance of poor soils, drought and high temperatures, it is often used in mine site rehabilitation in Australia. Due to its moderate tolerance of saline conditions, it is sometimes planted for rehabilitation of salt-affected agricultural lands; soil salinities of about 5 dS/m are associated with reduced tree growth and reduced survival occurs above about 10 dS/m. It is intolerant of brackish, waterlogged conditions.

Natural and planted stands of the species can provide sources of nectar for honey production and some tropical provenances (e.g. Petford, Queensland, provenance of subsp. *acuta*—previously recognised as subsp. *obtusa*) are able to yield 1,8-cineole-rich medicinal leaf oils.

Furniture made from wood of *E. camaldulensis*; Thailand (Photo: CSIRO)

Diversity and its importance

The natural range of *E. camaldulensis* encompasses considerable phenotypic and genetic variation between subspecies, provenances within subspecies and families within provenances for growth rate, stem form, wood properties, tolerance of salinity and alkalinity, drought tolerance, frost and cold tolerance, insect and leaf fungal disease susceptibility, leaf oil content and polyphenol composition. Even across limited geographical areas, considerable provenance variation can exist—trials in Thailand found a significant negative trend from west to east for volume growth between provenances of subsp. *acuta* from within the Petford region; those from western extremes grew more vigorously than those from the east.

While selected *E. camaldulensis* genetic material can exhibit notable tolerances for various environmental and biological stressors, such tolerances, adaptive traits and growth vigour are not ubiquitous throughout the species, nor are such traits and tolerances mutually exclusive. Many selection and breeding programs with this species have provided substantial genetic gains, and crossbreeding between subspecies and/or provenances might enable tolerance and trait combinations to be developed that are not found in the natural range.

Better performing tropical provenances of subsp. *acuta* (e.g. Petford) and subsp. *obtusa* (e.g. Katherine, Northern Territory) have been some of the more sought-after sources of the species for breeding programs in the seasonally dry tropics. Some Petford seedlots have a reputation for superior growth, higher density wood and higher yields of charcoal and/or pulp than many alternative provenances. However, material from such provenances of subsp. *acuta*, despite meeting early success in plantations in Thailand during the 1980s and 1990s, later proved increasingly susceptible to a range of leaf and shoot blight pathogens, such as *Cryptosporiopsis eucalypti*. Thai breeding programs soon identified subsp. *simulata* (and *E. tereticornis*) as being somewhat more resistant to leaf and shoot blights, and subsequently shifted their emphasis to such material as well as to development of *E. camaldulensis* hybrids.

For plantation environments with Mediterranean-type climates, provenances of subsp. *camaldulensis* from southern temperate Australia, particularly from areas of north-western Victoria, such as terminal wetlands of the Wimmera River (e.g. Lake Hindmarsh and Lake Albacutya), are known to perform well.

When tolerance of somewhat saline soils and/or groundwater is important, De Grey River in Western

Variation in performance between half-sibling families; Terai region, Nepal (Photo: L. Thomson)

Above: Variation in intermediate leaf morphology and salt tolerance; Whiteheads Creek field trial, Victoria, Australia (Photo: L. Thomson)

Left: Poor performance of local landrace (R) compared with northern Australian source (L), with Prof. Lê Đình Khá; northern Vietnam (Photo: CSIRO)

Australia (subsp. *refulgens*) is one of best northern provenances while Lake Albacutya (subsp. *camaldulensis*) along with Silverton and Wiluna (subsp. *arida*) are among the best southern provenances. On soils with a high pH, provenances from De Grey River (subsp. *refulgens*) and Fitzroy River (subsp. *obtusa*) have proven outstanding in Pakistan, while Silverton and Wiluna River provenances (subsp. *arida*) have performed well in more temperate environments.

Manipulated hybrids of various *E. camaldulensis* subspecies with at least *E. grandis*, *E. globulus* and *E. urophylla* have been developed in Australia, South Africa, Brazil, Thailand, India, China and possibly elsewhere. Such hybrids are often created to extend the economically viable range for eucalypt plantations to 'marginal' areas, including hot and dry environments, sites with saline soils and/or groundwaters, or to environments affected by heavy winter frost and cold. Various subspecies have found favour as hybrid parents on account of traits they can impart to progeny, particularly vegetative propagation ability and drought tolerance. In China, *E. camaldulensis* subsp. *obtusa* and subsp. *simulata* are valued as parents of commercial hybrid varieties on account of the typhoon tolerance they can impart to their hybrid progeny.

Conservation of genetic resources (including threats and needs)

Eucalyptus camaldulensis's predilection for riparian habitats combined with its widespread native range have resulted in vast natural populations still in existence. Much of its habitat is in remote, semi-arid to arid areas of little interest for intensive agriculture or other development. Thus, the species as a whole and each of the seven subspecies, while not yet formally assessed, are likely to fit within the IUCN conservation status category of Least Concern.

In Victoria and New South Wales, however, some populations of subsp. *camaldulensis* are considered to be in decline or locally threatened. Seed of the species germinates readily after floods and, for many populations of subsp. *camaldulensis*, occasional spring floods are required to foster regeneration and survival. In parts of the Murray–Darling Basin, such floods are now rare as river regulation for irrigation has long disrupted water flows. Such disruption of riparian hydrology in combination with livestock grazing pressures has led to significant reduction in natural regeneration. As a consequence, some populations are now dominated by stressed mature and overmature trees with a dearth of poles and sapling regeneration, including Lake Albacutya and various other populations in Victoria's Wimmera region and large stands in the Macquarie Marshes in the central-north of New South Wales.

Outside the Murray–Darling Basin, populations of subsp. *camaldulensis* in the east-flowing Hunter River catchment in New South Wales are also considered Endangered due to flood mitigation changing riparian hydrology and preventing periodic habitat inundation. In parts of north-eastern New South Wales, Queensland and north-eastern South Australia, ongoing extraction of artesian water from the Great Artesian Basin, mainly for stock, has played a continuing role in the decline of some artesian springs and subsequent decline of some spring-dependent populations. At least four subspecies—*camaldulensis*, *acuta*, *arida* and *obtusa*—are likely represented across such communities.

It has been recognised since around the early 1980s that managing water more effectively would ensure the maintenance of many riparian *E. camaldulensis* habitats. Such water management would include allowing controlled flooding of forests in suitable seasons.

Authors: Roger J. Arnold and Jianzhong Luo

Eucalyptus cloeziana

Family: Myrtaceae
Botanical name: *Eucalyptus cloeziana* F.Muell. In *Fragm*. 11: 44 (1878).

The specific epithet honours F.S. Cloez (1817–1883), French analytical chemist interested in eucalypt oils. This species is the only member of the *Eucalyptus* subgenus *Idiogenes*. Four ecotypes of *E. cloeziana* have been identified, but not formalised, based on variation in morphology, isozymes and DNA markers: northern coastal; northern inland; southern coastal; and southern inland.
Common names: Gympie messmate, messmate, dead finish

Summary of attributes and why diversity matters

Eucalyptus cloeziana is a fast-growing, coppicing hardwood species of warm humid to subhumid climatic zones. It grows best in acidic, deep, moderately fertile, freely drained soils in summer rainfall areas receiving >800 mm annually. This species tolerates a moderate dry season, fire and some frosts but may be damaged by high-intensity cyclonic winds. It has a reputation of being difficult to propagate from seed due to nursery pathogens, but this can be circumvented by proper management. On suitable sites, *E. cloeziana* is a premier species for timber and pole production.

Provenance trials within and outside Australia have demonstrated significant within and between provenance variation in growth rates, form and wood qualities. The Gympie (southern coastal) and Monto (southern inland) provenances generally rank best in terms of growth and survival on suitable planting sites for *E. cloeziana*. The introduction of a wide range of seedlots (provenances and families plus seed orchard seed from existing improvement programs) is recommended at the start of any new domestication program with this species.

Description

Habit variable in size and form across its range; near Gympie in the south, it can be a large tree of excellent form ≤55 m tall and ≤2 m dbh, while elsewhere it is usually a small to medium (10–35 m) tree of variable form depending on habitat. ***Bark*** near Gympie: rough on most or whole of the trunk and larger branches, soft, flaky, tessellated, light brown or yellow-brown; smooth, greyish-white or yellowish on the small branches; elsewhere, the extent to which the rough bark is retained varies with provenance. ***Leaves*** adult leaves alternate, petiolate, lanceolate to narrow lanceolate, 8–13 cm long, 1–3 cm wide, green, discolorous; those from the northern and western parts of the distribution generally narrower than from the southern coastal region around Gympie. ***Inflorescences*** compound and axillary with individual inflorescences 7 flowered. ***Flowers***

Buds and flower (Photo: Brooker & Kleinig © ANBG)

Mature tree in woodland habitat, northern inland ecotype; near Herberton, Queensland, Australia (Photo: J. Wrigley © ANBG)

Above: Well-formed young tree (pole stage), ex Lappa provenance (northern inland ecotype); Naitasiri province, Fiji (Photo: L. Thomson)

Top right: Fruit (Photo: I. Brooker)

Bottom right: Mature tree, southern inland ecotype; south of Mundubbera, Queensland, Australia (Photo: CSIRO)

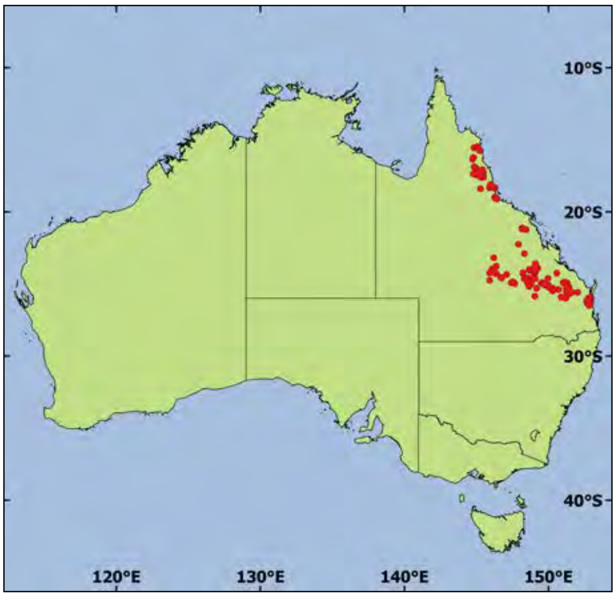
creamy-white, occurring November–April with peak flowering November–February. ***Buds*** ovoid to clavate, up to 1.0 × 0.6 cm; operculum hemispherical. ***Fruit*** shortly pedicellate, hemispherical to globose, 0.5–1.0 × 0.6–1.2 cm. ***Seed*** cuboid or elongated, yellow-brown, small.

Distribution

Eucalyptus cloeziana ranges along the eastern seaboard in Queensland of Australia from near Cooktown in the north (15°41′S) to Pomona (26°41′S) in the south. In the north of its distribution, it has discontinuous occurrences from Cooktown to Townsville and an altitudinal range from 40 m asl near the coast to 1,000 m asl on the Atherton Tableland, with an isolated occurrence at Eungella, west of Mackay. In the south, it is common around the Gympie region (the southern coastal ecotype). The southern inland ecotype has a fairly continuous distribution from Mundubbera to west of Tambo (550 km inland; west of Carnarvon Gorge).

It has been successfully introduced as a pole-producing species to several countries in southern Africa, principally in areas with 1,000–1,500 mm MAR and a dry season of 4–5 months. It also grows well in parts of Brazil, China, Congo, Fiji, Madagascar, Nigeria and Vietnam. In Australia, it has been grown in plantations in Queensland and northern New South Wales.

Eucalyptus cloeziana occurs across a large gradient of environmental conditions, from the dry tropics with 530 mm MAR and up to 6–8 months dry (<40 mm



average rainfall during a month) through to 2,100 mm MAR in the tropics and subtropics with only 3–4 months dry. There is also a large variation in MAT with a range of 18–24 °C. The species grows best on metasedimentary or volcanic-derived soils in the south and west of its distribution. It also occurs on infertile sandstone/granite–derived soils, but under these conditions it generally has poorer growth (e.g. grows to 10–15 m tall). The species is considered to have high cyclone resistance; however, susceptibility to intense cyclonic winds has inhibited its planting in some exposed coastal areas.

Uses

Eucalyptus cloeziana is a fast-growing, coppicing hardwood species grown mainly for its wood, as lumber or poles.

Wood—the pale, yellow-brown heartwood has an air-dry density of (490–)625(–730) kg/m³, if from plantations, or c. 1,000 kg/m³ from mature trees in native populations. The timber is heavy, strong and very tough, but is easy to dry. The strength, durability and termite resistance of the timber and its ease of sawing make it suitable for a wide range of uses. The sapwood is not susceptible to *Lyctus* borer attack. It is amenable to impregnation with preservatives, but the heartwood is extremely resistant.

The timber/logs of *E. cloeziana* harvested from native forests and plantations is used for framing, cladding, internal and external flooring, landscaping and retaining walls, as well as heavy construction and for marine pylons due to its resistance to marine borers. It is also one of the preferred species for transmission poles in Australia and in several countries in southern Africa (e.g. South Africa, Zambia and Zimbabwe). In Brazil, it is used for timber and charcoal production for the steel industry. It makes an excellent fuelwood but its density and colour make it only marginally suitable for paper pulp.

Non-wood—a modest source of both nectar and pollen for honey bees. Three chemotypes of *E. cloeziana* are known. The α-pinene and tasmanone chemotypes may have insecticidal and possibly therapeutic properties.

Eucalyptus cloeziana growing in timber plantation; north of Brisbane, Queensland, Australia (Photo: R. McGavin)

Eucalyptus cloeziana veneer billets ready for rotary peeling (Photo: R. McGavin)

Diversity and its importance

In Australia, unimproved pure *E. cloeziana* provenances are slow starters with productivity of better provenances in the order of 2.5–8.3 m³/ha/year at age 6 years in trials in southern Queensland. Growth of *E. cloeziana* accelerates as the plantation gets older, with MAIs at age 10 in the order of 2.7–10.3 m³/ha/year. Higher growth rates (e.g. >30 m³/ha/year) have been reported in trials outside Australia when well-adapted provenances are planted on high-potential forestry soils in a suitable climatic zone.

The Gympie (southern coastal) and Monto (southern inland) provenances generally rank well in terms

Bark, southern coastal ecotype; Queensland, Australia (Photo: D. Lee)

Bark, southern inland ecotype; Queensland, Australia (Photo: D. Lee)

of growth and survival, including in trials in Brazil, Pointe-Noire in the People's Republic of the Congo and northern Queensland. Studies in southern Queensland also support these findings, with these provenances performing best at age 11 years.

In Brazil, *E. cloeziana* is considered to be one of the most susceptible eucalypts to myrtle rust (also known as eucalyptus or guava rust) caused by *Puccinia psidii*. This has not been supported by studies in Australia, where the species has a similar overall susceptibility to the strain of myrtle rust now found in Australia as other eucalypt species tested. In glasshouse trials, approximately 50% of seedlings showed susceptibility to myrtle rust. There is, however, variation between provenances, with inland provenances displaying higher levels of resistance to myrtle rust than coastal provenances.

Domestication of *E. cloeziana* is well underway, with the largest Australian program based in Queensland including all four ecotypes of the species (Department of Agriculture and Fisheries) with a smaller domestication and breeding program running in New South Wales (Forest Corporation of NSW). Seed production has commenced, and seed could be collected from the seed orchards, if there is sufficient demand.

Conservation of genetic resources (including threats and needs)

Eucalyptus cloeziana is a common species across its natural range from Cooktown to Gympie. It readily regenerates by seedling growth and coppice from lignotubers and the species is considered as 'of Least Concern' for conservation of wild populations.

The broad genetic base in the domestication and breeding populations established in Queensland and New South Wales are at risk due to the current downturn in the hardwood plantation sector and subsequent refocusing of hardwood forestry on harvesting timber from native forests. There is a need to ensure ongoing investment in these genetic resources to facilitate development of the species both domestically and internationally.

This species is not considered amenable to propagation as rooted cuttings, so deployment is via seed. Many nurseries have problems growing *E. cloeziana* seedlings due to damping off diseases. This can be managed by growing the seedlings under light shade (e.g. 25%) until they are 10–15 cm tall, watering seedlings sparingly and judicious use of fungicides.

Author: David Lee

Eucalyptus deglupta

Family: Myrtaceae
Botanical name: *Eucalyptus deglupta* Blume. In *Museum Botanicum Lugduno – Batavum* 1: 83 (1849).

The specific epithet is from the Latin *degluptere*, to peel, or peeling skin, referring to the way the bark peels from the trunk in coloured strips. *Eucalyptus deglupta* is one of only four eucalypt species that are not native to Australia, the others being *E. orophila, E. urophylla* and *E. wetarensis*.

Common names: The trade name (from PNG Pidgin English) for the species is kamarere. Other names used locally in Indonesia include *leda* (Indonesia generally), *aren* (Maluki Islands) and *galang* (Sulawesi); and in the Philippines *amamanit*, *bagras*, *banikag* and Mindanao gum. In recent times, the species has attracted worldwide interest from gardeners because of its colourful bark and has been called rainbow gum, rainbow eucalypt and painted gum.

Summary of attributes and why diversity matters

Eucalyptus deglupta is a fast-growing hardwood suitable for planting in the lowland humid tropics where many other species of eucalypt do not thrive. This species is useful for a range of wood and non-wood purposes. It has excellent form, is easy to propagate from cuttings and is relatively free of diseases. Disadvantages include poor coppicing ability, its requirement for fertile well-drained sites for optimum growth, and fire and cyclone susceptibility.

There is considerable diversity among trees from different regions in terms of morphology, stem form, wood properties and resistance to pests and diseases. Breeding programs have capitalised on selection for fast growth, more cylindrical and straighter stems, and higher and more uniform wood density in plantation-grown wood destined for pulping. Selection of particular provenances and hybridisation of these with other tropical eucalypts have improved resistance to foliar leaf spot diseases and stemborers.

Description

Habit massive tree, commonly 35–60 m tall, 0.5–2.0 m dbh, occasionally reaching 80 m tall and 3 m dbh. The bole is typically straight, cylindrical and self-pruning, often clear of branches for >75% of the total height. Buttressing to 3–4 m high is common on individuals growing on unstable soils. ***Bark*** gum-like, smooth, 3–8 mm thick, exfoliating in strips of varying shape and size, leaving a smooth, white to pale green surface which ages through light green, green, grey, pink, red and orange to a deep purple, all colours often being visible on different parts of the trunk simultaneously. ***Leaves*** adult leaves opposite to subopposite, rarely alternate, shortly petiolate, ovate to ovate-lanceolate or acuminate, thicker than juvenile leaves, 10–20 cm long, 6–10 cm wide, occasionally larger; green to dark green and shiny above, pale green and dull below; lateral veins visible, few, initially inclined about 60° to the midrib then curving to form the intramarginal vein; leaves in some Philippine populations have distinct, partially crenulated or wavy margins and in the higher elevations of eastern Mindanao there are populations with glaucous juvenile leaves; leaves and terminal branches held horizontally, terminal branchlets and twigs mainly square or flattened in cross-section, often with 4 longitudinal keels. ***Inflorescences*** terminal or axillary panicles 5–20 × 5–18 cm, umbels 5–7 flowered. ***Buds*** peduncles terete or slightly angular, 5–10 mm long; pedicels about 5 mm long; young buds small, green, with double opercula; developed buds pale green or cream, globular, apiculate, 2–4 × 2–5 mm, operculum hemispherical, apiculate and wider than long. ***Flowers*** with many white to pale yellow

Planted tree; Kolombangara, Solomon Islands (Photo: B. Clarke)

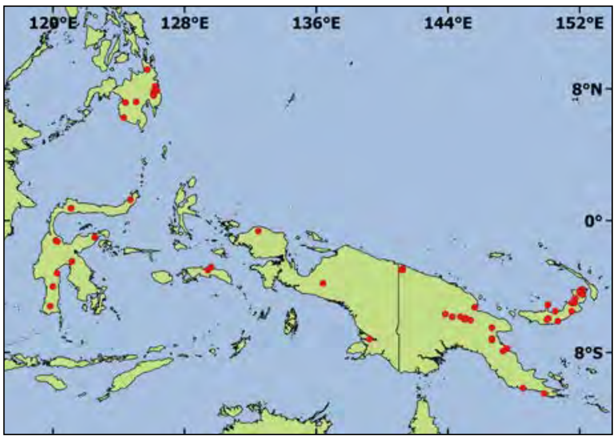
Above: Distinctive multicoloured bark on planted specimen; Espiritu Santo, Vanuatu (Photo: L. Thomson)

Right: Terminal flower heads and leaves; Hawai'i, USA (Photo: J.B. Friday)

or cream stamens, 2–10 mm long, strongly reflexed in the unopened bud, anther dehisces by separate slits. ***Fruit*** pedicellate, hemispherical, valves usually 4, thin, deltoid, commonly exserted to about 2 mm making the capsule appear globular, 3–5 × 3–5 mm, disc very narrow; mature fruit brown to dark brown with 3–12 well-formed seeds/valve. ***Seed*** minute (15,000–18,000/g, of which usually 2,000–4,000/g are viable), brown, flattened, with a small terminal wing.

Distribution

Eucalyptus deglupta occurs between tropical latitudes 9°N and 11°S in a markedly discontinuous distribution through eastern and southern Mindanao (Philippines), Sulawesi, northern coast of Seram Island, West Papua and Papua provinces (Indonesia) and several localities in



PNG, including West Sepik province, central highlands, eastern coastal lowlands of the mainland and most of the island of New Britain. The full altitudinal range is from sea level to 2,500 m asl.

Pre-1980, the best-developed stands occurred on riverine sites <150 m asl on the northern coast of East New Britain province, PNG, and near sea level in the Bislig Bay area of eastern Mindanao, the Philippines.

In addition to being planted in all three countries of its origin, *E. deglupta* has been planted as an exotic throughout the lowland humid tropics. Plantations have been established in the Pacific Islands (Fiji, Samoa, Solomon Islands) as well as Brazil, Cameroon, Costa Rica, Cuba, Honduras, Ivory Coast, Malaysia, Puerto Rico, Taiwan and other countries in Latin America, with minor plantings in Hawai'i (USA) and Bangladesh.

In PNG, *E. deglupta* comprises just over 40% of the total plantation area, or about 26,000 ha, located in three main industrial estates. In one location, the plantations have entered their third rotation. In Mindanao, about 13,600 ha were planted up to the 1990s, also including some areas in a third rotation. Most have been replaced by agricultural crops grown by squatters since the demise in 2007 of the company that owned the Mindanao plantations. *Eucalyptus deglupta* has been planted in about 14,000 ha of mainly mixed-species plantations on Kolombangara, Solomon Islands.

This species grows naturally in areas with 2,000–5,000 mm MAR with most commercial plantations found in 2,500–3,500 mm MAR zones. Monthly precipitation in these areas tends to be high and tending slightly to a summer maximum. Relative humidity is nearly always high at 70–80%. Altitudinal range is from sea level to 2,500 m asl. The best stands develop on river terraces and alluvial banks <150 m asl, on deep, moderately fertile sandy loams, but it also grows on volcanic ash and gravelly soils as well as on some limestone-derived soils (pH 6.0–7.5). This species is non-coppicing, fire intolerant and susceptible to cyclone damage.

Uses

Eucalyptus deglupta has been planted widely throughout the lowland humid tropics and is ranked among the world's fastest growing trees. It is renowned as a source of sulfate paper pulp grown in short rotations of 5–12 years but wood from natural stands and longer rotation plantations is also useful for a range of higher value purposes (see below).

Wood—the heartwood is reddish-brown and coarse ribbon-grained with good lustre. The sapwood is white to pale pink. The wood dries easily with little degrade and only moderate shrinkage (3.9% radial, 7.8% tangential). Of moderate strength, it saws and machines easily, except for some splitting on quarter-sawn faces, and polishes and glues well. Basic density is greater for old-growth natural forest trees (450–650 kg/m³) than for young plantation wood (350–400 kg/m³). The heartwood is resistant to *Lyctus* borers but is not termite resistant. The wood is not durable in contact with the ground unless treated with preservatives. Preservative treatment of old-growth wood is difficult, but it is relatively easy with young plantation wood. The wood is used for furniture (including veneer and plywood), joinery, mouldings, flooring, wood-based panels such as particle-board, hardboard and wood-wool board, both heavy and light construction, and boatbuilding. *Eucalyptus deglupta* is also used for firewood and charcoal. The wood makes a strong sulfate paper pulp that can be bleached to a high brightness.

Logs destined for furniture manufacture in Vietnam; Kolombangara, Solomon Islands (Photo: L. Thomson)

Buds and flowers, with honey bee foraging for nectar; Hawai'i, USA (Photo: J.B. Friday)

Non-wood—nectar from *E. deglupta* yields a good-quality honey. It also provides a measure of stream-bank stabilisation in areas prone to flooding. Because of its attractive bark, the species is frequently planted as an ornamental and as a shade tree, including shade for coffee in Costa Rica.

Diversity and its importance

Results of early provenance testing showed the best performing provenances to be from the northern coast of New Britain and from south-east of Bislig Bay, Mindanao. There is considerable variation among regions in morphology, stem form, wood properties and resistance to pests and diseases. Indonesian provenances have not been sufficiently tested against Philippine and PNG provenances.

In the immediate future, the importance of *E. deglupta* lies in capturing its fast growth, excellent form, ease of propagation by cuttings and almost complete freedom from the leaf spot diseases that afflict most other eucalypts when grown in the lowland humid tropics, by developing hybrid combinations with such species as *E. urophylla*, *E. wetarensis* (tolerance of a more diverse range of site quality, higher wood density and some disease tolerance) and New Guinea sources of *E. pellita* (syn. *E. biterranea*) (higher wood density, good disease tolerance). *Eucalyptus deglupta* × *E. pellita* was initially very successful in Mindanao, where the best hybrids were clonally propagated using cuttings.

Conservation of genetic resources (including threats and needs)

In New Britain, Mindanao and elsewhere, some of the best provenance locations are continually being cleared as a result of both legal and illegal harvesting and agricultural development. Security forces burnt the forests around Lake Paniai in West Papua in the early 2000s, severely impacting the relictual eucalypts. Without active conservation measures, valuable in situ genetic resources are being progressively lost.

Large seed stands (>150 ha) are reported to have been reserved in the 1990s in southern Sulawesi, where the species is native (in situ conservation). Localities included Porong, Sobang-Luwu, Tabo-Tabo, Pangkajeng, Salotuwa and Bantoparang. These stands were not provenance tested and their current fate is unknown and at high risk of local extinction. Plus trees were reported as being selected in plantations in Kalimantan and in natural forests at >50 locations in Indonesia (total >100 trees), also during the 1990s, but no current information on their status is available.

Elite trees from among a breeding population of 150 trees selected in PNG Keravat plantations for form and wood quality were held in a seedling seed stand at Geshes near Bulolo, PNG (along with a few grafted examples). Unfortunately, most have been lost to wildfires. Three progeny trials of this material in PNG were lost to fire before meaningful results could be achieved. Original plus tree records, survey books containing their locations at Keravat, seed orchard diagrams for Bulolo and early plot measurements were held in Port Moresby, but these were destroyed by a fire in the archives in the late 1990s.

Paper Industries Corporation of the Philippines (PICOP) started out with >200 plus trees selected in natural stands representing four different subprovenance areas in Mindanao. These were marcotted to form clonal seed orchards at Bislig Bay without formal progeny testing. With the demise of PICOP in 2007, these seed orchards have been overrun by squatters. Other advanced breeding materials, including hybrids of *E. deglupta* × *E. pellita* have also been lost.

The lessons from the almost 50 years of experiences with breeding *E. deglupta* in PNG and the Philippines are: in situ stands containing valuable genetic resources are continually at risk but that there may be even greater threats to economically valuable ex situ products of ongoing breeding programs, such as seed orchards, progeny trials, clone banks, hybrid trials and the like as well as vital associated records and documentation.

In Solomon Islands, an active breeding program in 2002–2007 resulted in the selection of 40 plus trees which were progeny tested and the trial culled to a seedling seed orchard with 20 families in 4 replications.

Seed collection being undertaken in grafted clonal seed orchard; Bulolo, PNG (Photo: D. Spencer)

The following populations are expected to provide useful base/breeding populations:

- Geshes Clonal Seed Orchard, Bulolo, PNG subline (seed is available from 9 ramets of 3 surviving clones)
- northern coast, East New Britain, PNG subline (new collections are required)
- northern coast, West New Britain, PNG subline (new collections are required)
- West Sepik, PNG subline (new collections are required)
- West Papua, Indonesia subline (new collections are required from surviving depleted stands in the two natural locations)
- Takalar Seedling Seed Orchard, South Sulawesi, Indonesia subline (present status needs to be determined, otherwise new collections are required)
- Kenangan Seedling Seed Orchard, East Kalimantan, Indonesia subline (present status needs to be determined, otherwise new collections are required)
- Mindanao, Philippines subline (new collections are required from natural stands surviving in New Bataan, Bislig, Monkayo and Pasian localities).

Authors: John Davidson, Brian Gunn and David Spencer

Eucalyptus pellita (including *E. biterranea*)

Family: Myrtaceae
Botanical name: *Eucalyptus pellita* F.Muell. In *Fragm*. 4: 159 (1864).

The specific epithet is from the Latin *pellitus*, covered with skin, probably referring to its leaves which Mueller described as thick and leathery. In a taxonomic revision, Hill and Johnson (2000) described the populations in New Guinea and Cape York, Queensland, Australia, as a separate species, *E. biterranea* (L.A.S.Johnson & K.D.Hill). This new species was distinguished from the more southerly *E. pellita* provenances in the vicinity of Cairns, Queensland, by their smaller buds, fruit and leaves. Foresters and tree breeders still refer to all the populations as *E. pellita*, and this review follows that practice.
Common names: red mahogany, large-fruited red mahogany

Summary of attributes and why diversity matters

Eucalyptus pellita is a fast-growing hardwood suitable for planting in the lowland humid/subhumid tropics. It is planted on a large scale in tropical South America and South-East Asia, primarily for pulpwood production on short rotations. It is easy to propagate by cuttings and displays better tolerance of economically significant eucalypt diseases than other tropical eucalypt species.

Within *E. pellita,* there are important genetic differences, recognised by taxonomists and supported by molecular genetic studies, between the more southerly provenances in the region near Cairns, Queensland, Australia, and the provenances further north in the Cape York region of Queensland and in southern New Guinea. The former have displayed better wind-firmness, while the latter have performed better under humid equatorial conditions. In addition to being planted as a pure species, it is important as a parent species in the development of interspecific hybrid combinations with other commercially important eucalypt species. These interspecific hybrids are widely planted as selected clones.

Description

Habit forest tree attaining a maximum height of 40 m; sometimes a multistemmed shrubby form (<10 m tall) occupies low-quality sites. ***Bark*** rough and persistent to the small branches, thick and brown to reddish-brown. ***Leaves*** adult leaves alternate, petiolate, 10–16 cm long, 2–4 cm wide, usually tapered to a long fine point and lanceolate; all leaf stages are green and discolorous, the adult leaves strongly so; juvenile and adult leaves held ± horizontally with the shiny adaxial surface uppermost; stomata are confined almost entirely to the abaxial surface. ***Inflorescences*** simple, axillary and usually 7 flowered. ***Buds*** hypanthium obconical, 0.9–2.1 × 0.6–1.2 cm; operculum variable,

Buds and flowers (Photo: © CANBR)

Fruit showing flat disc and exserted valves (Photo: Brooker & Kleinig © ANBG)

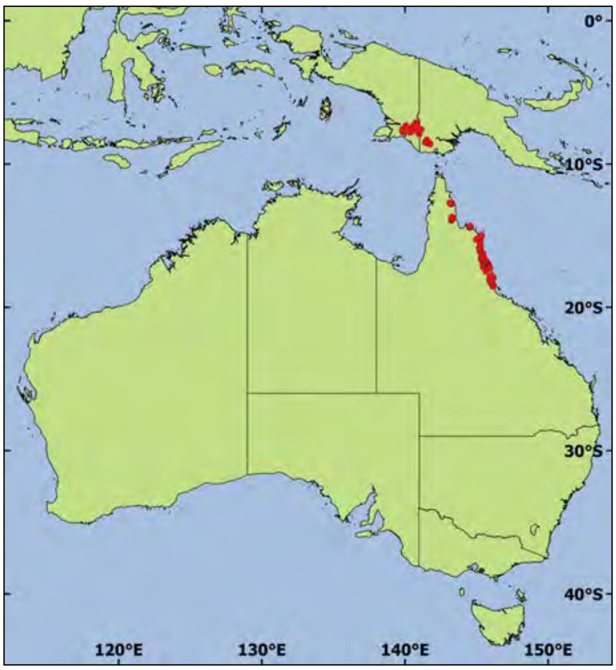
Two mature specimens from which the first botanical and seed collections outside Australia were made by CSIRO, and local research partners, in the 1980s: Keru, Western Province, PNG (left) (Photo: L. Thomson); and Muting, Merauke region, West Papua, Indonesia (right) (Photo: M. McDonald)

usually 1.0–1.5 times the hypanthium length. ***Flowers*** white. ***Fruit*** sessile or shortly pedunculated, hemispherical to obconical, 0.7–1.4 × 0.7–1.7 cm. ***Seed*** pyramidal and brown, with about 300 seed/g after cleaning. ***Reproductive phenology*** flowering period December–February with seed maturing by the following October–November.

Distribution

In Australia, the species occurs discontinuously in northern Queensland in scattered populations between latitudes 15°30′S and 18°30′S, from near sea level up to about 600 m asl, mostly within 50 km of the eastern coast. There is a major disjunction around latitudes 14–15°S, as the species does not occur in the dry Laura Basin. Small disjunct populations are found further north in Cape York around Lankelly Creek and Tozers Gap.

On the island of New Guinea, occurrences are restricted to the undulating Oriomo plateau and the heavily dissected Fly-Digoel Shelf. In the south of the range near Keru, PNG, it occurs in small populations at the margins between semi-deciduous rainforest and savannah woodland, where frequent fires prevent it from establishing. Further north, along the trans-Irian Highway in Papua province, Indonesia, it attains its maximum size, reaching heights of over 40 m with straight, clear boles. The northern and western boundaries of the species are not fully documented; it occurs at least to 7°21′S at Bupul, and west of Muting.



Since the 1970–1980s, when seed of Queensland provenances became more generally available, *E. pellita* (rather than the southerly *E. scias*, once named *E. pellita*) has been trialled in many countries in Asia, Africa, the Caribbean, the Americas and Oceania.

Eucalyptus pellita is a species of warm, humid climatic zones with a MAR in the range of 1,000–3,000 mm, with a distinct summer maximum, and a dry season range of 0–5 months. Altitudinal range is 0–800 m asl. It grows on a range of light to heavy textured soils of neutral to acidic pH and frequently occurs in a narrow band between rainforest and savannah woodland dominated by other eucalypt species.

Uses

Eucalyptus pellita is a fast-growing, coppicing species adapted to humid tropical environments with a dry season not exceeding 5 months. Under these conditions it has shown good pest and disease resistance, tolerance of low-fertility soils and is of moderate to good form. It is suitable for a range of wood products and honey production.

Wood—*E. pellita* is grown in plantations primarily for pulpwood. Young plantation-grown wood has been found to have very similar basic density and pulp yield to that of *E. urophylla*, making it generally acceptable for pulp production. There has also been interest in the production of logs for sawing and veneering. Wood quality evaluation and processing trials were conducted on 15-year-old logs from a northern Queensland plantation. Basic density was about 30% lower than that of mature native-forest timber and stiffness and strength were also substantially lower, being little greater than the levels previously reported for 8-year-old plantation wood.

Fifteen-year-old seed orchard of *E. pellita*; Binh Duong province, Vietnam (Photo: K. Pinyopusarerk)

Deck and railing constructed using *E. pellita* timber; Sarawak, Malaysia (Photo: R. Arnold)

Timber of *E. pellita* from natural stands in Queensland is rated as easily sawn and dried and, in the past, has been used for poles, sleepers, flooring, panelling and general construction, although most occurrences in natural forests are no longer available for harvest owing to land reservation for conservation. The heartwood is an attractive red-brown in colour, hence the species' common name of red mahogany. In PNG, logs from natural forests have been used on a small scale for bridge construction.

Non-wood—high-quality honey from the abundant, nectar-rich flowers is a commercial non-wood forest product provided by *E. pellita*.

Diversity and its importance

Eucalyptus pellita is one of nine eucalypt species in the subgenus *Symphyomyrtus* that dominate eucalypt forestry. The author estimated that these nine species and their interspecific hybrids account for over 90% of the global area of eucalypt plantations. Indonesia has about 0.3 million ha of *E. pellita* plantations, while Brazil, Cuba and Malaysia also have significant plantation estates. Commercial *E. pellita* plantations were established in northern Queensland in the early 2000s, but were destroyed by Tropical Cyclone Yasi in 2011.

Domestication of *E. pellita* is well advanced in Australia, Brazil, China, Indonesia and Vietnam. In Brazil, *E. pellita* has been found to exhibit superior tolerance of serious diseases that affect other tropical eucalypts, including *Cylindrocladium* leaf blight, *Puccina psidii* (myrtle or eucalypt rust) and the stem wilt *Ceratocystis fimbriata*. Consequently, *E. pellita* has become an important species in hybrid breeding, and development of multispecies interspecific hybrids incorporating *E. pellita* commenced in the 1990s. Clones of the natural hybrid between *E. pellita* and *E. brassiana* have been widely planted in Indonesia, while manipulated hybrids between *E. pellita* and *E. camaldulensis* and *E. pellita* and *E. grandis* are also planted. The manipulated interspecific hybrid *E. urophylla* × *E. pellita* has been produced in Vietnam, and selected clones are now planted commercially there. An early application of hybrid breeding involving *E. pellita* in the Philippines saw the

Above: Seed production stand; Tiwi Islands, Northern Territory, Australia (Photo: CSIRO)

Left: Variation in growth rate in provenance trial, with John Doran (L) and Sooalo Tito Alatimu (R); Falelima, Savai'i, Samoa (Photo: L. Thomson)

development of the hybrid combinations *E. deglupta* × *E. pellita* and *E. urophylla* × *E. pellita* via controlled pollination. *Eucalyptus pellita* has typically been used as the male parent in control-pollinated hybrid breeding, because pollen of other eucalypt species with smaller flower sizes often fails to grow down the long styles of *E. pellita* to reach the ovaries.

Isozyme studies of 17 natural provenances revealed a clear genetic division between the Cairns region provenances and the New Guinea and Cape York provenances, consistent with the taxonomic revision by Hill and Johnson (2000). They also found that some natural populations have high levels of inbreeding, with an outcrossing rate of only 46% for one population in Papua province. The high and variable rate of inbreeding and associated inbreeding depression of growth complicates the performance assessment of wild populations.

Significant provenance × environment interaction has been reported. In lowland equatorial environments, *E. pellita* provenances from New Guinea (PNG and Papua, Indonesia) have generally displayed better growth and survival than those from Queensland. However, Queensland provenances had faster early growth in high-elevation trials in Sumatra, Indonesia, while in coastal southern China they outgrew New Guinea provenances and were less damaged by typhoons.

Conservation of genetic resources (including threats and needs)

Eucalyptus pellita is relatively common in its natural range in northern Queensland, and this land base is protected in secure conservation reserves, notably the Wet Tropics World Heritage Area. In Western Province, PNG, and across the border in adjacent areas of Papua province, Indonesia, *E. pellita* occurs in remote areas with little major land development at present. Therefore, threats to these populations are currently not high, but this could change in the future as there is no security of conservation.

The natural populations in PNG and Indonesia are located in remote areas that are hard to access. Consequently, limited seed collections have been made from these provenances, and the genetic base populations available to most breeding programs from these sources comprise <100 unrelated families, which is an undesirably narrow base to support intensive and long-term breeding. In view of the globally important role of *E. pellita*, both as a plantation species in its own right and in hybrid breeding for tropical climates, it would be desirable to broaden the genetic base through additional collections spanning the New Guinea range. The genetic base of Queensland populations available to breeders has been broader, although future collections in the World Heritage Area could be problematic for commercial collectors.

Author: Chris Harwood

Eucalyptus urophylla (including *E. wetarensis* and *E. orophila*)

Family: Myrtaceae
Botanical name: *Eucalyptus urophylla* S.T.Blake. In *Austrobaileya* 1: 7 (1977).

The specific epithet is from the Greek *uro*, with an elongated appendage, and *phyllon*, a leaf, referring to the extended leaf 'drip' tip. Taxonomic analyses of the geographical range of *E. urophylla* by Pryor et al. (1995) resulted in the division of the complex into three species: *E. urophylla* S.T.Blake, *E. wetarensis* L.D.Pryor and *E. orophila* L.D.Pryor. For the purposes of this summary, the new taxa will be considered as synonymous with *E. urophylla*, as practised by most foresters and tree breeders working on this species complex.
Common names: Timor mountain gum (English); *airoo*, *ampupu* (Indonesia); *palavão preto popo* (Portuguese)

Summary of attributes and why diversity matters

Eucalyptus urophylla is among the most useful of tropical trees with its fast growth, good coppicing ability, adaptability to a range of tropical environments, ease of clonal propagation, relative resistance to fire, pests and diseases, and suitability for a variety of wood products.

This species is one of the most variable of all the eucalypts. It exhibits great variation between and within provenances in morphology, growth, stem form and disease resistance. Even though it is sometimes used as a pure species in plantation forestry, most often it is bred as a parent for the production of interspecific hybrids and for this reason is one of the most commercially important forest species in the world. It has a large flower and can be easily crossed with a host of other commercially important eucalypt species. One of its most important complementary traits in hybrid combinations is its good resistance to eucalypt canker, *Chrysoporthe cubensis*.

Description

Habit large forest tree 30–40(–50) m tall and 60–80(–200) cm dbh but also occurs as gnarled shrubs of only a few metres tall at high elevations; the bole is generally straight and cylindrical. ***Bark*** rough, subfibrous, red-brown but highly variable in retention from a short stocking (0–5 m) at low elevations to

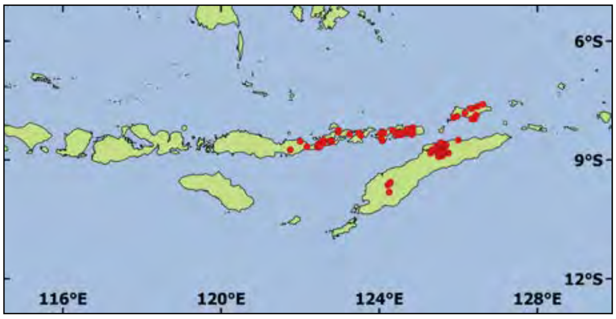
Multistemmed low tree growing on steep mountain side; Arnau, Wetar, eastern Indonesia (Photo: M. McDonald)

Left: Bud and flowers (Photo: V. Luangviriyasaeng)
Middle: Well-formed tree; Nuapin, West Timor, Indonesia (Photo: B. Dvorak)
Right: Bole of a large specimen; Wetar, Indonesia (Photo: CSIRO)

retained to the small branches at higher elevations. ***Leaves*** adult leaves subopposite to alternate, stalked, broad lanceolate, tapering to a narrow point, 12–20 cm long, 2.0–5.0 cm wide, moderately thin, discolorous. ***Inflorescences*** axillary 7–11(–13) flowered umbels; peduncles somewhat flattened, 1.0–2.0 cm long; pedicels angular, 0.4–1.0 cm long. ***Buds*** globular to ovoid, 0.5–1.4 × 0.5–1.0 cm, operculum rounded conical, slightly apiculate, the length about equal to the width. ***Flowers*** white. ***Fruit*** obconical or sometimes almost cupular, 0.6–1.4 × 0.8–1.8 cm, disc moderately wide, almost flat to obliquely depressed, valves 3–5 ± at rim level. ***Seed*** small, angular to ± semicircular, black. ***Reproductive phenology*** flowers present January–March; mature seed collected August–September.

Distribution

Eucalyptus urophylla is one of only four eucalypt species that is not native to Australia. It occurs from approximately 7°39′S to approximately 9°51′S in the Lesser Sunda Islands of Adonara, Alor, Flores, Lomblen (Lembata), Pantar, Wetar, and West Timor province in eastern Indonesia and Timor-Leste.



This species has been introduced to many countries in Africa, the Americas, the Caribbean, China, Oceania and South-East Asia. The largest planted areas of *E. urophylla* and its interspecific hybrids are in Brazil, southern China and Vietnam.

The natural range of *E. urophylla* is in humid and subhumid climatic zones. Annual rainfall varies from 600 to 2,500 mm but most often ranges between 850 and 1,300 mm MAR with a summer, monsoonal influence and a dry season of 4–6 months. The species most often occurs on well-drained, neutral to acidic (pH 6.0–7.0) soils (clays, podzols, volcanic soils) on the slopes of extinct volcanoes at altitudes of 500–2,000 m asl and also in moist valleys. However, populations of the species have been identified as low as 70 m asl on Wetar and as high as 2,960 m asl on the island of Timor.

Uses

Eucalyptus urophylla is a fast-growing, coppicing hardwood species suitable for the wet/dry tropics as a pure species or in hybrid combination with suitable species like *E. grandis*. Under favourable conditions, the species is capable of MAIs of 30–50 m³/ha/year after provenance selection. The species (or hybrids with it) is used for a variety of purposes in plantation forestry.

Wood—*E. urophylla* wood is used for framing and construction purposes on the islands where it naturally occurs. As an exotic, the wood is of moderate density (500–550 kg/m³) with above-average bark thickness at pulpwood rotation of 6 years. The heartwood has a pinkish- to reddish-brown colour. The wood is primarily used for pulp production, fuelwood and charcoal. Other uses include sawn timber, electrical transmission poles, durable posts and pilings, light and heavy construction, cabinetmaking, plywood particleboard, veneer and flooring.

Non-wood—it is useful in protecting river banks and providing shade and its nectar yields a honey with good properties.

Eucalyptus urophylla woodchip pile awaiting pulp production, Amapa Mill; northern Brazil (Photo: B. Dvorak)

Accelerated breeding orchards; Sappi Forests, coastal Republic of South Africa (Photo: B. Dvorak)

Above left: Natural stand of E. *urophylla*; Lasanisir, Wetar, Indonesia (Photo: B. Gunn)

Above right: Outstanding natural hybrid E. *urophylla* × *E. alba*; Samaru, Zaria, Nigeria (Photo: L. Thomson)

Left: Six-year-old Camcore provenance/progeny trial; Smurfit, Venezuela (Photo: B. Dvorak)

Diversity and its importance

Eucalyptus urophylla shows a wide range of variation in field trials around the world, possibly because of its large altitudinal range in Indonesia and Timor-Leste and the fact that progeny from collections in its natural range exhibit introgression with *E. alba*. In a series of 88 trials established with 38 provenances and 657 open-pollinated families in Colombia, Mexico, South Africa and Venezuela, provenance differences for volume ranged from 16% to 25%. The best provenances across all four countries were Mainang and Pintu Mas (Alor Island), Muda (Adonara Island) and Ile Meak (Flores Island). Unfortunately, the conservation status of all four of these lowland provenances ranges between Vulnerable and Endangered (see below). The high-elevation populations from Timor generally perform poorly relative to low-altitude sources from the other islands.

Because of its great natural variation, there is much opportunity to improve the quality of *E. urophylla* through traditional tree-breeding approaches. Intensive breeding programs exist for the species in tropical and subtropical Latin America, South-East Asia and southern Africa. Hybrid crosses with *E. urophylla* often exhibit heterosis and the species' future will be predominantly as a hybrid parent in combination with *E. grandis*, *E. pellita* and other eucalypts.

Conservation of genetic resources (including threats and needs)

A survey undertaken between 1996 and 2003, using the IUCN standards, of 62 natural populations of *E. urophylla* in its native range, indicated that the conservation status of 39% of the populations was classified as Least Concern, 24% as Vulnerable, 20% as Endangered and 5% as Critically Endangered. All populations on the islands of Flores, Lomblem (Lembata), Alor, Adonara and Pantar were under some risk, mainly from agricultural crop expansion. Populations identified as Least Concern all came from Wetar and West Timor. The Wetar provenances are protected because of their geographical isolation and by the fact that the human population pressure on the island is still minimal. However, mining activities on the island might change the conservation status of these populations in the future. The West Timor populations appear well conserved because most are within the boundaries of Mt Mutis Forest Park. No recent information is available on the conservation of *E. urophylla* populations in Timor-Leste.

There needs to be a coordinated effort by governments and the private sector to conserve selected provenances of *E. urophylla* ex situ that exhibit broad adaptability, good growth and disease resistance and are under high threat. Provenance results and molecular marker assessments can guide researchers in choice of seed sources to protect. Selection of some populations across all the islands to maintain broad adaptability with priority given to good performers seems to be the best overall conservation approach. One of the greatest challenges to ex situ conservation of *E. urophylla* is the fact that it naturally hybridises with *E. grandis* (and possibly other closely related eucalypt species) in some exotic environments. There is great difficulty, therefore, in maintaining species purity in conservation plantings.

A canker disease caused by *Chrysoporthe cubensis* (formerly *Cryphonectria cubensis*) is found on *E. urophylla* in West Africa and South America. Although some provenances are quite susceptible, especially in humid tropical lowland conditions without a marked dry season, the species generally is much more resistant than other tropical eucalypts. *Eucalyptus urophylla* is moderately susceptible to *Puccinia psidii* (eucalyptus, guava or myrtle rust).

Authors: Bill Dvorak, John Doran and Anto Rimbawanto

Falcataria moluccana

Family: Fabaceae
Botanical name: *Falcataria moluccana* (Miq.) Barneby & J.W.Grimes. In *Memoirs of the New York Botanical Garden* 74: 1–292 (1996).

The genus name is derived from *falcata*, sickle-like, referring to the shape of the leaflets, while the species name alludes to its occurrence—from the Moluccas (now known as the Maluku Islands). It was previously known as *Paraserianthes falcataria* (L.) I.C.Nielsen and *Albizia falcataria* (L.) Fosberg, both names still commonly used, as well as another nine superseded/lesser used names.
Common names: albizia (Pacific region and South-East Asia); peacock's plume (Hawai'i, USA); *sengon*, *jeunjing* (Indonesia); *batai* (Malaysia); Moluccan sau (Philippines); white albizia (PNG); *tamaligi* (Samoa)

Summary of attributes and why diversity matters

Falcataria moluccana is a rapidly growing species that naturally occurs in high rainfall, tropical environments from the Maluki Islands, Indonesia, through to Solomon Islands. It ranges from sea level to 2,300 m asl and exhibits rapid growth in diverse sites with high annual rainfall. It is mainly used for peeler veneer logs, sawn timber products, handicrafts and paper, but is also planted for shelter and fodder. It is widely planted in South-East Asia, including Java and Borneo, for its highly desirable pale-coloured timber, but has sometimes become an environmental weed in the Pacific region, including Fiji and Hawai'i.

Provenance/progeny trials have shown heritable variation in traits of economic significance, such as growth rate, branching, wood density, straightness and tolerance to pests and diseases. Intraspecific variation has been observed in the leaf rachis and associated characteristics, and seed pods to the extent that it was previously classified into three subspecies. Many natural populations consist of only a small number of trees.

Description

Habit large tree to ≥45 m with a large spreading, flat, sparse crown. ***Bark*** light grey with whitish blotches and warts. ***Leaves*** alternate, bipinnately compound, 20–40 cm long, with rusty pressed hairs and slender, angled axis, bearing gland above base; leaflets paired, 15–20 pairs/axis, sessile, small, oblong, 6–12 mm long, 3–5 mm wide, short-pointed at the tip, dull green and hairless above, paler with fine hairs below. ***Inflorescence*** large, paniculate racemes, 8–25 cm. ***Flowers*** axillary, bisexual, corolla 12 mm long, sessile, greenish-yellow to cream. ***Pods*** chartaceous, narrow and flat, 10–13 cm long, 2 cm wide, winged along ventral suture with many seeds. ***Seed*** olive-green, oblong, flat, 6.0–7.5 × 3–4 mm; the hard-coated seed remains viable for an extended period; seed of Solomon Islands origin is generally larger than seed of Indonesian (Java and New Guinea) origins.

Mature tree; Serui, West Papua, Indonesia (Photo: L. Baskorowati)

Buds and flower (Photo: L. Baskorowati)

Pods and bipinnate foliage (Photo: F. & K Starr)

Distribution

Falcataria moluccana is naturally distributed in the botanical regions of Papuasia (New Guinea, Bismarck Archipelago, PNG and Solomon Islands) and the east Malesia botanical region (Maluku Islands, Indonesia).

Introductions have been made throughout Asia, Africa and Oceania, and a few countries in the tropical Americas. Large plantation areas exist in Java, Indonesia, and on the island of Borneo.

Falcataria moluccana occurs naturally over a broad geographical region of latitude (3°N–11°S), longitude (125°E–163°E) and altitude (0–2,300 m asl). Annual rainfall ranges between 2,000 and 4,000 mm; optimal growth temperature is 22–29 °C with a maximum of 30–34 °C and a minimum of 20–24 °C. The species favours well-drained alluvial soils of high fertility, although it will survive on infertile sites and often thrives in sites of low fertility assisted by its nitrogen-fixing capacity.

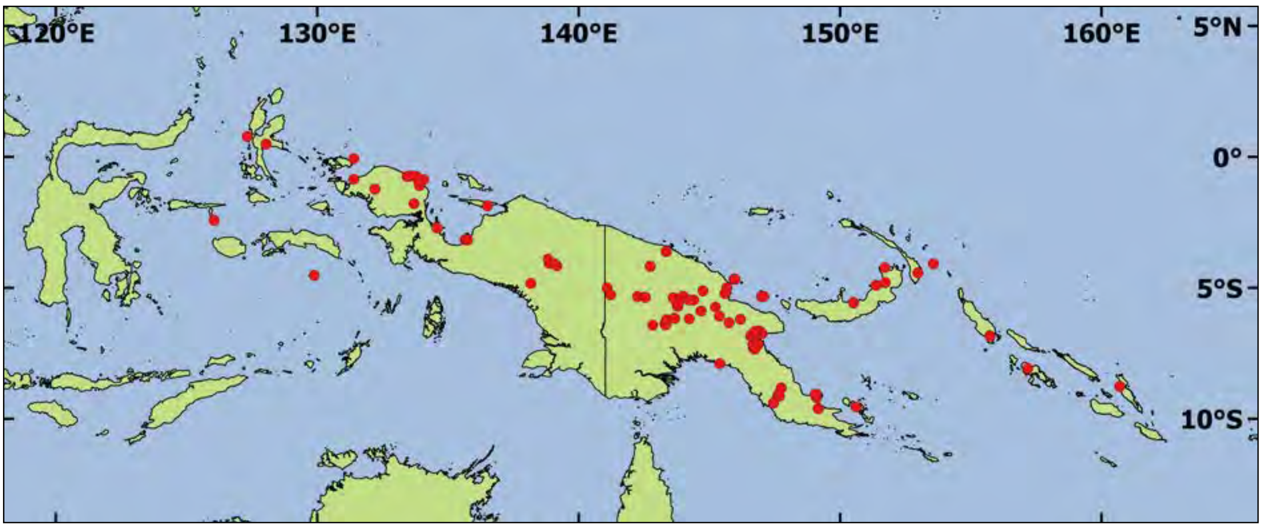
Uses

Falcataria moluccana is among the fastest growing trees in the world. On fertile sites in Borneo, the growth of superior provenance sources, such as Kolombangara, may be spectacular; for example, attaining 14.9 m tall, 13.1 cm dbh and MAI 44.9 m³/ha at 23 months of age. It is a pioneer species, sensitive to competition from grassy weeds, and requires a weed-free environment for the first 12–18 months for optimal growth. It will, however, persist with competition at the expense of diameter increment. In Fiji, it has a unique capacity to regenerate through *Merremia peltata* vine competition, which normally smothers other tree species. It is a highly susceptible to breakage and/or uprooting during cyclones, but may regenerate through vigorous coppicing.

Wood—*F. moluccana* is predominately planted for its timber. On the commercial scale, the best logs are used for rotary peeling and surplus either sawn for lightweight wood products and handicrafts, or chipped for paper manufacture. The white to pink, defect-free timber is highly sought after as face veneer and is the goal of most growers. It is used as fuelwood and charcoal despite its low specific gravity and calorific value.

Non-wood—it is also used for other purposes, such as to provide shelter and as a fodder crop. It was used for land rehabilitation for highly disturbed areas; however, the invasiveness of the species has seen this use curtailed in many places.

Double-hulled canoe made from *F. moluccana* wood; Hawai‘i, USA (Photo: J.B. Friday)



Diversity and its importance

Ivan Nielsen, in collaboration with other taxonomists, undertook a major review of the *Albizia/Paraserianthes/Falcataria* group. Nielsen (1992) separated the genus *Paraserianthes* into two sections, *Paraserianthes* and *Falcataria*, based on the structures of the inflorescence and pollen. He further segregated the *Falcataria* section into three subspecies, *falcataria*, *fulva* and *solomonensis*, based on differing leaf characteristics. Barneby and Grimes (1996) subsequently raised section *Falcataria* to genus level and did not recognise subspecific taxa.

The leaf variation observed by Nielsen (1992) can be broadly considered as geographical or provenance variation: (1) primary and secondary rainforest and also regrowth areas on sandy soils, altitude 0–1,600 m asl, in the Maluku Islands and the island of New Guinea; (2) primary and secondary montane rainforest and regrowth areas on peat soils as well as well-drained soils, altitude 1,250–2,300 m asl in the central montane part of New Guinea; and (3) lowland hills, primary and secondary forest, and ridge forest, altitude 0–600 m asl, in Solomon Islands, Bismarck Archipelago, Admiralty Islands and a few offshore islands north of PNG.

Many provenance trials were established during the mid-1980s in Java, representing over 50 provenances across 5 trials, and the Association of Southeast Asian Nations (ASEAN) – Canada Forest Tree Seed Centre Project established trials in participating countries from Maluku and West Papua/Papua, Indonesia, sources. Despite this, published data from provenance trials are scant. Those available report observations of differing growth rates, branching characteristics and bole straightness between the different origins. Material originating from Kolombangara in Solomon Islands is regarded as superior for diameter growth and bole straightness: 1-year-old plants were 5 m tall with a dbh of 5.7 cm; at 2 years, they had an average dbh of 16 cm increasing to 19 cm at 3 years. In terms of disease resistance, however, Solomon Islands provenances appear more susceptible to gall rust disease compared with material originating in Indonesia. Philippine sources—originally established from seed imported from Java in the 1970s—are generally heavily branched. A provenance trial in Sabah (Malaysia) showed Philippine sources to be inferior to the Kolombangara provenance for plantation performance.

Falcataria moluccana has been widely cultivated in Java and the Javanese material is considered to have originated from Baik, West Papua. While the genetic quality of the original introduction was likely high, that of subsequent collections is unknown and the genetic diversity has likely reduced with each collection through dysgenic selection. Studies of Javanese sources have generally shown low genetic diversity.

Improved seed has been produced in both Indonesia and Malaysia through local breeding programs. In Indonesia, seedling seed orchards comprising 100 families across three sites in East Java were established in 2012. However, improved seed is rarely available for purchase as it is in high demand for local replanting programs. There are large quantities of unimproved seed available from Javanese plantations and the Philippines. Due to the shortage of seed, multiplication of superior trees is via tissue culture. In future, and once field trials have concluded, plantlets of Solomon Islands origin are likely to become available from a company in Tawau, Sabah.

Progeny trial at 12 months in northern Sabah, Malaysia: Kolombangara provenance, Solomon Islands (L) and Philippines breeding program progeny (R). Kolombangara-origin saplings are faster growing, straighter and with fewer side branches (Photo: P. Macdonell)

Conservation of genetic resources (including threats and needs)

Overall, the species is not considered at risk as it readily regenerates following disturbance. The major threat to the natural stands of *F. moluccana* is logging. In West Papua province, many different stands have been recorded although trees may occur at low frequency. However, in Wamena (Papua province) at a higher elevation, there is a pure stand unaffected by logging pressures. On some Pacific and Indian ocean islands, it is widespread and considered an environmental weed.

An Indonesian study of susceptibility of 3-year-old trees to gall rust (*Uromycladium falcatarium*), incorporating sources from the Sabah Softwoods breeding program, Timor-Leste, East Flores, Maluku Islands, Wamena and central Java landraces showed that the Wamena provenance, although susceptible to gall rust, was the least affected of all the provenances tested. Based on its location, this provenance would likely fit into region-of-provenance type 3 (see above) which has a woolly leaf rachis.

Authors: Paul Macdonell and Liliana Baskorowati

Flueggea flexuosa

Family: Phyllanthaceae
Botanical name: *Flueggea flexuosa* Müll.Arg. In *Linnaea* 34: 76 (1865).

The genus is named after the German botanist John Flügge (1775–1816) while the specific epithet is from the Latin *flexuosa*, full of bends, a reference to the somewhat zig-zag appearance of branchlets.

Common names: local names in the Philippines include *anislag*, *katamangan* and *malagau* and in Solomon Islands include *mamufu'a*, *mamafua*, *mavua*, *mavuana*, *nganimau*, *nonimua* and *pomou*. In Vanuatu, it is widely known as *namaumau*. Local names in its introduced range in the Pacific Islands include *baumuri* (Fiji); *poutea* (Futuna); *pou* (Rotuma, Fiji); and *poumuli* (Samoa; 'Uvea, Wallis and Futuna).

Male flowers (Photo: L. Thomson)

Fruit (Photo: L. Thomson)

Summary of attributes and why diversity matters

Flueggea flexuosa is a fast-growing tree of small to medium stature and good form which provides multiple wood and non-wood products. It is an excellent candidate tree for agroforestry plantings, small-scale plantations and community forestry, especially on infertile soils in humid, lowland tropical zones.

There is an urgency to investigate genetic diversity in this species, and its extent and distribution, in order to underpin selection and breeding programs and plan conservation strategies. The example from Samoa, where farmers have selected straight-stemmed forms to supply highly durable building poles for use in construction of traditional fale houses, is indicative of the economic gains that can be made from such investigations. These straight-stemmed forms have vast, essentially untapped potential to provide durable poles and posts for small-holders in other humid, lowland tropical zones.

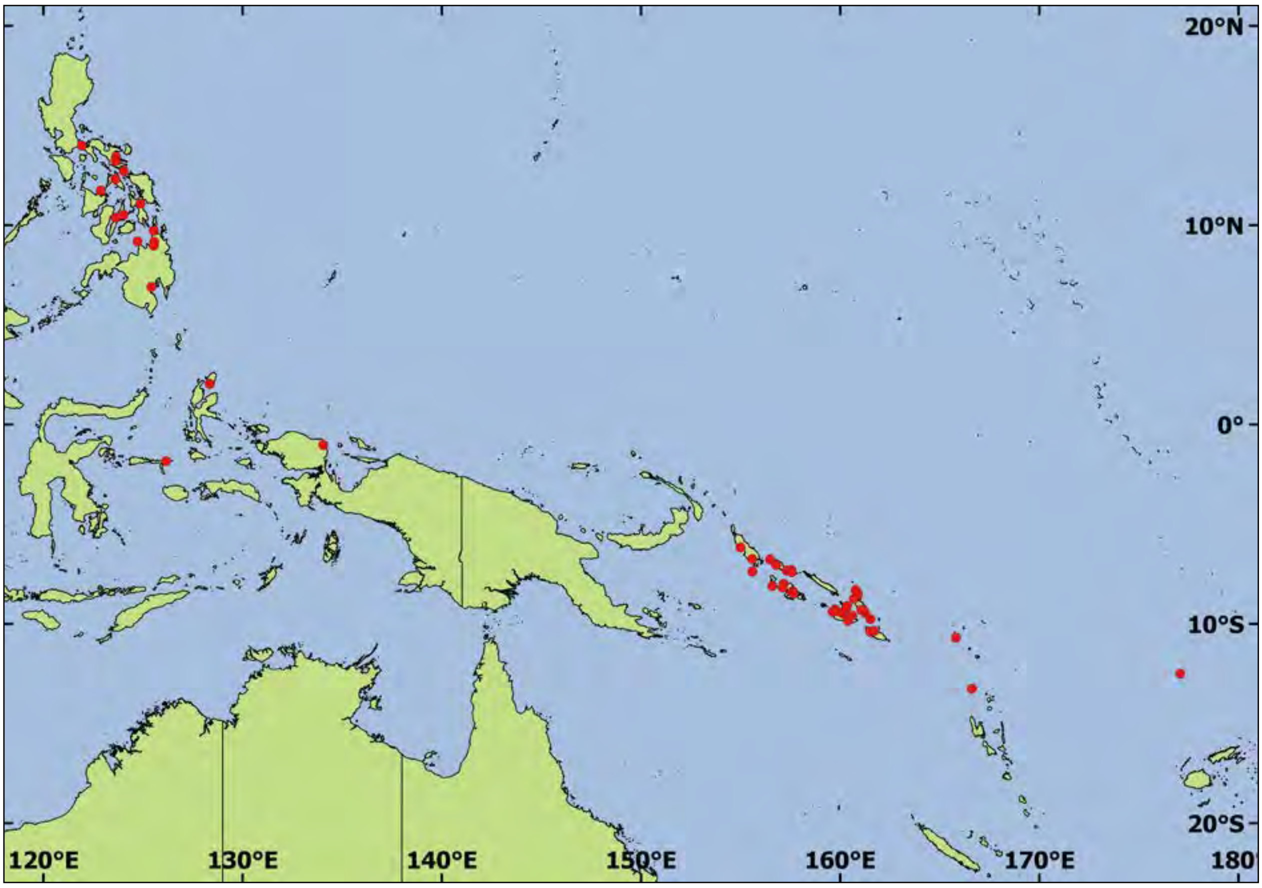
Description

Habit small to medium–size tree, 10–16 m tall and 20–30 cm dbh, rarely attaining 25–30 m tall and 75 cm dbh; crown narrowly conical with many small horizontal branches in young trees but becoming more spreading with age; older trees typically have straight, clear boles for the first 6 m, sometimes with indistinct buttresses. ***Bark*** shallowly furrowed, light greyish-brown. ***Leaves*** simple, alternate, oblong-elliptic, 8–14 cm long, 3–5 cm wide, shiny dark green above, light green below. ***Inflorescences*** short axillary clusters all along the twigs; male and female flowers are borne on separate trees (dioecious). ***Flowers*** numerous, small, light greenish-yellow. ***Fruit*** small, globose (3–5 mm) berries, dark purple-black at full maturity, typically 5,500 fruit/kg. ***Seed*** 4–6 angular seeds/fruit, about 1 mm long, average of 300,000 seeds/kg.

Distribution

The natural range of *F. flexuosa* is the Philippines, eastern Indonesia, Solomon Islands and northern Vanuatu (Banks Islands). The species has been introduced into American Samoa, Fiji including Rotuma, Samoa, Tonga, and Wallis and Futuna.

This species is adapted to the lowland, humid tropics. Annual rainfall is high, 1,500–5,000 mm, and mainly uniformly distributed such that there is no dry season. Altitudinal range is 5–900 m asl. *Flueggea flexuosa* grows well on a wide range of soils, including coralline soils, red clays, poorly drained sites and in coastal areas.



Uses

Remarkably, *F. flexuosa* is better known and more widely cultivated in Samoa than in its native range in South-East Asia and Melanesia. It is highly regarded in the Pacific Islands for its production of very durable round posts and poles which are widely used in building construction. Its short rotation period (e.g. 5–9 years for posts and poles) makes it an ideal species for agroforestry plantings, and interplanting with longer rotation timber species, such as *Swietenia* (mahogany) and *Endospermum* (whitewood). In Solomon Islands and Vanuatu, *F. flexuosa* grows rapidly, and reasonably straight without big branches, and is preferred wood where durability is needed.

One-year-old agroforestry planting of *F. flexuosa* with taro and banana; Falealupo, Savai'i, Samoa (Photo: L. Thomson)

Loading *F. flexuosa* poles; Falelima, Savai'i, Samoa (Photo: L. Thomson)

Wood—the heartwood is pale yellowish-brown or reddish-brown, the grain is straight, texture reasonably fine and density 770 kg/m^3 at 12% moisture content. Although very hard and strong, the timber is easily worked and very well suited for in-ground uses, as it is resistant to drywood termites and fungi. Favoured uses include house poles, fence posts, bridges, marine piles and fuelwood.

In Samoa, the main product is small durable poles, which are harvested at age 8–10 years. The price is about US$8 per 3 m length of small pole (10–15 cm diameter) with small, whole trees returning about US$15–20 to the farmer.

Provenance trial (Solomon Island provenances), selectively thinned and converted to seed stand; Poitete, Kolombangara, Solomon Islands (Photo: T. Blumfield)

Non-wood—traditional non-timber product uses in Melanesia include herbal medicine and dyes, while the flowers provide nectar and pollen for honey bees.

Diversity and its importance

Trees may differ in various morphological traits, such as in leaf shape, petiole and inner bark colour and length of main bole. The extent of intraspecific genetic diversity in *F. flexuosa* is unknown, but it is expected to be considerable given the extensive and disjunct natural distribution of the species. This is quite extraordinary given its unique potential to produce a highly durable timber on short rotation, ease of incorporation into different agroforestry systems and opportunity to contribute to rural livelihoods in humid, tropical zones. There is an urgency to investigate genetic diversity, its extent and distribution and variation in economic traits in this important species.

From an economic viewpoint, the most important harnessing of diversity thus far has been the development of a straight-stemmed landrace in Samoa. This appears to be the result of rapid farmer selection over only a small number of generations.

Conservation of genetic resources (including threats and needs)

There have been no recorded attempts to specifically conserve the genetic resources of *F. flexuosa*. In fact, the main form of conservation is ex situ through its extensive planting (and replanting) in Samoa and Vanuatu, but it is likely that such activities are only conserving a small fraction of the species' genetic resources.

Authors: Moafanua Afuvai Tolusina Pouli, Vaeno Vigulu and Lex Thomson

Garcinia sessilis

Family: Clusiaceae
Botanical name: *Garcinia sessilis* (Forst. f.) Seem. In *Viti*: 433 (1862), *Fl. Vit.*: 10 (1865).

The type was collected by J.R. & G. Forster on Tongatapu, Tonga, during Captain Cook's second voyage. The genus name is after the Franco-Swiss botanist Laurent Garcin (1683–1751), and the specific epithet refers to the sessile flower parts; in particular, the sessile anthers.
Common names: *heilala* (Tonga); *laubu*, *buluwai*, *kau yalewa*, *elala* (Fiji); *kwaefanefane* (Solomon Islands)

Summary of attributes and why diversity matters

Garcinia sessilis is an evergreen, small tree. It naturally occurs in Fiji and Solomon Islands in wet and dry forests, open thickets and occasionally on the edges of mangrove swamps. The species is widely cultivated in Tonga, and to a much lesser extent in Samoa. In Tonga, *G. sessilis* is considered to be the most important tree for cultural and ornamental purposes and an important medicinal plant. Minor uses include carving, timber, fuelwood and food (edible fruit).

Traditional selection in Tonga has produced deep pink and red forms (the national colour) of the exquisitely perfumed *G. sessilis* flower which are highly prized for cultural purposes such as in floral garlands. The main festival in Tonga is the Heilala Festival; the species is closely associated with royalty and has a special, spiritual significance for Tongans.

Description

Habit small tree to 8–12(–20) m tall and 30–40 cm dbh; monopodial form with a single or several boles and horizontal branching; in swampy sites, often develops short, basal prop roots. ***Bark*** persistent, grey with some brownish patches, roughened and becoming fissured in old specimens. ***Leaves*** simple, ovate to elliptic, 5–10 cm long, 3–6 cm wide, thinly fleshy; new leaves red, quickly turning orange/bronze then light green, and bright dark green at maturity; leaves and branches arranged oppositely, in a spiralled, near decussate pattern. ***Inflorescences*** dioecious (male and female flowers borne on separate trees). ***Flowers*** sessile, single or in axillary clusters of 3–9 flowers; opened flowers are typically 10–17 mm diameter; petal colour ranges from cream–light yellow, through yellow-orange and various shades of pink (salmon, peach and rosy) to blood red—in Fiji, lighter, cream and yellow-coloured flowers are common, while in Tonga, pink- and red-flowered forms predominate, presumably due to human selection. ***Fruit*** mature fruit ellipsoid, 4–6 cm long, 2.5–3.5 cm wide, yellow or red and sweetly aromatic; fertilised fruit have 6–13 seeds, embedded in an edible, white pulpy mesocarp. ***Seed*** banana-shaped pyrene (seed surrounded by hard endocarp); recalcitrant.

New shoots showing young red and bronze leaves; Mataika, Vava'u, Tonga (Photo: L. Thomson)

Female (L) and male (R) flowers (Photo: L. Thomson)

Above: Fruit (Photo: R.R. Thaman)

Left: Old planted specimen; Vava'u, Tonga (Photo: R.R. Thaman)

Distribution

Garcinia sessilis occurs naturally in the Pacific Island countries of Solomon Islands (Santa Cruz Islands) and Fiji. It also occurs in Tonga where it is considered a sacred and royal tree. However, it appears incapable of natural regeneration in Tonga, and is most likely a Polynesian introduction from Fiji which has been domesticated in Tonga as well as Samoa.

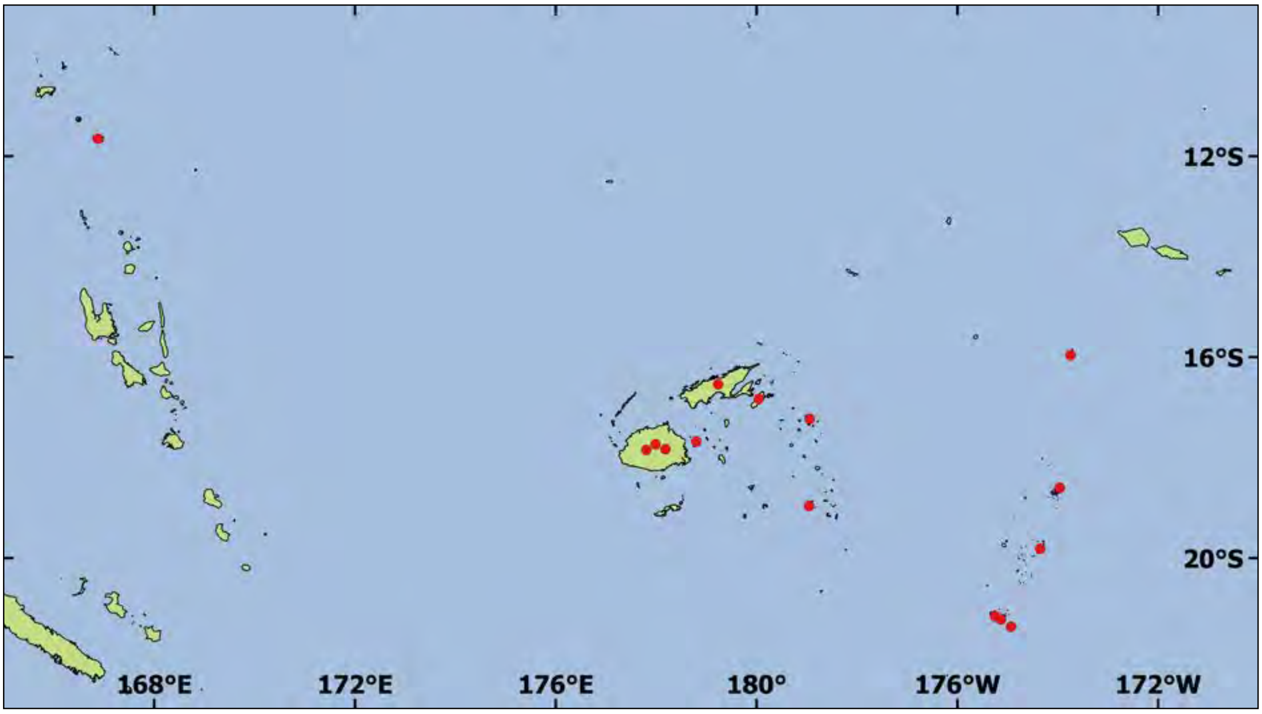
This species is found in both wet and dry forests, open thickets and on the edges of mangrove swamps; at elevations from sea level to 1,150 m asl.

Uses

Garcinia sessilis is much better known, frequently used and cultivated in Tonga than in its native range in Melanesia. In Tonga, *G. sessilis* is considered to be the most important tree for cultural and ornamental purposes and an important medicinal plant. Minor uses include carving, timber, fuelwood and food, with the fruit occasionally eaten by children. In Fiji, it has been reported to provide a useful timber for house construction.

Wood—the wood is used in the construction of traditional houses, and for carving and fuelwood.

Non-wood—in Tonga, the most important use for *G. sessilis* is for making *kahoa* (or garlands) and



Above left: *Kahoa* (garland) made from *G. sessilis* flowers, University of the South Pacific graduation ceremony (Photo: R.R. Thaman)

Above right: *Garcinia sessilis* being grown in home garden, with seedlings protected with posts of *Gliricidia sepium*; Pangaimotu, Vava'u, Tonga (Photo: L. Thomson)

Left: Bark harvested for traditional medicine; Holonga, Vava'u, Tonga (Photo: L. Thomson)

occasionally *sisi* (sashes). Flowers are collected late on the day before being made into *kahoa*. The subtle, unique perfume from the flowers increases in strength the day after picking. *Garcinia sessilis* is considered the most highly ranked of the sacred and fragrant plants of Tonga, known collectively as *kakala*. Different types of *kakala* act as symbolic insignia and are worn to indicate rank in society. Traditionally, *kahoa* made from *G. sessilis* flowers were preserved for the royal family, nobles and village chiefs. Nowadays, such *kahoa* may also be prepared and used by the general population for special occasions, such as baptisms, weddings, graduations and prize presentations. The starting price for an individual *kahoa* incorporating fragrant, beautiful flowers of *G. sessilis* is US$100 (in 2017).

The species is the most sought-after ornamental tree for home gardens in Tonga. It is also the most desired tree for planting in cemeteries and around traditional rural burial grounds.

Garcinia sessilis features widely in traditional Tongan medicine, with different parts of the plant used to treat a variety of ailments:

- leaves—used fresh or as an infusion—for hepatitis (in combination with *Macaranga harveyana* and *Tarenna sambucina* for babies, and *Alyxia stellata* for adults), skin diseases and rashes, conjunctivitis and styes, stomach-ache in children, digestive

Male flowers showing diversity of colours: blood red, pale yellow and light pink (L to R) (Photos: L. Thomson)

system complaints, morning sickness in pregnant women, problems with the umbilical cord and to aid removal of the placenta after childbirth
- roots—haemorrhoids
- bark—several uses, usually in combination with bark of other species.

The tree is occasionally harvested from the wild for its edible fruit which is eaten raw. It is infrequently cultivated for its fruit in Samoa.

Diversity and its importance

In Tonga, at least 17 traditional varieties of *G. sessilis* have been recognised. The main differentiation is between female and male plants. Male plants are preferred for making *kahoa* because the flowers are more robust and the petals do not break off easily. Particular individual trees are highly prized for the deep red (royal/ Tongan) colour of their flowers and suitability for sewing into *kahoa*.

Any *G. sessilis* plant may be used for medicinal purposes, but *pulu* (female) plants are generally preferred, presumably because they are not used for making *kahoa* (and inevitably harvesting of plant parts for medicines would reduce growth and flowering of the income-generating male trees).

Conservation of genetic resources (including threats and needs)

A conservation and management strategy has been developed for the species in Tonga in 2000 (revised in 2004). The major threat to *G. sessilis* has been insufficient replanting to replace trees dying from natural and other causes. Since the late 1990s, propagation and replanting of *G. sessilis* has greatly increased, led by Government of Tonga forestry personnel. Critical to the success of these efforts has been:
- development of composting technologies and improved potting media that incorporate a high percentage of compost
- appreciation of recalcitrant seed physiology and the need to sow seed immediately after collection and cleaning.

The Tongan Ministry of Agriculture and Food, Forests and Fisheries has promoted and encouraged replanting of *G. sessilis* through increased production of high-quality seedlings for public sale and distribution from its nurseries. It has also provided the public with information on how to propagate and care for the species. Establishment of an ex situ *G. sessilis* gene conservation stand and a seed production stand on Vava‘u have been slow to materialise due to unauthorised removal of larger specimens which can sell for US$50–100/plant.

In order to more effectively conserve and sustainably use the species, research is needed to fill critical gaps in knowledge regarding the natural and cultural ecology of *G. sessilis*, including propagation and cultivation, seed storage physiology, vegetative propagation, optimum water requirements, optimum light regimes, and reproductive biology, including in the native parts of its range.

It would seem likely that other related species in the genus *Garcinia* (which includes about 200 tropical species, including mangosteen) will have medicinal uses and values which need to be investigated and promoted in other areas.

Authors: Lex Thomson, Randolph R. Thaman and Leody Vainikolo

Gliricidia sepium

Family: Fabaceae
Botanical name: *Gliricidia sepium* (Jacq.) Kunth ex Walp. In *Nomenclatorum Botanicum* 2nd edn, 1: 688 (1841).

The genus name is derived from the Latin for 'mouse killer', a reference to the toxic properties of its seed and bark, while the specific epithet is derived from the Latin *saepes*, hedge. *Gliricidia sepium* is closely related to *G. maculata* with which it is sometimes confused: the two species have frequently been treated as synonyms but molecular studies indicate that they are genetically distinct. *Gliricidia sepium* is reliably distinguished from *G. maculata* by its papery as opposed to leathery leaflets, with pointed or acuminate instead of rounded apices, and erect as opposed to longer, pendulous inflorescences. The two species are known to hybridise.
Common names: gliricidia, madre de cacao, Mexican lilac, and many other names reflecting the wide international cultivation and use of the species

Summary of attributes and why diversity matters

Gliricidia sepium is an extremely versatile, nitrogen-fixing tropical agroforestry tree used in living fences and boundaries, to stabilise soils, to shade plantation crops, as an ornamental, a rodent poison, and in traditional medicine. It can be incorporated readily into smallholder farming systems and provide a range of wood and leaf products, including fuelwood, construction poles, crop supports, green manure, fodder and bee forage. It can thrive in a range of tropical environments, most commonly the seasonally dry tropics, in a range of soil types and at altitudes to 1,600 m asl. It has been estimated that between 150 and 200 million people—the majority of whom live in areas where this species is a cultivated exotic—use *G. sepium*, which is often considered to be the most widely cultivated agroforestry tree after *Leucaena leucocephala*.

The results of coordinated international provenance trials indicated that in some sites there were marked differences (≤500%) between provenances in biomass production. Some provenances had higher yields for both leaf and wood production across a wide range of sites, while others had poor wood production but excellent leaf production. Provenance/progeny trials should be established to allow selection of the best, with the objective of optimising yields of the required products from plantings.

Description

Habit small to medium–size semi-deciduous tree, 2–12 m tall with a spreading, irregular canopy; may have single or multiple stems; in agricultural environments, the size and shape are often modified by repeated lopping. ***Bark*** greyish-brown to whitish in colour, can be deeply fissured at the base of older stems. ***Leaves*** alternate and pinnate, 15–30 cm long with 7–17 leaflet pairs; leaflets papery, elliptic or lanceolate, with a distinctive pointed tip. ***Inflorescences*** clustered racemes on distal parts of new and old wood, 5–15 cm long, upward curving. ***Flowers*** borne singly with 20–40/raceme, usually pink in colour, fading to a whitish-brown or faint purple with age; individual pedicels and calyces usually hairless. ***Pods*** turn straw yellow-brown when fully ripe and are explosively dehiscent; pods contain 3–10 seeds. ***Seed*** yellow-brown to brown, nearly round. ***Reproductive phenology*** the main flowering season is the dry season, but if no pronounced dry season, flowering can occur at any time of the year but does not always lead to seed set.

Mature natural stand; El Roblar, Guanacaste, Costa Rica (Photo: C. Hughes)

Flowering specimen (Photo: D. Bush)

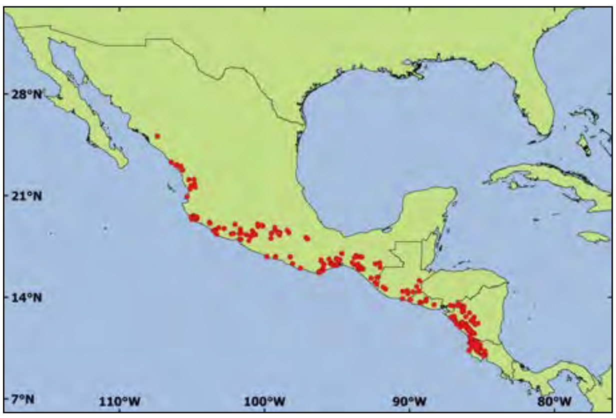
Flowers (Photo: D. Bush)

Distribution

Gliricidia sepium has undergone such a high degree of human disturbance through a long history of cultivation that the precise natural range of the species is difficult to determine. It is native to the Pacific seaboard of Mexico and Central America (Guatemala, El Salvador, Honduras, Nicaragua and Costa Rica). When the Spanish colonists arrived in Mexico and Central America they observed indigenous peoples using and cultivating *G. sepium* for a number of purposes, including shade for cocoa trees.

Introductions outside tropical America can be traced to the early period of Spanish influence, and in the early 1600s, it was introduced to the Philippines. Later, it was introduced to Sri Lanka in the 1880s as shade in tea plantations, and from there it spread to India, Indonesia, Malaysia and Thailand. A subsequent wave of introductions to West Africa and Uganda occurred in the early part of the 20th century, as shade for plantation crops.

Gliricidia sepium consequently now has a pantropical cultivated distribution. In some parts of the exotic distribution, it has become naturalised, reproducing itself without the need for further plantings. This is the case in parts of southern India and in South Africa. In many areas, however, climatic and biological conditions are such that trees are not able to reproduce sexually and therefore have to be planted or cultivated from cuttings. Its ease of propagation from seed or cuttings has facilitated the broad and effective spread of this useful tree. *Gliricidia sepium* can be readily propagated from large stakes and managed by regular pollarding.



Much of the material introduced into exotic locations during the colonial era is still of unknown origin. It is also likely that these introductions were from a narrow genetic base which has probably led to inbreeding.

Gliricidia sepium grows naturally in subhumid, seasonally dry tropical climates with 600–1500 mm MAR and a 4–5-month dry season. It is adaptable and can grow successfully in much wetter, humid, non-seasonal climates with MAR as high as 3,500 mm. *Gliricidia sepium* is found on a wide range of soil types, from pure sands of low fertility to heavy black clay soils. It tolerates both alkaline and moderately acidic soils with pH in the range 4.5–11.0.

Uses

Gliricidia sepium is a highly valued multipurpose tree and is used as fuelwood, construction poles, crop supports, green manure, fodder and bee forage. In addition, it is used in living fences, to stabilise soils and prevent erosion, to shade plantation crops and as an ornamental.

Wood—*G. sepium* coppices easily and can be lopped regularly for small firewood which burns slowly and produces good embers, giving off little smoke or sparks. Woody biomass production by *G. sepium* is dependent on climate and soils, management, planting density, length of rotation and the provenance used. Dry wood yields of ≤6.3 dry tonnes/ha/year from trees in Costa Rica have been recorded, and in the Philippines, when grown in woodlots on a 3-year rotation to provide wood for tobacco curing, yields of ≤23–40 m^3/ha/year were obtained.

Non-wood—the capacity of *G. sepium* to root and survive reliably from cuttings or stakes has resulted in several thousands of kilometres of living fences being planted throughout the tropics. These are commonly

Above left: *Gliricidia sepium* being used as marker post (with *Alternanthera* sp. used as host) for *Santalum* (sandalwood) planting, with Ponijesi Bulai; Vunimaqo, Viti Levu, Fiji (Photo: L. Thomson)

Above right: *Gliricidia sepium* used as a live fence and fodder tree; Nausori Highlands, Fiji (Photo: D. Bush)

Left: Poles of *G. sepium* for use in living fences (Photo: C. Hughes)

pollarded at a height of 1.0–2.5 m, and generally at least once a year. Individual posts may last beyond 30 years while loppings provide a ready supply of replacement posts or firewood and leaves may also be used for animal forage. The fences mark boundaries and keep livestock out of cropped fields.

The leaves of *G. sepium* are a useful green manure used, for example, as an organic fertiliser for coconuts in Sri Lanka; for improving taro yields in Samoa; and, as mulch, for increasing the yield and reducing time to harvest of yam tubers in the Ivory Coast. In Nigeria, 15 tonnes/ha/year of *G. sepium* leaf biomass produced on good agricultural soils provided the equivalent of 40 kg nitrogen/ha/year.

Both in its region of natural occurrence and as an exotic, *G. sepium* has also been used extensively as a shade tree in cocoa, coffee and tea plantations. It has also been used in traditional medicine and as a rodent poison.

Leaves of *G. sepium* are used as a high-protein supplement to low-quality basal animal feeds such as grass, straw and other crop residues and the leaves have a high feeding value, with crude protein comprising 20–30% of the dry matter, crude fibre content of only about 15%, and in vitro dry matter digestibility of 60–65%. In Indonesia, *G. sepium* leaves have higher crude protein content in the wet season than in the dry season. Although *G. sepium* is little used as forage within its native range in Mexico and Central America, it is an important forage crop in cut-and-carry systems in many parts of the tropics. Due largely to its high productivity and quality, *G. sepium* has been widely promoted and researched. However, there remain mixed perceptions of the species as a palatable forage crop but wilting

G. sepium leaves for 12–24 hours before feeding is found to increase animal intake as forage.

Diversity and its importance

Recognising the importance of the species as a multi-purpose, nitrogen-fixing tree and acknowledging that almost all of the early introductions were made in an entirely unplanned and undocumented fashion, CATIE (the Tropical Agricultural Research and Higher Education Center, Costa Rica), the Nitrogen Fixing Tree Association and the Oxford Forestry Institute (OFI) undertook comprehensive seed collections of *G. sepium* from tropical America during the 1980s. These valuable range-wide provenance seed collections were used in 160 international provenance trials set up by OFI in the mid-1980s, resulting in new introductions to 55 countries throughout the tropics. Progeny trials have now been set up of some superior provenances so that genetic parameters can be calculated with a view to converting the trials into seedling seed orchards to satisfy the demand for seed of this species.

The results from the OFI trials indicated that there were marked differences between provenances in biomass production. While some provenances demonstrated superior yields for both leaf and wood production across a wide range of sites, others showed poor growth in terms of wood production, yet they were outstanding for leaf production.

The perceived value of *G. sepium* as fodder varies greatly because of apparent differences in palatability. It was not known whether this is due to genetic variation in *G. sepium* or to differences in site, management practices or in the animals being fed. Provenance-based feeding trials were implemented in Colombia, Costa Rica, Indonesia, Nigeria and Sri Lanka but found no evidence that some provenances are intrinsically more palatable than others. Sheep and goats can distinguish between provenances of *G. sepium* and show a strong preference for material to which they have been previously accustomed. Implications from the results are that *G. sepium* provenances may be selected on the basis of high yield only, without any risk of a deterioration in fodder quality.

The World Agroforestry Centre (ICRAF) has established seed stands, based upon international collections, with partners in Malawi and Tanzania and is willing to share this improved seed with collaborators. In addition, researchers may wish to contact the Forest Tree Seed Bank (ESNACIFOR/COHDEFOR) in Honduras or the Centro de Mejoramiento Genético y Banco de Semillas Forestales in Nicaragua for seed from the native region of occurrence.

Conservation of genetic resources (including threats and needs)

Gliricidia sepium is widely grown and cultivated within its region of natural occurrence and is planted widely throughout the tropics. Comprehensive range-wide seed collections have been undertaken, international assessments completed and seed stands established. There appears to be no specific conservation and management strategy for *G. sepium*; however, no immediate threats to genetic resources have been identified.

Author: Stephen Midgley

Grevillea robusta

Family: Proteaceae
Botanical name: *Grevillea robusta* A.Cunn. ex R.Br. In *Suppl. Prodr. Fl. Nov. Holl.* 24 (1830).

The genus name honours English patron of botany, Charles Francis Greville (1749–1809). The specific epithet is from the Latin *robustus*—hard, strong, robust—in reference to its size in a genus of many shrubs.
Common names: silky oak (English); *chêne d'Australie* (French); *mgrivea* (Swahili)

Summary of attributes and why diversity matters

Grevillea robusta has gained widespread popularity in warm temperate, subtropical and tropical highland regions of many countries, originally as a shade tree for tea and coffee and now as an agroforestry tree for small farms. It provides economically valuable products including timber, poles, firewood and leaf mulch.

In the wild, this species is found in two distinct habitat types: along the banks of watercourses, and in araucarian vine forests and thickets. Much of the natural range has been cleared, though remnant natural stands remain. The size of individual local natural populations is typically small—commonly only a hundred or so adult trees. There is no pattern of morphological variation between the riverine and vine forest populations; however, the species displays strong provenance variation in tree growth and stem straightness characteristics. Thus, there is a need to maintain this diversity for future genetic improvement and breeding programs.

Description

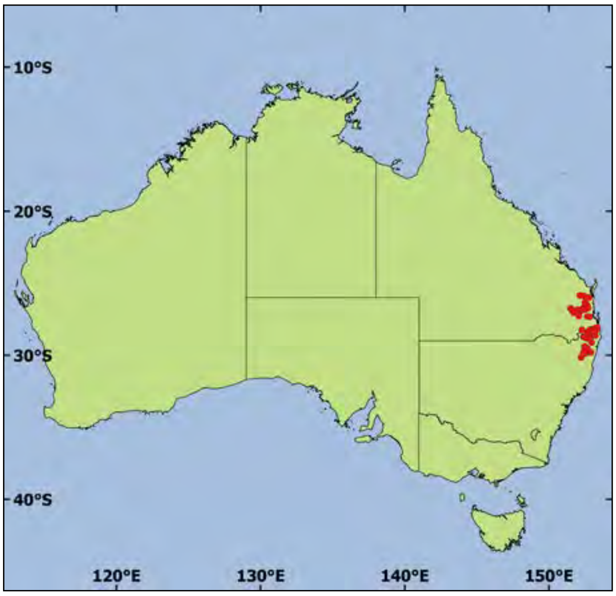
Habit erect, single-stemmed tree typically reaching 20–30(–37) m tall and ≤1 m dbh; crown conical and symmetrical with major branches spaced at intervals of about 1 m and projecting upwards at an angle of 45°. ***Bark*** dark grey, furrowed into a lace-like pattern. ***Leaves*** 10–34 cm long, 9–15 cm wide, variably pinnate to bipinnate, glabrous green above, silvery hairy below; petioles 1.5–6.5 cm long; young branchlets angular and ridged, covered in rusty hairs, but glabrous on older growth; the species is semi-deciduous in its natural range, being almost leafless shortly before flowering, but some trees are evergreen in East and Central Africa. ***Inflorescences*** racemes, 7–13 cm, simple to 6-branched from near the base. ***Flowers*** bright orange and occur in numerous pairs along the flower spikes, on pedicels 1.5 cm long; flowers bisexual and protandrous, opening acropetally; each flower contains 2 ovules. ***Fruit*** brownish-black, leathery follicles about 20 mm long containing 1–2 seeds. ***Seed*** brown, flat, ovate-oblong, 1.0 × 0.5 cm, broadly winged. ***Reproductive phenology*** in East and Central Africa, flowering and seeding may commence from as early as 3 years of age and occur in most years; and some trees display a continuous flowering pattern; in eastern Australia, flowering typically occurs in early summer.

Inflorescences of nectar-rich flowers (Photo: © CANBR)

Fruit capsules (Photo: K.C. Nixon)

Distribution

The species has a restricted natural range on the eastern coast of Australia from latitude 22°50′S to 30°10′S. The natural habitat of *G. robusta* is in northern New South Wales and southern Queensland, where it occurs from the coast to as far west as the Bunya Mountains, Queensland, some 160 km inland. The north–south range of the species is some 470 km, from just north of Gympie, Queensland (latitude 25°50′S), to the Guy Fawkes and Orara rivers (tributaries of the Clarence River in New South Wales, latitude 30°10′S). It is found across a wide range of altitudes from sea level to mountaintop occurrences at 1,120 m asl in the Bunya Mountains.



Grevillea robusta has been introduced to many countries in South and Central America, South Asia, and in the highlands of East and Central Africa where it is very common and popular for farm plantings. It has been introduced to most of the warm temperate and subtropical regions of the world, including India, Sri Lanka, African countries (e.g. Burundi, Democratic Republic of the Congo, Kenya, Rwanda, South Africa and Tanzania) and South American countries (e.g. Argentina, Brazil and Uruguay). It is also found in California (USA), Mexico and throughout the Caribbean. It is considered by the United States Department of Agriculture (USDA) to have become naturalised in Hawai‘i and southern Florida and is classed as a noxious weed on ranchland in Hawai‘i.

The natural distribution of *G. robusta* is in warm humid to warm subhumid climatic zones but climate varies widely because of altitudinal range. Climatic analysis of natural and exotic occurrences gives a MAR range of 700–2,400 mm of variable incidence, a dry season of 0–7 months and MAT of 13–24 °C, with an absolute minimum temperature of >–8 °C. The species is more common on rather fertile soils such as those derived from river alluvia or basalts but will grow on shallower, less fertile soils derived from sedimentary material. The pH range for good growth is around 4.5–7.5.

Uses

Grevillea robusta is a multipurpose tree species mainly used by farmers and as an ornamental. It is easy to propagate and establish and is relatively free of pests and diseases. Its proteoid roots help it grow in low-fertility soils and it does not compete strongly with adjacent crops. It tolerates heavy pruning of its roots and branches.

Wood—the heartwood is brown with yellow, pink or red hues and an 'oak-like' figure. Air-dry density is 550–675 kg/m^3. The timber seasons well and is one of the finest cabinet timbers. In Australia, it is used for furniture, turnery, indoor fittings and plywood, but supply is limited. Elsewhere, it is used for timber, firewood and poles.

Non-wood—*G. robusta* is used as a boundary tree, windbreak or shelterbelt, and among crops on small farms. It is grown as a shade tree for tea and coffee

Grevillea robusta as shade tree in tea plantation; Sri Lanka (Photo: CSIRO)

House constructed using *G. robusta* timber; Kenya (Photo: CSIRO) plantations, a soil stabiliser with leaves used for mulch, and is popular as an ornamental tree. The golden flowers are attractive to bees, making the species an important honey provider. The leaves contain a number of useful chemical compounds; in particular, rutin, which has pharmacological applications, although concentrations are too low for commercial use.

Diversity and its importance

Grevillea robusta has no recognised subspecies or varieties and no hybrids with other species have been recorded. The species displays strong provenance variation in tree growth and stem straightness characteristics. Although there are no advanced genetic improvement programs being implemented to date, the World Agroforestry Centre (ICRAF) is managing a provenance/progeny trial in western Kenya and is developing a clonal seed orchard using the best trees of the best families from the species' natural range. There is evidence that the initial introductions of *G. robusta* in East and Central African countries were made from a narrow genetic base of a few trees and/or from planted stands at botanic gardens. Recent provenance seedlots evaluated in field trials in several countries also comprised only a few (typically <10) individual seed trees per provenance. This narrow genetic base reduces the available population size for further genetic improvement in many countries.

The primary breeding behaviour of *G. robusta* involves cross-pollination. The main pollinating agents are nectivorous birds—in East Africa, mainly sunbirds and white-eyes. The flowers are too large for effective pollination by insects. Although the early introductions were from few trees, self-incompatibility may help to explain why the species has not shown substantial genetic deterioration as an exotic, especially in the eastern and central African highlands. Very few plants are generated through self-pollination. Therefore, severe inbreeding and associated decline in performance may not develop as rapidly as in, for example, eucalypts.

Two-year-old progeny trial; Malava, western Kenya (Photo: A. Kalinganire)

Techniques recently developed for controlled pollination and vegetative propagation could be used in improvement strategies for increased adaptability and production, including the creation of hybrids with other *Grevillea* species for the ornamental market.

Conservation of genetic resources (including threats and needs)

To date, there is no conservation and management strategy developed for the species. However, provenances collected in the species' natural range have been planted in ex situ conservation stands in Kenya and Rwanda. Moreover, a few provenance/progeny trials are being managed in Australia, Ethiopia, Kenya and Rwanda, and could be used as a source of plant material for extension and breeding. The extent of its intraspecific genetic diversity is known. Countries growing the species are encouraged to obtain seed from the natural range for ex situ conservation stands.

There is no immediate threat to most of the remaining populations in its natural range, and many are located within secure conservation reserves. However, seed from identified superior provenances is expensive to collect and the quantities that can be collected are insufficient to meet current global demand. It is proposed that small amounts of seed available from natural provenances of *G. robusta* be used for the establishment of ex situ conservation and seed production stands in areas where flowering is prolific and bird pollinators are abundant. It should be noted that *G. robusta* is an effective colonising species and does have the potential to become a weed.

Authors: Antoine Kalinganire, Chris Harwood and Bronwyn Clarke

Gyrinops ledermannii and *G. caudata*

Family: Thymelaeaceae
Botanical names: *Gyrinops ledermannii* Domke and *Gyrinops caudata* (Gilg.) Domke. In *Nitizblatt des Botanischen Gardens und Museums zu Berlin-Dahlem* 11: 349 (1932).

The genus name is derived from the Greek meaning resembling a tadpole, an allusion to the form of the seed of the type species of the genus, *G. walla*. One specific epithet honours Swiss horticulturist Carl Ludwig Ledermann (1875–1958), who collected the type specimen from the Sepik region (PNG) in 1912, while the other is derived from the Latin *cauda*, tail. *Gyrinops* is very close to the other eaglewood resin–producing genus *Aquilaria*. Species in the two genera are only distinguished by a single taxonomic character. In *Aquilaria* the number of stamens is twice the number of petals (10), while in *Gyrinops* there are equal numbers of stamens as petals (5). *Aquilaria* and *Gyrinops* have a natural distribution across Asia from India and Sri Lanka, through to Vietnam in the east and south through Malaysia, Indonesia and PNG. *Gyrinops* is found from Sri Lanka, eastern Indonesia and the island of New Guinea. Two species of *Gyrinops* have been identified in New Guinea, *Gyrinops ledermannii* and *G. caudata*.
Common names: eaglewood, agarwood, aloeswood (English); *gaharu* (Indonesia). These are the names widely used to refer to both the tree and more commonly the traded product (resin) in both PNG and internationally for species within *Gyrinops* and *Aquilaria*. This account refers to both *G. ledermannii* and *G. caudata* as eaglewood.

Summary of attributes and why diversity matters

Gyrinops ledermannii and *G. caudata* are small to medium size, resin-producing eaglewoods from rainforest in PNG and Indonesia. Eaglewood is internationally known for its fragrant resin found only in a very small percentage of trees in the wild. The resin is highly sought after for religious, medical, ceremonial and domestic activities by mainly Asian Buddhists and Muslims. Middle Eastern countries and Japan are major users.

High demand for wild eaglewood from traditional Asian sources (e.g. *Aquilaria crassna*) since the 1970s led to shortages of the product. This prompted exploration of other potential sources and led to the discovery of *G. ledermannii*, in the West Sepik province of PNG in about 1998. Since then, there has been wide-scale harvesting as new sources of resin-producing trees have been found across the country, including *G. caudata*. No work has been carried out on genetic variation in PNG eaglewood species to date.

Description

Gyrinops ledermannii—***Habit*** tree 5–10(–32) m tall, 5–30 cm dbh, straight, buttresses absent. ***Bark***

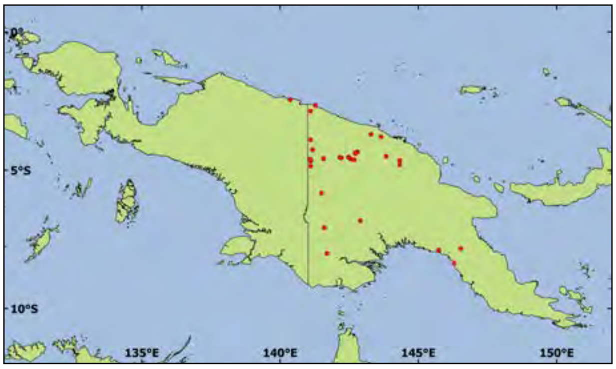
Flowers and leaves of *G. ledermannii*; Mapusi, East Sepik, PNG (Photo: F. Zich/TRAFFIC)

Bole of *G. ledermannii*; Gahom, East Sepik, PNG (Photo: F. Zich/TRAFFIC) outer grey to brown, rough; lenticels irregular; inner greenish-white or white, fibrous; bark thickness 10 mm, aromatic or faintly to non-aromatic, exudate absent. ***Leaves*** simple, alternate, petiolate, arranged spirally up branchlet, elliptic, pale green below, dark green above; indumentums present on juvenile leaves, cloudy white hairs, mature slightly glossy; lamina broadest at or near middle, 5–10 cm long; veins faint, inner veins with fibres; leaf base round, apex acute with entire margin. ***Inflorescences*** terminal, arising from a single point, with 2–3 flowers. ***Flowers*** bisexual, with distinct sepals and petals in whorls, 5 stamens. ***Fruit*** 15–18 mm long, green when immature, non-fleshy, simple dehiscent capsule. ***Seed*** to 10 mm long, not winged, dangling by filiform funicle, fleshy aril, recalcitrant.

Gyrinops caudata—differs from its close relative above in being more frequently a large canopy tree to 30 m tall and ≤55 cm dbh and having more flowers (3–10) per inflorescence.

Distribution

In PNG, *G. ledermannii* occurs from West Sepik province, with one record from adjacent locality in Papua province (Indonesia), parts of East Sepik province and into Madang province, specifically the Bogia and Middle Ramu areas. *Gyrinops caudata* has been identified in the southern part of mainland PNG, occurring in Central, Gulf and Western Provinces. In Western Province, the species occurs on the upper slopes of hills of montane rainforests in Kiunga, and on fairly flat lowland rainforest bordering Lake Murray and Suki.



The PNG eaglewoods are associated with tropical rainforest at an altitudinal range of 70–600 m asl with reports of their occurrence ≤1,000 m. The species are associated with MAR ranging between 1,700 and 5,200 mm, resulting in a seasonally high watertable but not extended inundation. Soils are typically yellow to red clays, acidic with thin humus layer and dense humus root mat. Distribution of plants in the forest appears to be strongly clumped with often a very high but usually localised density of trees. Seedling regeneration is commonly found.

Uses

Wood—the soft pale wood can be used for boxes and building materials.

Non-wood—eaglewood is prized for its fragrant resin used for thousands of years as incense, in perfumes, in traditional medicines and for ceremonial purposes. The resin is dark-coloured, fragrant and embedded in the otherwise whitish wood. In wild trees, it accumulates as small resin pockets or veins in damaged roots, trunks and branches of trees of varying age. It is formed by the tree's response to injury if the primary mechanism, formation of phloem callus tissue, is inhibited. The resin acts as a chemical barrier to attacks by fungi and insects. This only occurs naturally in a very low percentage of trees.

Cleaning eaglewood; Yigei, East Sepik, PNG (Photo: F. Zich/TRAFFIC)

Demand for the highly valued resin makes eaglewood an attractive non-wood forest product for resource owners. This results in economic benefits for remote communities proximal to natural occurrences or in areas suited to growing the species. The basic preparation of the resinous wood requires relatively low technology, with the wood being lightweight and therefore comparatively easy to transport. The development of technologies to stimulate resin in young planted trees and natural forest trees offers further economic opportunities for remote communities and an avenue for improving sustainable management of natural populations.

The inner fibrous bark has occasionally been used locally as raw material for clothing, *bilum* bags, ropes and cooking. The bark is also used for cooking fish over the fire in areas surrounding Lake Murray in Western Province, PNG.

Diversity and its importance

Very little, if any, work has been undertaken to determine the genetic diversity of eaglewood species in PNG or in neighbouring Indonesia. Further, the clandestine nature of the trade in eaglewood and potential for unscrupulous traders make it difficult to objectively assess the variation in both geographical terms and between species. Lack of transparent international grading standards makes it difficult to compare like products. Anecdotal information suggests a market preference for particular locations of eaglewood product often associated with traditional Asian sources. This may be associated with commercial interests rather than an objective quality assessment. The concentration of the resin within a sample has a large bearing on the product value. For example, large old trees may produce more densely resin–impregnated wood compared with younger trees. Product quality and price is also influenced by the skill in 'carving' the resinous wood from the pale non-resinous wood. Eaglewood from PNG was anecdotally reported to be of moderate quality but high in volume during the peak harvest years in the early 2000s.

Conservation of genetic resources (including threats and needs)

As a result of the high international demand for eaglewood, natural resources in the producing countries have dwindled to critically low levels. This has resulted in all species within *Aquilaria*, *Gonystylus* and *Gyrinops* being categorised under the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) Appendix II (see note in Table 1) in terms of international wood trade. In PNG, eaglewood appears to be fairly widespread in remote mountainous rainforest regions and harvesting has only been carried out since the late 1990s. The two species are here considered to be Critically Endangered, but they have not yet been assessed by IUCN.

Information on the extent of the resource and impact of harvesting is poorly understood, making it difficult to determine the level of threat. This information is required to enable communities, government and other agencies to manage the resource in order to ensure adequate conservation measures are in place. Ideally, these measures need also to optimise income from the eaglewood trade and ensure that benefits accrue to the resource owners who are invariably disadvantaged remote village communities. With the vast majority of land under customary title, the PNG Government may have limited opportunities to actively conserve native populations, and accordingly there is a need for range-wide seed collections for ex situ conservation plantings. These plantings would act as a repository of genetic variation and as a source of seed to address current shortages.

A taxonomic revision of eaglewood species is required following the significant commercial importance placed on this group of plants. In the case of PNG, it would be beneficial to compare resin production and quality from *G. ledermannii* and *G. caudata* with other eaglewood-producing species. This would be particularly relevant for *Aquilaria crassna*, of which seed is currently being imported into PNG for plantation establishment, and evaluation of inducement technologies to stimulate earlier resin production. Importers of *A. crassna* seed cite the difficulty in sourcing seed from the two local *Gyrinops* species as being a primary driver for this importation.

The shortage of eaglewood from natural sources and associated ban by many countries on harvesting from natural forests have led to a marked increase in development of eaglewood cultivation. It is estimated that, in recent years, at least 10,000 ha have been planted internationally. In PNG, smallholder plantings of *A. crassna* and *G. ledermannii* are in their infancy; however, introduction of inducement technologies to promote resin production of natural forest trees has shown promising results. This has the potential to greatly increase the production of commercially grown eaglewood, thereby taking pressure off the natural resource.

Authors: Anton Lata, Kipiro Damas and Kigube Fazang

Hibiscus storckii and three undescribed Fijian *Hibiscus* species

Family: Malvaceae
Botanical name: The genus name is derived from the Greek *hibiskos*, which was their name for mallows. *Hibiscus storckii* was first collected near Somosomo on the island of Taveuni, Fiji, in 1860. The species was formally described by German botanist Berthold Seemann in *Flora Vitiensis* [Seemann] part 1, p. 17 (March 1865) and the specific epithet is in honour of his botanical assistant, Jacob Storck. Three new endemic Fiji *Hibiscus* species, in section *Lilibiscus*, have recently been discovered and are in the process of being formally described.
Common names: Storck's hibiscus, *senitoa*, *senitoo*, *seni*, *kaute*, *seqelu*, *sekelu*, *kaute*, *loloru*, *tokalau* (Fiji)

Summary of attributes and why diversity matters

Tropical *Hibiscus*, in section *Lilibiscus*, are among the world's most widely planted woody ornamentals in warmer climates. *Lilibiscus* comprises about 25 *Hibiscus* species found mainly on mid-oceanic volcanic islands in the Pacific and Indian oceans. The distinctive and highly ornamental *Hibiscus storckii* was described from Fiji in 1865 but has generally been treated as conspecific with *H. rosa-sinensis.* Recent studies (in press) have revealed that *H. storckii* is indeed an endemic Fijian species. In addition, three new endemic Fijian *Hibiscus* species—*Hibiscus* sp. nov. 'Mt Delaikoro', *Hibiscus* sp. nov. 'Ruby Rose' and *Hibiscus* sp. nov. 'Ovalau'—have also been identified. At least two of these species—*Hibiscus* sp. nov. 'Ruby Rose' from Cakaudrove and *Hibiscus* sp. nov. 'Ovalau'—appear to have been widely used in the early breeding of modern tropical *Hibiscus* hybrids. The majority of *Lilibiscus* species, including the four Fijian endemic species, are rare and threatened in nature: indeed, they are better known in cultivation due to their ornamental appeal, cultural significance and medicinal qualities.

Description

Hibiscus storckii—***Habit*** evergreen, woody shrub to small, multistemmed tree, typically 3–4 m tall with spreading to semi-erect branching habit. ***Bark*** lower trunk somewhat roughed, mottled light grey and brownish-grey, often with patches of moss and lichen; upper stems light grey. ***Leaves*** ± discolorous, glossy above, glabrous or glabrescent, penninerved; mostly elliptic, basal portion rounded to obtuse, infrequently shallowly lobed (intermediate leaves on coppice/regrowth shoots); margin entire or with irregular serration/dentations on the apical portion, generally 6–11 cm long, 3–5 cm wide (L:W 1.9–2.4). ***Flowers*** solitary, axillary, showy; petals single whorl, lavender pink, obovate, 7–9 cm long, with large, dark-crimson serrated eye zone of radius 2.8–3.6 cm; peduncle articulated above middle; average ratio of pedicel section (above articulation point):flower stalk 0.21; epicalyx 5–9 linear to narrowly triangular free lobes, glabrous or glabrescent; epicalyx lobes shorter than calyx; calyx glabrous or glabrescent, united at base into a tube, 5-lobed, ± non-inflated; staminal column exserted and longer than the petals, monadelphous,

Hibiscus storckii, cultivated; Wai Village, Taveuni, Fiji (Photo: L. Thomson)

Top left: Close-up of *H. storckii* flower showing characteristic dark-crimson eye zone and red stigma pads; Matei, Taveuni, Fiji (Photo: L. Thomson)

Top right: *Hibiscus* sp. nov. 'Ruby Rose', flower; Waibula River, Taveuni, Fiji (Photo: L. Thomson)

Bottom left: *Hibiscus* sp. nov. 'Mt Delaikoro', flower and leaves of cultivated specimen; Rukuruku, Ovalau, Fiji (Photo: N. Perrault)

Bottom right: *Hibiscus* sp. nov. 'Ovalau'; south of Mt Tomuna, Ovalau, Fiji (Photo: L. Thomson)

antheriferous in the upper/distal half, stigma pads crimson. ***Fruit*** obovate, 5-sectioned papery capsule, glabrous or scabrous but never woolly. ***Seed*** irregular/blocky to kidney-shaped, brown to black, hairy to subglabrous.

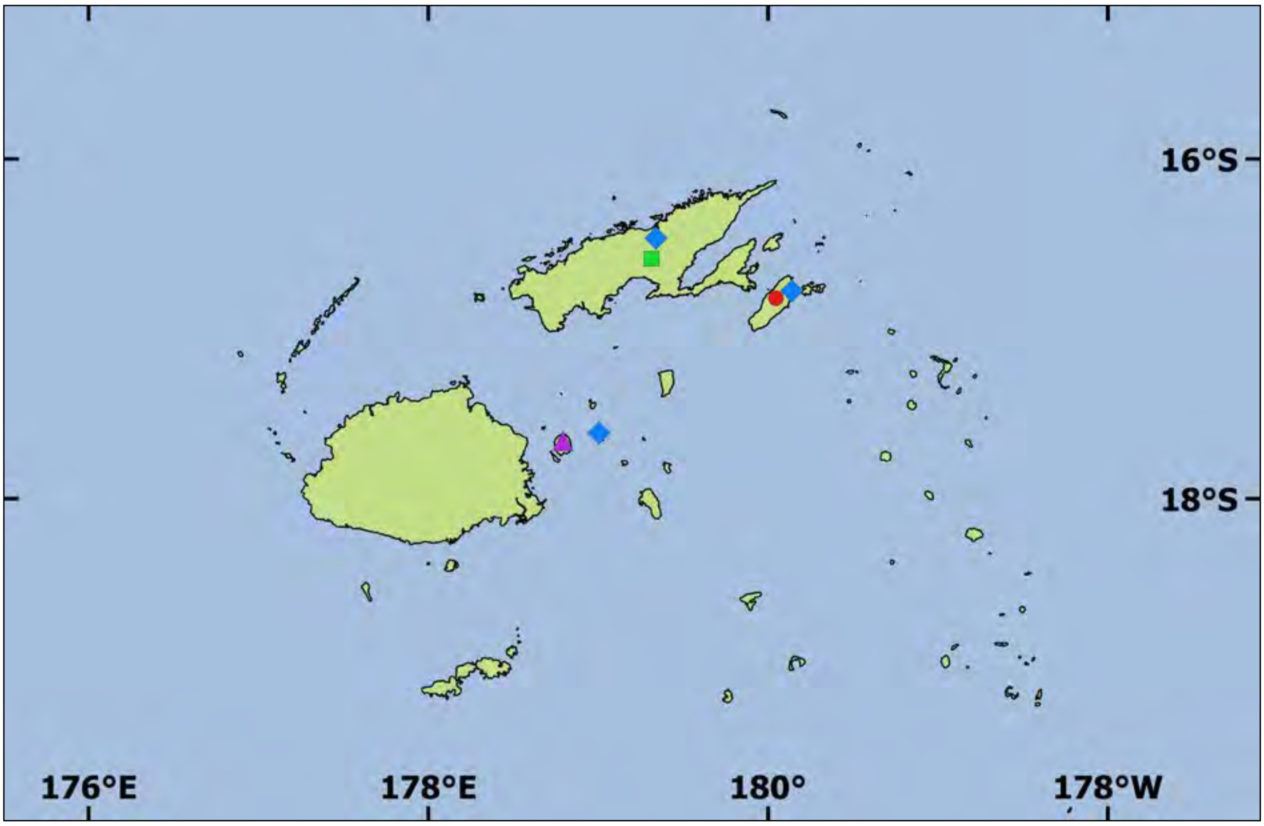
***Hibiscus* sp. nov. 'Mt Delaikoro'**—known only from the summit of Mt Delaikoro, Vanua Levu, and a close relative of *H. storckii*. Petals pink with a white edge or white/pale pink, 7–9 cm long, petal veins white, lobate dark red basal zone (c. 1.9–2.8 cm), stigma pads lemon yellow; average ratio of pedicel section:flower stalk is 0.13.

***Hibiscus* sp. nov. 'Ruby Rose'**—the natural distribution is north-eastern Taveuni (Caukadrove province) but with early collections, presumably from wild plants, undertaken near Labasa (Macuata province) and on Wakaya Island (Lomaiviti province). Mature plants exhibit extreme variation in leaf shape from ovate with irregular, sometimes deep serrations or lobes, through to deeply palmately lobed into 3 segments, generally 6–10 cm long, 4–9 cm wide (L:W 1–2), margin irregularly serrated; petals deep rose, <7 cm long, petal veins rose/deep rose, distinctive serrated dark red basal zone (c. 2.5–3.0 cm), stigma pads crimson; average ratio of pedicel section:flower stalk 0.10.

***Hibiscus* sp. nov. 'Ovalau'**—known only from the island of Ovalau (Lomaiviti province). It differs from other Fijian species in its floral form—conspicuously spirally arranged, narrow petals (<3.3 cm wide), overlapping near base and ± funnel-shaped corolla; style branches erect—and pigmentation; namely, outer petals burgundy–dark red or else rosy pink with broad white margin; anthers cream–pale yellow; filaments, style and stigma pads light pink; average ratio of pedicel section:flower stalk 0.24.

Distribution

Hibiscus storckii is a rare component of cloud forest, >900 m asl, on Taveuni, Cakaudrove province, while the related *Hibiscus* sp. nov. 'Mt Delaikoro' occurs in similar habitats on Vanua Levu. The extent of cloud forest in Fiji is limited, occupying only the ridges on the highest peaks, with a MAR of 5,000–10,000 mm. *Hibiscus* sp. nov. 'Ruby Rose' is known from three locations in



● = *Hibiscus storckii;* ■ = *Hibiscus* sp. nov. 'Mt Delaikoro'; ◆ = *Hibiscus* sp. nov. 'Ruby Rose'; ▲ = *Hibiscus* sp. nov. 'Ovalau'

Fiji, all in lowland (50–200 m asl) tropical moist forest, typically in gravelly sand among volcanic rocks and boulders in open to shaded forest sites adjacent to creeks and rivers: north-eastern Taveuni from Naselesele to Lavena; near-coastal mountain ranges in Macuata province, Vanua Levu; and lowlands of Wakaya Island (Lomaiviti province). The MAR is 3,000–3,500 mm distributed with a strong summer maximum. *Hibiscus* sp. nov. 'Ovalau' is known only from drainage lines in mountainous locations (c. 300–500 m asl) on the island of Ovalau in the Lomaiviti Group.

Uses

Wood—the wood is not known to have been used.

Hibiscus sp. nov. 'Ruby Rose' planted in roadside hedge; Taveuni, Fiji (Photo: L. Thomson)

Non-wood—all Fijian species are rare and highly restricted in nature in Fiji. Their main use is as planted ornamentals both in Fiji and throughout the lowland tropics and subtropics. Both *Hibiscus* sp. nov. 'Ruby Rose' and *Hibiscus* sp. nov. 'Ovalau' have been widely used in tropical *Hibiscus* breeding programs, and likely involved in the ancestry of hundreds of modern hybrid cultivars.

Hibiscus storckii flower used as an ear decoration (*tekiteki*); Taveuni, Fiji (Photo: L. Thomson)

Diversity and its importance

The Fiji *Lilibiscus* species have arguably the most spectacular and ornamental flowers in the section. They have contributed to modern tropical *Hibiscus* hybrids which are widely planted ornamentals in the tropical, subtropical and warm temperate zones. In cooler climates, tropical *Hibiscus* specimens are also widely used as expendable potted plants. The main observed genetic diversity is in petal colour both for *Hibiscus* sp. nov. 'Mt Delaikoro' which may vary from white to pink and *Hibiscus* sp. nov. 'Ovalau' which may vary from white to dark red, and in retention of juvenile foliage on old plants of both species. *Hibiscus* sp. nov. 'Ruby Rose' shows minor variations in petal size and pigmentation. The genetic diversity in the three new Fijian species may be important for resistance to pests and diseases, although *Hibiscus* sp. nov. 'Ovalau' appears especially attractive to leaf-eating insects. Further research into these species is likely to reveal intraspecific variation in other horticulturally important characters.

White-petalled variant of *Hibiscus* sp. nov. 'Mt Delaikoro' (Photo: L. Thomson)

Conservation of genetic resources (including threats and needs)

Although yet to be classified by IUCN, we consider *H. storckii* to be Critically Endangered in the wild based on its highly restricted natural geographical range, fragmented on mountain peaks (>900 m asl) on two Fijian islands, Vanua Levu and Taveuni, while *Hibiscus* sp. nov. 'Mt Delaikoro' is currently known only from three mature individuals in the wild on Mt Delaikoro. *Hibiscus* sp. nov. 'Ruby Rose' is considered Vulnerable due to its small population size (likely <1,000 mature plants in the wild), restricted distribution (known with certainty from only two locations) and threats from extreme climatic events, especially tropical cyclones and flooding, given its riparian distribution. From our assessment, *Hibiscus* sp. nov. 'Ovalau' is Critically Endangered in the wild following the total loss of the only known population near Mt Tomuna due to extensive landslips associated with Tropical Cyclone Winston in early 2016. There is an urgent need for further field surveys to identify additional populations and individuals of the four endemic Fiji *Hibiscus* species and to immediately implement complementary in situ and ex situ conservation strategies for the three Critically Endangered species (Thomson and Thomas 2017). It is further recommended that NatureFiji-MareqetiViti, together with Botanic Gardens Conservation International and Savurua Botanical Gardens, develop specific Fijian *Hibiscus* research and conservation proposals to submit to donors.

Authors: Lex Thomson and Luca Braglia

Inocarpus fagifer

Family: Fabaceae
Botanical name: *Inocarpus fagifer* (Parkinson) Fosberg. In *J. Wash. Acad. Sci* 31: 95 (1941) (spelt *Inocarpus fagiferus*).

The genus name is derived from the Greek *ino*, fibre, strength, and *carpos*, fruit, referring to the hard, drupaceous fruit. The specific epithet *fagiferus* is Latin for 'country'.

Common names: Tahitian chestnut, Polynesian chestnut (English); *châtaignier de Tahiti* (French); *i'i* (Cook Islands); *ivi* (Fiji, Solomon Islands); *te ibi* (Kiribati); *ihi* (Marquesas Islands, French Polynesia); *ifi* (Nuie; Samoa; Tonga; Wallis and Futuna); *aila* (PNG); *mworopw* (Pohnpei, FSM); *mape* (Society Islands, French Polynesia); *naqi* (Solomon Islands); *namambe* (Vanuatu); and others

Summary of attributes and why diversity matters

Inocarpus fagifer is a fast-growing species with wide adaptability in tropical humid zones and with multipurpose utility, especially known for the food value of its kernels. As a result, it ought to be a major component of multispecies agroforestry and reforestation programs in swampy, mangrove or low-lying coastal areas in high rainfall regions of the Pacific Islands.

Significant intraspecific variation has been observed in leaf and fruit shape and colour, with farmer-selected cultivars recognised in Samoa, Tonga and Vanuatu. There is great scope for a range-wide selection and breeding program to improve commercial traits in this species, especially kernel size and value as human food.

Above: Mature stand of *I. fagifer*; Lotofoa Swamp, Foa, Ha'apai, Tonga (Photo: D. Bush)
Top right: Flower spike (Photo: L. Thomson)
Bottom right: Fruit (Photo: B. French)

Description

Habit medium to large tree 10–30 m tall, often >75 cm dbh (in mature specimens) with a rounded spreading crown, trunk deeply fluted with large, wavy buttresses often ascending for many metres. ***Bark*** dark grey-brown, rough with numerous small swellings. ***Slash*** pale brown/creamy white on white wood, sap red. ***Leaves*** simple, alternate, leathery, petiolate, arranged in 1 plane of the stems, oblong, large, 16–40 cm long, 7–13 cm wide, margin entire, apex obtuse to emarginate, base obtuse-cordate, shiny green above, pale green below, glabrous. ***Inflorescences*** small terminal spikes at the apex of branches, stems and twigs. ***Flowers*** fragrant, c. 1 cm long, 5 mm wide; calyx white or pale pink, tubular-campanulate, thinly membranous and bilobed; petals 4–6, erect with curved tips, yellowish-white, glabrous; stamens 8–12; ovary subsessile with 1 ovule; style short with oblique stigma. ***Fruit*** subglobose, large, compressed laterally, 4.5–13.0 × 3.5–12.0 cm, green to yellow or orangey-yellow when ripe with a tough fibrous outer covering and a leathery inner layer, indehiscent, containing 1 seed. ***Seed*** large, 2–7 × 1.5–4.0 cm,

white, reniform, encased in thin, brown, fibrous testa. ***Reproductive phenology*** generally flowers (November–December) and fruits (January–February the following year) once a year although 2 seasons have been reported in Fiji.

Distribution

The species is native to Malesia and is naturalised after ancient introduction to Micronesia (Kiribati, Marshall Islands and Pohnpei in FSM), Melanesia (Fiji, PNG, Solomon Islands and Vanuatu) and Polynesia (Cook Islands, French Polynesia as far east as the Marquesas Islands, Samoa and Tonga). It is widely cultivated in the Pacific Islands as well as in Indonesia (especially Java and Sulawesi), Malaysia, the Philippines and occasionally in the neotropics. It has been introduced into Hawaiʻi, USA, in recent times.

Inocarpus fagifer is a species of the humid tropics with MAT of 24–28 °C and MAR of 1,500–4,300 mm, evenly distributed. It is common to abundant in disturbed lowland forest, particularly in poorly drained areas, on inner margins of mangroves, and along streams. Altitudinal range is from sea level to 500 m asl. It tolerates a wide range of light to heavy soils, from mildly acidic to very alkaline or saline coastal soils. The species is a fast-growing, nitrogen-fixing tree which coppices and self-prunes well, is cyclone resistant but is not drought or fire tolerant.

Uses

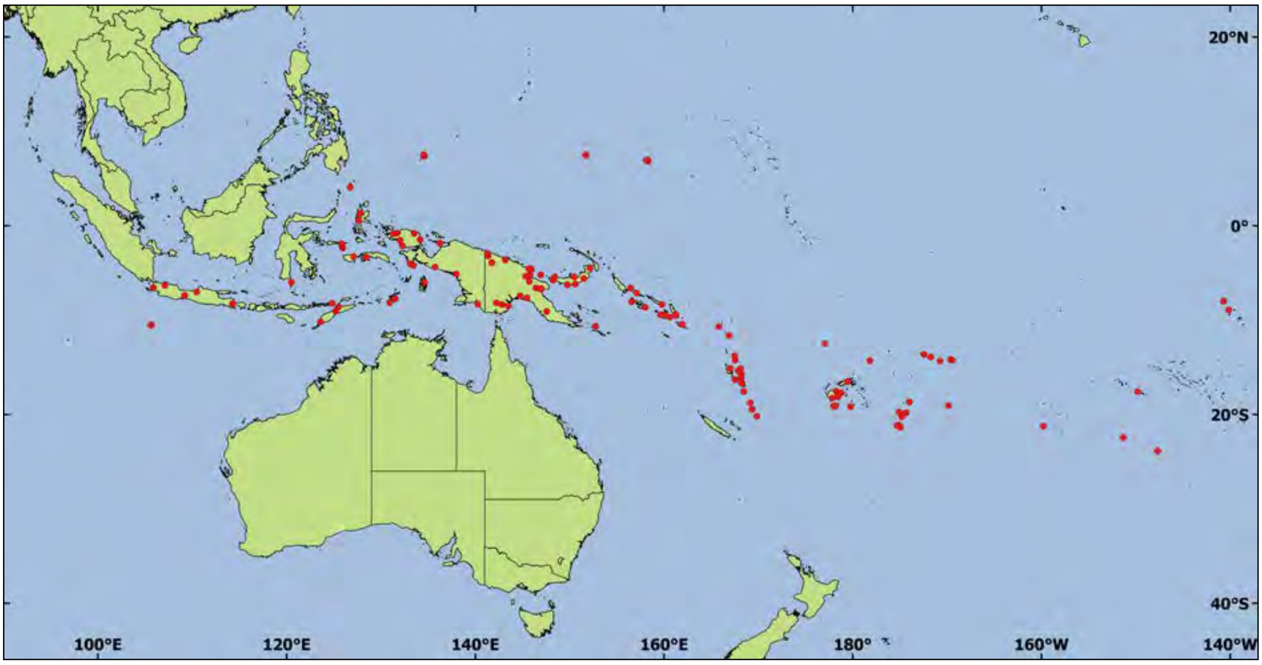
Inocarpus fagifer is an important agroforestry species that grows well with other multipurpose tree species.

Wood—the wood is sometimes used in general construction, furniture, wood carving, poles, canoe parts, tool handles, kava bowls, *tapa* beaters (used in making traditional bark cloth) and packing boxes. It makes good firewood.

Non-wood—a good candidate species for inclusion in home gardens, particularly as a boundary line species for shade, windbreak and a companion crop, and for coastal protection. It has vast, largely untapped potential for protecting river and creek banks from erosion while at the same time providing an economic crop.

Inocarpus fagifer is cultivated for its large, yellowish seed that is edible when cooked, and which is commonly strung on a skewer and sold in local markets. It is an important heavy and filling seasonal food source that is low in fat and high in carbohydrate which requires relatively little effort per unit of calorie consumed. In addition to the local market, there is a potential ready market available among expatriate Pacific Islanders in

Beach protection provided by interlocking roots of *I. fagifer* tree near freshwater seep; Qaranivai, Dogotuki, Vanua Levu, Fiji (Photo: L. Thomson)



Seed kernels of *I. fagifer* being sold in local market; Nausori, Fiji (Photo: L. Thomson)

New Zealand and Australia. However, *I. fagifer* imports are currently insignificant due to quarantine (fruit fly) and kernel perishability problems when removed from the fruit. New technologies being developed to increase shelf life, such as minimal processing being developed by the University of the South Pacific's Institute of Applied Sciences, may change this situation and open up potentially large new markets. Yet, major postharvest handling challenges remain.

The kernel of *I. fagifer* provides good feed for scavenging chickens. The leaves, bark, stems, sap and roots are used in traditional medicine. In Tahiti, French Polynesia, the bark is a source of dye, while gum from fruit is used for caulking canoes in Wallis Island. The large, mature leaves have many uses, including as fodder for cattle, wrapping parcels, sewn together to make sails for boats in Wallis and ground cover under mats in Tonga. In Fiji, the tender, juvenile leaves are edible and used to cover the food in the traditional pit oven, before it is buried with soil. The leaves are also used as stuffing. The flowers provide an attractive bee forage and wild honey bees use its hollows and overhangs for hive sites.

Diversity and its importance

Pauku (2006) states:

> Tahitian chestnut displays a variety of forms. There is great diversity in leaf and fruit size, shape and colour. In Vanuatu, four morphotypes can be distinguished mainly by fruit shape and colour—the most common morphotype bears broadly rounded or quadrangular fruits that are green or brown at maturity. Significant intraspecific variation was observed in fruit shape and colour in the Solomon Islands, but a quantitative characterization study is needed to accurate determine the extent to which this occurs elsewhere. Typically, the species has buttresses at the base of the trunk, but a type found east of Johore, Sarawak, and Sabah does not form these.
>
> Given the great diversity in the size, shape, colour, and form of the tree and its leaves, flowers and fruits and its long history of cultivation, it is highly likely that Tahitian chestnut has a number of farmer-selected cultivars that have not been formally recognized or described.

A number of cultivars or varieties are recognised in Samoa and Tonga. In Fiji, it is reported that certain trees produce better quality fruit for consumption (Sairusi Bulai, pers. comm.) and these individuals ought to be targeted during seed collection for reforestation and catchment restoration programs.

Conservation of genetic resources (including threats and needs)

Inocarpus fagifer remains fairly common throughout its natural and cultivated range and there are currently no general conservation concerns.

No major pests or diseases are known to attack mature foliage. Developing flowers and fruit are susceptible to fruit flies. Severe fruit-fly infestation may result in total loss of the edible kernel, with some types appearing more resistant to fruit-fly attack than others.

Author: Lex Thomson

Intsia bijuga

Family: Fabaceae
Botanical name: *Intsia bijuga* (Colebr.) Kuntze. In *Revis. Gen. Pl.* 1: 192 (1891).

The origin of the genus name is uncertain, while the specific epithet is from the Latin *jugum*, a pair of opposite leaflets. Two varieties of *I. bijuga* have been described; namely glabra and hirsuta. These are considered to be local modifications with little taxonomic significance.

Common names—the species has many common names:

- **trade name** is merbau and it is also known internationally under the names Moluccan ironwood, Borneo teak (English) and *cohu*, *faux teck* (French)
- **Asia**—*merbau*, *merbo*, *merkau*, *merkau ajer*, *taritish* (Indonesia); *merbau ipil* (Malaysia); *ipil laut*, *ipil* (Philippines); *pradu thale*, *maka-mong*, *lumpho-thale*, *lumpaw* (Thailand); *go nuoc* (Vietnam)
- **Indian Ocean**—*hinsty*, *tsararavina* (Madagascar)
- **Micronesia**—*kuren*, *nityanmis*, *tuamis* (Chuuk, FSM); *ifit*, *ifet*, *ipil* (Guam; Northern Mariana Islands); *kubok*, *kubuk* (Marshall Islands); *dort*, *wantal* (Palau); *choyo*, *show*, *kebuk* (Pohnpei, FSM); *dort*, *thort*, *zort*, *zolt*, *show*, *wantal* (Yap, FSM)
- **Melanesia**—*vesi*, *vesi dina* (Fiji); *kohu* (New Caledonia); *kwila*, *iban*, *mboan*, *bon*, *menau* (PNG); *yia nwola*, *vei*, *nkengia*, *kivili*, *huhula*, *rurula*, *gugura*, *u'ula* (Solomon Islands); *tora*, *tor*, *atora*, *nator*, *natora*, *n'tor* (Vanuatu)
- **Polynesia**—*fesi* (Rotuma, Fiji); *ifilele* (Samoa); *fehi* (Tonga).

Summary of attributes and why diversity matters

Intsia bijuga is among the most valued multipurpose timber trees within its zone of occurrence. It is especially highly regarded for its attractive, durable and strong timber. *Intsia bijuga* is also an ornamental, long-lived amenity tree which has many service functions and roles, including coastal protection, and climate change adaptation and mitigation. Its bark is used in a multitude of traditional medicines and remedies. Furthermore, it is a tree species of immense sacred significance throughout the Pacific Islands, including Micronesia, Melanesia and Polynesia.

There is diversity in wood properties between different populations and individuals which is exploited by traditional wood users both in building and in carving. *Intsia bijuga* is among the species of highest priority for conservation, genetic research, selection and improvement in the Pacific Islands.

Description

Habit medium-size tree, attaining 7–35 m tall at maturity, with a stout and often fluted bole; in forest situations the trunk is long and straight, while in open or coastal situations the bole may be crooked and leaning. ***Bark*** attractive, mottled/flaky, light yellowish-brown/greyish. ***Leaves*** pinnately compound usually with 4 leaflets each 8–15 cm long, broadly elliptic,

Bark (Photo: B. Clarke)

Buds and flowers; Asau, Savai'i, Samoa (Photo: L. Thomson)

Top left: Open-grown specimen with Prof. Randolph Thaman; Vava'u, Tonga (Photo: L. Thomson)

Top right: Pod and seed; Daku, Kadavu, Fiji (Photo: L. Thomson)

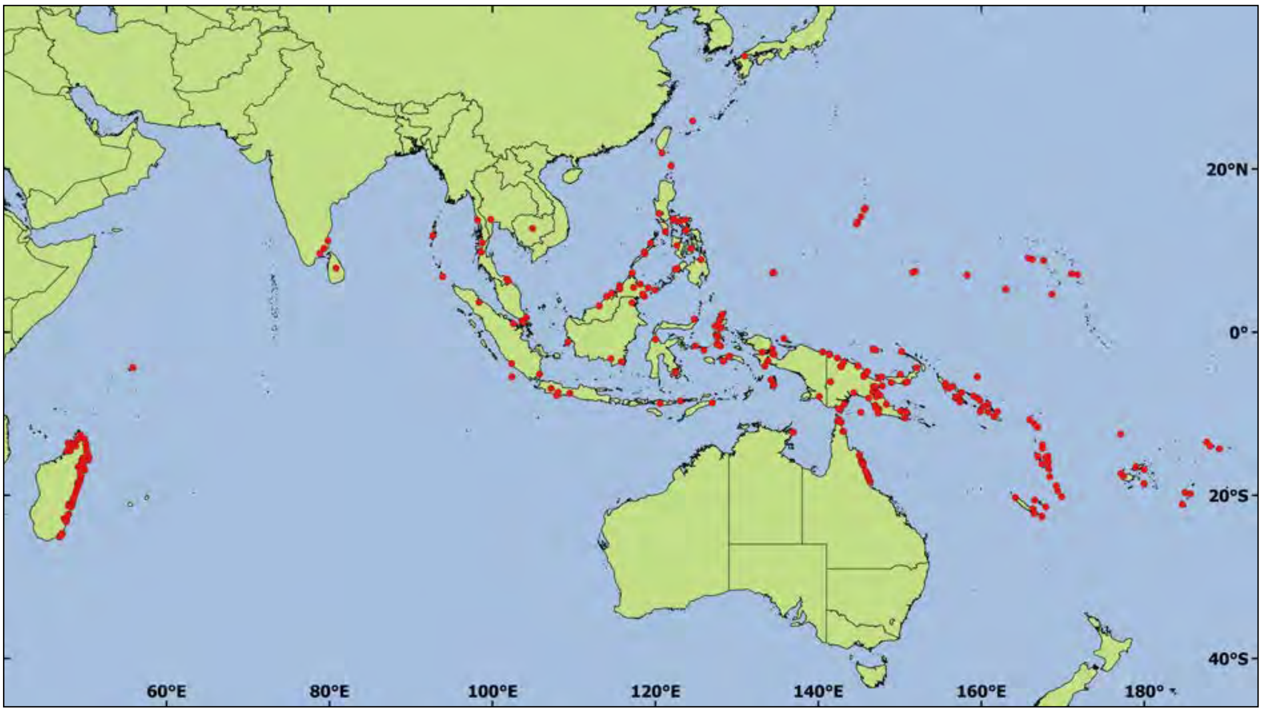
Bottom left: Pods and foliage (Photo: L. Thomson)

Bottom right: Mature tree; Malekula, Vanuatu (Photo: L. Thomson)

asymmetrical, medium to dark green. ***Inflorescences*** axillary or terminal panicles, short, dense, spreading, many flowered. ***Flowers*** bisexual, moderately large with 4 greenish sepals; corolla reduced to 1 large round/reinform petal (c. 1.5 cm across), white (red at base), pink-purple or red; stamens 3, filaments 3.5–5.0 cm long, red, with 4–7 red staminodes. ***Pods*** thick, rigid, oblong or pear-shaped, 16–25(–30) cm long, ≤10 cm wide, containing 2–8 seeds. ***Seed*** dull-brown, rounded, flattened, highly variable in shape and size, usually about 2–4 cm wide, with a hard seed coat.

Distribution

Intsia bijuga is found from the western Indian Ocean in eastern Madagascar and the Seychelles, through to India*, South-East Asia (Cambodia, Indonesia, Malaysia, Myanmar, Philippines and Thailand) and northern Australia (Queensland and Northern Territory**).



It is widespread in the Pacific Islands, including Melanesia (Fiji, New Caledonia, PNG, Solomon Islands and Vanuatu), the northern Pacific (southern Japan**), Micronesia (Palau, Guam, FSM—Chuuk, Pohnpei and Yap—and the Marshall Islands*) and Polynesia (American Samoa, Samoa and Tonga*). Some occurrences near the extremities of its range are considered rare and endangered (**) while others may be human introductions (*).

Intsia bijuga is found in lowland tropical rainforest with a uniformly distributed MAR range of 1,500–2,300 mm, and MAT of 26–27 °C. It has a broad tolerance of a wide range of site conditions. It is found in coastal and lowland forest and dry forest on limestone rock (makatea). It is also found on the edge of mangroves and in inland forests up to an elevation of 500 m asl. It is tolerant of periodic drought, sea spray and brackish soils (with good drainage and well aerated).

Uses

The cultural significance of *I. bijuga* is diverse and embedded in many Pacific Island cultural expressions and beliefs. The tree itself is considered sacred throughout the Pacific Islands—including Melanesia, Micronesia and Polynesia. In Fiji, its hardness and seemingly indestructible nature embodied admired human qualities. The tree was used as the main pole to hold up traditional temples and chiefly houses, to build the sacred canoe reserved for nobles, and to make the traditional gong used to announce important events. Many Fijian expressions incorporate the word *vesi* to indicate a person of noble birth or one of strong character.

Wood—*I. bijuga* produces a highly valued, naturally durable, strong and attractive timber with low shrinkage and good seasoning properties, although sawing and machining is sometimes difficult. It is a timber of choice for local construction, heavy construction (poles, sleepers, wharves, bridges) as well as for local

Furniture made from *I. bijuga* timber; Santo Joinery, Lugainville, Espiritu Santo, Vanuatu (Photo: L. Thomson) implements, heavy-duty flooring and outdoor furniture. *Intsia bijuga* is also a preferred species for traditional carving in the Pacific Islands, including for making handicrafts, kava bowls and durable canoes.

Non-wood—in Fiji, locals often use the juice extracted from the bark of the species for internal injuries. A decoction of the bark is used to treat rheumatism, chills, diarrhoea and, with the extracts of other plants, to treat broken bones. The juice of the stems is reputed to be used to treat asthma and the juice of the inner bark to treat pains in the bones, colds and influenza. *Intsia bijuga* has considerable potential as an ornamental, amenity tree in tropical landscaping.

Diversity and its importance

The genetic diversity within *I. bijuga* has yet to be properly investigated, although is likely to be substantial given its vast natural distribution in coastal regions throughout the Indian and Pacific oceans. Plants from different parts of the natural range are expected to have differing growth rates and adaptability to different climates and soils, which could be exploited for better performance in mixed forest plantings and agroforestry systems.

Variation has often been reported in wood properties, some of which may be explained by environmental factors that affect growth rate. In Madagascar, the wood ranges from yellowish and comparatively soft to reddish-brown and hard. In Samoa, where *I. bijuga* is a favoured timber for house posts, furniture, carving and kava bowls, several varieties are recognised based on wood properties (colour, hardness and grain straightness), including *ifilele ulu*, *ifilele oʻa*, *ifilele alaʻa*, *ifi toa*, *ifiʻulu*, *ififatu* and *ifisoga*. The variety *ulu* mainly refers to trees with softer wood and straight grain while the variety *toa* refers to the trees with harder wood and interlocked grain (Soʻoalo Tito Alatimu, pers. comm.).

In Vanuatu, two varieties of *I. bijuga* are recognised on Malekula and Espiritu Santo based on their wood properties and habitat: one is a smaller growing tree, a mangrove associated with river mouths; while the taller tree form is found growing in river valleys (Chanel Sam, pers. comm.).

Considerable variation has been reported in trees growing in Madagascar, including morphotypes with smaller leaves, fruit and seed. *Intsia bijuga* has considerable potential in tropical landscaping and, if the species were to be further developed in this role, then the different flower colour morphs might be utilised.

Conservation of genetic resources (including threats and needs)

Intsia bijuga is considered Vulnerable (IUCN Red List) and fast approaching commercial extinction: it is endangered throughout much of its native range, with almost all accessible and merchantable larger trees having been harvested. For example, in Fiji, Japan and PNG, *I. bijuga* is becoming rare and threatened by unsustainable logging. In Kabara Island, in Fiji's Lau Group, the World Wide Fund for Nature (WWF) has been working with local communities to sustainably manage their *Intsia* trees. It was determined that the conservation and management of *I. bijuga* in Kabara will require careful monitoring of the rate of felling and timber consumption by local people, including through recordkeeping of handicrafts production, as well as educating local people about the need for conservation, protection and replanting.

In Samoa, *I. bijuga* is considered to be one of the promising species for conservation and genetic improvement due to its local importance for woodcarving and its threatened status in the wild. The species has also declined in its Indian Ocean island habitats; for example, in Madagascar, remaining significant stands are few and restricted to protected and inaccessible localities along the eastern coast.

Authors: Lex Thomson, Randolph R. Thaman, François Martel and Craig Elevitch

Macadamia integrifolia and *M. tetraphylla*

Family: Proteaceae
Botanical names: *Macadamia integrifolia* Maiden & Betche. In *Proc. Linn. Soc. NSW* 21: 64 (1897); *M. tetraphylla* L.A.S.Johnson. In *Proc. Linn. Soc. NSW* 79: 15 (1954).

Macadamia was formally described in *Transactions of the Philosophical Institute of Victoria* 2: 62–73 (1857) by Ferdinand von Mueller who dedicated the genus to John Macadam, honorary secretary (and later president) of the Philosophical Institute of Victoria. The specific epithet *integrifolia* is derived from the Latin *integer*, entire, plus *folium*, leaf, referring to the entire margins of the adult leaves; while *tetraphylla* is from the Greek *tetra*, four, and *phylon*, leaf, referring to the grouping of leaves in whorls of four.

Common names: *M. integrifolia* is often described as 'smooth shell' macadamia, with 'rough shell' used for *M. tetraphylla*. The fruit of macadamias is variously known as macadamia nut, Australian nut, Queensland nut, Bauple nut, bopple nut, popple nut, Gympie nut, Marrochie nut or bush nut. Macadamia has also been called the Hawaiian nut due the role of this USA state in the commercialisation of the crop.

Aborigines of the Mt Bauple region refer to macadamia (*M. integrifolia*) as *jindilli* and further south *M. tetraphylla* is known as *kindal kindal*. In the Pine Rivers, north of Brisbane, where *M. ternifolia* and *M. integrifolia* co-occur, the local name is *burrawang*.

Summary of attributes and why diversity matters

These *Macadamia* species are typically small to medium–size trees adapted to subhumid and humid conditions and well-drained, fertile soils. Macadamia is the only Australian plant to have been widely developed as an international commercial food crop. The preferred species for cultivation is *M. integrifolia*, particularly as the edible kernel produced by this species is considered to be of the highest quality.

Genetic variation has been reported for a number of commercially important traits. However, most of the world's production of macadamia is based on cultivars developed from introductions of *M. integrifolia* into Hawai'i, at the end of the 1800s. This germplasm has a narrow genetic base, suggesting opportunities for genetic improvement to support the further development of the crop. Use of related species may also offer possibilities for extending the climatic range of the crop and as a source of novel traits.

Description

Habit all *Macadamia* species in the wild generally occur as small shrubs and bushy trees, with trees to 40 m tall being rare; in natural populations, macadamias generally exist as subdominant components of the rainforest canopy; trees may be spindly shoots or multistemmed with or without buttressing; macadamias in cultivation are trained to a central leader system. ***Bark*** greyish-brown, smooth or finely wrinkled, with numerous cream horizontal lenticels. ***Leaves*** *M. integrifolia* mature leaves shiny, oblong to obovate with a blunt apex, stiff textured,

Flowers and fruit of *M. integrifolia* (Photo: © M. Fagg, ANBG)

Multistemmed tree habit of *M. integrifolia*; Hawai'i, USA (Photo: F. & K. Starr)

Top left: Commercial macadamia plantation; Beerwah, south-eastern Queensland, Australia (Photo: S.H. Bai)

Bottom left: Flower spikes (*M. integrifolia* × *M. tetraphylla*) (Photo: S. Trueman)

Top right: Cluster of young fruit (*M. integrifolia* × *M. tetraphylla*) (Photo: S. Trueman)

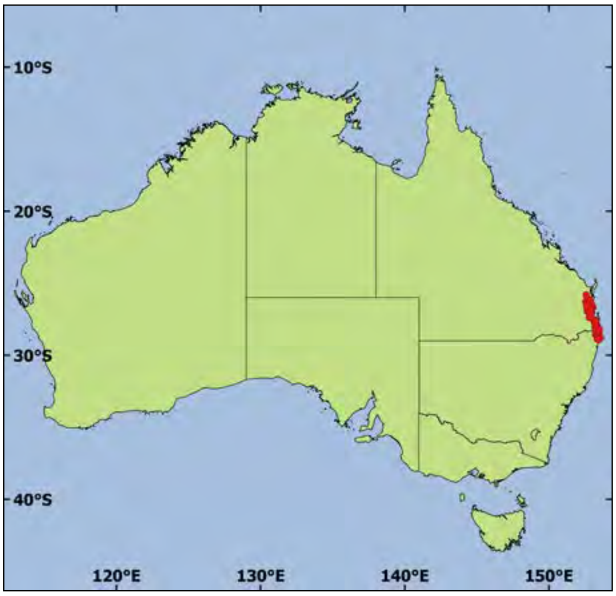
Middle right: Fruit and nuts at different stages of maturity (*M. integrifolia* × *M. tetraphylla*) (Photo: S. Trueman)

Bottom right: Nuts and kernels (*M. integrifolia* × *M. tetraphylla*) (Photo: S. Trueman)

wavy or slightly prickly margins when young, entire in later stages, in whorls of 3, 10–30 cm long, 2–4 cm wide; *M. tetraphylla* simple, oblong or oblong-lanceolate, abruptly rounded to a short sharp point at the tip, rigid in texture with the margins always prickly-toothed with 35–40 teeth on each side, in whorls of 4, 18–25 cm long, 2–5 cm wide. ***Inflorescences*** long, pendulous, cylindrical axillary racemes, ≤30 cm long. ***Flowers*** *M. integrifolia* white, up to 12 mm long; *M. tetraphylla* creamy pink to mauve, 10 mm long. ***Fruit*** globular, green at first, maturing brown, ≤35 mm across; hard outer covering and also a hard inner shell which conceals the seed or kernel. ***Seed*** ≤30 mm across; *M. integrifolia* globose and smooth; *M. tetraphylla* pointed at the apex and warty.

Distribution

Macadamia integrifolia and *M. tetraphylla*, along with two closely related macadamias, *M. ternifolia* and *M. jansenii*, occur in subtropical rainforest within 100 km of the eastern coast of Australia. *Macadamia integrifolia* is the most widely distributed species in this southern clade. Natural populations occur from Mt Bauple near Maryborough, Queensland, south to the Gold Coast hinterland, a distance of approximately 275 km. *Macadamia tetraphylla* grows in the coastal rainforest of the Richmond and Tweed River catchments in northern New South Wales and north to Mt Wongawallan, Queensland, about 50 km south of Brisbane, with populations distributed over about 100 km.



Trees with intermediate morphology between *M. integrifolia* and *M. tetraphylla* occur in natural populations in south-eastern Queensland where the distributions of the species overlap. The natural hybrid zone was believed to cover only a few kilometres; however, recent molecular analyses suggest the zone may be as wide as 20 km with a clear gradient in species composition of individuals across the hybrid zone. This suggests that hybrids are fully fertile and hybridisation has occurred over several generations. Controlled-crossing and grafting studies are further evidence of compatibility among the species. The distribution of *M. ternifolia* overlaps with that of the southern distribution of *M. integrifolia*. The existence of hybrid genotypes in these populations has been confirmed by DNA marker studies.

Macadamia integrifolia and *M. tetraphylla* occur in warm subhumid and humid zones at altitudes from near sea level to 500 m asl. Mean maximum temperature of the hottest month is 26–30 °C and the mean minimum of the coolest month is 8–12 °C. Temperature is the major climatic factor determining growth and productivity, with the optimum during the growing season being 25 °C. The species withstand only short-term, mild frosts. The minimum annual rainfall for successful growth is about 1,000 mm, well distributed throughout the year. They are best suited to deep, well-drained soils with good organic matter content and a pH range of 5–6. They are intolerant of heavy impermeable clays and saline or calcareous soils.

Uses

Macadamia integrifolia and *M. tetraphylla* are utilised primarily for their edible kernels. Kernels produced by *M. ternifolia* and *M. jansenii* are not edible, unless treated to remove cyanoglycosides.

Wood—the wood of *M. tetraphylla* is reddish and considered of good ornamental value, but the value of the kernel precludes the use of the species for timber production. Early experience in Hawai'i suggested that the wood is prone to checking on drying.

Non-wood—early settlers and botanists observed the widespread use of at least two different species of macadamia by Indigenous Australians. *Macadamia tetraphylla* is recognised as an important food source in contemporary Indigenous oral histories and there are reports that Indigenous people traded macadamias with settlers in the mid to late 1800s. Macadamia is the only internationally important commercial food crop developed from the Australian flora, with the crop initially developed in Hawai'i from the 1930s. The highly valued edible kernels are generally consumed as roasted snack food, chocolate-coated confectionary, ingredients in bakery products and ice-cream, and as edible oil. Macadamias can be characterised as a luxury good, as demand is elastic with income.

The high monounsaturated content (c. 78% of total lipids) may have potential health benefits. The oils are

Macadamia nuts being collected, with Bruce Randall; Beerwah, south-eastern Queensland, Australia (Photo: S.H. Bai) primarily oleic acid (18:1, 58% of monounsaturated lipids) and palmitoleic acid (16:1, 40% of monounsaturated lipids). This is the highest concentration of palmitoleic acid of any natural food. Polyunsaturated fats make up c. 5% of total lipids while saturated fats make up <20% of total lipids. Macadamia oil is suitable for use in cosmetics. The press cake remaining after oil has been extracted can be used as a replacement for full-fat soybean meals. The shell of macadamia appears suitable for the production of charcoal and activated carbon. It has also been suggested that the shell flour could be used as filler in plastics and adhesives. The outer husk of the macadamia fruit is used for soil amelioration or potting mix.

Diversity and its importance

A comprehensive DNA study of over 300 accessions from the wild of the four species of the southern clade concluded that *M. integrifolia* and *M. tetraphylla* were the most closely related species with *M. ternifolia* more closely related to this pair than to *M. jansenii*.

Many of the original seedling orchards in Australia appear to have been based on *M. tetraphylla*, although most of this germplasm seems to have been lost. In Hawai‘i, the development of dependable grafting techniques in the 1930s enabled the propagation of elite cultivars and supported the commercialisation of the crop. Cultivars developed in Hawai‘i produce much of the world's production; however, the base population of this selection program was almost entirely derived from two introductions of *M. integrifolia* in the late 1800s. DNA evidence suggests the natural origin of these cultivars is the northern range of *M. integrifolia* and that the diversity of the Hawaiian germplasm was much lower than available from the wild for this species. Due to limited selection history and low selection accuracy (use of mass selection of seedlings in orchards), it is highly unlikely this represents the only source of elite germplasm in the crop.

In Australia, several cultivars were produced from a selection program undertaken by state agriculture departments in the early 1950s. A series of cultivars was also selected in the 1950s and 1960s from the collections and plantings of Norm Greber, an early enthusiast. Three cultivars produced by a private breeding program (Hidden Valley Plantations, Queensland) initiated in 1972 were granted plant breeder's rights, and these and their newer cultivars have been adopted commercially in Australia, China and South Africa. Most of these are of hybrid type. A long-term breeding program based on a quantitative genetic approach using index selection was initiated in Australia in 1993. Cultivars have also been developed in Brazil, Israel, Kenya, New Zealand, South Africa and California, USA.

Genetic variation is evident for most selection criteria. Individual broad-sense heritability has been estimated from a trial of 40 cultivars planted at 4 sites, although this may underestimate the extent of genetic variation in progeny trials as it is a selected population. Heritability was high (>0.5) for kernel recovery (kernel mass/nut mass) and kernel size, moderate (>0.3) for canopy width and percentage whole kernel, and low (<0.2) for percentage oil content and yield. Significant genetic correlation was observed between kernel recovery and kernel size, but not between yield and tree size. Significant differences among cultivars also indicate genetic variation for a number of traits including: propagation success (seed germination, strike of cuttings, nursery growth and budding success); resistance to wind damage; number of fruit set per raceme; and phenology of fruit drop. However, little is known of the genetic architecture of key attributes of kernel quality and the effect of rootstock on scion properties. The potential of related species also remains unexplored.

There is considerable morphological variation among species. However, these characters may vary greatly within species and due to hybridisation, making classification difficult. Of particular interest is variability among

Variation in size of macadamia nut kernels (Photo: C. Hardner) species for the presence of elevated concentrations of cyanogenic glycosides in the kernel. These compounds impart a bitter taste and may be toxic in some cases. *Macadamia integrifolia* and *M. tetraphylla* have low levels of these compounds in mature seed but the concentration is over 100 times higher in the seed of *M. ternifolia*. Kernels of *M. jansenii* also contain detectable levels of cyanoglycosides.

Conservation of genetic resources (including threats and needs)

The limited development of the domesticated germplasm suggests that genetic resources will be important for the ongoing development of the crop, but conservation of domesticated and wild germplasm is limited. The USDA Pacific Basin Tropical Plant Genetic Resources and Disease Research germplasm repository has 41 accessions of developed cultivars from Australia, Brazil, California, Hawai'i and Thailand. Apart from this collection, no other efforts for conservation of domesticated germplasm have been reported in Australia or elsewhere.

Macadamia integrifolia and *M. tetraphylla* are here considered to be Vulnerable in the native habitats. In situ conservation of *M. integrifolia*, *M. tetraphylla* and *M. ternifolia* is threatened by land clearing and vegetation disturbance associated with the expansion of intensive agriculture and urbanisation. It is estimated that only 10–24% remains of the original extent of the ecosystem types that contain these species. Remnants generally occur as small populations (<50 individuals) in a highly fragmented landscape but recent studies indicate that these populations may be viable, at least in the short term. Fecundity rates are generally higher in disturbed populations compared with larger intact populations, and there is evidence of long-distance (>2.5 km) pollen dispersal that may support gene flow among individual populations. Better knowledge of the distribution, ecology, genetic structure and dynamics of these species is required to support effective in situ conservation planning.

A major collection has been undertaken of cuttings from about 400 trees of *M. integrifolia*, *M. tetraphylla* and *M. ternifolia* across 80 sites. Successfully rooted cuttings have been established in three trial plantations in geographically separate locations for ex situ conservation and testing to identify novel germplasm for future improvement activities.

Authors: Craig Hardner and Bruce Topp

Mangifera foetida

Family: Anacardiaceae
Botanical name: *Mangifera foetida* Lour. (syn. *Mangifera horsfeldii* Miq.). In *Fl. Cochinch.* 1: 160 (1790).

The genus name is derived from two Latin words—Latinised local name, *mangga*, for mango, and *ferre*, bearer, meaning mango-bearing tree. The specific epithet is derived from the Latin *foetidus*, stinking, alluding to the strong-smelling fruit.
Common names: bachang, horse mango (English); *svaay sââ* (Cambodia); *bachang*, *limus*, *asem hambawang* (Indonesia); *thayet-poh*, *lamut* (Myanmar); *bachang*, *badut*, *embang*, *jabing*, *kemantan*, *machang*, *pahu*, *pachu*, *pangin*, *pawak* (Malaysia); *amba* (Sri Lanka); *xoài hôi* (Vietnam)

Summary of attributes and why diversity matters

Mangifera foetida is a mainly lowland rainforest tree that attains a large size at maturity but is relatively slow growing. It is widely cultivated for its fruit in places where it grows naturally in Indonesia and Malaysia. Its timber is also useful for indoor light construction and plywood, but is non-durable in external applications.

Many different fruiting varieties have been identified, propagated and sold in local markets. Vegetative propagation of locally selected varieties, chosen for the compatibility of fruit characteristics with their intended end use, ought to continue to enhance the importance of this species to local communities. As an interbreeding crop and wild relative of the commercial mango, maintaining diversity in *M. foetida* is vital for any future breeding programs where new sources of variation and disease resistance may be needed.

Description

Habit tall tree to 35–40 m tall and 30–100 cm dbh with a straight bole and without buttresses; crown dense with dark green foliage on massive branches. ***Bark*** light brown to dark greyish-brown, shallowly fissured with broad flat ridges, containing irritant whitish sap turning black on exposure. ***Leaves*** elliptic-oblong to broadly elliptic, sometimes oblanceolate, 15–40 × 9–15 cm, stiffly coriaceous, dark green above, clear green below; apex subacute, sometimes rounded or slightly emarginate with a cuneate or attenuate base and ± bullate between the nerves; petiole 1.5–8.0 cm long, stout and swollen at the base. ***Inflorescences*** subterminal panicles, upright, pyramidal, 10–40 cm long, sparsely branched, rather densely flowered and deep reddish-pink; inflorescence axes stout, deeply red to copper red. ***Flowers*** 5-merous, scentless; sepals obovate-lanceolate, 4–5 mm long; petals reflexed, narrowly lanceolate, 6–9 × 1.5–2.5 mm, pale reddish-pink at the base and pale yellow towards the apex; stamens 5 with 1(–2) fertile, filaments connate at the base, about 8 mm long, pinkish-purple, anthers dark violet; ovary subglobose, yellow, with white excentric style 6–7 mm long. ***Fruit*** variable in size and shape; obliquely ovoid-oblong or almost globose drupe, 9–14(–16) × 7–12 cm, dirty dark olive-green

Mature tree; Machang, Melaka, Malaysia (Photo: R.C.K. Chung)

Mature tree in village garden; Malaysia (Photo: S. Idris)

Above left: Fruit and foliage (Photo: S. Idris)

Above right: Fruit, showing yellow flesh colour in cut portion (Photo: S. Idris)

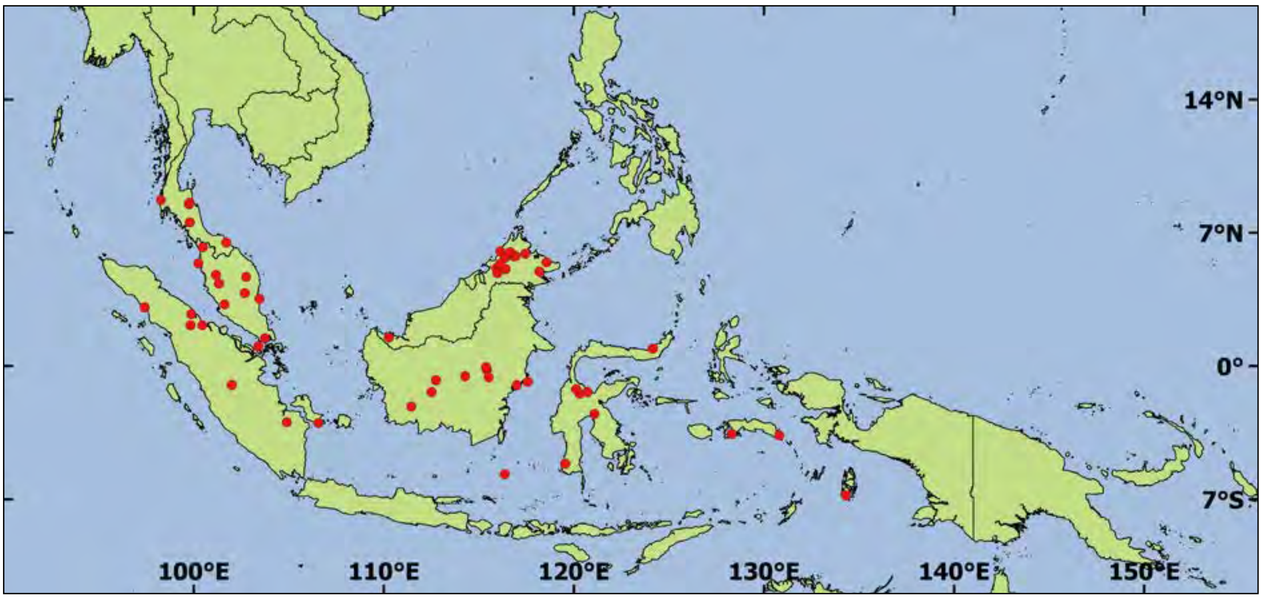
Left: Flowers (Photo: S. Idris)

or yellowish-green; skin c. 5 mm thick, smooth, dull, with brown lenticels; flesh pale orange-yellow or yellow, fibrous, juicy, with strong smell and taste of turpentine when ripe. ***Seed*** mostly mono-embryonic, contained within a coarsely fibrous plump stone 6 × 5 × 3 cm; seed loses viability quickly and only germinates well in the first 4–6 weeks. ***Reproductive phenology*** in Sarawak (Malaysia), flowering is in May–August, fruit ripening in August–November; in East Kalimantan (Indonesia), flowering is in April–September, ripening in August–January; fast-growing individuals produce fruit at 5 years.

Distribution

Mangifera foetida is native to the island of Borneo, other parts of Indonesia (Sumatra, Sulawesi and eastern Indonesia), Peninsula Malaysia and Thailand, and introduced to Cambodia, southern Myanmar and Vietnam. It is widely cultivated in Malesia (Sumatra, Peninsular Malaysia, Java and Borneo). In other South-East Asian countries, it is rarely cultivated.

It is found mainly in lowland rainforest areas, ≤1,500 m asl, with abundant and evenly distributed rainfall (1,600–4,000 mm MAR). Soils are light through to heavy, free draining and of neutral or acidic pH.



Uses

Mangifera foetida is widely cultivated in its area of origin for its fruit. It is rather slow growing and accordingly has low prospects for timber production.

Wood—the wood is non-durable and used for indoor light construction and plywood.

Non-wood—mature fruit are eaten fresh. It is not generally valued as a table fruit. Younger or unripe fruit contain an irritant juice, which has a strong smell and the taste of turpentine, and must be washed in salted water before use in fruit salads or pickles. At maturity, the irritant juice is restricted to the skin, so ripe fruit can be eaten fresh if peeled fairly thickly. In Malaysia, it is used to make chutneys as well as pickles.

The leaves are said to be antipyretic and the seed used in traditional medicine against trichophytosis, scabies and eczema. The juice of the leaves is given for bleeding dysentery, while an infusion of the young leaves is prescribed for chronic diseases of the lungs, coughs and asthma. An infusion or expressed juice of the bark is used in menorrhagia and leucorrhoea. When in flower, *M. foetida* is an attractive ornamental.

Diversity and its importance

Diversity is of enormous economic importance in the main cultivated mango species, *M. indica*, which is believed to have evolved through allopolyploidy. Almost all commercial cultivars of *M. indica* have arisen through seedling selection, with India having around 1,000 distinct varieties of which about 30 are commercially grown.

Similarly, different forms of the fruit of *M. foetida* are recognised by local people. Small, almost globose fruit (e.g. *limus piit* in West Java, Indonesia) are consistently distinguished from large and more oblong ones which are commonly sold in Malay markets. There is also another kind with large, oblong fruit, remarkable for its fine texture and low fibre. In West Java, it is called *limus tipung* (*tipung* meaning flour, referring to its fine texture). A similar kind known as *asem linggau* occurs in East Kalimantan, with a large proportion of fruit having abortive seed. Substantial variability in fruit characters is recorded in Borneo, particularly in South Kalimantan. A striking form, commonly seen in markets in Sarawak, has deep yellow unripe fruits. A program of vegetative propagation (via budding, marcotting and cuttings) of a range of local varieties, selected based on their fruit characteristics, could increase the contribution of this species to local economies.

Mangifera foetida and *M. odorata* are related to *M. indica,* source of the world's mango industry. However, these two species are classified into a different subgenus (*Limus*) from the subgenus *Mangifera* to which *M. indica* belongs. It has been suggested that *M. odorata* is a hybrid between *M. indica* and *M. foetida* due to morphological intermediacy, which appears to be confirmed through molecular marker studies. This also confirms that, despite being placed in different subgenera, *M. foetida* may be genetically much closer to *M. indica* than previously appreciated.

Conservation of genetic resources (including threats and needs)

Mangifera comprises 58 species naturally distributed in South, South-East and East Asia. Many of the crop wild relatives of *M. indica*, including *M. foetida*, are endangered through logging and utilisation for timber. There appears to be no specific conservation and management strategy for *M. foetida*. This species is poorly represented in ex situ collections and appears to be rare in the wild. However, it is cultivated in several parts of Malaysia (Sabah and Sarawak), Indonesia (Kalimantan) and Thailand. Efforts to conserve *M. foetida* on-farm have been made under a Bioversity International project funded by the United Nations Environment Programme (UNEP) Global Environment Facility (GEF) in some areas in these countries.

Authors: L.T. Hong, V. Ramanatha Rao and R.C.K. Chung

Melaleuca cajuputi

Family: Myrtaceae
Botanical name: *Melaleuca cajuputi* Powell. In *The Pharmacopoeia of the Royal College of Physicians of London* (transl.) pp. 21–22 (1809).

Numerous synonyms have been applied to this species. It is often treated in the older literature as *M. leucadendron*. The genus name is derived from the Greek *melas*, black, dark, and *leucon*, white, most likely for the bark of the first described species (*M. leucadendra*) which had burnt, black bark at the base and white papery bark above. The specific epithet is from cajuput, an English name of the oil distilled from the foliage of this species, itself probably a corruption of the Indonesian name for the plant; namely, *kayu putih*. Three subspecies (see descriptions below) are recognised as published in *Novon* 7: 113 (1997): subsp. *cajuputi*; subsp. *cumingiana* (Turcz.) Barlow in honour of Hugh Cuming (1791–1865), a botanist who collected plant specimens in the South-East Asian and Malesian regions; and subsp. *platyphylla* Barlow from the Greek *platys*, broad, wide, flat, level, and *phyllon*, leaf.
Common names: swamp tea-tree, cajuput (sometimes spelt cajeput) (English); *smach chanlos* (Cambodia); *kaya putih* (Indonesia); *gelam* (Malaysia); *samet* (Thailand); *chè dong*, *tram*, *chi cay*, *bach thien tang* (Vietnam)

Summary of attributes and why diversity matters

Melaleuca cajuputi is an adaptable, moderately fast–growing species suitable for cultivation in the wet/dry tropics. It is especially useful on waterlogged sites but will also grow on dry ridges. It is suitable for a wide range of wood and non-wood forest products and is best known as the primary source of the medicinal 'cajuput' essential oil produced mainly in Indonesia and Vietnam.

There is much variation in commercial traits within and between the three subspecies. Nowhere is this more pronounced than in the case of its foliar essential oils where four distinct chemotypes have been recorded. Only one of these chemotypes, the 1,8-cineole–rich form of some provenances of subsp. *cajuputi* and subsp. *cumingiana*, is the source of commercial oil. There is considerable scope for genetic improvement in this species given the extent of the heritable variation present in commercial traits. Careful selection of oil-rich, well-adapted and fast-growing seed sources of the cineole chemotype will be paramount for plantation development aimed at cajuput oil production.

Description

Habit tree or shrub, 2–35(–46) m tall. ***Bark*** papery, grey to whitish. ***Leaves*** dense, dull green, 40–140 mm long, 7.5–60.0 mm wide, 1.3–9.7 times as long as wide, alternate, lanceolate-elliptic, straight or curved, often hairy, 5–9 nerved, compressed petioles 3–11 mm long; oil glands moderately dense, obscure, scattered. ***Inflorescences*** spicate, pseudoterminal and often also

Plantation of mature trees; Indonesia (Photo: A. Rimbawanto)

Inflorescence (Photo: A. Rimbawanto)

Typical paperbark (Photo: A. Rimbawanto)

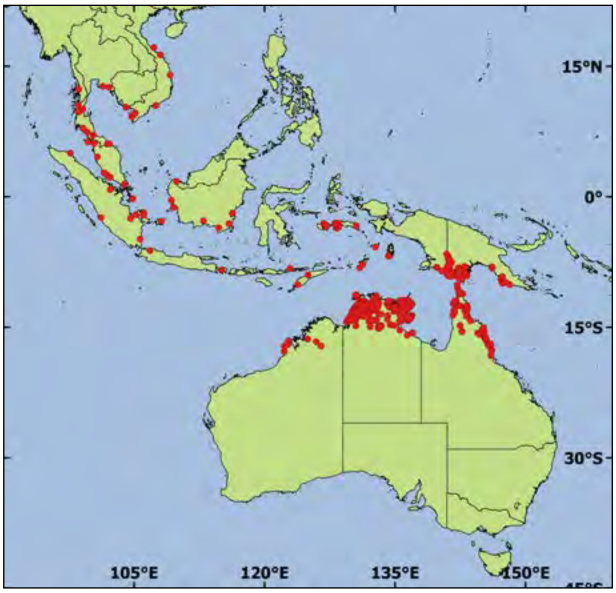
Mature fruit (Photo: A. Rimbawanto)

upper axillary, rarely interstitial, with 8–20 triads, ≤28 mm wide. ***Flowers*** hypanthium hairy or glabrous, 1.5–1.8 mm long; calyx lobes abaxially hairy or glabrous, 0.9–1.5 mm long, scarious in a marginal band 0.15–0.5 mm wide; petals deciduous, 1.7–2.5 mm long; stamens (6–)8–12(–15)/bundle, filaments white, cream or greenish-yellow, 9.0–10.5 mm long, bundle claw 1.0–3.5 mm long, 0.1–0.4 times as long as the filaments; style 7.8–11.2 mm long; ovules 35–55/locule. ***Fruit*** 3 mm long, calyx lobes deciduous; cotyledons obvolute or subobvolute (almost planoconvex). ***Seed*** very small, orthodox.

The three subspecies are distinguished as follows: subsp. *cajuputi*—leaves 2.8–9.7 times long as wide, 7.5–26.0 mm wide; stamens 7–10/bundle, the bundle claw 1.0–1.6 mm long; subsp. *cumingiana*—leaves 2.2–2.9 times long as wide; stamens 7–9/bundle, bundle claw 2.1–3.0 mm long; subsp. *platyphylla*—leaves 1.3–6.5 times long as wide, 15–50 mm wide; stamens 8–13/bundle, bundle claw 1.1–3.5 mm long.

Distribution

Melaleuca cajuputi is the only species out of about 300 in the genus to occur naturally west of Wallace's Line. One study based on allozyme variation in populations east and west of this line led to the hypothesis that the species originated in Australia and has spread north and west due to its propensity for invading disturbed sites. Natural occurrence by subspecies is subsp. *cajuputi*—Kimberley and Top End regions of Western Australia and Northern Territory, respectively, and Maluku Islands of eastern Indonesia; subsp. *cumingiana*—Malaysia, Myanmar, Thailand, Vietnam and western Indonesia (Sumatra, western Java, south-western Kalimantan); subsp. *platyphylla*—northern Queensland in Australia, eastern Indonesia and southern PNG.



This is a species primarily of the hot humid climatic zone. Mean annual rainfall ranges from (540–)1,300 to 3,400(–4000) mm with a strong monsoonal pattern and a dry season of ≤8 months. The species grows in a wide range of situations: subsp. *cajuputi* occurs in woodland, vine forest, gallery forest, savannah forest, on cracking black clay, black peaty sand, and clay loam; subsp. *cumingiana* occurs in coastal swamp forest; and subsp. *platyphylla* occurs in swamp forest, mixed open forest, swamp woodland, tall savannah, sedgeland, on sandy soil and claypans.

Uses

Melaleuca cajuputi is a moderately fast–growing tropical tree adapted to both waterlogged and well-drained soils. It is highly adaptable, being resistant to fire, exposure to salt-laden winds, acid sulfate soils and weed competition. It will coppice, reproduce from root suckers, and develops adventitious roots on soils subject to prolonged waterlogging. These roots are dense in aerenchyma cells which have large intercellular air spaces that improve internal root aeration and gas exchange during inundation and allow plants to survive and grow. *Melaleuca cajuputi* is used for a wide range of wood and non-wood purposes.

Wood—the wood is pale brown, fairly heavy, fine-textured, hard, tough, difficult to season when sawn as it warps and checks, but relatively easy to work. It is durable in contact with fresh or salt water and is generally used in the round or roughly fashioned (e.g. posts, poles, piles, mine timbers, rafters, fencing rails, boat knees and so forth). Woodchips for medium-density fibreboard are produced from *M. cajuputi* in Vietnam. It makes a good fuelwood although difficult to split.

Non-wood—*M. cajuputi* is a useful source of honey in northern Australia and Vietnam. It is sometimes used in urban areas as an ornamental tree. The bark has been used for caulking boats in Malaysia. It is an important source of foliar essential oil throughout South-East Asia and South Asia, with Indonesia and Vietnam the major production centres. The oil has medicinal properties (e.g. liniment, inhalant, mild antiseptic) and is also used in insect repellents and as a fragrance in soaps, cosmetics, detergents and perfumes.

Poles of *M. cajuputi* being transported by boat and then truck to Banjarmasin, South Kalimantan; Indonesia (Photo: W. Giesen)

Diversity and its importance

Significant within- and between- provenance variation in growth rate, survival and especially foliar oil characteristics has been recorded in this species. Different chemical forms predominate in different parts of its natural range. These forms are loosely associated with the three subspecies. *Melaleuca cajuputi* subsp. *cajuputi* is the principal source of cajuput oil. Leaves of this subspecies are usually rich (≤60% or more) in the therapeutic compound, 1,8-cineole. Foliar oil concentration ranges from 0.4% to 1.2% (w/w%, fresh weight). The essential oil of *M. cajuputi* subsp. *cumingiana* is even more highly variable in character. Most sources are non- or low-1,8-cineole forms of low oil concentration (0.3–0.5% w/w%, fresh weight) and are non-commercial. However, commercial populations giving 41–48% 1,8-cineole have been recorded in Vietnam. The essential oils of *M. cajuputi* subsp. *platyphylla* occur at concentrations of 0.1–1.2% (w/w%, fresh weight) in the leaves. They are of two presently non-commercial chemotypes, although there has been some past interest in the platyphyllol-rich (21–80%) form from PNG for its sunscreen and insecticidal properties.

Variation in leaf morphology (Photo: J. Doran)

The wide range of variation in morphology and oil traits in this species indicates considerable scope for genetic improvement. Caution should be exercised in selecting planting stock for oil production as several non-commercial chemical forms occur from various parts of the natural occurrence (see above). Careful selection of oil-rich, well-adapted and fast-growing seed sources of the cineole chemotype will be paramount for plantation development aimed at cajuput oil production.

A selection and breeding program aimed at improved production of 1,8-cineole–rich oil from *M. cajuputi* subsp. *cajuputi* is in progress at the Centre for Forest Biotechnology and Tree Improvement (CFBTI), Yogyakarta, Indonesia. Seedlots suitable for species and provenance trials are available from the Australian Tree Seed Centre of CSIRO (see 'Germplasm availability and propagation requirements' chapter for contact details).

Conservation of genetic resources (including threats and needs)

While the species remains relatively common throughout its wide geographical range, there are a number of current conservation concerns. In the Mekong Delta of Vietnam, the once vast natural *M. cajuputi* forests have been sorely depleted through land clearing and illicit cutting and burning. The wastelands that are created by this process are a priority for reforestation and melaleucas are favoured because they can tolerate the very harsh conditions for tree establishment and growth without expensive mounding. Mounding can expose the pyrite layer of potentially acid sulfate soils resulting in acidification of waterways. International action is being taken to assist the Vietnamese Government with revegetation. In its natural distribution in the Indonesian islands of Seram and Buru, *M. cajuputi* leaves are being harvested from the native stands by the locals. Frequent fires threaten the sustainability of the resources. Although some genotypes from these islands have been planted outside their natural range for genetic improvement and commercial plantations, conserving the native populations in situ is of importance for future use and breeding purposes.

Pests and diseases of significance have not been reported as affecting survival and growth of *M. cajuputi*, although localised problems are likely to occur. A disease not yet recorded on this species but of concern because of the high susceptibility of close relatives (*M. leucadendra*, *M. quinquenervia* and *M. viridiflora*) is the leaf rust *Puccinia psidii* (guava, eucalyptus or myrtle rust). This rust is on the move from its native South America and is now in Australia and some other countries. The rust causes spots or lesions on young leaves and shoots of susceptible Myrtaceae species. These become curled and distorted, stunting growth or even causing mortality after repeated destruction of new growth.

The wide adaptability and regenerative capacity of this species make it a potential weed in some environments.

Authors: Anto Rimbawanto and John Doran

Melaleuca quinquenervia

Family: Myrtaceae
Botanical name: *Melaleuca quinquenervia* (Cav.) S.T.Blake. In *Proc. Roy. Soc. Qld* 69: 76 (1958).

The specific epithet is from the Latin *quinque*, five, and *nervis*, nerved, in reference to the common number of longitudinal veins in the leaves.

Common names: broad-leaved paperbark, five-veined paperbark (Australia); niaouli (New Caledonia); Australian paperbark tree, Australian punk tree, punktree (USA)

Summary of attributes and why diversity matters

Melaleuca quinquenervia is a moderately fast–growing tree from warm subhumid to hot humid climatic zones. It has been widely introduced to tropical and subtropical lowlands around the world where it grows best on sites with annual rainfall exceeding 1,000 mm. While this species is adapted to a wide range of environments and is suitable for many wood and non-wood purposes, the best prospects for its widespread use presently appear to be on swampy sites for the production of foliar essential oil through short-rotation coppice cropping, as is the case in Vietnam.

In Vietnam, significant differences between provenances in growth and oil quality have been recorded. A selection and breeding program is underway there to improve growth rates and medicinal oil (niaouli) qualities. Elsewhere also, careful selection of oil-rich, well-adapted and fast-growing seed sources of the cineole chemotype will be paramount for plantation development aimed at niaouli oil production. This species has become a noxious weed in multiple countries where it has been introduced. Caution is strongly advised, therefore, when introducing *M. quinquenervia* (and its close relatives) to sites where its weediness potential is unknown.

Description

Habit tree or multistemmed shrub, 1–25(–30) m tall. ***Bark*** papery, whitish or greyish. ***Leaves*** young shoots densely hairy, silvery in appearance; leaves dull green, alternate, 55–120 mm long, 10–31 mm wide, 3–8 times long as wide, long-petiolate; blade glabrescent or sericeous, narrowly elliptic to elliptic, rarely approaching falcate; apex acute or acuminate; veins longitudinal, 5 (rarely 3 or 7); oil glands dense, obscure to distinct, scattered. ***Inflorescences*** spicate, pseudoterminal and sometimes also upper axillary, with 5–18 triads, ≤40 mm wide. ***Flowers*** hypanthium glabrous or hairy, 1.5–2.5 mm long; calyx lobes abaxially glabrous, 1.0–1.8 mm long, scarious in a marginal band 0.3–0.4 mm wide; petals deciduous, 2.5–3.5 mm long; stamens 5–10/bundle; filaments white, cream, greenish-white, green,

Monospecific stand of *M. quinquenervia* in Tuan State Forest; Tinnanbar, south-eastern Queensland, Australia (Photo: P. Macdonell)

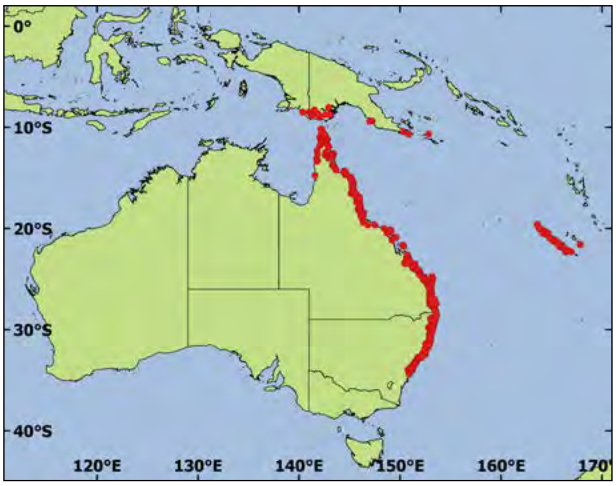
Inflorescences and foliage (Photo: CSIRO)

Immature and mature fruit (Photo: F. & K. Starr)

creamy-white or creamy-yellow, 10.5–20.0 mm long, the bundle claw 0.9–2.5 mm long, 0.1–0.2 times as long as the filaments; style 11–18 mm long; ovules c. 50–65/locule. ***Fruit*** 2.7–4.0 mm long, the calyx lobes weathering away. ***Seed*** very small, orthodox. ***Cotyledons*** obvolute.

Distribution

Melaleuca quinquenervia is a native of the coastal regions of eastern Australia, from around Sydney (New South Wales) to Cape York (northern Queensland). It occurs mainly in a belt within 40 km of the sea. Elsewhere, the native range extends into southern PNG, Indonesia (Papua province) and to New Caledonia, where the species is the national tree and has an extensive distribution, especially on the western coast of the main island.



In Australia and Papua, *M. quinquenervia* is generally confined to the lowlands (<100 m asl), but in New Caledonia, it also forms extensive stands in uplands to an altitude of 900–1,000 m asl.

The species has been introduced to >60 tropical and subtropical countries. It is listed as an invasive weed in more than a dozen of these and most notably in USA (Florida Everglades and the Hawaiian Islands).

Melaleuca quinquenervia occurs in the warm subhumid and humid climatic zones in the south of its distribution with rainfall fairly evenly distributed throughout the year, and occupies strongly monsoonal, hot humid zones to the north with a long dry season. Mean annual rainfall is about 900–1,250 mm. The species is adapted to a wide range of site conditions, including *Melaleuca* swamp forest, monsoon scrub, littoral rainforest, damp heathland, grassland, open forest, low shrubland on coastal dunes, along rivers, lagoon margins, on sand, sandy loam, sandstone, laterite over sand, silty soil and serpentine.

Uses

Melaleuca quinquenervia, like its similarly adapted close relatives *M. cajuputi* and *M. leucadendra*, is a moderately fast–growing tropical tree adapted to both waterlogged and well-drained soils. The best prospects for widespread use of the species, however, appear to be on swampy sites as more productive species are available for better-drained habitats. It is highly adaptable, being resistant to fire and tolerant of exposure to salt-laden winds, acid sulfate soils and weed competition. It will coppice, reproduce from root suckers and develop adventitious roots on soils subject to prolonged waterlogging. It is useful for a wide range of wood and non-wood purposes.

Wood—the sapwood is pale yellow to pink while the heartwood is pink to reddish-brown. The wood contains 0.20–0.95% silica that rapidly blunts saws and planes. Timber is hard, dense (air-dry density of 700–750 kg/m^3) and requires care in drying to minimise checking and warping. Uses include mine timbers, fence posts and rails, flooring, house timbers and woodchips which are used for pulp and garden mulch. It makes an excellent fuel and is a source of good-quality charcoal.

Non-wood—uses include bark as insulation and for caulking boats, honey, street tree, ornamental, windbreak and erosion-control planting, and foliar essential oil. The natural stands of *M. quinquenervia* on New Caledonia and plantations in Madagascar and elsewhere (e.g. Vietnam) are sources of 1,8-cineole–rich (60%) niaouli oil which is used in pharmaceutical preparations, aromatherapy and as a mosquito repellent. Niaouli oil production has declined in recent years due to the availability of cheaper alternative oils available to France

Amenity use as street tree; Sydney, New South Wales, Australia (Photo: J. Doran)

which is its main market. This species is also a potential source of E-nerolidol, which has a floral odour and is used in perfumery, but this oil type from this species has not yet been adopted commercially.

Diversity and its importance

Given the variation in the species and the natural habitats where it occurs, genetic differences in growth, adaptation and foliar oil characteristics can be anticipated with confidence. Careful selection of seed sources for specific characteristics (e.g. foliar oil characteristics combined with fast growth) and planting environments will almost certainly lead to improved performance and utilisation. This has been proven the case in Vietnam where *M. quinquenervia* outperforms the indigenous *M. cajuputi*. Provenances of *M. quinquenervia* from PNG and one provenance from New South Wales (Casino) were the best of 20 provenances tested for growth and foliar oil characteristics (concentration 1.4–1.6% w/w% fresh weight; 1,8-cineole 65–75% of total oils) on most sites at 3 years of age.

A selection and breeding program aimed at improved production of 1,8-cineole–rich oil from *M. quinquenervia* is in progress at the Institute for Forest Tree Improvement and Biotechnology, Hanoi, Vietnam. Seedlots suitable for species and provenance trials are available from the Australian Tree Seed Centre of CSIRO (see ‘Germplasm availability and propagation requirements’ chapter for contact details).

Genetic variation in *M. quinquenervia* field trial; Vietnam (Photo: Lê Đình Khá)

Conservation of genetic resources (including threats and needs)

Despite extensive clearing of natural *M. quinquenervia* forests for agriculture and urban development, the species remains fairly common throughout its natural range. Numerous native herbivorous insects and pathogens have been recorded in association with this tree and its close allies in Australia; however, none were reported as serious to the species’ survival. Overall, it was regarded as relatively free of pests and diseases. This was before the accidental introduction to Australia of the leaf rust *Puccinia psidii* (guava, eucalyptus or myrtle rust) from South America, first reported in Australia in 2010. Young trees of *M. quinquenervia* are highly susceptible to the disease which causes spots or lesions on young leaves and shoots. These become curled and distorted, stunting growth or even causing mortality after repeated destruction of new growth. The long-term effect of the rust incursion on native forests has still to be determined.

The wide adaptability and regenerative capacity of this species have led to it becoming naturalised and a major invasive weed in several countries. There is an extensive literature on how *M. quinquenervia* became a noxious pest in the Florida Everglades (after becoming naturalised in the 1920s), displacing native flora and fauna and wrecking the ecology of the region. Also reported are the many means that are being tried to eradicate the threat, including biological control measures. Caution, therefore, is strongly advised when introducing this species (and its close relatives) to sites where its weediness potential is unknown. Pest risk analysis before introduction and monitoring of new introductions for early signs of invasiveness are recommended.

Authors: John Doran and Lê Đình Khá

Metrosideros excelsa

Family: Myrtaceae
Botanical name: *Metrosideros excelsa* Sol. ex Gaertn. In *De Fructibus et Seminibus Plantarum* 1st edn, 172, t. 34, f. 8 (1788).

The genus name is derived from the Greek words *metra*, heartwood, and *sideron*, iron, referring to the dense wood typical of the genus. The specific epithet is from the Latin *excelsus*, exalted, noble, tall, which refers to the grand stature of mature trees. *Metrosideros* is in the myrtle family and contains some 60 species widely distributed across New Caledonia (21 spp., all endemic), New Zealand (12 endemic spp.), the island of New Guinea (7 endemic spp.), Hawai'i, USA (5 endemic spp.), elsewhere across small islands of the Pacific, and with 1 outlier species each in South Africa and South America. As the common name suggests, southern *rātā* (*M. umbellata*) has the most southerly distribution of all *Metrosideros* species and is consequently the most cold hardy. It occurs naturally from latitude 36°S in New Zealand to as far south as the subantarctic Auckland Islands.
Common names: New Zealand Christmas tree (English name, referring to flowering around Christmas time in New Zealand); *pōhutukawa* (Māori name, meaning 'splashed by the sea', referring to its coastal distribution)

Summary of attributes and why diversity matters

Metrosideros excelsa is the most widely cultivated of New Zealand's *Metrosideros* species. Flowers of this species are usually red, but may also be orange, yellow or white. *Metrosideros excelsa* is often cultivated for these showy flowers, as street trees or in gardens. *Metrosideros* timber is typically dense and durable. Seed of species in this genus are very light and easily dispersed by the wind which may account for their wide distribution. *Metrosideros* species are noted for their ability to colonise lava fields (e.g. *M. excelsa* and *M. polymorpha*) and mountain ridges.

It is estimated that only 5% of the original *M. excelsa* forests remain in New Zealand due to land clearing and other human impacts and failure to regenerate due to grazing by feral and domesticated animals and weed competition. A project (Crimson Trust) was formed in 1990 to halt the decline of *M. excelsa* and other *Metrosideros* species in the wild.

Description

Habit evergreen tree ≤20 m tall, often with a sprawling habit and a canopy spread of 10–50 m wide; trunk ≤2 m dbh, often multitrunked from the base; branches spreading and often arching, sometimes looping over the ground and/or with matted and fibrous aerial roots; branchlets numerous, twiggy, long-persistent and tomentose when young. ***Bark*** firm, persistent, often deeply furrowed, grey to grey-brown, somewhat corky. ***Leaves*** on short stout petioles; lamina 2.5–12.0 cm long, 2.5–6.0 cm wide, elliptic to oblong, acute or obtuse, coriaceous, thick, dark green above; clad in dense white

Typical red-flowered form; New Zealand (Photo: M. Dawson)

Fruit (Photo: M. Ritter)

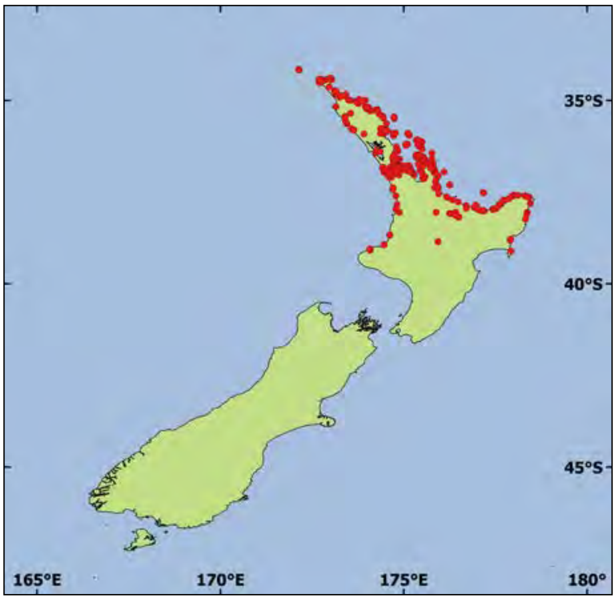
Aerial roots (Photo: M. Dawson)

Multitrunked form of over-mature specimen (Photo: M. Dawson)

tomentum below. ***Inflorescences*** compound, comprising about 14 showy, hermaphroditic, red (less commonly orange, yellow or white) brush flowers. ***Flowers*** borne on stout, tomentose pedicels; stamens numerous, 3–4 cm long, typically crimson, sometimes orange, pink or yellow, very rarely white. ***Fruit*** capsules, 7–9 mm long, tomentose, distinctly exserted 3-valved. ***Seed*** small and thin.

Distribution

Metrosideros excelsa is endemic to New Zealand, growing naturally on sea cliffs in coastal forest in the northern half of the North Island—areas north of Poverty Bay, on the shores of the Rotorua lakes, and on the Three Kings Islands.



In New Zealand, *M. excelsa* is cultivated much more widely than its natural distribution, typically in milder locations near the sea. It is widely cultivated in most North Island coastal cities. In Wellington, some have expressed concerns that it has the potential to encroach and genetically contaminate (through hybridisation) remnant populations of the related *M. robusta* (northern *rātā*). In the South Island, *M. excelsa* is cultivated in coastal areas (including Nelson, Greymouth, Marlborough, Kaikoura, Banks Peninsula and Otago Peninsula). It is also cultivated on the Chatham Islands and as far south as Stewart Island, far beyond its natural range.

Elsewhere, *M. excelsa* is cultivated in countries where there are milder climates, such as south-eastern Australia and coastal California, USA, including San Francisco. A famous and ancient tree is growing at La Coruña, capital of Galicia province in Spain, where it is the city's floral emblem. In the Western Cape province of South Africa, *M. excelsa* has escaped from cultivation and has become a serious weed of the fynbos (a major ecosystem renowned for its diversity of native plant species).

Uses

Metrosideros excelsa has been used for aesthetic purposes, as a nectar source, for timber, shelter and for traditional medicines.

Wood—*Metrosideros* wood is well known for its density and strength. Like all of New Zealand's native

The grand old dame of *pōhutukawa* trees, *Te Waha o Rerekohu*—the mouth of Rerekohu—in Gisborne, North Island, is reckoned to be the largest *M. excelsa* tree in New Zealand. At least 600 years old, it had a branch span of more than 37 metres when measured in 1950 (Photo: M. Dawson)

Growth habit of a mature *M. excelsa* tree in cultivation. This heritage tree is more than 80 years old and the largest specimen of this species in Christchurch, South Island, New Zealand (Photo: M. Dawson)

timber species, *Metrosideros* is no longer felled and milled in commercial quantities. Along with the related *M. robusta*, *M. excelsa* was once used by Europeans for boatbuilding, flooring timber and other construction projects that required great strength. *Metrosideros* firewood is long-burning, and *M. excelsa* sawdust is excellent for smoking fish. Traditionally, the indigenous New Zealand Māori have used *M. excelsa* wood for tools, staffs, weapons and canoe anchors.

Non-wood—when in flower, *M. excelsa* is New Zealand's most spectacular and colourful native tree. In frost-free regions, it is planted widely as an amenity street tree and in larger gardens. Nectar sourced from *M. excelsa* flowers produces a high-quality honey, and beehives are kept on Rangitoto Island in the Hauraki Gulf of Auckland to produce a niche honey of high purity. Traditionally, leaves and inner bark from *M. excelsa* were used by Māori for a range of medicinal uses, including as an antiseptic.

Diversity and its importance

Metrosideros excelsa is an iconic species in New Zealand with its abundant and colourful summer flowers and its ability to survive even on exposed coastal cliff faces. Its strength and beauty are recognised by Māori who regard *M. excelsa* as a 'chiefly tree'. Māori traditionally believe that their spirits depart to the next world via the sacred tree growing at Cape Reinga on the northern tip of New Zealand.

Metrosideros excelsa is also valued in cultivation. Plant form and flower size and colour vary between trees and this variability has allowed the selection of about 40 ornamental cultivars, more than any other species of *Metrosideros*. Ornamental selections are usually maintained through vegetative propagation, such as cuttings. Three well-known and distinctive cultivars are:

- *M. excelsa* 'Aurea' is a greenish-yellow-flowered variant that originated on Motiti Island in the Bay of Plenty. It was selected from the wild and first released in 1947.
- *M. excelsa* 'Variegata' is a cultivar with variegated leaves. This was one of the first cultivars selected.
- *M. excelsa* 'Vibrance' is an exceptional cultivar with vibrant orange-red flowers, selected from a source tree originally planted at Waiomu Bay, Coromandel Peninsula. This form has been commercially available since the late 1980s and is probably the best red-flowered cultivar.

Cultivar 'Aurea', a yellow-flowered variant of *M. excelsa;* New Zealand (Photo: M. Dawson)

Cultivar 'Variegata', selected for its variegated leaves and now widely planted in New Zealand and southern Australia (Photo: M. Dawson)

Cultivar 'Vibrance'; Christchurch, New Zealand (Photo: M. Dawson)

Conservation of genetic resources (including threats and needs)

Metrosideros excelsa and related species are seriously threatened by the brushtail possum (*Trichosurus vulpecula*), a marsupial introduced from Australia in 1837 to establish a fur trade in New Zealand. Browsing of the foliage and buds by possums reduces both tree growth and flowering and is responsible for the death of numerous *Metrosideros* throughout New Zealand.

Grazing on the seedlings by domesticated animals (such as cattle and sheep) and feral animals (particularly goats) also hinders natural regeneration. Regeneration is further prevented because the fine seed cannot germinate through thick layers of introduced grasses such as kikuyu (*Pennisetum clandestinum*).

Trees are also threatened by damage and root disturbance from coastal development, land clearing, fires, road widening and other human impacts.

It is estimated that >95% of *M. excelsa* forest has been eliminated from New Zealand and the species is considered to be Endangered. In 1990, the project Crimson Trust was formed in an effort to halt the decline of *pōhutukawa* and *rātā* species in the wild.

Rangitoto Island is a notable stronghold with the largest remaining *M. excelsa* forest. Because of the young age of that island, the trees there are no more than 150–200 years old and have rapidly colonised the volcanic lava. Mayor Island in the Bay of Plenty is also dominated by *M. excelsa* forest where there are some very mature trees.

Author: Murray Dawson

Metrosideros polymorpha

Family: Myrtaceae
Botanical name: *Metrosideros polymorpha* Gaud. In *Voy. Uranie* 482 (1830).

The specific epithet is from the Greek *poly*, many, and *morphus*, form, alluding to the highly variable form of the species. Eight varieties are recognised: var. *dieteri* J.W.Dawson & Stemmerm. (endemic to Kauaʻi); var. *glaberrima* (H.Lév.) H.St. John (occurs on Kauaʻi, Oʻahu, Molokaʻi, Lanaʻi, Maui and Hawaiʻi); var. *incana* (H.Lév.) H.St.John (occurs on Kauaʻi, Oʻahu, Molokaʻi, Lanaʻi, Maui and Hawaiʻi); var. *macrophylla* (Rock) H.St.John (occurs on Maui and Hawaiʻi); var. *newellii* (Rock) H.St.John (endemic to Hawaiʻi Island); var. *polymorpha* (occurs on Oʻahu, Molokaʻi, Lanaʻi, Maui and Hawaiʻi); var. *pseudorugosa* (Skottsb.) J.W.Dawson & Stemmerm. (endemic to Maui); and var. *pumila* (A. Heller) J.W.Dawson & Stemmerm. (occurs on Kauaʻi, Oʻahu, Molokaʻi and Maui).

Related Hawaiian species (four), one with two varieties, are: *M. macropus* Hook. & Arn. (endemic to Oʻahu); *M. rugosa* A.Gray (endemic to Oʻahu); *M. tremuloides* (A.Heller) Knuth (endemic to Oʻahu); *M. waialealae* (Rock) Rock var. *fauriei* (H. Lév) J.W.Dawson & Stemmerm. (occurs on Molokaʻi, Lanaʻi and Maui); and *M. waialealae* (Rock) Rock var. *waialealae* (endemic to Kauaʻi).
Common names: *ʻōhiʻa, ʻōhiʻa lehua, lehua*

Summary of attributes and why diversity matters

Metrosideros polymorpha is endemic to the Hawaiian archipelago and the most ecologically important tree of the Hawaiian forest. *Metrosideros* forests comprise 50% of all forests in Hawaiʻi and 80% of native forests. In native moist forests, over 80% of the stand basal area may be composed of *Metrosideros*. *Metrosideros* is valued above all other native Hawaiian trees for watershed protection, providing habitat to endemic flora and fauna, and for cultural importance to Native Hawaiians.

The eight named varieties of *M. polymorpha* and the four other endemic Hawaiian species of *Metrosideros* colonise a wide range of habitats, at different altitudes, on different soil types and receiving vastly different amounts of precipitation annually. The diversity of varieties of *M. polymorpha* inhabiting different environments in a young landscape provides an ideal system to study evolution and speciation.

Description

Habit highly variable in form; on favourable sites it is a medium to large tree, to 24 m tall with the largest individuals ≤30 m. Larger trees commonly have dbh of 80 cm with the largest reaching 2 m dbh; drought-stressed trees growing on young lava flows, in dry forests or at high elevations are much smaller, and dwarf forms only 1 m tall colonise bogs across the islands; boles

Dwarf form of *M. polymorpha*; Alakai Swamp, Kokee, Kauaʻi, Hawaiʻi, USA (Photo: J.B. Friday)

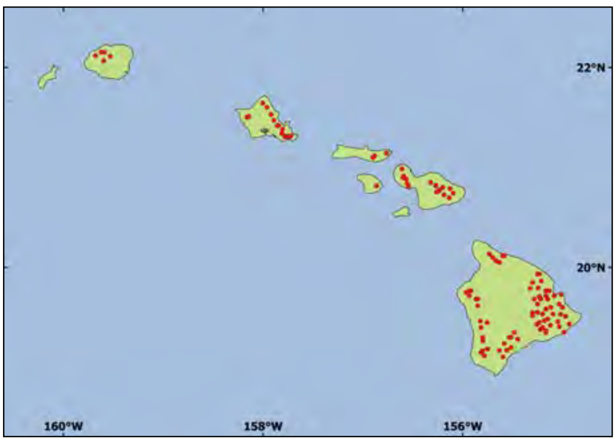
Large tree; Hakalau Forest National Wildlife Refuge, Hawaiʻi, USA (Photo: J.B. Friday)

Seed in capsules (Photo: J.B. Friday)

often fluted; multiple stems and aerial roots common; forest trees often seen growing high off the ground supported by several aerial roots, a form caused by the tree's habit of germinating on stumps or tree ferns that eventually rot away; the largest trees (those >1 m dbh) have been estimated to be >600 years old. ***Bark*** young bark smooth and light grey; becomes rough and scaly with age. ***Leaves*** opposite, elliptic to ovate, 1–8 cm long, 1.0–5.5 cm wide, glabrous above, sometimes pubescent below. ***Inflorescences*** brush-like cymes of 20–40 flowers. ***Flowers*** most commonly red but may also be yellow, orange or salmon; stamens and pistils long (2–3 cm). ***Fruit*** round capsules 3–8 mm wide. ***Seed*** mature capsules open to release many small (2 mm long) windblown seed; about 1,750 seed/g; no pre-treatment is needed but viability is typically only around 10%. ***Reproductive phenology*** flowering peaks in March to June but some flowering occurs all year round.

Distribution

Metrosideros polymorpha naturally occurs across the main Hawaiian Islands, USA, from 22°13′N to 19°4′N and from 159°44′W to 154°49′W. The species has been occasionally planted outside its native range for landscaping, although the New Zealand native, *M. excelsa*, is more popular for this use in the USA.



Metrosideros polymorpha colonises a wide range of habitats, from rainforests receiving 10,000 mm MAR to dryland forests receiving only 500 mm MAR, from elevations at sea level to 2,500 m asl, and from young lava flows to highly weathered soils and bogs.

Uses

Because of its slow growth rate and unstable wood, *M. polymorpha* is not planted as a timber species. The tree is commonly planted in mixed stands with *Acacia koa* and other native Hawaiian species in forest restoration projects, most often with the goal of increasing habitat for endemic birds.

Wood—*Metrosideros* wood is heavy (specific gravity 0.7–0.8), hard and strong, but the spiral grain makes the lumber unstable when dried and prone to checking and splitting. The most common uses of the wood are for flooring, posts, balustrades and firewood. In ancient times, Native Hawaiians used the wood for house posts and tools but also for carved *kiʻi* (statues of gods). In traditional Hawaiian religion, *Metrosideros* can be a physical manifestation of several deities, including *Pele*, the volcano goddess, with the red flowers symbolising the fires of the volcano.

Non-wood—the greatest value of forests dominated by *M. polymorpha* is in the ecological services they afford. By protecting the wet upper reaches of island watersheds, *Metrosideros* forests help recharge aquifers and provide

House posts made from *M. polymorpha* (Photo: J.B. Friday)

Red and yellow blossoms used in a ceremonial lei; Hilo, Hawai'i, USA (Photo: J.B. Friday)

water for agriculture and public use. Hawaiian foresters have recognised since the mid-19th century that the most important product of the Hawaiian forest is water. The forests also provide critical habitat for endemic forest birds, many of them endangered. The common native honeycreepers *'i'iwi* (*Drepanis coccinea*) and *'apapane* (*Himatione sanguinea*) and the endangered *'akepa* (*Loxops coccineus*) and Hawai'i creeper (*Loxops mana*) all depend on *Metrosideros* forests. The forests are also home to many native invertebrates, including endemic cerambycid beetles (*Plagithmysus* spp.) and other insects that are obligate herbivores on *Metrosideros*. While *Metrosideros* forests have low tree species diversity, the understorey flora is much more diverse, with many endemic species in the families Campanulaceae, Lamiaceae and Rubiaceae.

The bright red or, less commonly, yellow flowers, the moderately slow growth rate and evergreen crown make *Metrosideros* trees favourites for landscaping in Hawai'i, especially at higher elevations.

Diversity and its importance

The ancestral species to *M. polymorpha* probably colonised the Hawaiian archipelago from the South Pacific about 4 million years ago, at a time when, of the current main islands, only Kaua'i was above sea level. As newer islands were created by volcanoes rising from the sea, *Metrosideros* colonised them and evolved into a diverse array of five species, including *M. polymorpha*, currently divided into eight named varieties. The species *M. macropus*, *M. rugosa* and *M. tremuloides* only occur on O'ahu, while *M. waialealae* occurs on Kaua'i, Moloka'i, Maui and Lana'i but not on O'ahu or Hawai'i islands. Three of the named varieties of *M. polymorpha* occur only on one island each, while the others occur on multiple islands.

Yellow-flowered cultivar; Hilo, Hawai'i, USA (Photo: J.B. Friday)

Red-flowered form; Manoa Cliff Trail, Tantalus, O'ahu, Hawai'i, USA (Photo: © J.T. Johansson)

Different populations of *M. polymorpha* are adapted to environmental stresses at different sites, including freezing at high elevations, drought stress and the ability to survive on new lava flows. Some morphological features have been shown to increase fitness; for example, leaf pubescence increases tolerance to drought stress. Some varieties are only found in specific habitats, such as var. *newellii*, which only grows on stream banks and in ravines on East Hawai'i Island, while others grow in a wide variety of environments. It is still unclear whether the different morphological varieties represent ecotypes that evolved similar characteristics on different islands or multiple colonisation events with each variety moving down the island chain. Different varieties hybridise readily where populations overlap, and the windblown seed can travel long distances. However, phenotypic variation in both morphology and physiological characteristics is heritable.

Analysis of microsatellite markers has shown a molecular basis for most, but not all, of the named varieties on Hawaiʻi Island. The diversity of varieties of *M. polymorpha* in Hawaiʻi most likely represents incipient speciation and makes the system an ideal one to study evolutionary biology.

Conservation of genetic resources (including threats and needs)

The greatest threats to *M. polymorpha* and other native Hawaiian *Metrosideros* species are exotic diseases. In 2014, two new species of the pathogenic fungus *Ceratocystis* were found to be killing *Metrosideros* on Hawaiʻi Island. By 2016, the diseases were affecting over 20,000 ha of forest, with mortality ranging from 10% to 98%. Genetic studies have so far failed to pinpoint the origins of the fungi. Investigations on whether tolerance to the diseases exists in the great diversity of *Metrosideros* genotypes in Hawaiʻi commenced in 2016. In 2005, the foliar rust pathogen *Puccinia psidii* was first discovered in Hawaiʻi on *Metrosideros* seedlings. The introduced strain of the fungus, however, proved to be only a weak pathogen on *Metrosideros*, although virulent on the Hawaiian endemic tree *Eugenia koolauensis*. Investigations in Brazil, in the native range of the fungus, have shown that other strains of *Puccina psidii* are pathogenic on *Metrosideros* and would be a severe threat to the *Metrosideros* forest if they were introduced into Hawaiʻi.

Much of the pre-settlement *Metrosideros* forest in Hawaiʻi has been converted to agriculture or ranching or has been lost because of wildfires. The original Polynesian settlers to Hawaiʻi cleared some areas, but loss of forests increased dramatically after Western contact and the introduction of cattle, sheep, and goats. Today, most *Metrosideros* forests are in forest reserves and are protected against deliberate clearing. However, low-elevation forests, in particular, are vulnerable to invasion by non-native understorey trees, such as *Psidium cattleianum*, *Miconia calvescens* and *Schinus terebinthifolius*, which grow so densely that they prevent seedling regeneration of any native plants. Feral ungulates found in many forests also destroy regeneration, while wildfires are a constant threat to dryland forests.

Author: James B. Friday

Musa troglodytarum (fe'i)

Family: Musaceae
Botanical name: *Fe'i* bananas are sometimes referred to by the Latin binomial *Musa troglodytarum*. However, since they are *Musa* hybrid cultivars, they are better described as a cultivar group—namely, *Musa* (*fe'i* group) *Utin Iap*. *Fe'i* bananas were independently domesticated and are distinct from the widely known and cultivated banana cultivars descended from *Musa acuminata* and *M. balbisiana* in the *Eumusa* section of the genus. The origins of *fe'i* bananas are poorly understood but their wild ancestors belong to the section *Australimusa*. Relationships between, and common names for, the various clones in different geographical areas are unclear. Detailed study is much needed.
Common names: At the present time, the classification of *fe'i* bananas into subgroups is still a work in progress. As this account highlights diversity relating to micronutrient composition, the focus is particularly on *fe'i* cultivars of FSM which have been analysed more extensively; that is, the *Karat* types: *Karat Pako*, *Karat Pwehu*, *Karat Kole* (Pohnpei, FSM; synonyms—*Danon* [Chuuk, FSM], *Usr Kulasr* [Kosrae, FSM], *Arai* [Yap, FSM]; all considered to be *Karat*). Other FSM *fe'i* bananas are *Utin Iap* (Pohnpei, FSM; synonym—*Usr Kolontol* [Kosrae, FSM]) and *Utimwas* (Pohnpei, FSM), which is closely related to *Utin Iap*.

Further cultivar names and general terms for *fe'i* bananas in other regions include: *Utu*, *'Otū*, *'Utū*, *'Uatū*, *Ve'i* (Cook Islands); *Soaqa* (Fiji); *Borabora*, *Polapola*, *Mai'a He'i* (Hawai'i, USA); *Tongka Langit Alifuru*, *Telo Mata Lala* (Maluku Islands, Indonesia); *Huetu* (Marquesas Islands, French Polynesia); *Daak* (New Caledonia); *Hulahula* (Niue); *Erasch* (Palau); *Tongka Langit Papua* (syn. *Asupina* of PNG) (Papua and West Papua, Indonesia); *Asupina*, *Menei*, *Sar*, *Rimina*, *Utafan*, *Wain* (PNG); *Soa'a* group (Samoa); *'Afara*, *'Aiuri*, *'A'ai'*, *Arutu*, *'A'ata*, *Ha'a*, *Mahani*, *Oeoe*, *Paru*, *Poti'a*, *Rureva*, *Tati'a*, *Toro Aiai* (or *Arapoi*), *'U'ururu* (Tahiti, French Polynesia); *Toraka Akeakesusu, T. Bonubonu, T. Gatagata, T. Suria, T. Baubaunio, T. Warowaro, T. Morikera, T. Fagufagu, T. Parao* (Makira, Solomon Islands); *fe'i* and *Soanga* type (Tonga); *Chongk*, *Nalak* (Vanuatu). *Fe'i* bananas are also referred to as the mountain banana or mountain plantain because of their occurrence in mountainous zones.

Summary of attributes and why diversity matters

Fe'i bananas, in particular *Karat* and *Utin Iap*[1] of FSM, are recognised internationally for their high micronutrient content and unique flesh colouration. These cultivars are considered to be indigenous to Pohnpei and Kosrae, where they have a long association with oral traditions. However, the crop has been greatly neglected over several decades due to the shift towards cultivation of other banana cultivars and consumption of imported processed foods. The rarity of *Karat* and other *fe'i* bananas is now a cause for concern.

In 1998, *Karat* was analysed for micronutrient content and found to be rich in β-carotene and other provitamin A carotenoids, which are converted in the body to vitamin A. Studies showed that banana flesh colouration (ranging from white to cream, yellow, yellow/orange and orange) is a good indicator of carotenoid content, with highest levels in cultivars with deeper-coloured flesh. The raw fruit of orange-fleshed *Utin Iap* and *Utimwas* contain the highest recorded β-carotene levels of any banana in the world, with maximum levels at 8,508 μg/100 g,[2] compared with the internationally marketed white-fleshed *Cavendish*, with 21–70 μg/100 g.[3] Assuming efficient absorption and conversion to vitamin A in the body, this level of β-carotene in a single fruit would potentially far exceed the normal daily adult vitamin A requirement.[4] Other yellow/orange-fleshed *fe'i* bananas also have high β-carotene levels: *Karat* contains up to 2,230 μg/100 g—over 100 times the level in the common *Cavendish*; *Asupina* contains 1,412 μg/100 g and yellow-fleshed *Wain* contains 486 μg/100 g. Further study on the bioavailability of carotenes in banana-based foods will be important to evaluate the use of the cultivars as a carotenoid-rich food to address micronutrient deficiency, which currently afflicts one-third of children in developing countries.

Description

Habit typical banana pseudostem—frilly leaf bases with ruffles where leaf bases clasp the trunk; sap blood-like.

1 In this account, the names *Karat* and *Utin Iap*, as used in Pohnpei, are also used to refer to the same cultivars that go by other names in the other FSM states.

2 All levels of carotenoid and other nutrient contents in this paper represent fresh weight samples.

3 Reports on bananas analysed in the United States of America, United Kingdom and Australia.

4 The estimated vitamin A requirement for a non-pregnant, non-lactating female is 500 μg retinol equivalents (RE)/day. The RE content in food is calculated from the level of β-carotene equivalents (β-carotene plus half the content of other provitamin A carotenoids divided by the conversion factor of 6:1 from β-carotene equivalents to RE).

Above left: *Fe'i* banana bearing stout upright bunch of red-orange fruit; Ke'anae Arboreatum, Maui, Hawai'i, USA (Photo: A.K. Kepler)

Above right: Typical flower spike with fruit forming (Photo: J. Daniells)

Left: Emerging flower spike; Vallée de Aiurua, Tahiti, French Polynesia (Photo: © Q. Braun-Ortega)

Leaves very long, thick-tissued, pointed, often markedly narrower than those of many bananas and characterised by strong cross-corrugations; edge of the petiole base distinctively frilly. ***Fruit*** *fe'i* bananas are characterised by erect bunches[5], borne on short, thick peduncles; sap pink through to dark purple (colour depending on cultivar); flesh deep yellow, iridescent lime green, yellow/orange or orange. ***Seed*** although described generally as parthenocarpic (non-seeded), there are reports indicating some cultivars form mature seed; seeded types are generally found in more remote mountain locations and are less palatable due to the seediness, coarse-grained texture and less flavour of the flesh; in *Poti'a*, large seed can develop near sea level.

Within *fe'i* bananas, there are many different bunch shapes and sizes, fruit shapes, skin types, flesh colours, tastes and growth differences. *Karat* bunches are large, ≤25 kg, but *Utin Iap* bunches are often much larger, ≤50 kg. *Karat* fingers are fat and relatively short (mean finger weight 166 g, girth 19 cm, length 13 cm); *Asupina* and *Wain* fingers are smaller (mean finger weight 140 g and 104 g, respectively, girth 16 cm, length 14 cm); and *Utin Iap* fingers are even smaller (mean finger weight 68 g, girth 12 cm, length 11 cm). Although *Karat* peel is thick and mostly reddish-coloured, *Utin Iap* peel is thin and coppery-coloured. *Karat* flesh is yellow/orange whereas *Utin Iap* flesh is markedly orange.

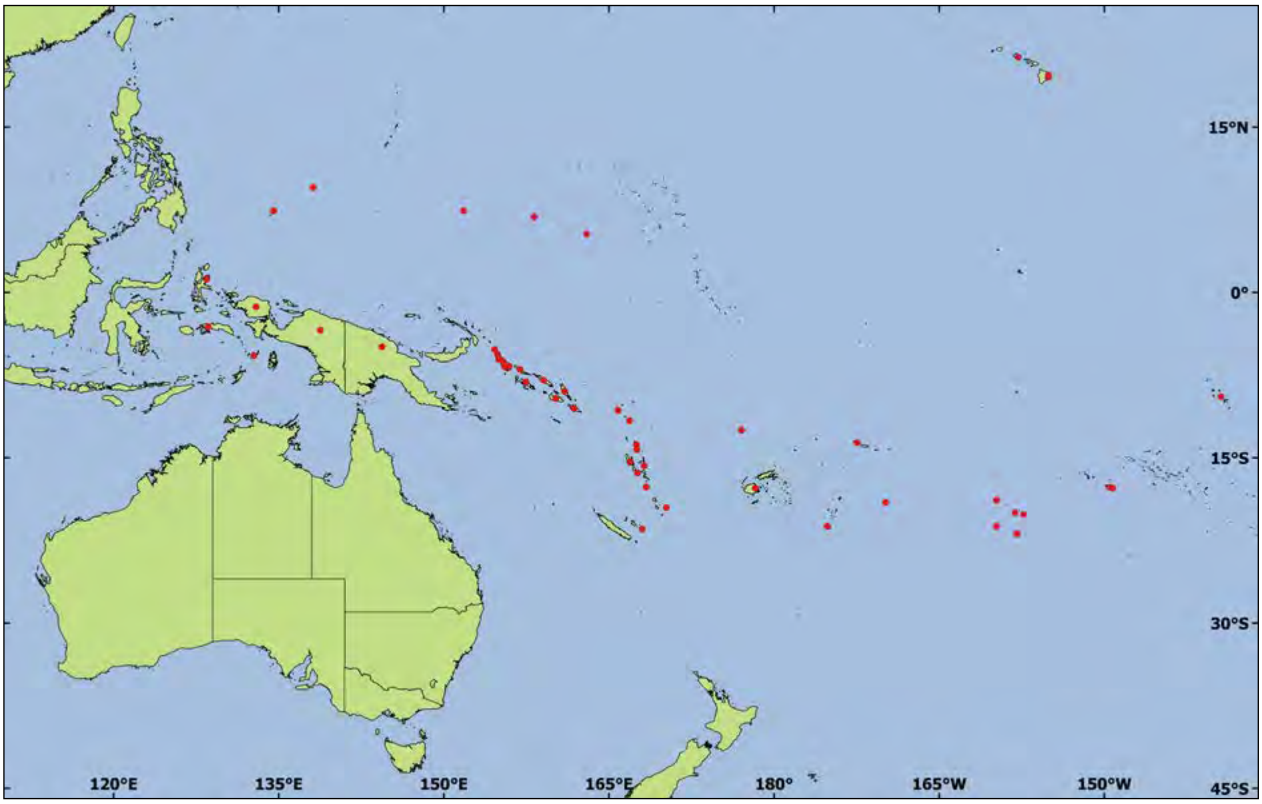
Fe'i bananas (both cooked and raw) have a distinct effect on the consumer's urine, often turning it bright yellow, which is due to the strikingly high levels of riboflavin[6] (14.3 mg/100 g compared with 0.06 mg/100 g in *Cavendish*) and other unidentified flavonoids. *Karat* also contains relatively high levels of other vitamins (niacin and α-tocopherol) and the mineral calcium, as well as vitamin C and potassium similar to other bananas.

Distribution

Fe'i bananas are believed to originate in the New Guinea area but have been distributed both by humans and birds throughout the Pacific region, following a belt from Indonesia (Maluku Islands) in the western Pacific to French Polynesia in the east. Because of their distribution throughout the South Pacific Islands by pigeons and parrots, they are likely native to most volcanic islands. Generally *fe'i* bananas grow best in upland areas; they can also be grown on atoll islands but generally do not

5 Some *fe'i* bunches are not entirely upright, e.g. *Utafan, Asupina, 'Afara, Tati'a, Telo Mata Lala*. Sometimes this trait is correlated with superior taste and may be indicative of introgression of *fe'i* with *Musa acuminata*.

6 Riboflavin is important in cell metabolism and there is increasing evidence of the role of riboflavin in iron absorption and utilisation, thereby possibly alleviating anemia, the most widespread micronutrient deficiency worldwide. While carotenoids are digested in the intestine, excess riboflavin is excreted in the urine after it is consumed, imparting a yellow colour.



thrive. *Fe'i* bananas are unique to Oceania and have been cultivated in Tahiti (French Polynesia) and other Pacific Islands for many centuries.

Uses

Fe'i bananas have lower sugar and higher starch contents than some banana cultivars, and are frequently consumed roasted, boiled or pounded, often with rich coconut cream as a sauce. Many *fe'i* types are highly astringent unless very ripe and thus, throughout much of the Pacific, they are generally preferred cooked. In Pohnpei, *Karat* and *Utin Iap* can be eaten raw when ripe and, in Pohnpei and Kosrae, *Karat* is treasured as a traditional infant food, with unique health benefits and a quality for 'cleansing the stomach'. *'Afara* (Tahiti) is also considered a good infant food. The texture of *Karat*, being very soft, creamy and less sugary compared with other cultivars, is particularly suitable in infant foods and processed dishes. *Fe'i* bananas are appreciated in fruit salads, as their flesh does not turn brown like other bananas. Pounded ripe *fe'i* is also used in recipes with taro, cassava and yam and there is a potential market for dried *fe'i* snacks and powder, although it appears that *Utin Iap* (and possibly other *fe'i* varieties) sometimes cause a throat irritation, which appears to be worse after drying.

As with other bananas, *fe'i* cultivars have many non-food applications relating to the use of leaves, pseudostems and fibres for medicine, thatching, shelters, ropes, packing, cigarette papers and litter bedding (for livestock). The sap of some *fe'i* cultivars, in particular *Utin Iap*, is dark purple and has an application as a dye or ink.

Legends relating to *fe'i* bananas illustrate their importance and long history in human culture and agriculture in the Pacific. A Samoan legend tells how mountain *fe'i* and lowland bananas fought; the *Soa'a* (*fe'i*) winning and, flushed with victory, raised their heads (hence their erect bunches), with the vanquished lowland bananas so humiliated that they never raised their heads again. The Never-ending Night Legend is told in Pohnpei, in which a leader had a vision of the sun not shining and food being in short supply; he therefore planted *Utin Iap*, known for its large bunches. Another Pohnpei legend describes *Karat* peel (thick and large) used as a canoe. *Usr Kulasr* (*Karat*) is famous in Kosrae as the favourite banana of the legendary giant Goth, proclaimed for extraordinary eyesight and strength. *Karat* and *Utin Iap* were used for ceremonial

Villagers with harvested bunches of *Toraka Bonubonu*, a traditional *fe'i* variety, at different stages of ripeness; Makira, Solomon Islands (Photo: J. Daniells) presentations to paramount chiefs. In contrast, *Arai (Karat*) in Yap is classed as a low-caste food.

Diversity and its importance

Seeded populations are known from a few areas, confined to the western Pacific around north-eastern PNG, Solomon Islands and Niue. But *fe'i*-type bananas appear to have been most intensively cultivated further east in the Society Islands (French Polynesia). Several historical accounts of expeditions to the Pacific by naval explorers from the West cite the plentiful supply of *fe'i*-type bananas and their use as a principal food source for the islands' inhabitants. Reports from Tahiti, Kosrae and Pohnpei indicate that *fe'i* bananas were previously the main bananas consumed on those islands and were an important part of the diet. The French post-Impressionist painter Paul Gauguin featured *fe'i* bananas in three of his canvases completed in Tahiti in the late 1800s. By contrast, *fe'i* grows in Solomon Islands but, except for the island of Makira, it is not cultivated and rarely eaten, reportedly because local people are concerned about the banana's effects on the colour of their urine.

Some *fe'i* cultivars are harvested largely from wild populations in the forests lining mountain valleys, most probably from the remnant sites of more ancient gardens. Today, a number of cultivars are still only found in wild populations. Few surveys of cultivar diversity have been made; 'nearly 20 kinds' were reported to occur in the Society Islands and some 13 distinct forms were reported 90 years ago, from Tahiti by MacDaniels (1947). However, the fate of this diversity is closely associated with the fortunes of the people who cultivated it, and records in the early 20th century already indicated that previously known diversity was disappearing. Today, despite their nutritional importance, *fe'i* bananas play a much less significant role in the diet of Pacific Islanders. Aside from the overall neglect of locally grown food crops in the Pacific, the increasing rarity of *fe'i* bananas appears to be related to both a lack of market demand and to their demanding cultivation needs compared with introduced varieties. *Karat* and other *fe'i* bananas require good soil fertility, moderate shade (particularly breadfruit trees) and protection from animals (pigs can eat young suckers). On the other hand, *fe'i* bananas are highly resistant to leaf diseases such as yellow sigatoka (*Pseudocercospora musicola*) and black leaf streak (*P. fijiensis*).

However, campaigns have been organised in Pohnpei and Kosrae to promote the cultivation of *Karat* and other *fe'i* bananas, using traditional methods for banana propagation (Pohnpei and Kosrae) and tissue culture plantlets (Kosrae). In 1999, after 1 year of promoting *Karat* in Pohnpei, markets started selling this cultivar for the first time. Sales have been slowly but steadily increasing. In 2005, *Karat* was proclaimed the State Banana of Pohnpei, in recognition of its importance to

Above: The rare *fe'i A'ata*; Papeari, Tahiti, French Polynesia (Photo: A.K. Kepler)

Top right: Seeded *fe'i* fruit; Tapuaehu, Marquesas Islands, French Polynesia (Photo: M. Wong)

Bottom right: *Fe'i Poti'a* fruits have thick, fine-grained pulp of a brilliant yellow hue and are quite tasty—presumed extinct in its native Tahiti and now considered the world's rarest banana; ex situ conserved in Waimea Arboretum, O'ahu, Hawai'i, USA (Photo: A.K. Kepler)

Above left: *Fe'i* traditional varieties *Toraka Bonubonu* (L), Huki Mata (R, back) and *Twistis* (R, front), with Lois Englberger; Makira, Solomon Islands (Photo: J. Daniells)

Above right: *Toraka Bonubonu* traditional variety; Makira, Solomon Islands (Photo: J. Daniells)

Left: *Utimwas*, an *Utin lap*–type cultivar; Pohnpei, FSM (Photo: L. Englberger)

nutrition, infant feeding and culture. National postage stamps, billboards, posters, booklets, car bumper stickers, logos, songs, t-shirts, film and video distribution, radio, television and trainings have also formed part of the promotion campaign. *Karat* and other *fe'i* cultivars also feature prominently during Pohnpei's celebrations of World Food Day, held each year on 16 October.

Conservation of genetic resources (including threats and needs)

Rare *fe'i* (and other) bananas are maintained in field collections at the Solomon Island's Makira Collection, Pohnpei Pilot Farm and Kosrae Agriculture Department. *Fe'i* cultivars collected in PNG are also maintained at the South Johnstone Research Station, Queensland Department of Agriculture and Fisheries, Australia. Many of these accessions have been duplicated in vitro in the International *Musa* Germplasm Collection maintained by Bioversity International at the Katholieke Universiteit Leuven in Belgium. A Pacific regional collection is located at Papara, Tahiti, at the Rural Development Service (SDR). Several cultivars present in Hawai'i (mostly originally from Tahiti) were placed in tissue culture in 2014 at the USDA facility in Hilo, Hawai'i, with plans to distribute these to the public and grow at the USDA facility in Mayagüez, Puerto Rico.

The conservation status of *fe'i* cultivars and wild populations is highly insecure. The seeded populations of *fe'i* are narrowly restricted in distribution, poorly studied and under-represented in ex situ collections. A significant number of previously known *fe'i* cultivars are extremely rare or have become extinct. In order to understand the magnitude of genetic erosion and the extent of remaining genetic diversity, collection and characterisation are urgently needed. To ensure long-term conservation and use, further projects are required to evaluate cultivars agronomically and nutritionally, and more intensive conservation efforts are needed in situ, in the field, in medium-term in vitro collections and cryopreservation. A framework for ex situ conservation has been developed in the form of the Global Conservation Strategy for *Musa* with support from Bioversity International and the Global Crop Diversity Trust. The Trust also led a global project to regenerate and duplicate priority crop collections, including banana collections in the Pacific. Further efforts are being made to determine a specific strategy for banana conservation in the Pacific and for wild banana species and threatened cultivars. Funding is being sought to finance the implementation of these strategies.

Authors: Lois Englberger, Jeff Daniells, Adelino Lorens, Anne Vezina, Charlotte Lusty and Angela Kay Kepler

Ochroma pyramidale

Family: Bombacaceae
Botanical name: *Ochroma pyramidale* (Cav. ex Lam.) Urb. In *Repert. Spec. Nov. Regni Veg. Beih.* 5: 123 1920.

The genus name is from the Greek *ochroma*, pale yellow, referring to either the colour of the flowers or possibly the wood, while the specific epithet is from the French for pyramid and refers to the capsule shape. The literature identifies a range of synonyms for *O. pyramidale*, including *Ochroma lagopus* (Swartz), *O. grandiflora* (Rowlee), *O. bicolor* (Rowlee), *O. concolor* (Rowlee) and *Bombax pyramidale* (Cav. ex Lam).
Common names: balsa, cork wood (English); balsa (Central and South America); *tami* (Bolivia); *pau-de-balsa* (Brazil); *enea*, *pung* (Costa Rica); *lana* (Dominican Republic; Panama); *corcho* (Mexico); *gantillo* (Nicaragua); *palo-de-balsa* (Peru). The name 'balsa' is derived from the Spanish word for 'raft'.

Summary of attributes and why diversity matters

Ochroma pyramidale has a very low–density hardwood and is the lightest and softest of all commercial timbers; the wood is both strong and versatile and possesses a high impact strength, good acoustic and thermal insulation properties, excellent fatigue resistance and a wide operating temperature range. Balsa wood has a wide range of uses but the global market is now dominated by its use in sandwich composite applications deployed in many industry sectors.

Balsa wood usually ranges in density from 100 to 170 kg/m^3 but can vary from 50 to 410 kg/m^3. Wood basic density has been found to vary within trees with stem height and across the stem profile. Wood density and other properties vary greatly depending upon origin and growth conditions.

Given experience with other widely occurring tree species, it is inevitable that an abundant pioneering species such as *O. pyramidale*, which occurs across a broad natural range, will possess considerable genetic variation. This variation provides opportunities for a range of wood products. Given the taxonomic complexity and morphological variation within *O. pyramidale,* it is highly likely that such genetic variation exists in key characters such as growth, form, wood density, internode length, and pest and disease resistance.

Description

Habit evergreen, medium to large tree, 30(–50) m tall, 100(–200) cm dbh, usually with short, straight, cylindrical bole, buttressing in older trees; crown broad, spreading and sparsely branched; branches form in sets of 3 (trichotomous) with 1 branch asserting apical dominance to form the next internode. ***Bark*** smooth, greyish-brown, mottled, with small prominent lenticels and approximately 11% of stem over-bark volume. ***Leaves*** spirally arranged, large (typically 10–40 × 11–35 cm but can be much broader in young trees), cordate or 3- to 5-lobed, simple, alternate with long petioles (3–40 cm) ending in broadly ovate and deciduous stipules. ***Inflorescences*** axillary with a single flower, carried toward the end of the branches, singly or in groups of 2 or 3. ***Flowers*** bisexual, large (c. 13–15 × 8–10 cm), bell or trumpet shaped, showy with whitish corolla; stamens united into a staminal column wrapped

Typical habit of mature planted trees; Ecuador provenance trial, East New Britain, PNG (Photo: D. Lea)

Flower buds (Photo: R.R. Thaman)

Flower, young fruit and mature fruit beginning to dehisce and release abundant whitish-brown seed-bearing ‘kapok’; San Augustin, Colombia (Photo: G. Bourke)

Green unopened fruit (L) and mature fruit (R) (Photo: D. Lea)

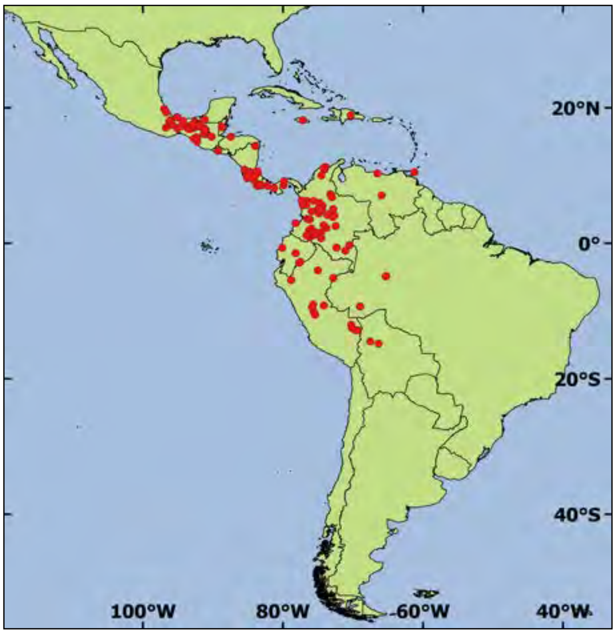
Cleaned seed (Photo: D. Lea)

around the style and stigma; anthers sessile, wavy from the middle to the apex, pollen grains sticky; ovary superior, 5-celled with many ovules per cell; style club-shaped, 9–10 cm long; stigma spiralled. ***Fruit*** oblong capsules, 12–25 × c. 2.5 cm, ribbed, 5-valved, dehiscing at maturity to expose abundant pale brown ‘kapok’ with many embedded seeds. ***Seed*** pear-shaped, 4–5 × c. 1.5 mm, 100,000 viable seed/kg, oily, wind dispersed and orthodox in storage behaviour.

Distribution

Ochroma pyramidale is native to the broadleaved evergreen and secondary forests of tropical America from southern Mexico to Bolivia, including islands of the West Indies. Latitudinal range is 21°N to 10°S.

Ochroma pyramidale plantations have been established throughout its region of natural occurrence and in a wide range of other tropical countries in Asia (China, India, Indonesia, Malaysia, Philippines and Sri Lanka), East and West Africa (Cameroon, Ghana and Zimbabwe) and PNG, mainly in East New Britain province.



Ochroma pyramidale is a species of the humid tropics with a MAT range of 22–35 °C and uniform or bimodal rainfall of 1,500–3,000 mm annually. It tolerates a dry season of up to 4 months, but only if relative humidity remains high (>75%). This species prefers deep, light to medium, fertile, well-drained soils of neutral to alkaline pH for optimum production of lower density wood. Harsh sites slow growth which in turn leads to higher density wood. The selection of site, therefore, is very important for production of balsa wood of the desired quality. *Ochroma pyramidale* is a relatively short-lived (25–50 years), colonising, non-coppicing, self-pruning species, extremely sensitive to root and stem damage when young, waterlogging and forest fires. Stands can be damaged by wind and insect pests (both at a young age and at maturity).

Uses

Wood—interest in the use of balsa wood increased during the First World War where it was used for many

Top left: Harvested logs of *O. pyramidale*; East New Britain, PNG (Photo: J. Doran)

Top right: Harvested stand (foreground) of poorly formed seedlot (ex Oomsis seed stand near Lae); East New Britain, PNG (Photo: J. Doran)

Bottom left: End-grain balsa composite panels, PNG Balsa factory; Kokopo, East New Britain, PNG (Photo: G. Vinning)

Bottom right: Excellent weed control in young *O. pyramidale* plantation; East New Britain, PNG (Photo: L. Thomson)

purposes, including the packing of armour plates in battleships. Balsa wood now has a wide range of end uses and is well known for its use for hobbies and crafts, such as model boats and aeroplanes and models of buildings. Due to its buoyancy, it is used for surfboards and has been used historically for life rafts and lifebelts. However, the global markets for balsa wood are dominated by the demand for end-grain panels which are used widely as cores for sandwich composite applications—comprising a low-density core material sandwiched between two high-modulus face skins to produce a lightweight panel with exceptional stiffness. In this form, it is widely used in industry sectors such as: marine, road and rail; renewable energy; aerospace; defence; and industrial and construction.

As a planted tree, *O. pyramidale* exhibits rapid growth over short rotations. Trees are generally harvested at age 5–7 years before the onset of red heart which causes decay and stain of the heartwood. Stands on high-quality sites in PNG have been determined to carry 840 m^3/ha of over-bark biological stemwood volume at age 6 (total height of 32–38 m and dbh over bark of 27–50 cm). The stand yielded 400 m^3/ha of under-bark log volume.

Between 2008 and 2014, the estimated global area planted to *O. pyramidale* increased from 25,000 ha to 55,000 ha. Production of balsa wood also increased, with global trade rising from 155,000 m^3 (worth an estimated US$71 million) to 208,000 m^3 (worth US$123 million). Within this global context, Ecuador contributed 90%, PNG 9% and other countries 1% to the global supply of balsa wood.

Non-wood—the 'kapok' from the fruit is suitable for use as stuffing in mattresses, pillows and cushions. Rope is made from the fibrous bark which is also reported to have medicinal properties. The tree is sometimes planted as an ornamental or to provide shade and might have potential in soil stabilisation.

Diversity and its importance

Ochroma pyramidale displays considerable morphological diversity across its natural range and this has been reflected by as many as 11 species being recognised in early literature. Given experience with other widely occurring tree species, it is inevitable that species such as *O. pyramidale* will possess considerable genetic variation. This study has been unable to locate any

Top left: Planted stand of *O. pyramidale*; East New Britain, PNG (Photo: J. Doran)

Bottom left: Balsa seed production stand, established in old coconut plantation; Vimy, East New Britain, PNG (Photo: L. Thomson)

Above right: Progeny of L65 candidate seed tree; East New Britain, PNG (Photo: D. Lea)

detailed assessments of genetic variation in this species, including information giving relative performance of provenances in field trials. The high rate of stem defects offers potential benefits from improved silviculture and genetics to increase merchantable yields and grower returns.

Conservation of genetic resources (including threats and needs)

As an abundant pioneering species demonstrating excellent regeneration throughout its native range, *O. pyramidale* is not considered biologically threatened. There have been no recorded concerns regarding the conservation status of the species in Mesoamerica.

There have been no reports of widespread and comprehensive collections of *O. pyramidale* from its range of natural occurrence and subsequent assessment in provenance trials. Observed variation suggests considerable opportunities for selection and deployment of improved germplasm. To date, there has been no commercial success in developing vegetative propagation techniques for the species and this limits options for capturing genetic gain. Another challenge facing tree improvement is the floral biology of the species—with bats pollinating the night-blooming flowers, control of pollinating vectors is challenging.

Ochroma pyramidale's abundant seeding habit and ease of propagation confer a strong capacity to quickly colonise disturbed habitats. The species is considered to be invasive in some Pacific Islands and, in some situations, it has become naturalised and formed dense, closed-canopy, nearly monospecific stands that shade out other species, and/or compete for water and sunlight, suppressing growth and regeneration of understorey plants.

As part of an ACIAR project (FST/2009/016, *Improving the Papua New Guinea balsa value chain to enhance smallholder livelihoods*), PNG's University of Natural Resources and Environment and collaborators established four progeny trials in East New Britain province in 2012: these trials included seed from 105 locally selected candidate plus trees and, in one case, also seedlots imported from Central America. The progeny trials have been assessed and thinned and are ready to function as seedling seed orchards (SSOs), with seed being collected from the ground in the fallen seed pods and 'kapok'. The SSOs will supply genetically improved open-pollinated seed for plantation establishment and form the base population for ongoing genetic improvements.

Authors: Stephen Midgley and Braden Jenkin

Pandanus tectorius

Family: Pandanaceae
Botanical name: *Pandanus tectorius* Parkinson ex Du Roi. In *Naturforscher (Halle)* 4: 250 (1774).

The genus name is derived from the Malayan *pandang*, which a local dialect name for several *Pandanus* species, and the specific epithet derives from the Latin *tectorius*, to cover. *Pandanus tectorius* hybridises naturally with the related *P. odoratissimus*, a native to South and South-East Asia and the western Pacific. *Pandanus odoratissimus* is also highly variable, with the main morphological difference from *P. tectorius* being the larger and paler leaf spines in *P. odoratissimus*. More detailed DNA, field and morphological studies are required to confirm their taxonomic status and relationships.

The nomenclature for the genus *Pandanus* is confused, with most taxonomists classifying cultivars and clones of Pacific Islands coastal *Pandanus*, both edible and non-edible, as forms of *P. tectorius*. Previously, a few taxonomists considered them to comprise distinct species, often listing numerous species or varieties for a given area. For example, *P. odoratissimus* L.f. has long been thought to be synonymous with *P. tectorius*, but is now considered to occur only east of Malaysia. Similarly, *P. odoratissimus* L.f. var. *pyriformis* Mart. has been used as a synonym for a wild and doubtful variety of *P. tectorius*, whereas Stone (1970) considers *P. fragrans* Gaud. to be the common wild species on Guam and does not consider *P. tectorius* to be present. *Pandanus dubius* Spreng. is a widespread edible species while *P. spurius* Miq. cv. Putat—syn. *P. tectorius* Warb. var. *laevis* Warb. and syn. *P. odoratissimus* L.f. var. *laevis* (Warb.) Mart—are widely cultivated in the Pacific Islands for their leaves which are highly valued for plaiting mats.

Common names: pandanus, beach pandanus, screwpine (English); *pandanus*, *vacouet* (French); *deipw*, *fach*, *far* (Chuuk, FSM); *vadra*, *voivoi* (Fiji); *kafu* (Guam; Northern Mariana Islands); *hala*, *pū hala* (Hawai'i, USA); *binu* (Kapingamarangi, Pohnpei atoll, FSM); *te rekenibeti*—wild, *te kaina*—cultivated (Kiribati); *mweng* (Kosrae, FSM); *bōb* (Marshall Islands); *épo* (Nauru); *hala* (Nukuoro, Pohnpei atoll, FSM); *ongor* (Palau); *deipw*, *kipar* (Pohnpei, FSM); *hata*—wild, *hosoa*—cultivated edible, *s'anga*—cultivated for weaving (Rotuma, Fiji); *fala*, *lau fala* (Samoa; Tuvalu); *fa*, *fafa*, *laufala*, *falahola*, *kukuvalu*, *lou'akau* (Tonga); *pandanas* (Vanuatu); *choy*, *fach*, *far* (Yap, FSM)

Summary of attributes and why diversity matters

Pandanus tectorius is an extremely diverse and highly valued, multipurpose small tree for coastal plantings and protection in the tropics. It is especially vital for plantings in the challenging atoll environments in the Pacific Islands. It provides timber, leaves for thatch, edible fruit and traditional medicines. *Pandanus tectorius* is extremely well adapted to diverse climates and future climate change extremes, including warmer temperatures, drought, saltwater incursion and fire. While breadfruit trees may die, and coconuts fail to produce nuts during times of drought on equatorial atolls, *P. tectorius* survives and becomes an even more important food.

Hundreds of named and vegetatively propagated clonal varieties are known in the Pacific Islands. Selected female clones or varieties with low levels of oxalates are highly preferred for consumption: some clones in the central and northern Pacific have high levels of provitamin A carotenoids and are vital for combating vitamin A deficiency. It is recommended that other Pacific Island nations follow the lead of Kiribati and initiate programs to conserve *P. tectorius* diversity and the underlying cultural knowledge that has fostered and maintained this diversity.

Description

Habit typically a multistemmed, spreading large shrub or small tree 2–18 m tall; trunk stout, forking and often spiny, attains maximum dbh of about 12–25 cm

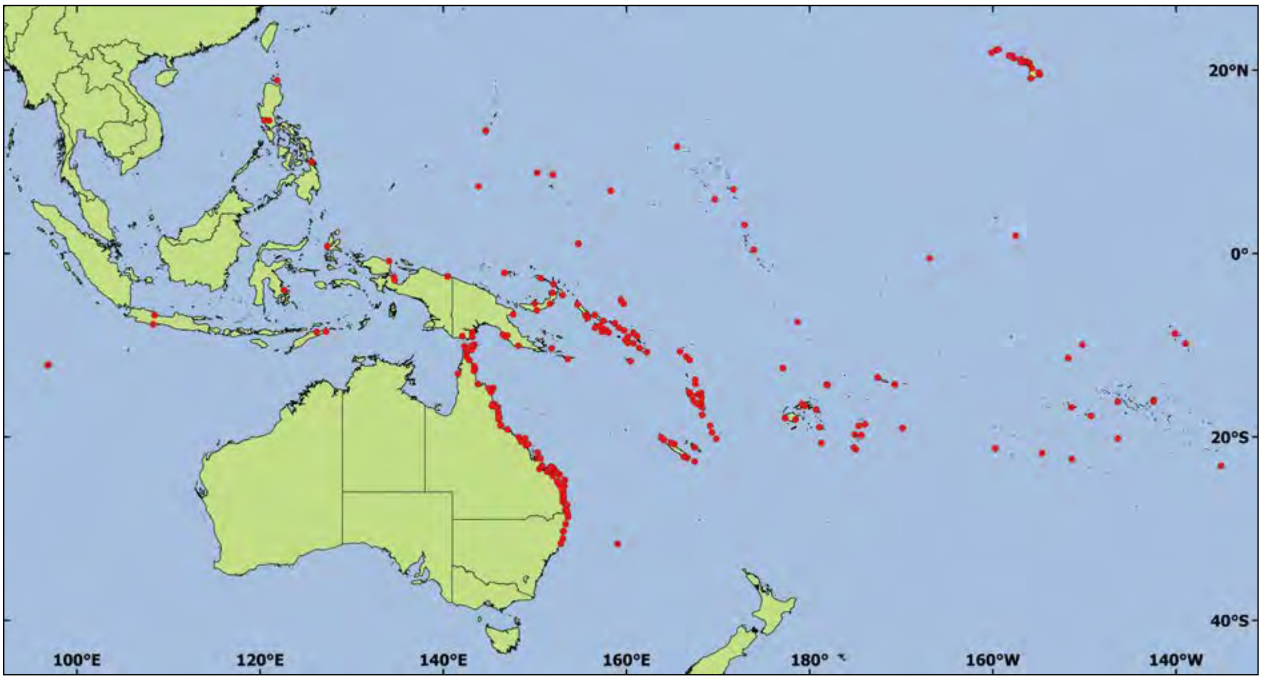
Mature fruit head of a green *P. tectorius* variety comprising many individual keys (phalanges); Houma, Tongatapu, Tonga (Photo: L. Thomson)

Above left: *Pandanus tectorius* on raised coralline outcrop; Uoleva, Ha'apai, Tonga (Photo: L. Thomson)

Above right: Mature specimen showing basal prop roots; Butaritari Atoll, Kiribati (Photo: L. Thomson)

Left: Male flowers (Photo: R.R. Thaman)

(thicker in female plants); root system dominated by thick, slightly spreading prop roots originating from the basal portion of the trunk; in some plants, there is a small number of aerial roots hanging vertically from the branches. ***Bark*** greyish- to reddish-brown, smooth/flaky, with characteristic undulating leaf scars and rows of prickles. ***Leaves*** shape and size highly variable, both within and between plants; spirally arranged in 3 rows, clustered at branch apices, dark green, 1–3 m long, 11–16 cm wide, V- to Y-shaped in cross-section, with spiny/prickly margins and midribs; marginal prickles usually 0.8–2.5 mm long; in fully expanded leaves, the midrib is bent, and the upper third of the leaf hangs down, giving the species its characteristic drooping appearance. ***Inflorescences*** in heads at the apex of shoots; the species is dioecious (separate male and female plants). ***Flowers*** *male flowers* fragrant, tiny, white, pendant, arranged in racemes or branched in clusters, with large white showy bracts, flowers only last for about a day, with the inflorescence decaying within 3–4 days; *female flowers* green globular (pineapple-like) cone, developing into highly variable fruit heads which may be ovoid, ellipsoid, subglobose or globose. ***Fruit*** mature fruit heads typically 8–30 cm long, 4–20 cm diameter, comprising many (about 40–200) tightly bunched, wedge-shaped fleshy phalanges or keys; individual keys narrowly oblong to ovoid, 2.5–11.0 cm long, 1.5–6.7 cm wide; endocarp (internal tissue surrounding the seed) dark reddish-brown, hard/bony, 15–35 mm long; apical mesocarp, formed in the apex of each carpel, elongated cavern with aerenchyma of a few longitudinal fibres and white membranes; basal mesocarp fibrous and fleshy, about 10–30 mm long; apical profile of individual keys ranges from truncate and subtruncate to convex; carpels 1–15/key, arranged either radially or in parallel rows. ***Seed*** obovoid, ellipsoid or oblong, 6–20 mm long, red-brown and whitish/gelatinous inside.



Distribution

Pandanus tectorius occurs naturally in strandline and near-coastal forests in South-East Asia, including the Philippines and Indonesia, extending eastward through PNG and northern Australia, and throughout the Pacific Ocean islands, including in Melanesia (Fiji, New Caledonia, Solomon Islands and Vanuatu), Micronesia (FSM, Guam, Kiribati, Marshall Islands, Nauru, Northern Mariana Islands and Palau) and Polynesia (American Samoa, Cook Islands, French Polynesia, Hawai'i [USA], Niue, Samoa, Tokelau, Tonga, and Wallis and Futuna).

Pandanus tectorius grows in maritime, tropical, humid and subhumid climates. Mean annual rainfall varies from 1,500 to 4,000 mm, typically without, or with only a short, dry season. It is adapted to an extraordinarily wide range of edaphic enviroments; from acidic to alkaline (pH 6–10), light to heavy textured soils and tolerant of impeded drainage. The species is very well adapted to exposure to strong, often salt-laden winds and mature plants will tolerate moderately intense fires.

Uses

Different parts of the *P. tectorius* plant are used to provide a myriad of end products throughout the Pacific Islands, where it is especially important on atolls.

Wood—the trunk and large branches are used for building materials in house construction, and for ladders. Male trees have hard, solid trunks with a yellow interior containing dark-brown fibre bundles. The male wood is very strong, but brash, meaning that it can suddenly break under a heavy load. It is also a difficult trunk to split. Trunks of female trees are hard on the outside, but soft, pithy or juicy in the interior. Slats made from the clean, dried aerial/prop roots are used for walls of houses and food cupboards. The trunks are also used to make headrests, vases and fish traps, used as glue or caulking for canoes, to extract cream from grated coconuts and as an aid in making string. Trunks, branches and dried keys may be burnt for fuelwood or used to make compost.

Non-wood—prop/aerial roots are used to produce dyes and traditional medicines as well as for supports, basket handles, paintbrushes and skipping ropes. The leaves of selected varieties are treated by soaking in the sea and/or boiling or heating and drying in the sun: they are then used to make mats, baskets, hats, fans, pillows, toys and other plaited wares. The leaves are also used for wall and roof thatching and for making compost, including composting baskets for giant swamp taro, balls for children's games and ornaments. They are also used as a cooking aid in some recipes, while young leaves are used in decoration and for pig feed.

Conditioning *P. tectorius* leaves in sea water before drying and weaving into fine mats; Lifuka, Ha'apai, Tonga (Photo: L. Thomson)

Above left: *Pandanus tectorius* fruit for sale in local market; Tongtapu, Tonga (Photo: L. Thomson)

Above right: Weaving of *P. tectorius* mat; Butaritari, Kiribati (Photo: L. Thomson)

Left: Dried *P. tectorius* fruit paste (*te tuae*); Tarawa, Kiribati (Photo: L. Thomson)

Throughout the atoll island countries of the central and northern Pacific, the fleshy keys of the fruit of many traditionally selected, named and cultivated varieties are eaten fresh or made into various preserved foods. Preserved pandanus pulp (*te tuae*, *mokwan*) mixed with coconut cream makes an exquisite and delicious food item. The fruit are also eaten in Solomon Islands and PNG; however, fruit of wild forms may contain oxalate crystals that irritate the mouth unless broken down by cooking.

In Polynesia, the fragrant, ornamental fruit of different varieties are strung into leis or garlands and are also used to make perfume. The fibrous dried mature phalanges are used as paint brushes for painting *tapa* cloth, and as fuel, compost and fishing line floats. In Kiribati, the fruit may also be used as bait for catching lobster. The fragrant male flowers are used to scent coconut oil, to perfume *tapa* and to make garlands.

Pandanus tectorius is an important medicinal plant, with certain varieties being preferred for incorporation into treatments for specific illnesses. Leaves, especially the basal white section of young leaves, and roots are used. In Kiribati, *P. tectorius* leaves are used in treatments for colds and flu, hepatitis, dysuria, asthma, boils and cancer, while the roots are used in a decoction to treat haemorrhoids. In Hawai'i, the fruit, male flowers and aerial roots are the main parts used in making traditional medicines. These are used individually or in combination with other ingredients to treat a wide range of illnesses, including digestive and respiratory disorders. The root is used in Palau to make a drink that alleviates stomach cramps and the leaves are used to alleviate vomiting.

Plants growing along the beach or in near-coastal locations are able to cope with periodic and short-duration, shallow saltwater inundation from king tides. However, plants may die or display dieback if exposed to longer duration saline/brackish waterlogged conditions, depending on factors such as soil type and plant age. Mature *P. tectorius* palms growing in less well aerated substrates are at greater risk from rising sea levels. *Pandanus* spp. have been noted as being resistant to strong steady winds and gale-force winds associated with

Category 1–3 cyclones. During such low to moderately intense cyclones, it has been reported that *P. tectorius* was either mostly undamaged or had merely suffered broken branches. During more intense cyclones, *P. tectorius* may be uprooted as a result of beach sand being washed away during storm surge. Plants generally recover from branch and stem damage, with about 10% of larger individuals in exposed sites being broken and dying following more severe cyclones (Category 3–5).

Diversity and its importance

There are multiple fruit head forms with considerable plant-to-plant variation in morphology, size and colour. Many of the traditionally named cultivated varieties (females) are recognised by their particular combination of fruit head characteristics. There is a great diversity of Kiribati *P. tectorius*, with most reports suggesting that there are approximately 170 varieties. Other reports list 200 and 259 varieties, some of which are thought to be different names given for the same variety. Names are given according to taste, speed of ripening, seasonality and other local discretionary factors. The named varieties in the central and northern Pacific Islands are almost exclusively vegetatively propagated female clones which have been selected for low oxalate content in their fruit and suitability for human consumption. There is substantial diversity in the level of provitamin A carotenoids in fruit, which is an extremely important trait given that vitamin A deficiency is a major health problem in Micronesia (central and northern Pacific). There is a significant range of provitamin A carotenoid levels found in a selection of *P. tectorius* varieties from Kosrae (FSM) and Kiribati, with higher levels found in those varieties of deeper colour. In Kiribati, the provitamin A carotenoid content of seven of nine varieties tested met all or half of estimated daily vitamin A requirements within normal consumption patterns.

There is also considerable variation in leaf properties which affect the suitability of different vegetatively propagated cultivars for conversion into mats and other woven handicrafts. A few traditionally recognised and named varieties have leaves with smooth margins well suited to weaving, e.g. *Tutu'ila* in Tonga, *Nei Naobua* in Kiribati, *Laufala* in Samoa, and at least one variegated form in Fiji.

Conservation of genetic resources (including threats and needs)

In Kiribati, the Division of Agriculture (Ministry of Environment, Lands and Agricultural Development), with support from SPC/FAO/SPRIG/University of the South Pacific has established a field genebank of traditional *P. tectorius* varieties. The genebank is located in Bikenibeu South, South Tarawa, and includes >60 varieties. It is recommended that other Pacific Island nations undertake similar programs to conserve *P. tectorius* diversity and the underlying cultural knowledge that has fostered and maintained it. In Kaua'i, Hawai'i, the National Tropical Botanical Garden maintains a modest collection of *Pandanus* species and cultivars at its Allerton and McBryde Gardens.

Authors: Lex Thomson, Randolph R. Thaman, Luigi Guarino, Mary Taylor and Craig Elevitch

Above: Fruit head of a red traditional variety, Vava'u, Tonga (Photo: R.R. Thaman)

Left: Study of *P. tectorius* varietal diversity, with Tearimawa Natake; Butaritari Atoll, Kiribati (Photo: L. Thomson)

Piper methysticum

Family: Piperaceae
Botanical name: *Piper methysticum* Forst.f. In *Diss. Pl. Esc.* 76 (1786).
The plant derives its name from *piper* (Latin for pepper) and *methysticum* (Greek for intoxicating). Morphological, chemical, cytological and genetic evidence indicates that *P. methysticum* derives from the wild species, *P. wichmannii* C.DC., through domestication and selection. These two taxa are now considered as a single species, with the cultivars identified as var. *methysticum* and the wild forms as var. *wichmannii.* The species is dioecious and decaploid ($2n = 10x = 130$).

Piper methysticum cultivars are exclusively propagated by stem cuttings and do not reproduce sexually. Neither seed nor fruit have ever been described and are absent from all herbarium vouchers preserved in all major herbaria of the world. Studies using isozymes, amplified fragment length polymorphisms (AFLPs), single sequence repeats (SSRs) and diversity arrays technology (DArT) revealed little genetic variation among cultivars grown throughout its area of distribution. Based on the limited sexual reproductive biology of the plant, it is thought that cultivars are most likely the result of human selection and preservation of somatic mutations in a few genetically similar, vegetatively propagated plants.
Common names: The most common name in English is kava, which derives from the same name in Tongan. The original Polynesian name was *kava* and it was changed to *'ava* or *'awa* in Samoa, Hawai'i, Tahiti and some other places. Outside of Polynesia, there are several other names in the Pacific Islands, including *malogu* in northern Vanuatu, *sika* or *kau* in PNG, *yaqona* in Fiji and *sakau* in Micronesia.

Summary of attributes and why diversity matters

Piper methysticum is an economically vital crop species for smallholder farmers in Fiji, Samoa, Tonga, Vanuatu and several other Pacific Islands. The species has been domesticated principally in Vanuatu where 80 morphotypes or cultivars are known. A traditional beverage is made from the roots and lower stems which is used ceremonially and socially, and increasingly as a medicinal treatment for depression and other illnesses. Different cultivars have different kavalactone profiles and may be grouped into three distinct use categories corresponding to traditional classification: noble, medicinal and *tudei* (two-day), with the last being unsuitable for consumption.

Description

Habit a shrubby plant, 1–4 m tall; slow-growing perennial, generally resembling other *Piper* species with main stems monopodial and lateral branches sympodial; lateral branches grow from young parts of main stem and, as they age, fall away leaving cicatrices on the nodes; at maturity, the plant is a bouquet of ligneous stems

Mature 4-year-old plant, with Graham Mala'efo'ou; Vava'u, Tonga (Photo: R.R. Thaman)

Inflorescences and foliage (Photo: F. & K. Starr) clustered together at their base; remarkable morphological variation between cultivars, some being prostrate with short internodes, others are normal with many stems, or erect with few stems and very long internodes. ***Bark*** stems green to dark purplish. ***Leaves*** alternate, light green, petiolate, heart-shaped, 13–20 cm long and similar width; blades have 11–13 veins radiating from their base. ***Inflorescences*** narrow spikes; the species is dioecious (produces male and female inflorescences on separate plants) but does not reproduce sexually; female inflorescences fall off before they produce fruit. ***Flowers*** male flowers appear continuously but are sterile. ***Seed*** never observed on cultivars.

Distribution

Piper methysticum is the only cultivated plant of economic importance with an area of distribution restricted entirely to the Pacific Islands. Wild forms of the species are found in the lowland forests of PNG, Solomon Islands and northern Vanuatu.

Cultivars of *P. methysticum* have been clonally distributed by humans throughout Melanesia (Fiji, PNG, Vanuatu, and Papua province, eastern Indonesia), FSM (Kosrae and Pohnpei) and Polynesia (French Polynesia, Hawai‘i [USA], Samoa and Tonga).

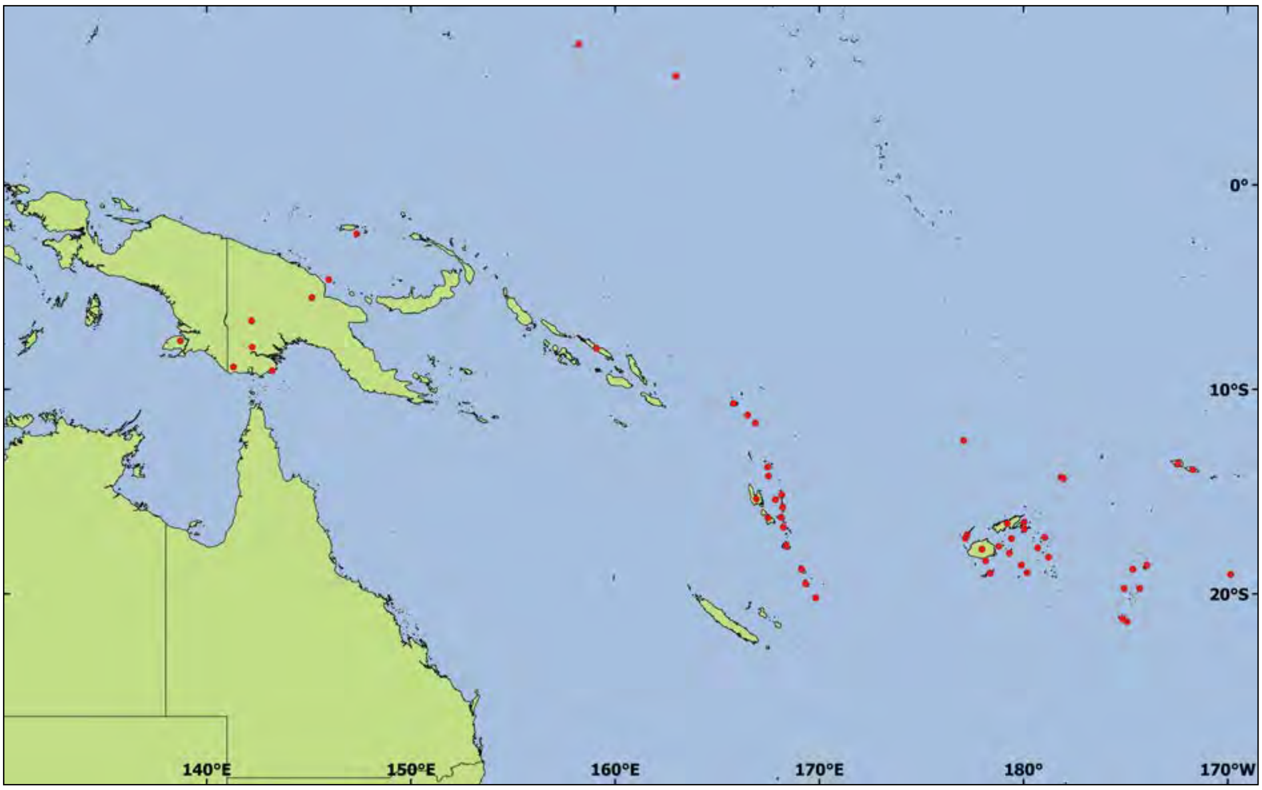
The distribution of *P. methysticum* is no longer as extensive as before the first contact with Europeans. *Piper methysticum* has been left to die out in many valleys of Hawai‘i; the Marquesas Islands, Society Islands and Tubuai (French Polynesia); the Cook Islands; and Niue. Due to interdiction by missionaries, its consumption and cultivation was abandoned and neglected; devastation caused by the wild pigs, competition from weeds and climbing vines were contributing factors to its near extinction on these islands. Nowadays, especially in Hawai‘i, there is an attempt to develop its cultivation as an economic crop.

Piper methysticum grows best in humid subtropical to tropical climates (MAT range 20–25 °C) on fertile well-drained soils (pH 5.5–6.5) with protection from high winds. It thrives in shaded tropical agroforestry settings at lower elevations (0–800 m asl) with high rainfall (1,000–3,000 mm MAR).

Uses

The most important product continues to be the traditional beverage—also known as kava, the plant's common name—made from the roots and lower stem portion of the *P. methysticum* plant. The plant is very well suited to incorporation into traditional agroforestry systems, given its tolerance of partial shade, and provides growers with substantial cash income after several years (e.g. 3–7 years). This fills a gap between income from annual and short-term crops and that from long-term timber and fruit/nut tree crops.

Non-wood—the traditional beverage of the Pacific Islands is prepared by cold water extraction of the underground organs of the noble cultivars of *P. methysticum* var. *methysticum* (var. *wichmannii* is



Natural and traditionally cultivated distribution of *P. methysticum* (excluding French Polynesia and Hawai‘i)

Left: Roots of *P. methysticum* (referred to in Fijian as *waka*) specially wrapped for use as traditional gift (*sevusevu*) in local market; Savusavu, Vanua Levu, Fiji (Photo: SPC-LRD)

Top right: *Piper methysticum* with pineapple in agroforestry planting; Vava'u, Tonga (Photo: R.R. Thaman)

Bottom right: Mixing of *P. methysticum* extract (grog) in kava ceremony; Vanua Levu, Fiji (Photo: SPC-LRD)

never used). The most frequent use is a social drink taken for its relaxing properties. There are two different methods of preparation depending on whether fresh or dried roots are used. The grinding, squeezing and filtering process is very simple but efficient for producing a suspension of lipid-like compounds, known as kavalactones, which are non-soluble in water. The molecules are unique to *P. methysticum* and present a wide range of scientifically proven physiological properties, with efficient bactericidal, antifungal, anaesthetic, anxiety-relieving, sleep-inducing, muscle-relaxant and even anticancer effects. In the Pacific, *P. methysticum* is traditionally used to treat inflammations of the urogenital system, gonorrhoea and cystitis, feminine puberty syndrome and menstrual problems, painful migraine headache, chills and rheumatism.

Diversity and its importance

Since the early 1980s, a standardised list of 8 morphological descriptors has been used to discriminate >100 different morphotypes of *P. methysticum* throughout the Pacific Islands: 80 in Vanuatu, 12 in Fiji, 11 in Hawai'i, 7 in Tonga, 6 in Samoa, 4 in PNG, 3 in Wallis and Futuna, 3 in Tahiti, 2 in Pohnpei, and 1 in each of the Cook Islands, Marquesas Islands and Kosrae. Based on high-performance liquid chromatography (HPLC) chemotypes, wild forms of var. *wichmannii* are clearly differentiated from cultivars of var. *methysticum*. Cultivars are separated into three distinct use categories corresponding to traditional classification: noble, medicinal and *tudei* (two-day). These categories are based on the physiological effects of beverages made from the roots, which depend largely on the levels of six major kavalactones. Noble cultivars, which are safe for daily drinking, and medicinal cultivars have a chemotype rich in kavain and produce relaxing effects; however, noble cultivars have a higher kavain content. Medicinal and noble cultivars do not differ significantly in their kavalactone profiles and their classification refers to their uses: as a medicinal plant or for daily consumption of the beverage. However, *tudei* cultivars—low in kavain and rich in dihydrokavain and dihydromethysticin —are not suitable for consumption and are known for their deleterious side effects and nausea. In Vanuatu, these cultivars are considered as illegal for trade under that country's *Kava Act 2002*.

A selection of the diversity of stems in different Fijian *P. methysticum* varieties, the names of which reflect their stem characteristics: (top) *Vula Kasa Leka*—pale with short internodes; (middle) *Vulu Kasa Balavu*—pale with long internodes; and (bottom) *Loa Kasa Balavu*—blackish colour and long internodes (Photos: B. Wiseman)

Piper methysticum is susceptible to a wide range of insect pests and diseases. Following silvicultural practices that avoid or mitigate problems, such as crop rotation, are recommended. Some *P. methysticum* cultivars show significant resistance to important diseases and offer the potential for higher yields from monocultures if generally adopted.

Conservation of genetic resources (including threats and needs)

Distinct morphotypes share a common molecular profile and this illustrates that mutations may arise following several or many generations of clonal or vegetative propagation which are able to be selected. Farmers from the Pacific Islands are prompt at tagging novel variants and integrating them into their cultivar portfolio as soon as they appear. The selection of particular mutants, therefore, is a continuous and conscious process conducted in *P. methysticum* fields. This selection is still dynamic and efficient in the species, where new cultivars have been found in farmers' fields over a 20-year period, but some are also disappearing.

For beverage plants such as *P. methysticum*, morphological characters are less prone to human selection than are chemical characters. Noble and medicinal cultivars belong to a single clonal lineage but important variations in total kavalactones exist between and within these cultivar categories. Although environmental factors may play a role, clonal selection is exerted on the total content of kavalactones as farmers judge the physiological effects of the beverage obtained from a single plant. In villages, this can occur on a daily basis and represents a continuous clonal selection process. However, if noble cultivars of *P. methysticum* are represented by clearly distinct morphotypes, these cultivars are genetically vulnerable and their potential to adapt to forthcoming climatic changes is limited.

Author: Vincent Lebot

Pometia pinnata

Family: Sapindaceae
Botanical name: *Pometia pinnata* J.R. & G.Forst. In *Characteres Generum Plantarum* p. 110 (1775).

The genus name is derived from Latin *pomus* (fruit tree) in reference to the edible fruit, while the specific epithet is from the Latin for 'feather-like' in reference to the compound leaves. There has been considerable confusion concerning the taxonomy of *P. pinnata* due to its complex and bewildering variation patterns. Jacobs (1962) recognised eight distinct forms, plus a number of less-distinct paramorphs, and a residue of polymorphic, unclassified material. Populations in the Philippines, north-eastern Sulawesi, the Maluku Islands and New Guinea island comprise three forms—namely, *pinnata*, *glabra* and *repanda*—along with intermediates, with remarkably few individual oddities. All trees in the Pacific Islands belong to the form *pinnata*. Whitmore (1976) has referred to *P. pinnata* as an ochlospecies, whose complex variation patterns cannot be satisfactorily accounted for by conventional taxonomic categories. A better understanding of the taxonomy and genetic variation in *Pometia* will require a combined approach of ecological, morphological and molecular marker studies.

Common names: Within Oceania, >70 names for the species are known in different languages and regions, while hundreds of names exist to describe particular varieties in different areas. More widely recognised names include: oceanic lychee (English); *dawan* (Ambon, Indonesia); *dawa* (Fiji; Solomon Islands); *matoa* (Maluku Islands and West Papua/Papua, Indonesia); *malugai* (Philippines); *taun*, *tauna* (PNG); *tava* (Polynesia); *fao*, *fava* (Rotuma, Fiji); *dawa*, *ako*, *tava* (Solomon Islands); and *nandao* (Vanuatu).

Summary of attributes and why diversity matters

Pometia pinnata is one of the most variable tree species in the Asia–Pacific region, with at least eight distinct forms and numerous traditional varieties, mainly differentiated on the basis of fruit characters. Throughout its native range, *P. pinnata* is a major timber and medicinal species, while in parts of Melanesia and Polynesia, large and sweeter fruited forms are a favourite seasonal fruit and appear to have been enhanced through traditional selection processes. Its centre of diversity appears to be in eastern Indonesia, where wild forms still coexist alongside a range of named edible cultivars that are sold at local markets. A breeding program to combine desired fruit characteristics, including an extended fruiting season, with a well-formed bole for timber production would provide a multipurpose tree of tremendous utility and value to Pacific Island farmers and agroforesters.

Where *P. pinnata* fruit are an important seasonal food, diversity and traditional knowledge of fruit characteristics are most well developed: the species has become semi-domesticated, with better fruit morphotypes managed and protected. Nevertheless, it appears that the genetic and economic potentials of *P. pinnata* remain considerably undeveloped in the Pacific Islands.

Furthermore, concerted efforts are needed to protect this extremely important multipurpose agroforestry species, including steps to preserve the rich traditional ecological and cultural knowledge associated with *P. pinnata*. Awareness programs need to be developed to highlight the importance of this tree as a component of agroforestry development models, both rural and urban, that are truly sustainable in the small islands of the Pacific.

Description

Habit medium to large tree up to 50 m tall and about 1.5 m dbh; bole length and shape varied, frequently twisted and asymmetric with short buttresses. ***Bark*** grey to light brown, may be smooth or mottled. ***Leaves*** large, highly variable, paripinnate with 4–13 pairs of leaflets, at first pink quickly turning bright red then mid-green. ***Inflorescences*** terminal or sub-terminal axillary panicles, 15–70 cm long, conspicuously projecting beyond the foliage. ***Flowers*** small, usually borne in clusters, separate

Mature tree; Fausaga, near Togitogiga, southern Upolu, Samoa (Photo: L. Thomson)

Above: Fruit and seed; Jayapura, Papua, Indonesia (Photo: B. French)

Right: Sapling, showing intermediate pinnate leaves, in rainforest regeneration plot, with John Doran; southern Upolu, Samoa (Photo: L. Thomson)

male and female flowers borne in the same panicle. ***Fruit*** smooth skinned, varying from round to elliptic, 1.5–5.0 cm long, 1.0–4.5 cm diameter, variously coloured at maturity (green, yellow, red, purple, blackish or brown); inside the fruit is a gelatinous, sweet, edible, white to slightly pinkish translucent pulp partially encasing a single seed. ***Seed*** large (to 2.5 × 1.5 cm), recalcitrant.

Distribution

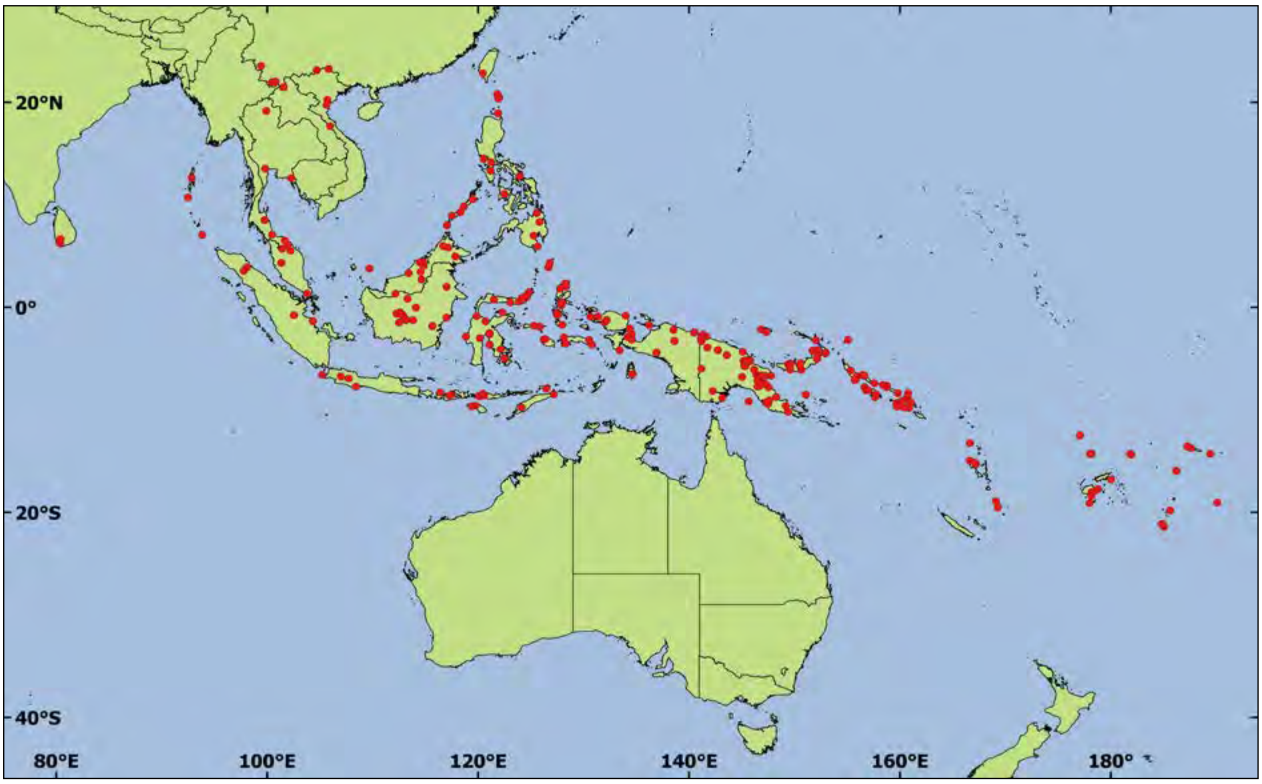
Pometia pinnata occurs throughout most of Oceania, extending from the Philippines, Indonesia, PNG, Solomon Islands, Vanuatu, Fiji and Polynesia. It also occurs throughout South-East Asia, with extensions into southern China and South Asia (Sri Lanka and Andaman Islands).

The species is possibly an ancient introduction into the more eastern parts of its range (Tonga and Samoa, and possibly Fiji), where it is rarely seen in native forests but rather in shifting agricultural areas and village tree groves. *Pometia pinnata* may be a post-European contact introduction into New Caledonia, the Cook Islands, Tahiti (French Polynesia) and the northern Pacific. It has not been reported from Micronesia.

It favours the warm to hot humid tropics: 22–28 °C MAT and 1,500–5,000 mm MAR, with a short dry season of ≤3 months. It attains its best development on well-drained, fertile loams and clays.

Uses

Pometia pinnata is one of the most important multi-purpose trees in the Pacific Islands. Throughout most



of its range it is an important timber, fuelwood, fruit, medicinal and amenity tree.

Wood—an excellent general-purpose timber which is widely utilised locally throughout its range for a variety of end uses. It is one of the most commonly used construction hardwoods in PNG and the most important native timber species in Samoa. In Tonga in the 1960s and 1970s, the wood was also used in woodcarving to make *tapa* mallets (*ike*) and cut to provide shooks for banana boxes. It is an excellent firewood and during the 1970s it was among the most widely sold fuelwood species at the Apia Market, Samoa, and the Nuku'alofa Market, Tonga, although is now rarely sold because of its threatened status. With increasing scarcity, its timber should, wherever possible, be reserved for high-value end uses, such as decorative furniture and flooring.

Non-wood—fruit are edible, bearing some resemblance to lychees, thus the common name of oceanic lychee. The fruit are highly regarded in parts of Melanesia, particularly in Fiji, PNG, Tonga and Vanuatu. An agricultural survey on >100 rural bush allotments in Tongatapu, Tonga, in 1971 showed that out of >30 fruit tree species, *P. pinnata* was, after the coconut palm, the second most frequently encountered. In the same survey, it was the fourth most important fruit tree encountered in almost 200 town allotments, after breadfruit, mango and coconut. The University of the South Pacific developed a '*dawa* in syrup' product that appears to have tremendous export market potential; however, lack of entrepreneurs and a consistent source of high-quality fruit has inhibited this market opportunity from being realised.

In some lowland parts of PNG, *P. pinnata* is planted as an agroforestry crop, with its dried leaves used as fertiliser mulch in yam cultivation in the Sepik region. It is also planted around villages and planted or protected in garden areas in other parts of the South Pacific. This is mainly for the purpose of providing fruit, medicine and firewood, and, in the case of Tonga, pollarding to provide low trellising or *felei* for yams.

Preparations from the leaves and bark are widely used in traditional medicines to treat various ailments. In PNG, masticated bark is applied to burns. In Solomon Islands, an oral medicine is prepared from the bark to protect babies from evil spirits. In Fiji, both leaf and bark extracts are used, either individually or in combination with other plants, to treat a wide range of ailments, including stomach complaints, diarrhoea, dysentery, pain relief (bones, muscles, joints, chest, headache), colds, influenza, diabetes and mouth ulcers. Interestingly, the bark of one variety was credited with having contraceptive properties, while an infusion of the bark and leaves together with *Ipomoea batatas* (sweetpotato) was considered to be a successful cure for sterility. In Tonga,

Fruit of *P. pinnata* in woven *bilum* bags; Madang, PNG (Photo: B. French)

an infusion of the bark was used to treat diarrhoea in children, stomach trouble, serious coughs accompanying fever and constipation, and the leaves were also used medicinally. In parts of Sarawak, Malaysia, a traditional treatment for chickenpox patients is bathing in a hot water infusion of the bark.

The future for *P. pinnata* is unclear: in the Pacific Islands, it is likely to be less utilised for timber as supplies dwindle over the next two decades. Thereafter, supplies might increase from both revitalised stocks deriving from assisted natural regeneration programs, as in Samoa, and from increased plantings in agroforestry systems. For fruit, it will likely be increasingly planted in the Pacific Islands, especially superior, longer-season fruit types, while it is likely to remain neglected in South-East Asia due to the presence of more highly regarded local fruit.

Diversity and its importance

The greatest consumption of *P. pinnata* fruit occurs in Fiji, PNG, Solomon Islands and Vanuatu. In Fiji, Tonga and Vanuatu, when in season, the fruit are sold at urban produce markets. Utilisation of fruit for food is associated with the selection and domestication of superior fruit types and the absence, until recently, of related Asian fruits trees such as rambutan and lychee. Its centre of origin and diversity is thought to be in eastern Indonesia in the area between Sulawesi, Maluku Islands and Papua province, where both wild forms and forms selected for their fruit exist. There are two selected fruit types, distinguished by their texture and taste: *matao papeda*, which has texture like rambutan; and *matoa kelapa*, which is characterised by more fleshy fruit. Numerous other traditional varieties within the form *pinnata* are recognised on the basis of fruit characters, especially size, shape, skin colour, taste and sweetness. Superior fruit morphotypes have been reported from:

- Indonesia—near Jayapura, Papua—*Kablauw* and *Iwa* varieties have thick sweet flesh, tasting like rambutan

- PNG—Tanga Islands, located east of New Britain—large sweet-tasting fruit with very thin, red skin
- Solomon Islands—Santa Cruz Islands, Tevai
- Vanuatu—Aneityum, Banks Islands, Epi, Espiritu Santo and Malo
- Fiji—Gau, Kadavu and south-eastern Viti Levu
- Tonga—Tongatapu.

In Tonga, for example, where *P. pinnata* is normally only found in human-modified garden areas and fallow forests, and is increasingly uncommon, there are the named varieties *Tava Kula*, *Tava Hina*, *Tava Toua* and *Tava Moli*, some of which are rarely seen today. Superior fruit morphotypes such as these need to be protected from harvesting for timber or fuelwood.

The seed storage behaviour of *Pometia* is highly recalcitrant, making it impossible to store seed for more than a few weeks and, therefore, difficult to transport and exchange between countries. *Pometia pinnata* can be vegetatively propagated from cuttings derived from coppiced hedges and treated with 0.3% indole-3-butyric acid (IBA) rooting hormone. There is a need to develop tissue culture techniques for the species to enhance exchange and movement of germplasm, and enable mass propagation and in vitro conservation of selected, improved genotypes.

A breeding program is warranted to incorporate the large and sweet-fruited characters into the good timber forms through a program of hybridisation, selection and backcrossing. The first step is the identification of promising genotypes; that is, good timber phenotypes with larger than average fruit and large-fruited types that also possess rapid growth and good bole form, for use in such a program.

Conservation of genetic resources (including threats and needs)

Coincident with programs for the selection and genetic improvement of *P. pinnata*, there should be programs to conserve varietal diversity and to establish national and community-based replanting and germplasm collections.

Sacks of *P. pinnata* fruit in local market showing diversity in fruit skin colour; Jayapura, Papua, Indonesia (Photo: B. French)

Studies in Fiji, Tonga and the Cook Islands indicate that most villages are concerned that *P. pinnata* is threatened and is slowly disappearing from agricultural and village landscapes. Some traditional varieties are also rare or have been lost in some localities. The main reason for the disappearance of *P. pinnata* is related to the process of agrodeforestation, or the failure to protect or replant trees during the agricultural development process in active agricultural areas. The major factors leading to agrodeforestation include indiscriminate burning, removal or ringbarking of trees, overuse for firewood or medicinal purposes and the abandonment of traditional practices. In the past, valuable trees such as *P. pinnata* were almost always protected when establishing new garden plots, and practices such as pruning or pollarding and selective weeding were preferred to tree removal and indiscriminate weeding—including use of herbicides—which remove and kill valuable tree seedlings.

Accordingly, the main components of a *P. pinnata* conservation and management strategy include:

- protecting or sustainably harvesting *P. pinnata* in primary and secondary forests, and discouraging removal of remaining forest stands
- protecting existing trees from felling, removal or mortality during land clearing for agricultural or other purposes
- encouraging selective weeding around *P. pinnata* seedlings, and other useful tree species, avoiding use of herbicides in polycultural agricultural systems, and pruning or pollarding to let in needed sunlight, rather than ringbarking or removing trees during agricultural land preparation
- actively collecting and planting seed—after human consumption, from fallen fruit, after predation by fruit bats, birds and so forth—including protecting or transplanting self-sown seedlings
- introducing systematic planting programs in all appropriate forestry and agroforestry ecosystems (e.g. secondary forests, shifting agricultural areas, village tree groves, village and home gardens, and in school compounds and other institutional gardens or landscaping schemes)
- establishing national, regional and local community germplasm collections of *P. pinnata,* especially of recognised traditional varieties
- preserving the rich traditional ecological and cultural knowledge associated with *P. pinnata*
- undertaking systematic public-awareness campaigns, in which the cultural, economic and ecological importance of *P. pinnata* is stressed, with consideration also given to having national or regional village, community or landowner/tenant competitions for the planting of useful trees, including *P. pinnata*.

Authors: Lex Thomson and Randolph R. Thaman

Pterocarpus indicus

Family: Fabaceae
Botanical name: *Pterocarpus indicus* Willd. In *Species Plantarum* 4th edn, 3(2): 904 (1802).
The genus name is from the Greek for winged fruit, while the specific epithet refers to its origin from the East Indies. Two forms of *P. indicus* are recognised, forma *indicus* which has smooth fruit, and forma *echinatus*, from South-East Asia (including the Philippines and Lesser Sunda Islands of Indonesia), which has fruit with bristle-like prickles. Some authorities consider the forms to be distinct species, as there are other differences that support their status as different species, although morphologically intermediate forms are known.
Common names: rosewood, narra (English); *santal rouge*, *amboine* (French); *padauk* (Bangladesh); *sena*, *linggod*, *sonokembang*, *angsana*, *angsena* (Brunei; Indonesia; Malaysia); *vaivai vavalagi* (Fiji); *chan deng* (Laos); *ansanah*, *pashupadauk* (Myanmar); Papua New Guinea rosewood, *nar* (PNG); *pinati* (Samoa); *liki* (Solomon Islands); *praduu baan*, *pradoo*, *duu baan* (Thailand); *bluwata* (Vanuatu)

Summary of attributes and why diversity matters

Pterocarpus indicus is a large tree of moderate growth rate adapted to humid and subhumid climates and a wide range of edaphic conditions. It occurs naturally in South-East and East Asia, the northern Pacific and the island of New Guinea, Solomon Islands and Vanuatu, but is in decline in most parts of its wide natural range. The species produces one of the world's most highly prized furniture and cabinet timbers and is one of the most promising multipurpose (timber, nitrogen-fixing and traditional medicine) tree species for reforestation, village-level woodlots, border planting, live fencing and use as a large amenity tree in the humid tropics, including the Pacific Islands.

Pterocarpus indicus exhibits intraspecific variation throughout its extensive range, including in leaflet, flower and fruit characteristics. There appears to be considerable scope for improvement in *P. indicus* in economic traits (growth rate, form and wood quality, including early heartwood formation) through selection and breeding. This should commence with the determination of better-performing provenances, following range-wide seed collection and a program of coordinated provenance/progeny trials.

Description

Habit large, deciduous or evergreen tree, 25–35(–48) m tall and ≤2 m dbh; bole often irregular and variously fluted; crown large, spreading, with drooping branchlets. ***Bark*** rough, scaly, fissured, light sandy brown to greyish. ***Leaves*** imparipinnate, each leaf has 2–3 pairs of alternately arranged, ovate leaflets, about 6–12 cm long, 3–7 cm wide, margin entire; new flush light green turning dark, shiny, mid-green. ***Inflorescences*** borne in axillary racemes about 5–7 cm long. ***Flowers*** numerous, bright deep yellow, about 1.5 cm long, mostly single, very showy and fragrant; calyx turbinate to campanulate, shortly 5-lobed; petals 5, standard usually suborbicular with a well-developed claw, wings obliquely obovate to spathulate, keel petals usually shorter than wings; stamens 10–11; ovary sessile or stipitate, ovules 2–8; style filiform, slightly incurved; stigma small. ***Fruit*** indehiscent pod (samara) surrounded by broad undulating wing, orbicular, about 6 cm diameter, usually smooth and without spines, although the seed-bearing part of the fruit may have ± sparsely to densely set bristles which are the basis for distinguishing two forms of *P. indicus*; internally, fruit divided by cross walls into 4 or 5 seed chambers of which 1–2(–3) may contain a developed seed. ***Seed*** flattened, bean-shaped, 6–8 mm long with a leathery but brittle seed coat.

Tree planted at entrance to Thurston Gardens; Suva, Viti Levu, Fiji (Photo: L. Thomson)

Bee harvesting nectar from *P. indicus* flowers; Nausori, Viti Levu, Fiji (Photo: L. Thomson)

Fruit nearing maturity (Photo: F. & K. Starr)

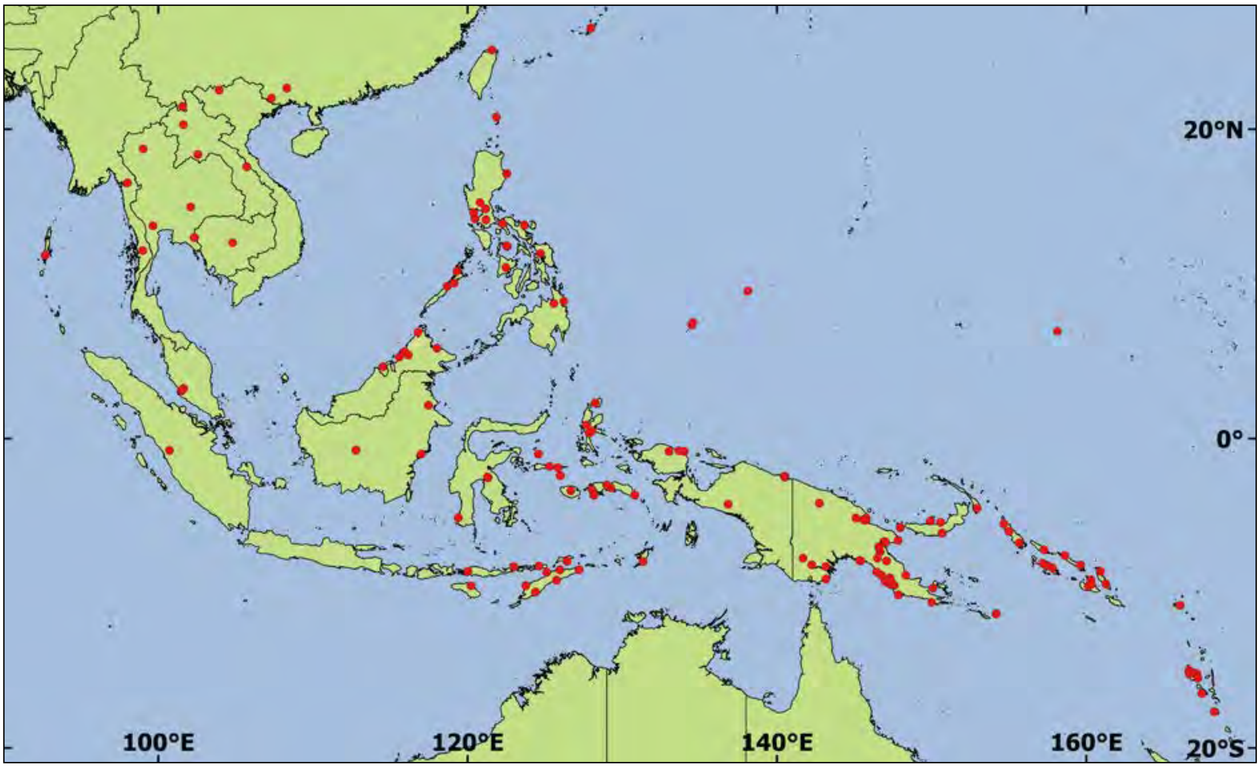
Reproductive phenology flowering often initiated before new leaf flush and continuing in short sporadic bursts; fruiting period varies geographically; in Fiji, seed matures around March–April or about 3–5 months after flowering but every region is different.

Distribution

Pterocarpus indicus has a wide distribution in South-East and East Asia, including Andaman Islands (India), southern Myanmar, Cambodia, southern China, Vietnam, the Philippines, Brunei, Malaysia and Indonesia. It extends east to the northern Pacific (Ryukyu Islands, Japan; Pohnpei and Yap, FSM; and Palau) and south-east to PNG, including New Britain, New Ireland and Manus islands, Solomon Islands and Vanuatu. *Pterocarpus indicus* is the national tree of the Philippines, and >100,000 ha of plantations of this species were established in that country from 1960 to 1990.

The species has been introduced to other tropical regions and countries, including the Caribbean and the tropical Americas (Cuba, southern Florida [USA], Grenada, Guyana, Honduras, Jamaica, Panama, Puerto Rico, Trinidad and Tobago), Africa (Congo, Sierra Leone and Tanzania), Asia (India, Sri Lanka and Taiwan) and some Pacific Islands (Fiji, Guam, Hawai'i [USA] and Samoa).

The natural distribution of *P. indicus* extends from about 20°N to 19°S with an altitudinal range of 0–600(–1,300) m asl. It is best adapted to subhumid and humid lowlands with 22–32 °C MAT, 1,500–3,000 mm MAR and a dry season of 0–6 months. It is found in both evergreen and semi-deciduous forest (deciduous forests, secondary forests, rainforests, mountain forests and



savanna woodlands). The preferred habitat for *P. indicus* is riparian—along the banks of rivers and coastal tidal creeks, behind mangrove swamps and on rocky shores—but it is highly adaptable to other conditions. It is adapted to a very wide range of soils, attaining its best development on deep, fertile, loamy alluvial soils. It is normally found growing in well-drained, sandy loam to clay loams of slightly acid to slightly alkaline pH. However, particular populations may be adapted to different soil types, such as infertile, alkaline, stony soils on Sumba, East Nusa Tenggara province, Indonesia, and calcareous soils as in the Philippines.

Uses

The growth rate of *P. indicus* is slow to moderate for a tropical species (0.5–2.0 m/year) and wood yield can be limited by the tendency for the species to have short boles and large, spreading branches. Long rotations of 30–40 years for sawlog production are typical. Despite these disadvantages, *P. indicus* has many positive traits: it is a nitrogen-fixing (*Rhizobium* spp.) tree which reproduces readily (sexually by seed and vegetatively from cuttings), coppices well, and tolerates strong winds and drought.

Wood—timber is the principal commercial product from *P. indicus*, although international trade in this is now limited due to supply shortages from overexploitation. *Pterocarpus indicus* produces one of the world's most highly prized furniture and cabinet timbers. It is also used to produce decorative sliced veneer, interior wall panelling, feature flooring (including strip and parquet), musical instruments, gun stocks and rifle butts, turned articles and knife handles, as well as in boatbuilding, specialised joinery, light building construction purposes, including posts, and for making craft items. Some trees, especially physiologically diseased trees from the island of Seram (Indonesia), produce strongly figured wood known as Ambonese gnarl wood or amboyna which is highly sought after for craftwood. In the Philippines, Solomon Islands and Vanuatu, the large plank buttresses are cut into doors and seats, while burls are favoured for making ornate bowls. *Pterocarpus indicus* produces excellent fuelwood but it is rarely used for this purpose.

The wood is moderately hard and heavy (550–900 kg/m^3 at 15% moisture content), with excellent working and technical properties. The heartwood is streaked, light yellowish-brown to reddish-brown and readily distinguished from the pale, yellowish sapwood. The wood is highly durable in interior uses but variable in durability in-ground. The sapwood is susceptible to attack by *Lyctus* borers, while the heartwood is only infrequently attacked by termites.

Non-wood—*P. indicus* is one of the most promising multipurpose tree species for reforestation, village-level woodlots, boundary plantings, shade, windbreaks, soil stabilisation, live fencing and amenity/ornamental plantings in the humid tropics, including the Pacific Islands.

The bark has tanning properties, and the bark and heartwood have been used to produce red-coloured dyes. In contact with water, the wood/bark imparts a blue fluorescence which gives rise to the common name in Vanuatu Bislama of *bluwota*. The very young leaves and flowers are sometimes eaten. The flowers are also highly sought after by bees foraging for nectar.

Traditional medicinal uses are many, especially from bark extracts. In several regions, the shredded bark is boiled and the fluid taken orally for treatment of dysentery and diarrhoea. In PNG, it is used to treat tuberculosis, headaches, sores and as a purgative. In

Pterocarpus indicus being used as live fence posts; Espiritu Santo, Vanuatu (Photo: R.R. Thaman)

Sawn buttress of *P. indicus* showing attractive flame figure; Espiritu Santo, Vanuatu (Photo: L. Thomson)

Solomon Islands, it is used to treat dysentery, heavy menstruation and gonorrhoea. In Vanuatu, it is used to treat cuts and wounds, stomach-ache and diarrhoea in infants. In Malaysia, juice extracted from the roots has been used to treat syphilitic sores and mouth ulcers. In Indonesia, the young leaves have been used in the treatment of boils, ulcers and prickly heat rashes. It exudes a gum or resin, called *kino* or *sangre de drago* (dragon's blood), which is a powerful astringent.

Herbal teas and pills made from *P. indicus* extracts have been popularised in the Philippines for treating a wide range of diseases and ailments, including leprosy, period pain, influenza, rheumatoid arthritis and diabetes.

Diversity and its importance

There is considerable intraspecific variation in the morphological characteristics of *P. indicus*, such as leaflet, flower and fruit size, shape and hairiness, as expected for a species with a wide geographical and ecological range. The only formally named variety is forma *echinatus* from South-East Asia (including the Philippines and Lesser Sunda Islands, Indonesia). This form is distinguished from the type form (forma *indicus*) by the bristle-like prickles that cover the fruit. Larger-fruited forms are found in Melanesia (PNG, Solomon Islands and Vanuatu). There is also considerable variation in wood properties. In different parts of Vanuatu, two traditional varieties are often distinguished on the basis of wood characters (such as width of sapwood and colour of heartwood). The most highly valued timber, known as 'red narra', comes from smaller trees than the so-called 'yellow narra', suggesting that the deep red colour is associated with slow growth under adverse environmental conditions. In Indonesia, a study of phenotypic variation of *P. indicus* provenances from central southern West Timor identified potential seed sources in East Nusa Tenggara.

There appears to be considerable scope for significant improvement in economic traits (growth rate, form and wood quality, including early heartwood formation) in *P. indicus* through selection and breeding, starting with selection of better-performing provenances. Seed collections from provenances throughout the natural and exotic range of the species would be highly desirable to allow a systematic screening to take place on multiple sites where the species has potential. Currently there is only limited evaluation of genetic resources and tree improvement of the species taking place in Indonesia, Malaysia and the Philippines.

Conservation of genetic resources (including threats and needs)

Pterocarpus indicus is in decline in most parts of its natural range due to overexploitation, exacerbated by illegal harvesting for timber, and has been considered for CITES nomination. The Vietnamese population of the species has been extinct for several centuries, while the species is rare and/or threatened throughout its range, including in Andaman Islands (India), China, India, Indonesia, Malaysia, Myanmar and the Philippines. The largest remaining populations are in Melanesia (PNG and Solomon Islands), but these are under heavy commercial timber-harvesting pressures.

Pterocarpus indicus is susceptible to a wide range of common pests and diseases, but none are considered threatening to the survival of the species. Larger trees may be affected by potentially serious root and stem rots, including *Fomes lamaoensis*, *Ganoderma lucidum* and *Phellinus noxius*. Trees established from large branch cuttings have a greater tendency to be affected by heart rot, and this propagation method should be avoided if timber production is a major objective of planting.

Author: Lex Thomson

Santalum album

Family: Santalaceae
Botanical name: *Santalum album* L. In *Species Plantarum* 1: 349 (1753).

The genus name is derived from the Greek *santalon*, sandalwood, and the specific epithet from the Latin *albus*, white, in reference to the colour of the wood which is lighter than some other *Santalum* species. Several morphological forms based on leaf pattern (small- or large-leaved forms) are recognised locally in India, but taxonomists regard such forms as part of normal natural variation and undeserving of formal classification.
Common names: Indian sandalwood, East Indian sandalwood, sandalwood, sandal, cendana and many more, especially in India

Planted tree; Mangaia, Cook Islands (Photo: L. Thomson)

Buds and flowers at different stages of maturity (Photo: L. Thomson)

Summary of attributes and why diversity matters

Santalum album is a hemiparasitic, small tree of the seasonally dry tropics of India, Indonesia, Sri Lanka, Timor-Leste and northern Australia where it grows under a wide range of environments. It is prized for its fragrant essential oil extracted from the heartwood which is also highly valued for carvings. The oil is used in perfumes and personal hygiene products and commands a high price on world markets because of declining supplies from natural sources. Establishment of *S. album* plantations, as is taking place in Australia, China, India, Indonesia, Sri Lanka, Thailand and elsewhere, is seen as the best way to secure the future of the industry and to conserve the species.

Santalum album is a highly variable species in terms of its adaptability, growth and habit, and essential oil content and composition. There is considerable scope for improvement of commercial traits through tree breeding but there are many questions around the basic biology of the species and the extent of genetic variation in key traits and their heritability that have still to be answered. Selection and breeding programs are underway in Australia, China, India and Indonesia and these programs will help address some of these knowledge gaps in the future. Superior genetic material is not yet generally available and this is limiting the wider establishment of the species.

Description

Habit evergreen, glabrous shrub or small tree, 4–20 m tall and may reach >50 cm dbh; it is an obligate root hemiparasite. ***Bark*** tight, rough and fissured, dark greyish-brown to reddish-brown or nearly black.

Leaves opposite, ovate or broadly lanceolate, mostly 2.5–7.0 cm long, 1.5–4.0 cm wide, light green above, slightly paler below, tip rounded or pointed, on a grooved stalk 5–15 cm long; venation noticeably reticulate. ***Inflorescences*** small terminal or axillary clusters. ***Flowers*** small, turning from green through cream then pink to dark red, about 4–6 mm long, ≤6 in an inflorescence. ***Fruit*** fleshy drupe, almost stalkless, smooth, roundish, 7–10 mm diameter, coloured shiny

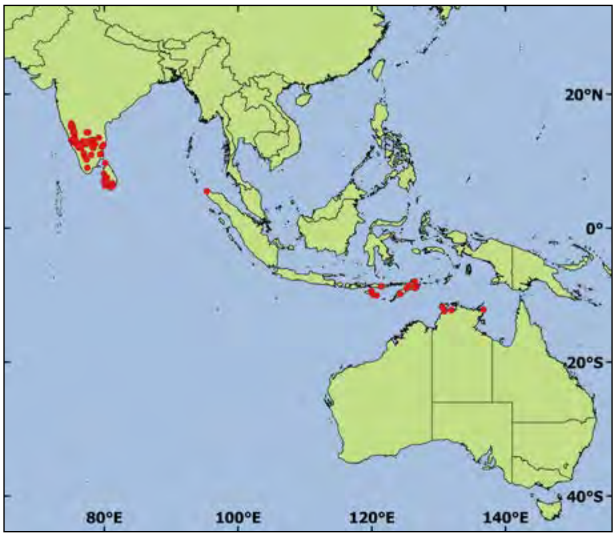
Fruit at different stages of ripeness; ʻEua, Tonga (Photo: L. Thomson)

Tree in open woodland; Top End, Northern Territory, Australia (Photo: D. Lea)

dark red, purple to black when ripe. ***Seed*** drupe single-seeded. ***Reproductive phenology*** flowers, buds and mature fruit can be found on individual trees at the same time; most trees, however, flower and fruit twice a year with phenology varying with location; main flowering events may occur in both the wet and dry seasons with the former being the most prominent; fruit ripen over a 2–3-month period.

Distribution

The main natural distribution is in the drier tropical regions of southern India, Sri Lanka, Indonesia (especially on West Timor and Sumba Island, and also Aceh, north-western Sumatra), Timor-Leste and with a limited occurrence on the extreme northern coastline of the Northern Territory, Australia. There is still debate as to whether *S. album* is endemic to Australia or introduced from eastern Indonesia by fishers or birds many centuries ago



Santalum album has been introduced into many tropical countries because of its economic importance, including China (Guangdong), Taiwan and various countries in southern Africa and Oceania. Plantations have expanded in India, Indonesia, Australia (14,000 ha planted) and China (4,000 ha) over the past 20 years.

The natural distribution of *S. album* is mainly in the wet/dry tropics where the mean annual, mainly summer rainfall is 400–3,000 mm with a dry season that can extend to several months. Altitudinal range is 0–2,000 m asl. This species is capable of growing on a range of soil types from light to heavy (e.g. laterite, loam, sand and clay, including vertisols). It is able to tolerate sodic and alkaline soils (pH ≤9.0), but is unable to tolerate waterlogged conditions. The natural distribution of *S. album* is outside the recognised cylone belt, and planted *S. album* trees are more likely to be uprooted or snapped off by cyclonic winds compared with two native South Pacific species, *S. austrocaledonicum* and *S. yasi*.

Uses

In Oceania, *S. album* is considered a commercially attractive agroforestry species on sites suitable for its cultivation and is ideal for home gardens where it can be grown with a mixture of ornamental and productive plants that serve as hosts.

Wood—the wood is used for carving, incense and perfumed fuelwood (in the past, the wood was preferred for funeral pyres in India). Larger pieces of heartwood of *S. album* are mostly used for carvings which are in strong demand and sell for high prices. The sapwood and spent charge from distillation are used in the production of *agarbatti* (sweet smelling incense, such as joss sticks).

Non-wood—heartwood unsuitable for carving is prized as a source of sandalwood oil, produced by steam distillation of the wood after it has been chipped and ground to powder, and used in expensive perfumes and attars. The oil also has traditional as well as modern medicinal uses and is employed in aromatherapy and in personal hygiene products.

There are many challenges in determining accurate sandalwood production and trade data, including commercial secrecy, illegal harvesting, substitutes and adulterants. Statistics for the sandalwood industry summarised from various sources and based mainly on *S. album* from natural stands have been reported by Thomson et al. (2011). The annual global demand for sandalwood heartwood for handicrafts has been estimated to be about 5,000–6,000 tonnes; however, production has declined markedly over the past 20–30 years. China, Taiwan, Singapore, Korea and Japan, with no natural resources of sandalwood, are the main markets for heartwood, together with India, which has its own production capability. Current world demand (with USA and Europe the main importers) for sandalwood oil was estimated to be about 250–300 tonnes/year, which equates to over 15,000 tonnes of wood. India (85% of world production) produces about 120–150 tonnes/year of sandalwood oil, with about 80 tonnes/year used domestically and the remainder exported (c. 40 tonnes/year); Indonesia (10% of world production) exports about 15 tonnes/year; while other sources (including substitutes) accounted for 5% (7.5 tonnes/year) of world production. Sandalwood heartwood and oil have increased in price throughout the entire traded history of sandalwood in response to increasing demand and diminishing supply. Indian sandalwood heartwood prices at auction in India were about US$150/kg in July 2014 and East Indian sandalwood oil presently trades for >US$5,000/kg on the international market.

The foliage of *S. album* is palatable to grazing animals and the fully ripe fruit are edible.

Diversity and its importance

Provenance variation in growth of this species has not been fully explored but can be predicted to be substantial given the large range of climatic, physiographical and soil conditions in which the species naturally occurs. Oil content of the heartwood ranges between 0.5% and 7.0% (w/w, fresh weight). Oil quality, determined primarily by

Santalum album fruit (from a plant in Kupang, Indonesia) displaying variation in fruit shape (compare with previous fruit photo) (Photo: Sumardi)

proportions of α- and β-santalol of total oil, also varies considerably among individual trees, location within the tree (highest in the heartwood at stem base and in large roots) and site (harsh sites for tree growth usually best). This, combined with individual tree variation in growth rate and interaction of growth rate with age of first formation of heartwood and its subsequent rate of development, indicates considerable scope for improving oil production in *S. album* plantations through selection and breeding.

A synopsis of the process of hemiparasitism in *S. album*, and of the suitability of host plants to sustain the growth of seedlings that require pot hosts and final crop plants that require intermediate and long-term hosts, is provided by da Silva et al. (2016). It is of paramount importance in optimising the survival and growth of *S. album* to identify and use locally adapted, suitable host species. Host plants that cast a light uniform shade, act as good windbreaks and fix nitrogen are usually preferred.

Superior germplasm sources exhibiting disease resistance, rapid growth, good bole form, early heartwood formation and desirable heartwood oil composition are being developed for *S. album* in India, Indonesia, China and Australia. Progeny trials, seed stands and clonal seed orchards of *S. album* have been established on multiple sites in India. Indonesia and Australia are able to provide improved seed for planting programs. First-generation progeny from clonal seed orchards in India are reported to be performing well. Substantial numbers of candidate plus trees have been identified in southern India and their seed is maintained at the Indian Council of Forestry Research and Education's Institute of Wood Science and Technology Germplasm Bank in Gottipura, Bengaluru and Karnataka. In Indonesia, the responsible body for breeding *S. album* is the Centre for Forest Biotechnology and Tree Improvement, Yogyakarta.

Investigations into clonal multiplication of *S. album* are continuing. The review by da Silva et al. (2016) highlights the successes and failures within the fields of plant tissue culture, and discusses the usefulness of somatic embryogenesis and transgenic strategies in producing more-robust and faster-growing plants.

Conservation of genetic resources (including threats and needs)

The IUCN Red List and CITES (2013) have listed *S. album* as Vulnerable and Endangered, respectively, because of serious declines in natural populations through overexploitation (legal and illegal), disease (spike disease in India) and poor recruitment due to grazing and fire.

A serious threat to *S. album* stands in India is 'spike disease' which causes widespread mortality. It is caused by a phytoplasma-type organism that shortens the internodes, reduces leaf size, kills haustoria and blocks vascular tissue which ultimately leads to tree mortality. An integrated package of treatments has been reported as showing promise in India in reducing incidence of the disease. While spike disease is the main threat to *S. album* in India, the species is also susceptible to a range of other serious pathogens and insect pests that cause economic losses in wild stands, nurseries and plantations.

Synthetic substitutes for the santalols of sandalwood oils are seen as a threat to the sandalwood industry. They are increasingly competing with the natural product in perfumery and cosmetic uses. This trend is expected to continue, at least in the short term, because of the supply and demand imbalance for natural oils and their escalating cost.

There are no reproductive barriers between *S. album* and at least three other commercial tropical species, including *S. austrocaledonicum* and *S. yasi*. This can be viewed either as an opportunity allowing better-performing, site-specific hybrids to be developed or as a threat with conservation implications. Introduction of compatible exotic *Santalum* species within the natural range of *S. album* will likely result in uncontrolled gene flow between them and modify the genetic structure and diversity of natural stands.

Development of a substantial plantation resource, as is taking place in northern Australia, China and elsewhere, is seen as the main means of increasing *S. album* populations and maintaining diversity. However, further silvicultural research is needed on *S. album*, including propagation techniques, studies of heartwood formation—including treatments to promote early heartwood formation and santalol oil content—and estimates of heritability, host selection, control of spike disease (in India) and tree breeding to optimise development of *S. album* as a plantation species.

Authors: Lex Thomson, Anto Rimbawanto and John Doran

Santalum austrocaledonicum

Family: Santalaceae
Botanical name: *Santalum austrocaledonicum* Vieillard. In *Ann. Sci. Nat., Bot.*, sér. 4, 16: 61 (1862).

The specific epithet refers to the location of the type specimen from New Caledonia. Four varieties are recognised: var. *austrocaledonicum*, var. *pilosulum,* var. *minutum* and var. *glabrum*.
Common names: Coral Sea sandalwood, sandalwood, Loyalty Islands sandalwood (var. *glabrum*) (English); *sandalwud* (Vanuatu); *bois de santal*, *santal* (French)

Summary of attributes and why diversity matters

Santalum austrocaledonicum is native to the island archipelagos of New Caledonia and Vanuatu where it grows as a small, root-parasitic shrub or tree, typically with a short, crooked bole and spreading crown. It produces a highly valuable heartwood and essential oil. The species is mainly harvested from the wild and has been an important source of income for poor rural peoples for centuries. Most native populations are greatly depleted and major replanting efforts are now underway.

In Vanuatu, continuous variation is found in the commercially important santalol content of its heartwood essential oil, ranging from trees with very low (1%) to very high (47%) oil concentrations. Trees with high proportions of heartwood and rich in oil with high santalol concentrations are being used for seed supply and for breeding to develop high-quality forms for smallholder plantings in Vanuatu. In New Caledonia, the essential oil varies mainly between individuals, and the different harvesting areas present similar-quality oils. Harvesting is regulated and new results have permitted the delineation of conservation zones that take into account genetics and both chemical and morphological variation.

Description

Habit small hemiparasitic shrub or tree, 5–12 m tall with ≤30–50 cm dbh; crown round, bushy, with many individuals forking at a low level; often with crooked

Above: Buds and flowers (Photo: L. Thomson)

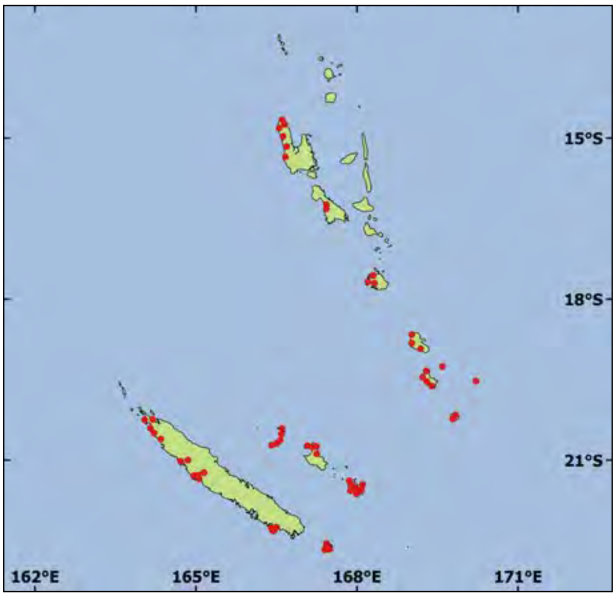
Top right: Fruit at different stages of ripeness (Photo: L. Thomson)

Bottom right: Planted tree growing in village; Erromango, Vanuatu (Photo: T. Page) bole in open situations and straight bole in denser forest situations. ***Bark*** greyish, rough, longitudinally fissured. ***Leaves*** opposite, usually in 1 plane, decussate on erect new growth, simple, entire, glabrous, dark green/shiny above, dull light green/glaucous below; initially long and thin in seedlings and young plants, becoming narrowly elliptic or ovate, lanceolate or obovate, 4–6 × 1.5–2.5 cm, tapering equally to the base and blunt tip, as they mature; there is wide variation in foliage characteristics between trees and populations. ***Inflorescences*** terminal and axillary panicles of bisexual flowers. ***Flowers*** small (±5 mm across), tepals 4 or rarely 5, remaining greenish-white to cream through to maturity; yellow disc lobes alternate with tepals and anthers; long unicellular hairs occur at base of each filament and extend to anther; pollen shed via longitudinal slits in anther; stigma typically 3-lobed (rarely 2- or 4-lobed), fused into a single style. ***Fruit*** subglobular or ellipsoid, single-seeded drupe, green and firm, ripening red, turning purplish-black and thinly fleshy when mature; longitudinal ridges 4, square calyx scar at the apex; size can vary between populations. ***Seed*** kernel woody, enclosing light-coloured endocarp and single seed.

Like many of the sandalwood species, *S. austrocaledonicum* trees can flower at an early age, from about age 3 years onwards. Fruit take about 3 months to reach maturity and fruiting is generally abundant on each tree.

Distribution

Santalum austrocaledonicum occurs naturally in the island archipelagos of New Caledonia and Vanuatu in the south-western Pacific. In Vanuatu, it mainly occurs on the islands of Aneityum, Aniwa, Efate, Erromango (north-western, western and south-western areas), Espiritu Santo (western coast), Futuna, Malekula and Tanna. In New Caledonia, the distributions of the four varieties are distinct. Var. *austrocaledonicum* is common on Isle of Pines, and less common on Grand Terre, the main island. Var. *pilosulum* is restricted to near Noumea and surrounding area at low elevations on Grand Terre. Var. *minutum* is restricted to the north-west of Grand Terre. Var. *glabrum* is common in the Loyalty Islands.



Santalum austrocaledonicum has not been planted commercially outside its natural range. Experimental plantings have been established at: Kununurra in northern Western Australia and Atherton Tableland in northern Queensland (Australia); Nukurua, south-eastern Viti Levu, and Ovalau (Fiji); Rarotonga and Mitiaro (Cook Islands); and ʻEua (Tonga).

This species prefers warm to hot, lowland, subhumid or wet/dry tropical climates with a mean annual, mainly summer, rainfall of 800–2,500 mm and a short to lengthy (0–5 months) dry season in the cooler months. Altitudinal range is 5–800 m asl. Tropical cyclones are a feature of the entire distribution range, occurring mainly during the hot wet season from December to April. The species prefers well-drained acidic to alkaline soils and does not grow well on waterlogged soils and strongly acidic, clayey soils.

Uses

Carvings, incense production and sandalwood oil are the three major wood uses of *S. austrocaledonicum* and they are highly valued for their therapeutic and religious significance. The species was exploited heavily over about three decades in the mid-1800s and has been utilised periodically since then. Projected rotation lengths for plantations of this species range between 20 and 40 years reflecting a moderately fast rate of growth under suitable conditions.

Wood—the heartwood is close-grained, very finely and evenly textured, hard, durable and renowned as a carving material. It has a specific gravity of 0.92 and weighs 897–1,137 kg/m^3. Timber seasons well when dried slowly. The wood can be worked to a smooth finish and takes on a satin-like polish. The heartwood has been used for many centuries for carvings, prayer poles and other religious artefacts, valuable handicrafts, fuel for funeral pyres, coffins and joss sticks.

Non-wood—pure distilled sandalwood oil products have demonstrated anti-inflammatory and antimicrobial properties. The oil has been used topically to treat fungal and bacterial skin infections and inflammation related to sunburn and joint and muscle pain. Inhalation of the oil fragrance has a mild sedative effect and contributes to relieving anxiety, sleep disorders and promoting relaxation and a feeling of wellbeing. Sandalwood oil has been used as a coolant, astringent, antipyretic and aphrodisiac. It is also used to treat migraines, erysipelas (skin bacterial infections), gonorrhoea and cystitis.

Above left: Commercial *S. austrocaledonicum* plantation, Summit Estate; near Mele, Efate, Vanuatu (Photo: L. Thomson)

Above right: Loading logs of *S. austrocaledonicum*; Ponkil Bay, Erromango, Vanuatu (Photo: T. Page)

Left: Boiler for distillation of essential oil, with Phila Raharivelomanana; Maré Island, Loyalty Islands, New Caledonia (Photo: L. Thomson)

Sandalwood oil is used widely in the cosmetic, fragrance and soap industries. It has a highly sought-after fragrance, particularly those oils rich in santalols which give the oil with its distinctive aroma. The oil is also of considerable value for its exceptional binding qualities for other fragrant components that may be added to create a characteristic bouquet for a branded perfume.

In terms of volume consumed, its use in the perfumery industry currently outweighs its use in medicinal and natural therapies. It is produced commercially by steam distillation with an average commercial yield of 3–5%. However, individual tree yields can vary between 0.1% and 8.0%. This variation in oil content is attributed to tree age and position of heartwood within the tree and is also expected to be partly influenced by genetic and environmental factors.

Diversity and its importance

The quantity of heartwood in its timber, concentration of oil in the heartwood and the levels of α- and β-santalol in the distilled oil determine the market value of *S. austrocaledonicum*.

There is significant tree-to-tree variation in percentage heartwood—in Vanuatu, it was reported to vary from 1% to 73% with a mean of 27%. Similarly, heartwood santalol content in Vanuatu varied from 1% to 47% with a mean of 20%. Populations on the northern islands of Espiritu Santo and Malekula had a higher frequency of trees with elevated levels of santalols. Total oil yield also varied between trees with a range of 0.1–8.0%. No geographical pattern was identified for trees with high oil yields.

Deployment of improved germplasm has progressed in Vanuatu with the establishment of elite grafted seed orchards on several islands (Efate, Espiritu Santo and Malekula). These orchards consist of a genetically diverse range of trees with an average of 33% α-santalol. Seed produced from these orchards will be used to improve the sandalwood plantation resource in Vanuatu for both livelihood and conservation benefits.

In New Caledonia, the santalol content of *S. austrocaledonicum* heartwoods did not vary as much as in Vanuatu. The mean percentage of α-santalol in the concrete was 39.4% with a standard deviation (σ) of 11.2, and 16.4% for β-santalol with σ of 5.23. However, the E-lanceol content, a molecule characteristic of New Caledonian sandalwood, varied considerably between individuals (mean = 13.7%, σ = 16.6). The majority of the variation was between individuals within populations (81% of the total variance of the molecules) rather than between populations (19% of the total variance), so it is challenging to delineate candidate provenances for domestication.

Above: Variation in juvenile leaf morphology in school planting of *S. austrocaledonicum*; Onerua, Mangaia, Cook Islands (Photo: L. Thomson)

Left: Variation in heartwood colour of *S. austrocaledonicum* in Vanuatu (Photo: L. Thomson)

Throughout New Caledonia, *S. austrocaledonicum* exhibits a high level of morphological variation, particularly in juvenile leaf morphology and seed characteristics. Field experimental designs have shown that this variation is partially under genetic control. This could result from adaptation to local ecological conditions, especially for rainfall, which varies markedly between the western coast of Grande Terre and the Loyalty Islands.

Genetic diversity in New Caledonia

Due to the geographical isolation of islands across the New Caledonian archipelago, gene flow between islands is reduced and populations have been evolving separately: this is leading to significant genetic differentiation as assessed by molecular genetic markers. The populations of Grande Terre were found to be different to each other, reflecting the impact of anthropogenic fragmentation which has led to the isolation of small remnant populations. Genetic diversity within each population was also variable between islands and noticeably lower on the island of Maré (Loyalty Islands) where *S. austrocaledonicum* appears to reproduce mainly through self-fertilisation and by root suckering. This could be due to a lack of pollinators in this particular island, or resprouting due to numerous bushfires.

Genetic diversity in Vanuatu

The genetic diversity of *S. austrocaledonicum* across the islands of Vanuatu was generally higher than that observed in the islands of New Caledonia. In Vanuatu, population differentiation due to genetic structure was lowest among the three southern islands, Erromango, Tanna and Aniwa. The small island of Aniwa exhibited the lowest genetic diversity, not unexpectedly given the small population size and its possible anthropogenic introduction. Small clusters of genetically related trees, full siblings, were observed on Espiritu Santo and Malekula which may be the result of localised inbreeding or due to the planting by people of seed from a single source tree. Some level of inbreeding in *S. austrocaledonicum* is likely given the general presence of self-compatibility in the genus.

Conservation of genetic resources (including threats and needs)

Intense exploitation of the sandalwood resource in Vanuatu and New Caledonia occurred from the 1820s to the 1860s until the industry became unprofitable. The resource has since recovered but is only a small fraction of its original size. High levels of interrelatedness of trees on some islands in Vanuatu may be a genetic bottleneck caused by harvesting in the 1800s.

The sandalwood industry in Vanuatu is based primarily on harvesting of wild trees of *S. austrocaledonicum* and the Department of Forests has developed a conservation strategy for the species. An inventory in 2008 found a low aggregated density (0.4 trees/ha) in known *S. austrocaledonicum* regions. In the mid-2000s, the mean annual harvest was >100 tonnes, which exceeded the then

80-tonne sustainable limit. The current annual quota is 60 tonnes, although harvesting rates in the mid-2010s were between 30 and 40 tonnes. While much of the wild resource has been commercially exhausted, smallholder plantings now represent a modest commercial supply.

In New Caledonia, the current quota is 29.2 tonnes/year, and *S. austrocaledonicum* can only be harvested in the Loyalty Islands. The genetic, chemical and morphological data recently obtained supplemented this measure by enabling the delineation of conservation zones (evolutionarily significant units) where seed transfer has to be regulated.

In Vanuatu and New Caledonia, *S. austrocaledonicum* is currently grown in small plantings or managed in natural stands. It grows at moderate rates and can produce substantial quantities of the valuable heartwood on a rotation of 25–40 years. This species has good commercial potential; in particular, to generate cash revenue for rural communities in remote areas. There is increasing interest among villagers, other small-scale entrepreneurs and government agencies to expand the scale of planting in both countries.

Santalum austrocaledonicum can freely hybridise with other species, including *S. album* and *S. lanceolatum*. This opens the potential for introgression of desirable traits between species and/or development of vigorous hybrids. While the productivity benefits of hybrids are evident, consideration must be given to potential incompatibility or other deleterious factors that could manifest in later generations. Production of hybrids may also have unpredictable consequences in terms of potential disruption of a species' genetic integrity; for example, *S. album* introduced to Vanuatu was much less resilient to high wind speeds associated with cyclones than *S. austrocaledonicum*. It is unclear what effect uncontrolled hybridisation between these two species would have on the wind firmness, or other traits of natural *S. austrocaledonicum*. There is concern that introduction of other varieties of *S. austrocaledonicum* into the Loyalty Islands may eventually lead to loss of the distinctive Loyalty variety (var. *glabrum*) through hybridisation and subsequent introgression. Market acceptance of, and demand for, products derived from hybrid sandalwood is also yet to be defined and may jeopardise the development of a niche market and brand for pure *S. austrocaledonicum* oil. Sandalwood is a culturally significant product with a long history of trade and consumers are sensitive to quality differences between species.

Authors: Tony Page, Lorraine Bottin, Jean-Marc Bouvet and Hanington Tate

Santalum insulare

Family: Santalaceae
Botanical name: *Santalum insulare* Bertero ex A.DC. In *Prodr*. [A.P. de Candolle] 14(2): 685 (1857).

The specific epithet is from the Latin *insularis*, insular, island, referring to the distribution of the species. Nine varieties are currently recognised in this species: var. *insulare*, var. *alticola*, var. *raiateense*, var. *marchionense*, var. *deckeri*, var. *mitiaro*, var. *raivavense*, var. *margaretae* and var. *hendersonense*, but taxonomical revision to come will increase this number up to 10 (2 new varieties to describe and 1 to put in synonymy).
Common names: Polynesian sandalwood (English); *bois de santal polynésien* (French); *a'i* (Cook Islands); *puahi* (Marquesas Islands, French Polynesia); *ahi* (Society and Austral Islands, French Polynesia)

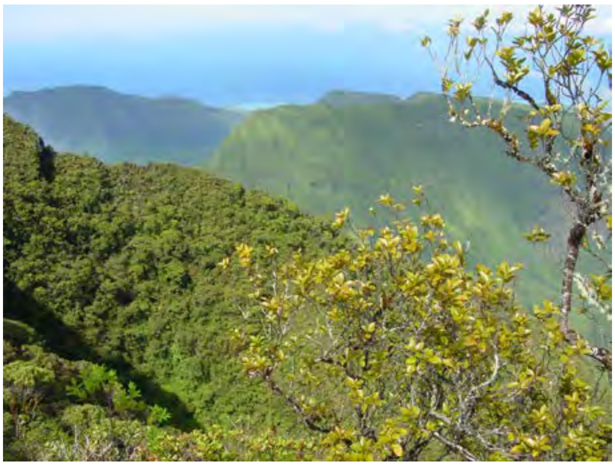
Summary of attributes and why diversity matters

Santalum insulare is a highly valuable, naturally renewable resource for the small isolated islands that make up French Polynesia. It was heavily exploited in the past for its heartwood, rich in fragrant and sought-after santalols, and is now an endangered species over the vast majority of its natural range. All harvesting is now banned in French Polynesia while conservation strategies are implemented and production plantations are established by local communities.

In French Polynesia, up to four traditional varieties of *S. insulare* based on wood colour and fragrance are recognised in each archipelago. *Puahi* is the symbolic tree of the Marquesas archipelago where its uses are numerous, especially as medicine but also for its unique fragrance which is associated with sensuality. Sandalwood oil or *monoï* (*pani puahi*, *mono'i ahi*) can be found in most of the Polynesian markets. While most *S. insulare* populations give commercial santalol-rich heartwood essential oils, three populations from the Marquesas Islands have a different, (Z)-nuciferol chemotype, which has limited or no commercial value.

Description

Habit shrub or small tree ≤8–12 m tall, maximally reaching 15 m tall and 50 cm dbh; hemiparasitic with parasitic root haustoria fused to the roots of host plants. ***Bark*** brown-black, becoming fissured in old specimens. ***Leaves*** simple, ovate to elliptic, 3.5–15 cm long, 1.5–9.5 cm wide; new leaves orange in high-elevation populations, quickly turning dark green at maturity, whereas light green to yellow-green leaves in low-elevation populations; leaf size highly dependent on ecological conditions—small-leaved plants restricted to lower mean temperatures (extra-tropical islands or high-elevation populations) or windy areas, whereas larger-leaved forms at lower elevations on tropical islands. ***Inflorescences*** terminal or pseudo-axillary panicles. ***Flowers*** hermaphroditic, shortly pedicellate; tepals (3–)4(–5), ovate to triangular, ≤3 mm long; colour ranges from greenish-white through cream white or yellowish to red and brown-red; at higher elevations, the fragrant flowers open whitish before turning red. ***Fruit*** mature fruit oval, globose to pear-shaped drupe (14–48 mm long, 10–43 mm wide), red to purple and black at maturity, with thick fleshy mesocarp and several petal scars; single, rugose stony shell or endocarp (9–34 mm long,



Santalum insulare var. *alticola* in moist ridge forest, Mount Aorai (2,000 m asl); Tahiti, French Polynesia (Photo: J.-F. Butaud)

Buds and flowers of *S. insulare* var. *mitiaro*; Mitiaro, Cook Islands (Photo: L. Thomson)

Fruit of *S. insulare* var. *raivavense* from Raivavae (sea level); Austral Islands, French Polynesia (Photo: J.-F. Butaud)

6–31 mm wide) encompassing single seed. **Seed** relatively large and a favourite food of introduced rats.

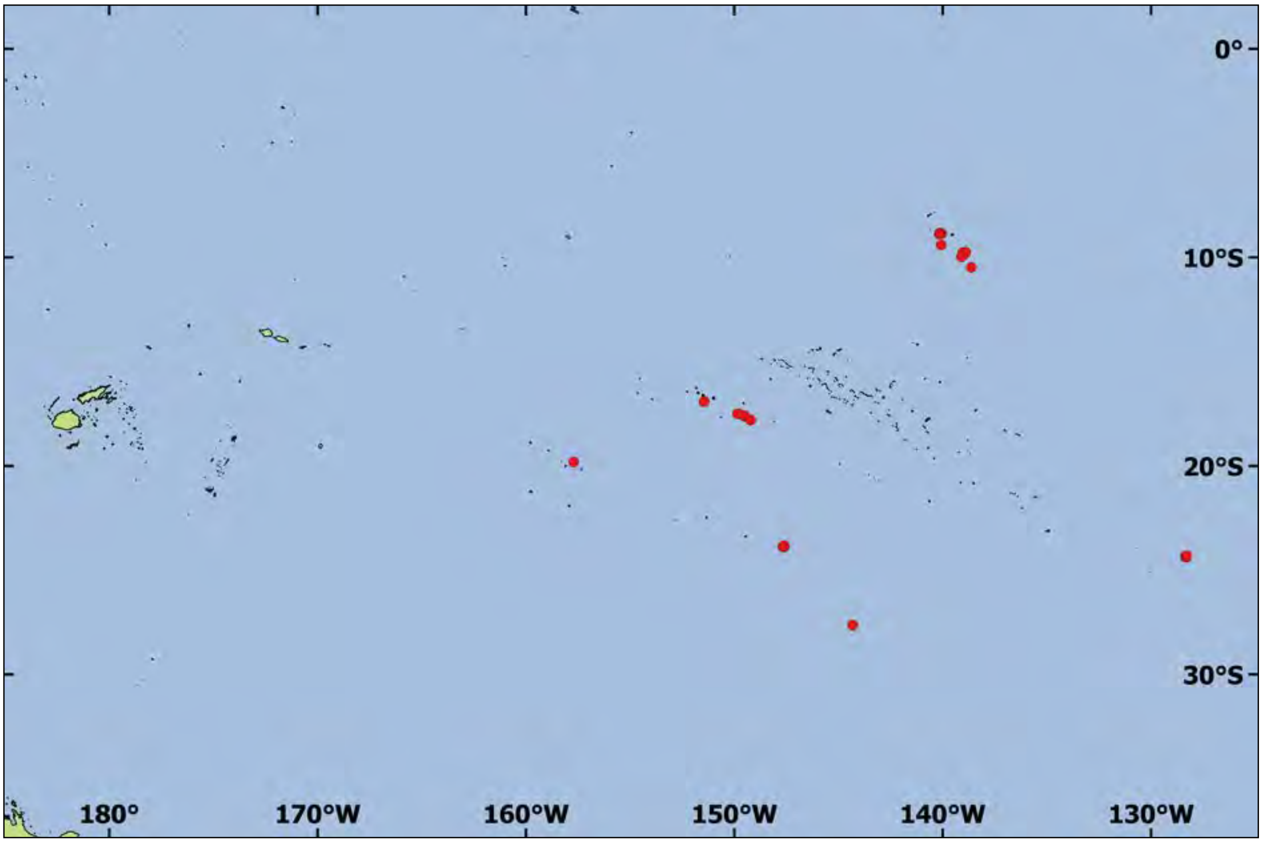
There is substantial polymorphism in fruit and seed size with the smallest seed being produced by plants in windy sites at high elevation (>1,600 m asl) on Tahiti (var. *alticola*) and the largest seed by plants at rainy sites of intermediate elevation (700–1,100 m asl) on Nuku Hiva (var. nov.), Marquesas Islands. This polymorphism in fruit size can also be correlated with the size of fruit-dispersing pigeons and doves.

Distribution

Sandalum insulare is endemic to eastern Polynesia and occurs as nine different botanical varieties in French Polynesia (10 islands in 3 archipelagos), the Cook Islands (var. *mitiaro* on Mitiaro Island) and Pitcairn Islands (var. *hendersonense* on Henderson Island). In French Polynesia, var. *marchionense* and var. *deckeri* are known in the Marquesas Islands of Nuku Hiva, Ua Pou, Hiva Oa, Tahuata and Fatuiva; var. *insulare* and var. *alticola* are endemic to Tahiti; var. *raiateense* is restricted to Moorea and Raiatea in the Society Islands; and var. *raivavense* and var. *margaretae* grow on Raivavae and Rapa, respectively, in the Austral Islands. A planned taxonomic revision will affect Marquesan varieties with var. *marchionense* (syn. var. *deckeri*) on Nuku Hiva, Ua Pou, Hiva Oa and Tahuata, a first new variety for high-elevation populations from Nuku Hiva, and a second for Fatuiva populations.

The natural range of the species has contracted through human-related factors, such as harvesting and introduction of the black rat (*Rattus rattus*): *S. insulare* is now presumed extinct on several islands; namely, Ua Huka in the Marquesas Islands, Makatea in the Tuamotu Islands and Tubuai in the Austral Islands.

Santalum insulare occurs from sea level on coralline soils up to 2,200 m asl on volcanic soils, under various temperature and rainfall conditions, from semi-dry to cloud forests.



Uses

Although sandalwood was already used by Polynesians, sandalwood traders overharvested *S. insulare* resources from the Austral and Marquesas archipelagos between 1810 and 1830. Remaining populations are sorely depleted today as a result of those activities and traditional harvesting of the species.

Wood and non-wood—the main traditional uses of *S. insulare* involved its fragrant heartwood. Most traditional uses required the production of wood shavings or powder which were soaked in coconut oil for several days to obtain *mono'i ahi* or *pani puahi* (sandalwood *monoï*). The heartwood was gathered from natural populations which sometimes could only be reached after several days of walking. The heartwood harvest was destructive as each tree was uprooted to obtain the heartwood in major roots, as well as the trunk and larger branches.

Puahi/ahi heartwood is widely used in traditional medicines for the treatment of several ailments. Heartwood powder is mixed with coconut water or *monoï* for internal or external remedies: skin diseases, wounds, earache, sinusitis, rheumatic pains, conjunctivitis and throat infection. Moreover, massages with sandalwood *monoï* are often applied for muscle pains, tiredness, chills or stretch marks. Sandalwood *monoï* is also widely used as a cosmetic in skin and hair care. In Tahiti, babies of royal lineage were massaged at birth with *mono'i ahi*, as is the common practice nowadays for Marquesan babies using *pani puahi*. The benefits of these traditional uses, mainly for medicinal purposes, have recently been supported by the identification of antibacterial and antifungal constituents in the heartwood of *Santalum* species.

Some special bark clothes called *'aeu pipi* or *kaeu pipi* were perfumed with sandalwood powder in Marquesas Islands as were some *hei* or necklaces called *hei keka'a*, *kumu hei* or *'umu hei*. In these *hei*, pineapple eyes are sprinkled with sandalwood powder. Handicrafts in sandalwood have been recently developed, mainly in response to the demand for souvenirs by tourists and expatriates. *Tiki* (statuettes), bowls and hair sticks are some of the items fashioned out of sandalwood. In the Society and Marquesas archipelagos, sandalwood powder and *monoï* were used in the embalming process for the deceased of important families. Sandalwood was also burnt during the burial rituals to purify the atmosphere and repel evil spirits. Sandalwood was also revered as a vital, if not sacred, and precious material in weddings, and is recorded in traditional songs (*rari o te puahi*) in Marquesas Islands. Nowadays, continuance of traditional uses is at risk due to the scarcity of the natural stands and the complexity of sustainable management of this depleted natural resource.

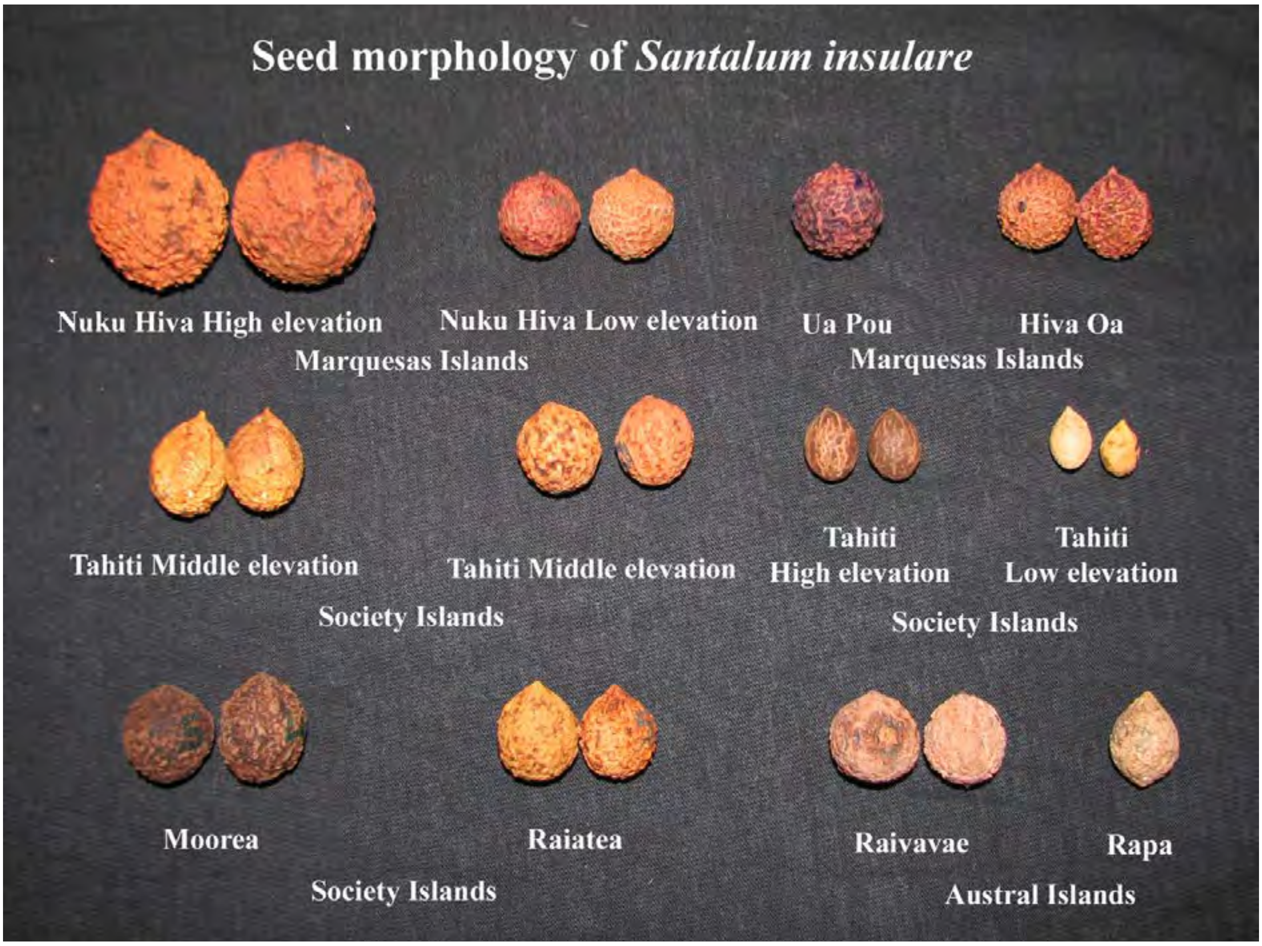
Handicrafts from *S. insulare* heartwood—tiki figures surrounded by garland in wood shavings (Photo: J.-F. Butaud)

In the Marquesas Islands the seed was sometimes eaten by Polynesians, while in Tahiti the bark was used as a red dye. The fragrant flowers were possibly also used in *hei* (floral wreaths).

Diversity and its importance

Santalum insulare is morphologically highly variable (adaptive diversity), probably due to its wide natural distribution and the diversity of ecological conditions under which it grows. This has resulted in the differentiation of 10 morphologically distinctive varieties, each being endemic to a particular archipelago. In addition, typically about three traditional varieties are recognised in each archipelago mainly on the basis of heartwood quality (colour, fragrance and toughness).

Chemical studies showed that the diversity of heartwood sesquiterpenoid composition is organised into two general chemotypes characterised by the distinct carbon skeletons of their main constituents: the typical santalol chemotype of commercial quality in most of the natural populations; and a new (Z)-nuciferol chemotype of limited commercial value restricted to three populations of Marquesas Islands. Moreover, some minor variations exist within the santalol chemotype and tend to differentiate several provenances linked with geographical distribution. Thus, these moderate variations between populations conjugated with important variations within populations support the conclusion



Above: Morphotypes of *S. insulare* seed from French Polynesia (Photo: J.-F. Butaud)

Left: Three-year-old seed orchard of *S. insulare* var. *marchionense* from Nuku Hiva planted at sea level in Taiohae; Nuku Hiva, Marquesa Islands, French Polynesia (Photo: J.-F. Butaud)

of the occurrence of a stabilising selection. Other chemical studies indicate that flavonoids—in particular, *C*-flavonoid glycosides—can be used as chemotaxonomic markers for *S. insulare*, whereas fatty acid seed oils could be useful to investigate diversity in the genus.

Genetic studies using chloroplast and nuclear microsatellite markers showed: moderate diversity; a high proportion of clones (60%) explained by vegetative multiplication (root suckering); and differentiation into four metapopulations (evolutionarily significant units) in French Polynesia corresponding to archipelagos or islands separated by large oceanic barriers; namely, Marquesas Islands, Society Islands, Raivavae island and Rapa island. These characteristics can be interpreted as the consequence of the insular syndrome due to the small founder effect (one or few individuals), subsequent limited gene flows and high genetic drift.

Thus, whereas speciation processes mainly occur at the archipelago scale, substantial morphological and chemical diversity is observed at the island scale. This diversity impacts on both wood quality and artificial regeneration, with seed size and provenance habitat influencing nursery practices.

Conservation of genetic resources (including threats and needs)

Although sandalwood was already used by Polynesians, the first documented threats to *S. insulare* came from the sandalwood trade with European settlers and visitors from Australia, USA and France. Furthermore, sandalwood from Austral and Marquesas archipelagos was overexploited for incense production in China between 1810 and 1830. Remaining populations constitute relics from that period and the different varieties are here assessed as either Endangered or Critically Endangered. A negative selection has occurred with the extirpation of the best-quality sandalwood populations (shape of the tree and quality of the wood) leaving a residue of inferior-quality trees (shrubby and faintly fragrant heartwood).

The introduction of the black rat at the beginning of the 19th century prevented natural reproduction by seed, a favourite rat food source, and contributed to the drastic decline in *S. insulare* populations. Moreover, these rats and other introduced predators (cats, swamp harriers and even humans) have contributed to the extinction of several species of fruit-eating birds which aided *S. insulare* seed dispersal and regeneration. In addition, modification of natural Polynesian ecosystems by humans (fire, agriculture and urbanisation), introduced herbivores (goats, horses and cattle) and/or invasive plant species has led to the extirpation of many *S. insulare* populations and contributed to its rarity throughout its natural range. In some islands, natural ecosystem processes can be restored but, in others, ongoing human intervention and management is now necessary to preserve remnants of former *S. insulare* populations.

In order to preserve and sustainably manage the sandalwood resource, the Government of French Polynesia has, since 1998, been implementing a management program for *S. insulare* in the Marquesas, Society and Austral archipelagos.

This program is based on several preliminary studies undertaken by several collaborators:

- inventory of populations and ecological studies on the 10 islands where *S. insulare* occurs in French Polynesia (Rural Development Service—SDR)
- investigations of variation in heartwood chemistry (University of French Polynesia—UPF)
- analyses of the genetic diversity and structure of most of the populations (International Cooperation Centre in Agronomic Research for Development—CIRAD).

Legal protection has been provided to the more threatened varieties (i.e. var. *margaretae*, var. *alticola*, var. *insulare*, var. *marchionense* and var. *deckeri*). Physical protection is also practised with the enclosure of small populations (mainly to protect plants from wild goats and cattle) and rodent control to permit fruit production and harvest. Our observation of major genetic differentiation between populations has led to the definition of management units based on evolutionarily significant units. Thus, exchanges of plant material between these units are banned to minimise future hybridisation.

Santalum insulare nurseries have been established in each unit in order to conserve local provenances (seed orchards, conservatory plantations and enrichment of small natural populations) and promote their cultivation by communities. Indeed, *S. insulare* is a highly valuable, naturally renewable resource for the small isolated islands that make up French Polynesia. A particular case involves trees/populations representing the rarest chemotype with no actual commercial value. These populations have not been multiplied for production plantations but are only protected from the feral herbivores by enclosure and several conservation plantations have been established in Marquesas Islands (two on Nuku Hiva and one on Hiva Oa) and in the Society Islands (one on Tahiti, two on Moorea and one on Tahaa).

This program will be complete once conservation plantations have been established and are well managed in each management unit and production plantations have been made by the local communities. Experience has shown that the success of such conservation activities, for a great part, depends upon the enthusiasm of key persons in each island. Indeed, *S. insulare* plantations are a long-term investment given the long rotation (>30 years) and are unattractive to most farmers who have the option, for example, of growing fruit trees that may produce a commercial harvest within a few years. Agroforestry could be a way to make sandalwood cultivation in French Polynesia more attractive; for example, in mixed plantings with *noni* (*Morinda citrifolia*) or *Citrus* species.

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Santalum yasi

Family: Santalaceae
Botanical name: *Santalum yasi* Seem. In *Flora Vitiensis*, 2: t. 55 (1873) [W.H.Fitch].
The specific epithet is the name by which this species is commonly known in Fijian.
Common names: *yasi* (Fiji; Niue); *'ahi* (Tonga); *asi manogi* (as an exotic in Samoa)

Summary of attributes and why diversity matters

Santalum yasi produces a prized fragrant heartwood that is rich in an essential oil high in α- and β-santalols; that is, the most highly sought-after and characteristic components of sandalwood oil. *Santalum yasi* grows well when planted with suitable host plants in home gardens and in smallholder agroforestry systems and mixed indigenous forest stands. Under reasonable growing conditions, it will provide harvestable quantities of heartwood in about 25 years.

Different *S. yasi* populations have become adapted to a range of soil types and climatic regimes, while different families show considerable variation in vigour and growth rate. Such variation is vital for adaptation and successful growth in Fiji, Tonga and Niue, and also for use in development of fast-growing hybrids with *S. album*, which are capable of growing in more humid areas that are less suitable for pure *S. yasi*.

Description

Habit root-parasitic, often multistemmed, small tree to 10–13 m tall with a light, spreading crown; may

Above: Buds, flowers and fruit (Photo: L. Thomson)

Top right: Two-year-old plant in avenue planting; Taveuni, Fiji (Photo: L. Thomson)

Bottom right: Mature tree; Galoa Island, Vanua Levu, Fiji (Photo: L. Thomson)

Tree in native habitat, with Sonu Dutt; Tubenasolo, Nausori Highlands, Viti Levu, Fiji (Photo: L. Thomson)

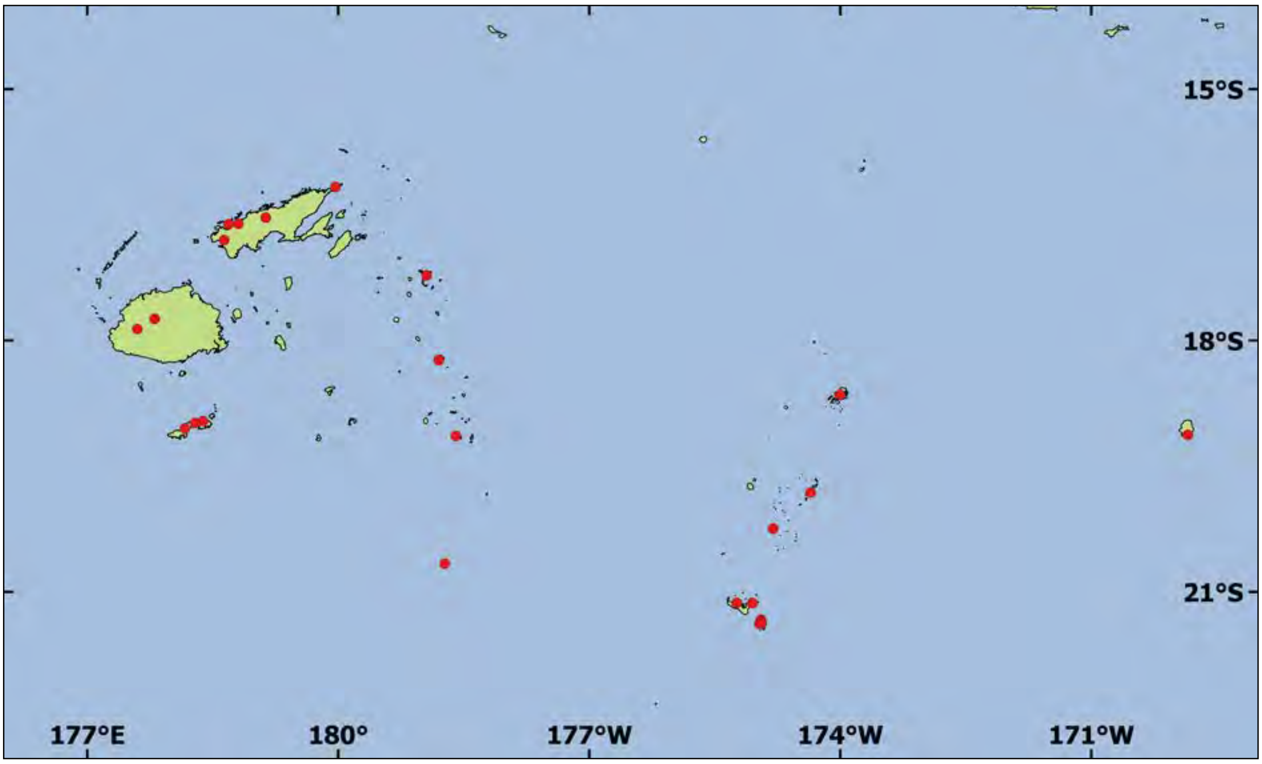
attain >40 cm dbh after 40–50 years but nowadays such specimens are extremely rare. ***Bark*** smooth to rough, greyish- or reddish-brown, mottled with patches of lichen. ***Leaves*** mature leaves simple, opposite, light to mid-green, shiny, narrow to broadly lanceolate (6–7 cm long, 1.5–2.0 cm wide); plants growing in the open with few host trees often have a yellowish appearance; juvenile leaves very slender, light green. ***Inflorescences*** terminal or axillary panicles about 4.5 cm long. ***Flowers*** small, bell-shaped, tepals 4 or 5, at first greenish-white but turning pink then red. ***Fruit*** 1-seeded drupe, ellipsoid, 9–11 × 6–8 mm, with a small, round, calyx scar (c. 2 mm diameter) at the apex, enclosing a rather stout, cone-shaped point; immature fruit light green, turning reddish-purple, and dark purple or black at full maturity. ***Seed*** kernel woody with light-coloured endocarp enclosing single seed.

Distribution

Santalum yasi occurs in lowland, more open forest types in Fiji, Niue and Tonga. The natural range extends from Niue and ʻEua, a southern island in the Tongan archipelago, through Tongatapu, Haʻapai, Vavaʻu and Niuas (Tonga), west and north through parts of Fiji—the Lau Islands, to Bua and Macuata provinces (western Vanua Levu), Udu Peninsula (north-eastern Vanua Levu), Kadavu and Nausori Highlands (western Viti Levu).

A small number of *S. yasi* plants have been introduced into other South Pacific Islands, including Savaiʻi, Samoa. It was unsuccessfully introduced into Bengaluru, India, for trials where it became infected with spike disease.

Santalum yasi is capable of growing on a diverse range of soil types, such as sandy, clayey, rocky and brackish/seaside, with a wide pH range from acid (pH 4.3, Bua, Fiji), through to neutral (pH 6.5–7.5) and alkaline (pH >7.5, Lau Group, Fiji; ʻEua, Tonga; and



Niue). Climate is also variable, with MAT varying from 23 °C to 29 °C and rainfall regimes ranging from 1,400 to 2,500 mm MAR distributed with a strong summer maximum or bimodally. *Santalum yasi* occurs in locations where tropical cyclones are frequent; typically with some cyclone exposure every 4–5 years. While remarkably tolerant to strong winds, *S. yasi* will usually sustain some crown damage from the winds associated with more severe cyclones (Category 3 and above).

Uses

As with the other *Santalum* species, sandalwood oil, carvings and incense production are the three major uses of *S. yasi* heartwood. In Tonga, the oil was traditionally used to scent *tapa* cloth and anoint corpses in royal funerals. *Santalum yasi* is also featured in Tongan legends and songs. In Fiji, the oil was traditionally used to scent coconut oil and during marriage ceremonies. *Santalum yasi* grows well when planted with suitable host plants in home gardens, in smallholder agroforestry systems and native woodland. Under suitable growing conditions, *S. yasi* may attain harvestable size (20–25 cm diameter at base with substantial heartwood development) within 25 years.

Wood—the heartwood of *S. yasi* was a major export during the early 19th century with the sandalwood trade being one of the first attractions to draw Europeans into the South Pacific. The price for *S. yasi* heartwood in 2005 was US42/kg, climbing to around US$100/kg (farm-gate price) in 2015. In recent times, the export of *S. yasi* heartwood from Fiji and Tonga has been mainly associated with illegal harvesting.

Non-wood—essential oil extracted from the heartwood from the lower bole and main roots contains an essential oil with high concentrations of the valuable santalols, typically 34–40% α-santalol and 29–31% β-santalol. These levels are similar to those of *S. album*, East Indian sandalwood oil and the industry benchmark oil.

Stockpile of *S. yasi* heartwood; Vanua Levu, Fiji (Photo: L. Thomson)

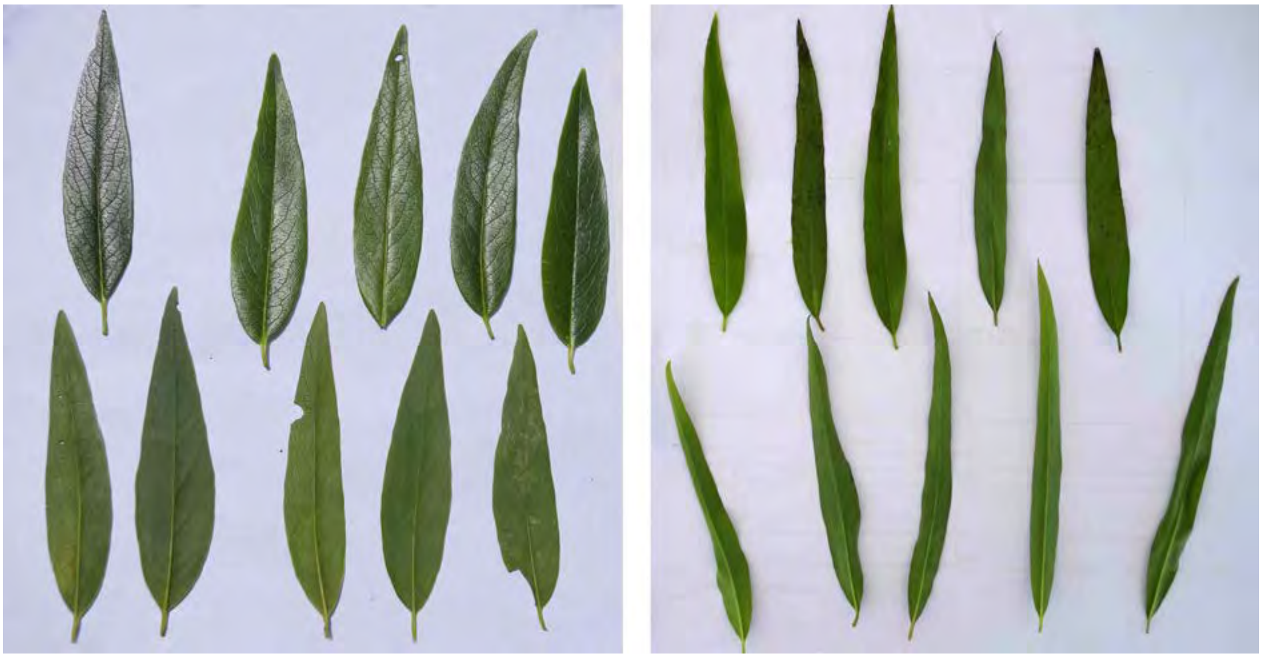
Diversity and its importance

The genetic diversity of *S. yasi* has been assessed throughout its range in Fiji and Tonga using microsatellite markers. Though the species has been heavily harvested and is now restricted to fragmented populations in the wild, moderate genetic diversity still resides in the overall population, which now mainly comprises planted stands and individual trees in many villages and urban areas. There is significant population differentiation among the Fijian and Tongan subpopulations (overall genetic distance F_{ST} = 11%), with some differences among Kadavu, Vanua Levu and Viti Levu, while subpopulations from the different Tongan Island groups (ʻEua, Tongatapu, Haʻapai and Vavaʻu) appear to be very similar to one another. Samples taken from the Lau Island group (Fiji) appear to have closer affinity to the Tongan subpopulations than to others from Fiji. Though diversity is moderate, it would appear that inbreeding is a general problem in all subpopulations from Fiji and Tonga. This is probably due to fragmentation of the wild stands and propagation of planting stock using seed drawn from a narrow genetic base.

A potential threat to the genetic diversity and integrity of *S. yasi* is the widespread planting of other, non-native *Santalum* species, particularly *S. album*, in Fiji and Tonga. *Santalum yasi* hybridises spontaneously with *S. album* and hybrids are both vigorous and fertile. It is therefore possible that introgression of genes via pollen flow from planted and naturalised stands of *S. album* and hybrids will result in the eventual loss of *S. yasi* as a discrete species. Molecular marker studies have identified a small number of hybrids among putatively pure *S. yasi* individuals; however, in most cases, F1 (first-generation) hybrids can be readily identified by morphological characters.

Santalum yasi × *S. album* hybrids have the reputation for rapid growth relative to pure *S. yasi*, at least on some site types, making their planting a more attractive commercial option. However, the quality of the essential oil from the heartwood of the hybrids is as yet unknown (although early indications are that it likely will meet the International Organization for Standardization [ISO] standard for East Indian sandalwood oil). It should also be borne in mind that nearly all subpopulations of *S. yasi* appear to be suffering from inbreeding, which normally results in lower growth rates. The establishment of broad-based *S. yasi* seed orchards may result in significant productivity gains.

The expression of intraspecific diversity in terms of economically important traits has yet to be comprehensively studied by means of field trials. This is mainly due



Variation in leaf shape of two *S. yasi* specimens from Tonga (Photo: D. Bush)

to the difficulties of collecting sufficient quantities of seed from populations that have been decimated through two centuries of heavy exploitation. Nevertheless, it is evident from its natural distribution that different populations of *S. yasi* have become adapted to widely differing environmental conditions.

In terms of heartwood development and oil content, there is considerable variation between individuals growing in the wild, but well-designed field trials will be required to make clear the relative importance of genotype, age, environment and their interactions on heartwood development.

Santalum yasi is fast approaching commercial extinction throughout its native range, with almost all accessible larger trees having been harvested, and the species is here rated as Endangered. Depletion of wild *S. yasi* trees has been hastened in recent years by illegal harvesting in Tonga and Fiji in response to high international demand and high prices. Assembly of broad-based seedling seed orchards and establishment of well-protected ex situ conservation stands are actions required to maintain genetic diversity of the species in the face of ongoing fragmentation of wild populations and illegal harvesting.

The Fijian and Tongan governments, in collaboration with SPC and CSIRO, have been developing strategies to ensure that the vital genetic resources are not lost in the process. Conservation and management strategies have been developed for *S. yasi* in Fiji and Tonga, and a separate strategy for Niue where a previously unknown population was identified in 2002. Several of the key recommendations from the strategies are now being implemented, including:

- Replanting of *S. yasi* using local germplasm sources is being promoted, through training of villagers, provision of information on technical and economic aspects of sandalwood cultivation in local languages, and production of high-quality seedlings in their extension nurseries. In Fiji and Tonga, the Department of Forests, Ministry of Fisheries and Forests, and the Forestry Division, Ministry of Agriculture, Food, Forests and Fisheries, respectively, are implementing these recommendations.
- Gene conservation/seed stands of nearby sandalwood populations are being established locally. In Fiji and Tonga, local communities and landholders have been supported to do this. The forestry departments have also grafted gene conservation/seed stands in large pots in protected locations (Colo-I-Suva, Fiji, and Tokomololo, Tonga) to conserve the genetic resources of as many remaining trees as possible.
- Research on *S. yasi* is being undertaken or encouraged to assist in the scientifically sound conservation and management of its genetic resources.

Authors: Lex Thomson, David Bush and Ponijese Bulai

Swietenia macrophylla

Family: Meliaceae
Botanical name: *Swietenia macrophylla* King. In *Hookers Icon. Pl.* 16: t. 1550 (1886).

The genus is named for Dutch-Austrian physician Gerard van Swieten (1700–1772). The specific epithet is derived from the Greek *macros*, large, and *phylon*, leaf, and refers to the large paripinnate leaves up to 40 cm in length.

Common names: big-leaved mahogany, broad-leaved mahogany, large-leaved mahogany, Honduras mahogany, mahogany (English); *mahoni* (Indonesia); *arawakan* (Philippines); *mogno* (Polynesia); *mahokani* (Samoa; Tonga)

Summary of attributes and why diversity matters

Swietenia macrophylla is renowned for its timber, used in high-value furniture and cabinetwork. It is moderately fast growing, producing sawn timber under a 30–35-year rotation and has generally favourable plantation silviculture characteristics. *Swietenia macrophylla* is widely planted both in its zone of natural occurrence in the neotropics, where it has become endangered in places due to overexploitation, and as an exotic. It grows best in humid and subhumid climates with MAR of about 2,000–4,000 mm distributed uniformly or with a dry season of up to 4 months. However, *S. macrophylla* is genetically diverse and adapted to a wide range of climatic and edaphic conditions.

Significant intraspecific variation has also been reported in economic traits such as volume growth, bole form and wood density. New *S. macrophylla* tree improvement programs will ideally commence with introduction of a wide range of germplasm from the species' natural and exotic ranges, followed by intensive screening and selection across the range of planting sites. There appears to be great scope for infusions of new genetic material into existing improvement programs in the Asia–Pacific region to broaden their genetic base and increase rate of gain.

Description

Habit medium-size to large, straight, self-pruning, evergreen to briefly deciduous tree ≤40(–60) m tall, ≤150(–250) cm dbh; crown dome-shaped, often consisting of a few large ascending branches; frequently with broad and plank-like buttresses up to 5 m tall and extending out ≥10 m from the stem. ***Bark*** grey and smooth when young, turning rough, brownish-grey to reddish-brown, vertically furrowed, flaky when old. ***Leaves*** alternate, paripinnate, large, 16–40 cm long, (2–)3–6(–8) pairs of leaflets, stipules absent; leaflets opposite or occasionally subopposite, oblong-lanceolate to ovate-elliptic, slightly falcate, 8–18 cm × 3–5 cm, entire, dark green above, lighter below, on slender petiolules. ***Inflorescences*** axillary panicles 10–20 cm long, consisting of small cymes. ***Flowers*** small, unisexual, trees monoecious with both sexes similar, 5-merous, fragrant, greenish-yellow; pedicel slender, 1.5–2.5 mm long; calyx with broadly rounded lobes, 1.0–1.5 mm long, hairy at margins; petals 5, free, slightly contorted in bud, ovate-oblong, 5–6 mm long; stamens united into a tube with 10 sessile anthers at the mouth of the tube; ovary superior, usually 5-celled; style short with disc-shaped stigma.

Candidate plus tree, with Ponijesi Bulai (L) and Vilisoni Nataniela (R); Nukurua, Viti Levu, Fiji (Photo: L. Thomson)

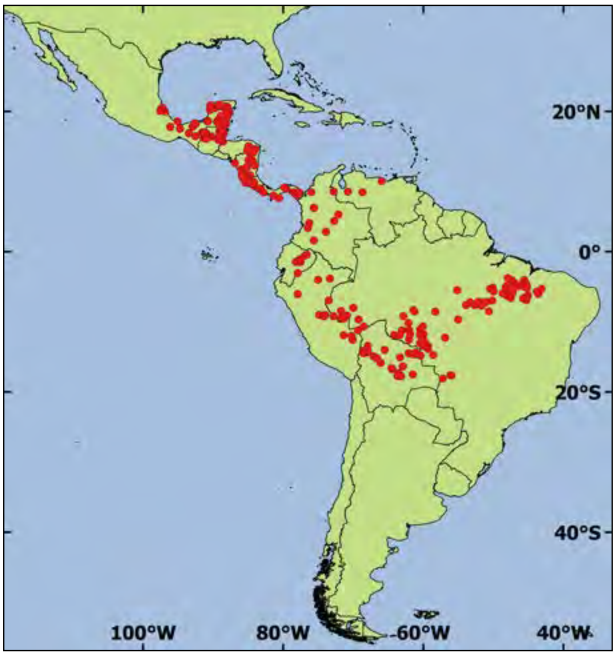
Mature fruit (Photo: K. Aken)

Fruit woody, erect, elongate-ovoid capsule, 10–15(–22) × 6–8 cm, greyish-brown, opening by 5 valves with seeds briefly hanging by their wing, leaving conspicuous seed scars after their release. ***Seed*** usually 35–45 in each fruit, with large wing, flat, 7.5–10 cm long, 2.0–2.5 cm wide, dark brown. ***Reproductive phenology*** flowering takes place annually when trees are briefly deciduous and/or just coming into new leaf and shortly before the rainy season; fruit mature in 10–11 months; the month of flowering/fruiting varies between locations according to climate and is being impacted by climate change.

Distribution

Swietenia macrophylla occurs naturally from the Atlantic regions of south-eastern Mexico, through Central America (Belize, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica and Panama), northern South America (Colombia, Venezuela, Ecuador and Peru) and in an arc across the southern Amazon Basin, in Bolivia and Brazil. Due to the high value of its timber, the species has been widely planted in South and South-East Asia, the Pacific Islands, the Caribbean and tropical Africa. Substantial areas of plantation have been established in Fiji, Indonesia, Sri Lanka and parts of Central America.

Swietenia macrophylla is primarily a species of the wet/dry and humid climatic regions. It has a wide altitudinal range, from near sea level to 1,500 m asl. Optimum conditions for growth of *S. macrophylla* appear to be 2,000–4,000 mm MAR, which may be uniformly distributed or with a dry season of up to 4 months, and 24–28 °C MAT. The species occurs in broadleaved evergreen forests, including dry forests, moist forests, riparian forests and secondary forests. It occurs naturally on a wide variety of soils ranging from deep, poorly drained, acid clays to well-drained alkaline soils, with optimal development attained on deep, fertile, moist, well-drained, neutral to mildly alkaline soils.



Uses

Wood—*S. macrophylla* produces decorative and attractive timber with good technical characteristics which have made it one of the world's most valuable and best-known furniture timbers. While it is principally used for furniture and face veneers, being easy to work and strong for its weight, it is suited to a wide range of uses, including light construction work, panelling, doors, decorative borders, boatbuilding, musical instruments, instrument cases, clocks, models, pattern making, wood carvings and turnery. It has high potential in the plywood industry although colour variation, wavy grain, pin knots and pinhole borer damage sometimes preclude its use as face-quality veneer.

Felled logs of *S. macrophylla,* with Inoke Wainiqolo; Nukurua, Viti Levu, Fiji (Photo: L. Thomson)

The light yellowish- to reddish-brown sapwood, up to 40 mm wide, is fairly distinctly demarcated from the pinkish or reddish heartwood, darkening to deep red or brown on exposure to ultraviolet (UV) radiation. *Swietenia macrophylla* timber is medium density and moderately tough: the density of plantation-grown timber is usually in the range of 510–570 kg/m^3 (at 12% moisture content) compared with that from native forests of 530–670 kg/m^3. Grain is straight or interlocked. The wood seasons well with low rates of shrinkage and with minimal checking or distortion. It saws, planes and moulds easily in both dry or green condition. Nailing, polishing, gluing and staining properties are good. It generally produces a fine and decorative veneer and satisfactory plywood and kraft pulp. It is not considered suitable for in-ground applications, although plantation-grown wood may be pressure treated with preservatives (boron) to improve durability.

Non-wood—*S. macrophylla* has been used in agroforestry systems (e.g. Central America and parts of Indonesia) to provide shade and fuelwood. A wide range of minor uses have been reported for the species, including traditional medicines such as antibacterial and antifungal agents derived from seed and stems, as well as being used to treat various diseases, and for dyes and tannins. In Fiji, a dye from the bark is used to provide a red-brown hair colour. In South-East Asia, the seed (under the name 'sky fruit') is used to make a drink rich in flavonoids and reputedly with health benefits. The tree is widely planted as an ornamental and amenity tree

Diversity and its importance

Swietenia macrophylla has a wide, disjunct natural distribution from 23°N to about 18°S latitude in the neotropics where it occurs in a range of vegetation types, climates and edaphic conditions. It can be expected, therefore, that intraspecific genetic variation will be high with substantial genetic differentiation between populations. This was confirmed in a 2010 study of chloroplast DNA microsatellite markers that revealed contrasting phylogenetic structure in *S. macrophylla* from the Amazon Basin and Central America.

Despite its economic importance, studies of intra-specific variation in commercial traits at the provenance and individual family level are limited as are estimates of genetic parameters and reports of tree breeding activities. Provenance variation in economic traits such as height and diameter (as a proxy for volume growth), form, wood density and resistance to shoot-borer attack has been demonstrated in trials in various countries (e.g. Costa Rica, Cuba, Fiji, Philippines, Puerto Rico, Trinidad). In Fiji, superior early growth has been displayed by trees from certain Costa Rican provenances and from the Lancetilla seed stand (Honduras), while elsewhere, Nicaraguan sources have performed well. Genetic parameter estimates for height and diameter in progeny trials in the Philippines were consistent with estimates for other tropical tree species: height and diameter had low to moderate heritability with reasonable levels of additive genetic variation. Economic gains in growth traits can be expected from recurrent selection and breeding activities in this species given the heritable genetic variation indicated in this and other studies, but only as long as the best genotypes are selected for each site type to allow for significant genotype × environment variation.

There is a need to enhance local landraces, often of narrow genetic base, by infusion with a wider range of genetic diversity from the species' natural range in Central and South America—*S. macrophylla* improvement programs need to do likewise. Another largely untapped opportunity to increase genetic variation is through hybridisation. Interspecific hybridisation does occur between *S. macrophylla* and its close relatives *S. mahogani* and *S. humilis* where they co-occur. This offers the potential for producing artificial hybrids combining the desirable traits of the parent species; for example, the fast growth of *S. macrophylla* combined with the superior wood quality of *S. mahogani* and greater resistance to pests and diseases. Selection and breeding programs for *S. macrophylla* have been implemented in Fiji and Indonesia and these countries are potential sources of improved seed.

Provenance trial; Kolobagara, Solomon Islands (Photo: L. Thomson)

The larvae of shoot-boring moths, *Hypsipyla* spp., are the major limitation to successful plantation establishment of *S. macrophylla* in the neotropics. This pest has also caused serious damage in nurseries and plantations in India, Indonesia, Solomon Islands and elsewhere. Shoot-borer damage can be reduced through a combination of silvicultural, biological and chemical means, including planting at low frequency in mixed-species plantations and agroforestry systems. Brown butt rot (*Phellinus noxius*), often in combination with termites, may also cause mortality in plantations, especially in second rotations. Ambrosia beetles may attack the sapwood of living trees, especially saplings aged around 5–10 years, and cause variable levels of pinhole damage in sawn timber, thus reducing its value for decorative purposes. The extent to which there is genetic variation in resistance to key pests and diseases warrants further research.

Conservation of genetic resources (including threats and needs)

Swietenia macrophylla has become rare in parts of its natural range due to overexploitation and classifies as Vulnerable on the IUCN Red List. It has been included in Appendix II of CITES since 2003 when it joined the other two *Swietenia* species. Export and trade of wood from natural stands is, therefore, strictly controlled but no such regulations apply to export and trade of plantation-grown timber. This species is a high-priority candidate for in situ and ex situ conservation strategies.

Authors: Lex Thomson, Liliana Baskorowati and John Doran

Syzygium malaccense

Family: Myrtaceae
Botanical name: *Syzygium malaccense* (L.) Merr. & Perry. In *J. Arnold Arboretum* 19: 215 (1938).

The genus name is derived from the Greek *suzugos*, joined, because of the paired leaves and branchlets, which are similar to a Jamaican species (*Calyptranthes syzygium*). The specific epithet is derived from *pomme Malac*, meaning 'Malayan apple' in French. The genus comprises about 500 species and occurs in the tropical and subtropical regions of the Old World. It is closely related to the mainly American genus *Eugenia*. Some botanists include *Syzygium* in *Eugenia*. Synonyms include *Eugenia malaccensis, E. domestica* and *Jambosa malaccensis.*

Common names: Malay apple, pink satinash, mountain apple (English); *pomme Malac*, *Poirier de Malaque*, *jambosier rouge* (French); *ahi-ngakapika* (Ambrym, Vanuatu); *inyhueg* (Aneityum, Vanuatu); *faariyap*, *fasniyaap*, *feniyap* (Chuuk, FSM); *ka'ika* (Cook Islands); *waveh* (Erromango, Vanuatu); *kavika* (Fiji); *makupa* (Guam); *'ōhia'a 'ai*, *'ōhi'a* (Hawai'i, USA); *jambu bol*, *jambu merah* (Indonesia; Malaysia); *acpuhl* (Kosrae, FSM); *kehi'a*, *kehika*, *kehika inana* (Marquesas Islands, French Polynesia); *thabyo-thabyang* (Myanmar); *fekakai* (Niue); *kidel* (Palau); *yanba*, *tersana*, *makopang-kalabaw* (Philippines); *apel* (Pohnpei, FSM); *nonu fi'afi'a* (Samoa); *'ahi'a* (Society Islands, French Polynesia); *apuchu*, *gafiga*, *gahiga*, *ghabiga*, *hahika*, *hipala*, *kabirai*, *kapika*, *karukae*, *kaviha*, *sa'u* (Solomon Islands); *chomphu mamieo*, *chomphu saraek*, *chomphu daeng* (Thailand); *cay dao*, *cay roi*, *dièu-dò* (Vietnam); *kafika* (Wallis and Futuna); *arfatlh*, *harafath*, *faliap*, *faliyap* (Yap, FSM)

Summary of attributes and why diversity matters

Syzygium malaccense is a widely dispersed, fast-growing, medium-size tree of socioeconomic importance for its edible fruit and as a source of traditional medicines. Despite having a short shelf life, the fruit are refreshing and popular locally. This species grows well and is naturalised in many Pacific Islands having been widely dispersed by early Polynesian voyagers. It is commonly cultivated from Java to the Philippines and Vietnam, also in Bangladesh and India (West Bengal and South India).

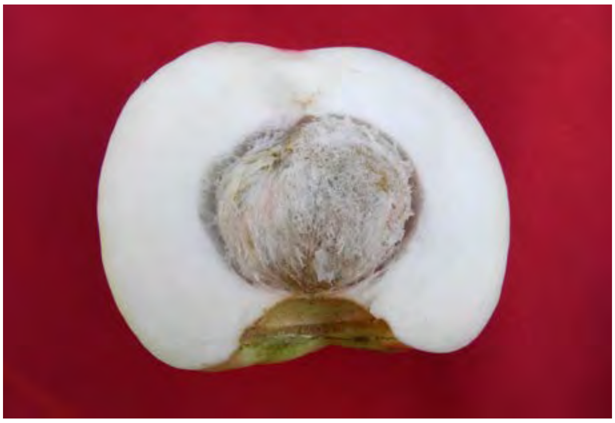
There is variation in fruit colour, size and taste, and superior forms are recognised and propagated locally. However, there have been no formal trials to determine the extent of genetic variation in the species, the phenology of flowering and fruiting and to compare the more promising forms. This work is needed to underpin selection and breeding programs to increase yields and quality of edible fruit in this species.

Description

Habit medium-size tree 5–12(–20) m tall and 20–45 cm dbh; crown oblong, pyramidal or cylindrical, sometimes subtiered, with many small horizontal to ascending branches; bole short and often fluted. ***Bark*** greyish-brown, somewhat flaky. ***Leaves*** opposite, glossy green, subcoriaceous with entire margins, elliptic-oblong to obovate, 15–38 cm long, 7–20 cm wide, principal lateral veins 8–15 pairs, 10–25 mm apart, submarginal vein sinuate, apex short acuminate, base cuneate, petioles 0.8–1.5 cm long. ***Inflorescences*** short (6 cm long), few-flowered (1–12) cymes on upper trunk or leafless parts of older branches. ***Flowers*** abundant, 5–7 cm diameter; stamens red, pink or white with yellow anthers, ≤4 cm long; style ≤4.5 cm long, generally

Flowers (Photo: F. & K. Starr)

Mature tree in orchard planting (Photo: B. French)



Cut fruit showing seed (Photo: B. French)

exceeding the stamens. ***Fruit*** large, fleshy berry, 5–8 cm in diameter, glossy, red, pink, purplish-yellow or yellow-white, ovoid or ellipsoid with waxy skin, crowned by incurved calyx segments; flesh crunchy, often juicy, with a mild sweet flavour. ***Seed*** usually single (sometimes in pairs or occasionally seedless), large (1.5–2.0 cm diameter), subglobose, fleshy, brown, recalcitrant; testa fibrous, closely coherent to cotyledons. ***Reproductive phenology*** seasonality of flowering and fruiting varies widely from place to place and from year to year; in some places, *S. malaccense* flowers 2–3 times/ year.

Distribution

The origin of *S. malaccense* is uncertain but it is thought to be a native of Malaysia, Indonesia (Java, Sumatra), PNG and Australia (northern Queensland). It has been spread by humans throughout much of South-East Asia (Myanmar, Philippines, Thailand and Vietnam) and the Pacific Islands since very early times. *Syzygium malaccense* was an important fruit of the Polynesians and it has naturalised on the Hawaiian Islands, USA, and elsewhere in the Pacific Islands. It is now cultivated widely in the tropics, including in Micronesia and Central and South America.

It thrives in humid to subhumid tropical conditions usually from near sea level to 600 m asl, in areas where rainfall is high (>1,500 mm MAR) with no or only a very short dry season. It will tolerate a range of soil types from sands to heavy clays of acidic to neutral pH (6.1–7.4). It is intolerant of highly alkaline or waterlogged soils. Trees usually require little care other than a year-round adequate moisture regime.

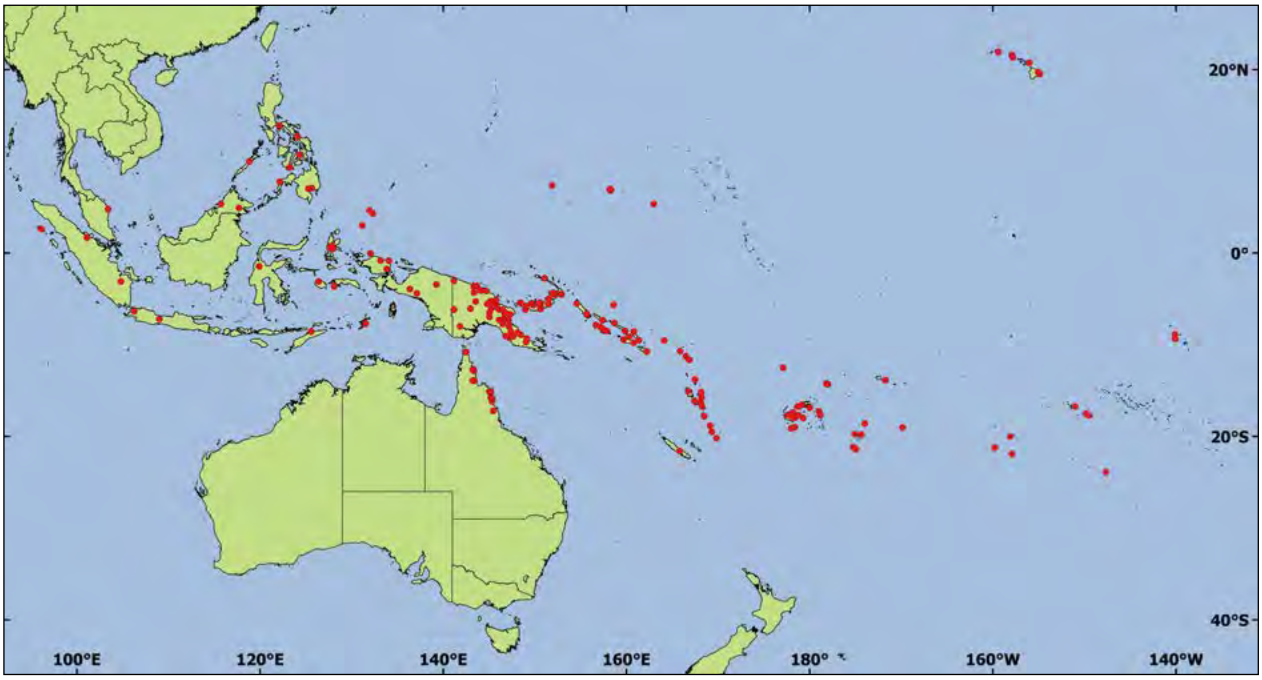
Uses

Syzygium malaccense is mainly grown as individual trees in home gardens and incorporated in multispecies agroforestry systems, as well as plantations as a supplemental source of fruit and income. Growth can be fast on suitable sites with good silviculture. Fruit production from seedling-derived plants can start from 5 years of age.

Wood—reddish, tough, heavy, difficult to work and with a tendency to warp. It is a sacred craftwood in Hawai'i and used to make canoes in Vanuatu. It finds occasional use locally for construction purposes (as house and fence posts, rafters, railway ties, carving bowls and outrigger booms) and as firewood.

Non-wood—the fruit is crisp, delicate and rather watery, with a very short shelf life. It is eaten fresh or cooked in various ways. The half-ripened fruit can be pickled. Wine is made from the fruit in the Americas.

Different parts of this plant, such as seed, bark, fruit and leaves have been used in traditional medicine.



Syzygium malaccense displays considerable variation in fruit characteristics including shape and skin colour of ripe fruits; Solomon Islands (Photos: L. Thomson & B. French)

Extracts of seed, fruit, bark, stem and leaves show varying degrees of antibiotic activity against *Micrococcus pyogenes* var. *aureus*. A fruit extract (without seed) is moderately effective against *Escherichia coli* and that of bark and leaves against *Shigella paradys*. The root is used as a remedy for itching, as a diuretic and is given to alleviate oedema. The powder from dried leaves is useful against cracked tongue and the juice of crushed leaves is applied as a skin lotion and is added to bathwater. Leaves of *S. malaccense* have been used for a wide variety of inflammatory conditions in Samoa. The plant is used in Polynesian traditional medicine for the treatment of infectious diseases, including coughs and colds, and has been found to elicit antiviral, antifungal and antibacterial activities. It is one of the most important medicinal plants in the Pacific Islands.

A dye for *tapa* cloth is made from the bark in Hawai'i. *Syzygium malaccense* provides useful shade and has potential as an ornamental for parks and gardens.

Diversity and its importance

Several forms of *S. malaccense* are recognised by fruit colour, size and taste. The flavour of the fruit is quite variable, and may be insipid, sweet or sour. It is always refreshing. Accordingly, four to six different forms of *S. malaccense* are recognised in Vanuatu. Among them is a rare form with white flowers and fruit which is popular because it is sweeter and less often infested with fruit-fly larvae than the red-fruited form. Superior varieties are propagated by seed or via budding, marcotting and cuttings.

Despite its socioeconomic and nutritional importance, there has been no detailed examination of genetic diversity in this species. Formal studies are needed throughout its range to determine the extent of genetic variation in the species, the phenology of flowering and fruiting and to compare the more promising fruit forms. Surveys are needed to determine the range of variation that is maintained in agroforestry conditions and home gardens.

There have been few genetic studies to assess the relationships between different *Syzygium* species. Based on the waxy fruit skin trait, *S. malaccense* appears to be closely related to: *S. aqueum* (bell fruit); *S. cumini* (jambolana); *S. jambos* (rose apple); *S. pycnanthum* (wild rose apple); and *S. samarangense* (wax jambu).

Conservation of genetic resources (including threats and needs)

Genetic erosion is serious for the species, although *S. malaccense* has not yet qualified for the list of 46 *Syzygium* species in the IUCN Red List, mainly because it is cultivated in home gardens. *Syzygium malaccense* is rare in the forests of northern Queensland. A disease not yet recorded on this species but of concern because of the high susceptibility of close relatives (e.g. *S. jambos*—extremely susceptible; *S. aqueum*—moderately susceptible) is the leaf rust *Puccinia psidii* (guava, eucalyptus or myrtle rust). This rust is on the move from its native South America and is now in Australia and Indonesia. The rust causes spots or lesions on young leaves and shoots of susceptible Myrtaceae species. These become curled and distorted, stunting growth or even causing mortality after repeating destruction of new growth.

Authors: L.T. Hong, V. Ramanatha Rao and R.C.K. Chung

Tectona grandis

Family: Lamiaceae
Botanical name: *Tectona grandis* L.f. In *Supplementum Plantarum* p. 151 (1782).

The genus name is derived from the Malayalam (in the Malabar region, south-western India) word *theka* or *tekka* for teak. The specific epithet is from the Latin *grandis*, large, big, tall, which refers to the large size this species commonly attains. Several morphological forms have been recorded and distinguished principally on the basis of leaf characteristics. There are two other species in this genus; namely, *T. hamiltoniana* in Myanmar and *T. philippinensis* from the Philippines.
Common names: teak, Indian oak (English); *sagwan* (India); *jati* (Indonesia); *sak* (Laos); *kyun* (Myanmar); *mai-sak* (Thailand)

Summary of attributes and why diversity matters

Tectona grandis, a forest tree of wide adaptability and occurrence in tropical Asia, produces one of the world's most sought-after timbers. It is found in a variety of habitats with an altitudinal range from near sea level to almost 1,000 m asl. Climatic conditions in its region of occurrence vary from semi-arid areas with only 500 mm MAR to moist forests with ≤5,000 mm MAR. Its best development is in the intermediate rainfall zone (1,250–3,750 mm MAR) with a marked dry season. The native *T. grandis* forests of Asia are considered vulnerable and conservation initiatives have been put in place in India, Laos and Thailand.

Numerous studies have demonstrated provenance variation in growth and stem quality in *T. grandis*. Substantial genetic gains in commercial traits for various planting environments have been achieved through selection and breeding among superior provenances. Operational *T. grandis* improvement programs are now in progress in many countries. Despite this, there is a substantial shortfall in the availability of improved germplasm for high-quality plantation development. There is an urgent need for an expansion of existing programs and initiation of new breeding programs with the aim of providing progressive, economically significant genetic gains into the future while maintaining genetic diversity.

Description

Habit large, dry-season-deciduous tree to 30–40(–50) m tall; in dry zones, tree habit becomes stunted, forked, branchy, and bushy; on good sites and with close spacings, clear boles of ≥15–20 m can be obtained as lower branches are shaded out; fluting and buttresses often found at the base of older trees. ***Bark*** pale brown with shallow longitudinal grooves; cracked and scaly in mature trees. ***Leaves*** simple, opposite decussate (rarely 3 at a node), margin entire, broadly ovate to elliptic-ovate, large to very large, 15–60(–90) cm long, 15–35(–50) cm wide, held on 2–4 cm long stalks, dark green, glabrous above, pale glabrous to tomentose or often silvery below. ***Inflorescences*** terminal from the axils of upper leaves forming large panicles, 70 × 45 cm, with opposite, widely

Flowers (Photo: F. & K. Starr)

Fruit (Photo: F. & K. Starr)

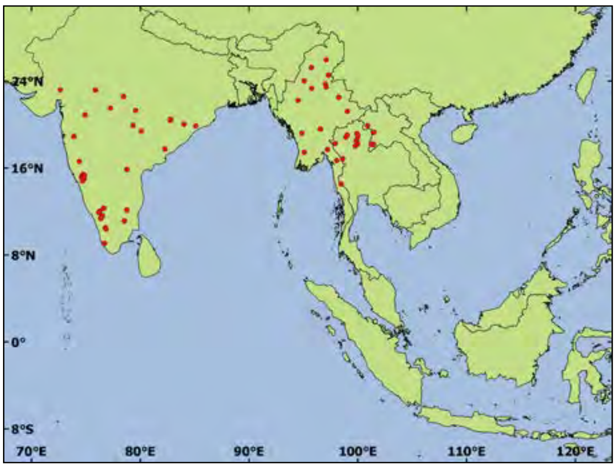
Fourteen-month-old *T. grandis*; Kolombangara, Solomon Islands (Photo: L. Thomson)

Twenty-year-old *T. grandis*; Vaisala, Savai'i, Samoa (Photo: L. Thomson)

divaricate, many branched cymes that each contains a few thousand flowers. ***Flowers*** small, fragrant, bisexual, weakly protandrous, mainly insect-pollinated (or, less commonly, wind-pollinated)—major pollinators are from the genus of stingless bees (*Ceratina*); corolla white, lobes obtuse 2.5–3.0 mm long, 2 mm wide; stamens (5–)6(–7); ovary superior, ovoid, 4-celled, 1 ovule in each. ***Fruit*** subglobose drupe, 1.2–1.8 cm diameter, densely hairy. ***Seed*** ovoid, c. 6 × 4 mm, without endosperm, 1–4/fruit. ***Cotyledons*** with a notched apex.

Distribution

Tectona grandis is native to India, Myanmar, northern Thailand and Laos. The natural occurrence of the species is discontinuous, with extant *T. grandis* forests being



separated by mountain ranges, plains and other forest types.

Tectona grandis plantations have been established around the tropical world to complement dwindling timber supplies from 27.9 million ha of natural *T. grandis*–containing forests. The total area of *T. grandis* plantations worldwide is estimated to be 5.7 million ha—mainly in tropical Asia, including India, Indonesia, Laos, Myanmar, Sri Lanka, Thailand and Vietnam. In Solomon Islands, there are an estimated 5,000 ha of *T. grandis* plantations, mainly under smallholder management.

In nature, *T. grandis* grows best on deep, well-drained alluvial soils derived from limestone, schist, gneiss, shale and some volcanic rocks such as basalt. It prefers sites with a marked dry season, and MAR of 1,250–3,750 mm, minimum daily temperatures of 13–17 °C and maximum daily temperatures of 30–43 °C. *Tectona grandis* prefers low-elevation sites (<500 m asl) and relatively fertile soils with high calcium, phosphorus, potassium, nitrogen and organic matter contents and a soil pH of 6.5–8.0. The species thrives on limestone, volcanic and coralline soils which are prevalent in the Pacific Islands. In contrast, it performs poorly on brackish, acidic, compacted, waterlogged or shallow soils.

Uses

Tectona grandis produces one of the world's premier timbers, for which demand outstrips supply. The resulting high international prices and unmet demand,

Mixed planting of *T. grandis* and *Flueggea flexuosa*; Saika, Western Province, Solomon Islands (Photo: L. Thomson)

coupled with a high degree of species' plasticity and ease of cultivation, are key reasons why *T. grandis* has become a major tropical timber plantation species. *Tectona grandis* cultivation is a viable long-term investment, with potential rates of return of >30% under favourable conditions and requiring lower inputs of labour and materials than other cash crops. It is widely planted in most subtropical and tropical regions in South and Central America, Africa, South Asia, South-East Asia and the South Pacific. In the Pacific Islands, *T. grandis* cultivation is constrained because, even though land for plantations is often available, labour is scarce, producers fragmented and markets difficult to access as international buyers need substantial volumes. Shipping can be justified, however, where large mercantile teak logs of high quality are available in sufficient volumes.

Wood—the strong, durable heartwood is of dark-brownish to reddish colour. The sapwood, whitish to pale yellowish or greenish in colour, is much less resistant than the heartwood to fungal attack, termites and borers. Density is medium (480–)610–750(–850) kg/m^3 at 12% moisture content. The wood is easily worked and seasoned. It has high oil content, high tensile strength and tight grain, making it extremely weather resistant (e.g. as exposed ship decks). The uses of teak are well known and numerous, including in heavy construction (bearing poles, whole or half-timber, and cut timber), reconstituted products (plywood and sliced veneers), decorative building components (doors, window frames, flooring), shipbuilding and furniture (both indoor and outdoor).

Non-wood—the species is a useful source of oils, medicinal products and dyestuffs isolated from the bark, wood, roots, flowers and leaves.

Diversity and its importance

Tectona grandis has sometimes been negatively judged as an exotic timber plantation species when initial introductions comprised inappropriate provenances or inbred seed sources. Numerous examples of this exist, particularly in West Africa and Central America, where initial introductions proved far less suitable than later introductions of superior provenances. Any tree improvement program will reach early limitations if not working from the most suitable and heterogenic material to provide a wide, healthy base population. Such a population will allow for refined and continued selection pressure for specifically desired traits which may change over time due to changing preferences and market demands.

Most countries with large areas of *T. grandis* have tree breeding programs to provide improved germplasm and enhance the quality of their plantations. The importance to subsequent growth and stem quality of selecting the correct provenance (seed source) for a planting site was clearly demonstrated by the results of many (75 provenances in 16 countries) international *T. grandis* provenance trials coordinated by FAO and the Danish International Development Agency (Danida) from the early 1970s. These trials showed that growth and stem quality could be improved by 23% and 17%, respectively, through selection of the best-performing provenance(s) for a particular planting site. Further economic gains can then be captured by recurrent selection and breeding programs making use of the moderate to high heritability estimates (0.4–0.9) for most commercial traits (e.g. diameter growth, stem straightness, forking, earliness of flowering) in *T. grandis* coupled with substantial levels of phenotypic variation in these traits.

Major *T. grandis* improvement programs are taking place in India (since 1962), Indonesia (1974), Thailand (1965) and several African countries. In the Pacific region, *T. grandis* improvement programs are underway in PNG and Solomon Islands. In Solomon Islands, early introductions of *T. grandis* seedlots performed poorly until a plus tree (45 trees) selection and clonal seed orchard (CSO) program started in 1992 on Kolombangara Island. The Kolombangara CSO is currently supplying seed and stumps for farmer woodlots. Growth observed in plantings is spectacular, with trees growing >5–6 m/year in the first 3 years and having very straight stems, little forking and fine branches. This source is highly recommended for wider use in the South Pacific

Above: *Tectona grandis* clonal archive based on collections of Basil Gua (on right); Kolombangara, Solomon Islands (Photo: B. Clarke)

Right: Superior growth and form from *T. grandis* clonal archive seed (L) compared with progeny from a routine seedlot (R); Kolombangara, Solomon Islands (Photo: B. Clarke)

region. New CSOs established in Western Province of Solomon Islands are starting to produce seed and are likely to deliver even greater economic gains.

Despite the many operational *T. grandis* improvement programs around the world, there is a substantial shortfall in the availability of improved seed for high-quality plantation development. This calls for the urgent expansion of existing programs and initiation of new breeding programs with the aim of providing ongoing, economically significant genetic gains into the future while maintaining genetic diversity.

Conservation of genetic resources (including threats and needs)

In Asia, the decline of natural *T. grandis* forests has been substantial and rapid, and is here considered to be rated as Vulnerable (IUCN category). The main causes are common to all regions and include excessive harvesting, encroachment for agricultural land and other developments, overgrazing and forest fires. Harvesting of *T. grandis* from natural forests is now banned or severely restricted in all countries within the species' natural range, except Myanmar. All countries have considered conservation strategies and a number of in situ and ex situ gene conservation initiatives supported by regional and international forest genetic resources agencies are in place in Thailand, Laos and India.

Because of the widespread planting of the species, evolution of local landraces and spread of research plots of known origin, the genetic diversity of the species is not regarded as threatened. Molecular genetic analysis shows that there are at least two major groupings within the species: the highly diverse Indian group, which is subdivided into populations from the humid, semi-dry and dry zones, and the more homogeneous Thai group, including some populations planted in Indonesia and Africa.

Though *T. grandis* is a hardy species, it is prone to attack by a number of fungal pathogens that cause diseases of roots, stems, branches, tip dieback and heart rot. Insects can also cause serious damage to *T. grandis* plantations, including defoliators and stemborers. 'Water blister', a physiological disorder that affects wood quality, occurs in localised areas of India on soils subject to waterlogging. While these conditions can cause serious economic loss in specific cases, they do not threaten the survival of the species as a whole.

Authors: Anders Pedersen and Basil Gua

Terminalia catappa

Family: Combretaceae
Botanical name: *Terminalia catappa* L. In *Mantissa Plantarum* 1: 128 (1767).
The genus name is derived from the Latin *terminus*, in reference to the leaves appearing at the terminal ends of the shoots. The specific epithet is taken from the plant's Bahasa Indonesian name *katapang*.
Common names: tropical, beach, sea or Indian almond (English); *tavola* (Fiji); *kamani haole* (Hawai'i); *ketapang* (Indonesia; Malaysia); *te kunikun*, *te ukin* (Kiribati); *kauariki* (Mangaia, Cook Islands); *ma'i'i* (Marquesas Islands, French Polynesia); *talisay* (Philippines); *talise* (PNG); *talie* (Samoa); 'autara'a (Society Islands, French Polynesia); *alite* (Solomon Islands); *telie* (Tokelau; Tonga; Tuvalu; Wallis and Futuna); *natapoa* (Vanuatu). These are but a selection of common names in Oceania and Asia, and there are many more reflective of the extensive distribution of the species.

Summary of attributes and why diversity matters

Terminalia catappa is a hardy, fast-growing, briefly deciduous multipurpose tree. It has been widely planted throughout the tropics for wood (sawn timber), non-wood products (edible nuts, traditional medicines, dyes, leaves for live aquarium trade and tea) and amentity, including shade and ornamental, and especially along sandy seashores where it plays a vital role in coastline stabilisation.

Selected cultivars of this species will have great potential as a new plantation and/or agroforestry crop for joint production of timber and edible nuts. Phenotypes with large kernels and easily shelled nuts have already been selected in parts of Melanesia (PNG, Solomon Islands and Vanuatu). There is an urgent need for early selection of superior individuals that have desirable nut characteristics and long internodes for production of clearwood. Complementary research is also needed concerning the productivity and marketing of cultivars with large nuts, nut-processing technologies and efficient methods of vegetative propagation. The species would be an ideal model species for studies of heritability and improvement in tropical nut tree species, given the level of variation in nut characteristics and its early nut production (with a generation interval of <3 years).

Description

Habit medium to large tree to 25–40 m tall and with a similar crown spread in open situations; younger trees display a characteristic pagoda form, with a single bole and monopodial horizontal branching in regular false whorls of 4–5 branches; bole usually fluted at the base, then straight and reasonably cylindrical, but in exposed coastal situations it is often crooked and/or leaning. ***Bark*** dark grey-brown and shallowly fissured: in populated areas in the Pacific Islands, there is often evidence of bark

Evidence of harvesting of bark for traditional medicine; Houma, Tongatapu, Tonga (Photo: R.R. Thaman)

Flowers (Photo: L. Thomson)

Above: Outstanding bole form of *T. catappa* of Santa Cruz provenance, with Shane Tutua; Kolombangara, Solomon Islands (Photo: L. Thomson)

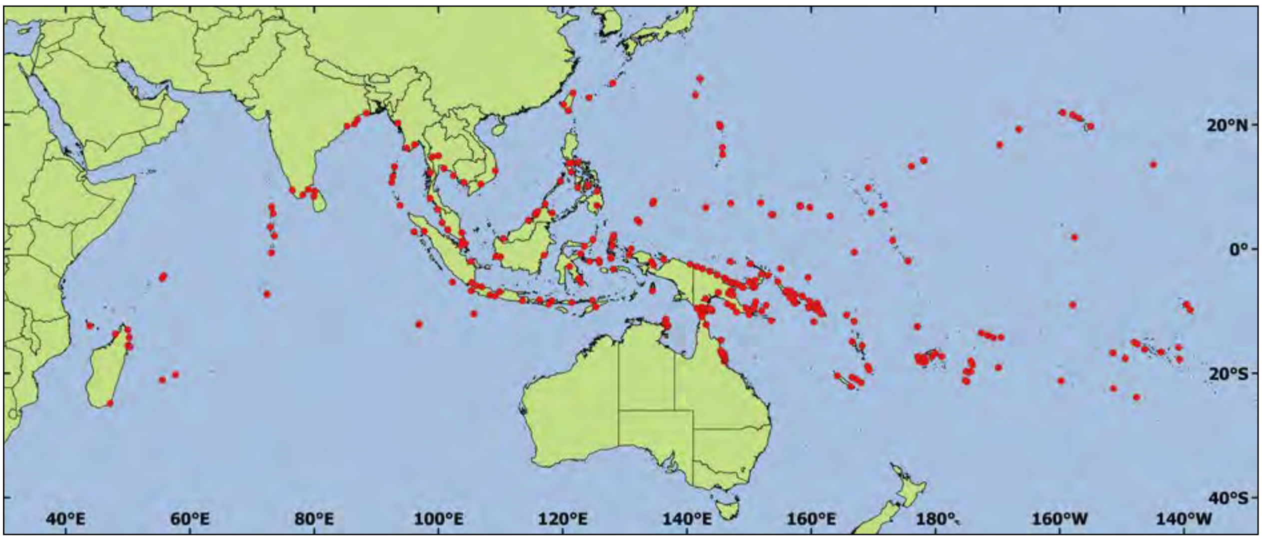
Top left: SPRIG project progeny trial of candidate plus trees (superior nut morphotypes); Shark Bay, Espiritu Santo, Vanuatu (Photo: L. Thomson)

Bottom left: Fruit (Photo: D. Bush)

harvesting for traditional medicine. ***Leaves*** large, broadly ovate, 8–25(–38) × 5–14(–19) cm, bright mid-dark green and arranged in close spirals; trees go briefly deciduous once or twice a year, with leaves turning yellow and bright red before falling. ***Inflorescences*** long (8–25 cm) axillary spikes. ***Flowers*** small (4–6 mm wide), white, 5-lobed; within a spike, majority of flowers male, with only a few bisexual flowers located toward the base. ***Fruit*** large, 3.5–7.0 cm long, laterally compressed, fleshy drupe which changes colour from green through yellow to bright red or dark purplish-red at maturity. ***Seed*** edible kernel comprised of intricately entwined white cotyledons inside hard woody testa.

Distribution

Terminalia catappa has a vast natural and human-assisted distribution in near-coastal areas of the Indian and Pacific oceans, and tropical South and South-East



Asia. The species extends from the western Indian Ocean and Madagascar, to Seychelles through Sri Lanka, India, the Andamans and adjacent islands, and throughout South-East Asia (Myanmar, Thailand, the Malay Peninsula, Vietnam, the Philippines and Indonesia) to PNG and northern Australia. It occurs throughout the South Pacific region, including Solomon Islands, Vanuatu and Fiji, and is present on nearly all the raised archipelagos of Polynesia and Micronesia.

Terminalia catappa has been introduced, and frequently naturalised, in many tropical parts of the world, including Brazil, the Caribbean and East Africa. It is naturalised in the tropical states of the USA (Florida and Hawai'i), as well as Puerto Rico.

Terminalia catappa is well adapted to maritime subtropical and tropical climates. Range in MAR is 1,000–3,500 mm, uniformly distributed or with a summer maximum, and a dry season range of 0–6 months. The species is typically found near the coast within a few metres of the high tide mark, but may range up to 800 m asl. It is adapted to a wide range of soil types, preferably light- to medium-textured soils, and including heavier-textured clayey soils, if well drained. It tolerates brackish conditions and has a wide soil pH range from 4.0 to 8.5.

Uses

After coconut, *T. catappa* is arguably the most multipurpose of all tropical woody species. It is an ideal tree for inclusion in agroforestry systems, due to its fast growth, multiple useful products, and soil-enriching and leaf-mulching attributes.

Wood—the heartwood is brown to reddish-brown, with a wide, rather indistinct band of lighter-coloured sapwood. The timber is tough, moderately hard and of medium density (530–540 kg/m^3 at 12% moisture content). It is not suitable for in-ground applications unless preservative treated. Traditional wood uses in the South Pacific include canoe hulls and paddles, kava bowls, tool handles, war clubs, walking sticks, drums and fuelwood. It provides an excellent general-purpose building timber with good working properties, and its wood is a high-quality fuel, both as fuelwood and for charcoal production.

Non-wood—a vast range of traditional medicinal uses worldwide utilise the leaves, bark, fruit and other parts of *T. catappa*; throughout Polynesia, the bark is a crucial ingredient in traditional medicine. The nuts are edible either fresh or can be dried and salted; while the edible pulp can be fermented into wine. The leaves of *T. catappa* have many uses, including in the live aquarium trade to increase fish survival; in a medicinal tea; to feed silkworms; and they also yield a dye and tannins.

Extensive lateral root system of *T. catappa* providing coastal protection; Taveuni, Fiji (Photo: L. Thomson)

Harvesting of root crops in *T. catappa* agroforestry planting; Shark Bay, Espiritu Santo, Vanuatu (Photo: L. Thomson)

Furthermore, the tree is an excellent shade tree, including in town areas and beachside locations; with a spreading, mid-dense canopy reasonably tolerant of salt-laden winds. Trees have a well-developed shallow lateral root system ideal for beach protection, including during cyclones and associated storm surges.

Diversity and its importance

Three main sources of intraspecific diversity contribute to *T. catappa*'s status as one of the most important and versatile multipurpose trees for the humid tropics, especially for beach and near-coastal sites. These include:

- broad site adaptability with different provenances adapted to maritime and low-elevation, subtropical and tropical climates; MAR ranging from 1,000 to 3,500 mm; and diverse edaphic conditions
- variability in nut morphotypes—individual trees with large kernels and easily shelled nuts have been selected in different parts of its range in Melanesia (Mussau Island and Marshall Bennett Islands, PNG; Temotu province, Solomon Islands;

Above: Variation in nut size in Shark Bay progeny trial; Espiritu Santo, Vanuatu (Photo: L. Thomson)

Right: Variation in *T. catappa* nuts being sold on coconut skewers; Port Vila, Vanuatu (Photo: L. Thomson)

and Vanuatu). There is genetic variation in age to fruiting, with some trees fruiting from a young age (18 months after planting out), making them attractive as food production components in agroforestry systems

- variation in key traits for wood production, such as straightness, growth rate and inter-whorl length (which affects production of knot-free timber).

Terminalia catappa is an ideal candidate tropical tree species for genetic improvement through implementation of carefully planned selection and breeding programs for particular sites and end uses. These programs should start with comprehensive provenance/progeny trials to select superior seed sources for future work. Rapid improvement in nut characteristics will be aided by the high levels of variation in nut characteristics coupled with short intergeneration times—at 2–3 years, trees are fruiting and selections can be made. Selections for timber plus trees might also be undertaken at a young age; namely, 7–8 years (or half the projected rotation age under good growing conditions). Further research is needed to determine the most practical means of vegetative reproduction. Controlled pollination, if required in any breeding programs, will be facilitated by ready access from the ground to *T. catappa* flowers borne on low lateral branches.

Conservation of genetic resources (including threats and needs)

In Melanesia, *T. catappa* was traditionally an important and nutritious food, with nuts highly valued by children as a snack food. In some areas, consumption of *T. catappa* and other indigenous nuts has been replaced by processed snack foods which are harmful to human health and contributing to the current plague of obesity, diabetes and heart disease among South Pacific Islanders. With less interest in *T. catappa* nuts by villagers comes a risk that valuable nut morphotypes will die out and not be replanted or be cut for timber. In some places, such as Nukuʻalofa (Tonga) and Suva (Fiji), bark harvesting for traditional medicines, including as a treatment for diabetes, is reducing tree health and leading to premature tree mortality. Rising sea levels associated with anthropogenic climate change pose a major longer term risk to the genetic resources of *T. catappa* as most trees and native populations are found at <5 m asl.

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Terminalia richii

Family: Combretaceae
Botanical name: *Terminalia richii* A.Gray. In *U.S. Expl. Exped.* 1: 616 (1854) from a specimen collected on Upolu.

The genus name is derived from the Latin *terminus*, referring to the fact that the leaves appear at the terminal ends of the shoots. The specific epithet is after William Rich, the botanist on the United States South Seas Exploring Expedition of 1838–1842. The genus *Terminalia* comprises about 150–250 tropical tree species. The closest relative of *T. richii* is *T. complanata*, a useful timber species from PNG and Solomon Islands. The *T. complanata* group also includes two other PNG species, *T. sogerensis* and *T. longispicata*.
Common names: *malili* (Samoa)

Summary of attributes and why diversity matters

Terminalia richii is one of the most wind-resistant trees in the tropical world, typically able to withstand—with minimal damage to its main bole—the intense winds associated with Category 4 and 5 cyclones: this is true of both saplings and mature trees. Accordingly, *T. richii* ought to be one of the most important trees for planting in both agroforestry and timber plantations in cyclone-prone parts of the tropics, including the South Pacific Island countries of Samoa, Niue, Fiji, Solomon Islands, Tonga and Vanuatu.

The species was naturally uncommon throughout its restricted native range in the Samoan archipelago and Niue, and nowadays it is rare. This is due to the impacts of agricultural clearing and the combined impacts of selective logging, cyclones and the invasive native vine *Merremia peltata*, which takes advantage of gaps in the canopy and prevents opened-up forests from effectively regenerating. Capturing and maintaining the likely now-depleted genetic variation in the species will be vital for future improvement of *T. richii*. This will also be vital for its anticipated much wider forestry and agroforestry planting in different environments in the South Pacific Islands, as an adaptation measure against extreme climatic events.

Description

Habit well-formed forest tree to 25–30 m tall; canopy tiered with branches in horizontal false whorls becoming irregular with age; bole usually long and straight, with small steep buttresses in older trees. ***Bark*** grey, persistent, shallowly longitudinally furrowed to tessellated; in older specimens, bark becomes covered in an attractive patchwork mosaic of different coloured lichens and mosses. ***Leaves*** simple/entire, lanceolate, discolorous, dark shiny green above, light green below; new shoots and young leaves covered in silvery to light-rusty, short, silky hairs. ***Inflorescences*** axillary spikes at the ends of branches. ***Flowers*** small, yellowish-white; calyx 5-lobed and star-shaped; anthers 10, long. ***Fruit*** ovoid drupe, flattened on 1 side, with thin flesh covering a single stone, c. 3 × 2 cm, green ripening reddish-purple.

Flowers (Photo: L. Thomson)

Excellent bole form in SPRIG project field trial; Falelima, Savai‘i, Samoa (Photo: L. Thomson)

Above: Flower buds and mature fruit (Photo: L. Thomson)

Left: Open-grown mature tree; Fausaga, Upolu, Samoa (Photo: L. Thomson)

Seed c. 2,600 seed/kg, after removal of the flesh; typically 35–40% germination rate and limited storage life.

Reproductive phenology flowering occurs after flush of new leaf growth from September to January; fruit mature 4–5 months later.

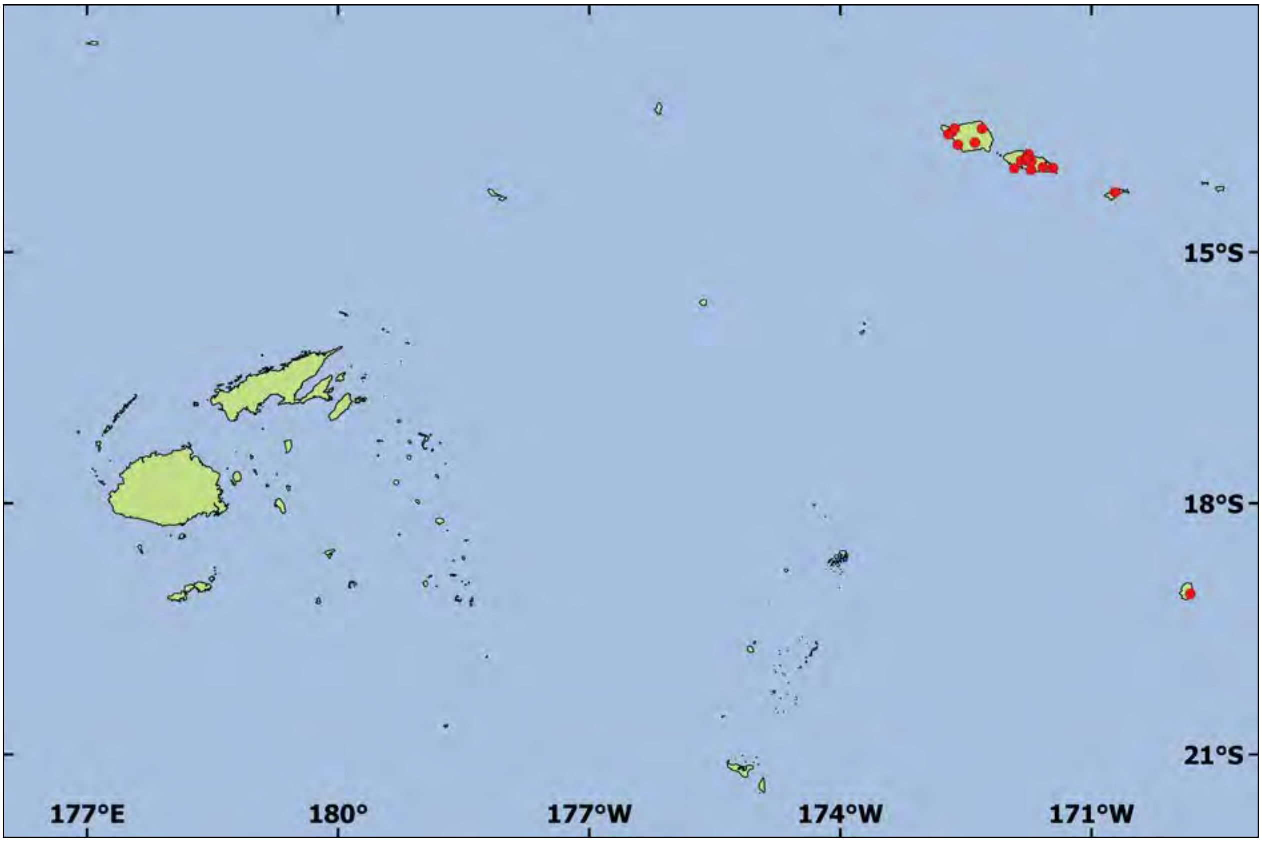
Distribution

Terminalia richii is native to the Samoan archipelago (Samoa and American Samoa) and Niue in the central South Pacific. It has been only rarely cultivated outside of its countries of origin, including in trial plantings in Australia and Fiji.

This species occurs in lowland and lower montane rainforest, sometimes emergent above the forest canopy. The climate in its native habitats is maritime, humid tropical with distinctive wet (November–April) and dry (May–October) seasons. It occurs up to an elevation of 830 m asl. The soils are mainly fertile, neutral, well drained, heavy textured and of basaltic origin.

Uses

Terminalia richii has potential as a major timber plantation species for South Pacific countries because



Clonal hedge for vegetative propagation of *T. richii*, with Sooalo Tito Alatimu; Falelima, Savai'i, Samoa (Photo: L. Thomson)

it grows rapidly with good single-bole form, provides useful timber and has admirable tolerance of the most severe cyclones periodically experienced in this region. Early height growth rates are 2.0–2.5 m/year with trees reaching an average dbh of about 50 cm at 27 years of age by which time they are ready to harvest for sawn timber. The estimated rate of volume growth (MAI) is 13–17 m^3/ha/year.

Terminalia richii appears to be the most cyclone-resistant timber tree species in the Pacific Islands, and certainly among the most wind-resistant tropical trees. Mature 30-year-old planted *T. richii* trees at Masamasa, Samoa, withstood the ravages of two Category 4 cyclones (Ofa and Val) in the early 1990s with very little damage to boles, while neighbouring native forests and trials of many different forest plantation species were devastated. Subsequent trials by the Forestry Division of Samoa/ SPRIG project demonstrated that young *T. richii* trees of different ages were also highly resistant to the strong winds, in excess of 200 km/hour, from Category 5 Cyclone Heta in January 2004.

Wood—*T. richii* produces a light-coloured, medium-density hardwood (550 kg/m^3 at 12% moisture content) with low shrinkage and excellent working and machining properties. It is suitable for a wide range of interior uses, including panelling, cabinetwork and furniture, as well as general construction. However, its present-day use in the timber and building industries in Samoa is very limited due to its rarity. The main traditional uses for *T. richii* were for production of canoes and as timber in local building construction (non-ground-contact situations).

Non-wood—*T. richii* is an excellent tree for inclusion in boundary plantings around farms. Its excellent cyclone resistance, surface rooting habit, lower stem buttressing and small–medium leaves which break down at an intermediate rate combine to make this a species of choice for soil-erosion control. An important strategy for minimising future losses to Pacific Island agroforests and plantations from more extreme cyclones will be to incorporate *T. richii* into such plantings.

Terminalia richii was included in watershed rehabilitation work undertaken in Samoa by the Ministry of Natural Resources and Environment on behalf of the Ministry of Finance and the European Union. On almost every site surveyed and monitored, well-maintained young *T. richii* trees had an excellent growth rate (F. Martel, pers. comm.). In another forest restoration project in Samoa, *T. richii* is one of the priority trees (along with *Pometia pinnata*) being grown at Mt Vaea: it has displayed characteristics of an ecological framework species, being very fast growing and producing fruit eaten by native pigeons (J. Atherton, pers. comm.). Indeed, the tree has been favoured by pigeon hunters as its fruit are highly attractive to pigeons.

Diversity and its importance

There have been no formal studies of genetic diversity in *T. richii*. Variation in leaf size between trees has been

Progeny trial of *T. richii*; Falelima, Savai'i, Samoa (Photo: L. Thomson) reported and it is expected that variation will exist in many economically important and adaptive traits. There is an urgent need for range-wide seed collections and provenance/progeny trials, which will need to be managed to also serve a much-needed gene conservation function.

Conservation of genetic resources (including threats and needs)

The genetic resources of *T. richii* are highly threatened throughout its range, with the small population on Niue having already been extirpated. The key threats come from clearing of forested land for agriculture, selective logging of remaining stems and a lack of natural regeneration. The lack of regeneration is caused by:

- absence of seed sources—both rarity of mature trees and inability to flower and fruit heavily for up to 4–5 years after a major cyclone
- hostile and altered regeneration environment dominated by the native vine *Merremia peltata* and vigorous, environmentally invasive weed tree genera and species, including in *Albizia*, *Castilla*, *Cinnamomum*, *Falcataria*, *Funtumia* and *Spathodea*.

The *T. richii* conservation strategy developed during the SPRIG project by James Atherton and the Samoan Forestry Division in 1999 needs to be revised and fully implemented, including:

- develop and implement initiatives to conserve *T. richii* along Richardson Road, eastern Upolu
- encourage the conservation of three small *T. richii* stands at Togitogiga (south-central Upolu), Cross-Island Road (central Upolu) and Vaia'ata Road (north-eastern Savai'i)
- encourage replanting of *T. richii* by landholders in areas where it was formerly common, such as Afiamalu and Salamumu (Upolu)
- implement a vegetative propagation program
- develop ex situ conservation measures, including in American Samoa and Niue
- develop a research program on *T. richii* in support of conservation of genetic variation.

As indicated in the previous section, there is a need for range-wide seed collections for development of multipurpose field plantings, including ex situ and circa situm conservation. There is also a need for seed germination research, including pre-treatment to improve on the species' typically low (35–40%) and slow (over several months) rate of germination.

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Xanthostemon melanoxylon

Family: Myrtaceae
Botanical name: *Xanthostemon melanoxylon* Peter G.Wilson & Pitisopa. In *Telopea* 11: 399–403 (2007) from a specimen collected on Choiseul, Solomon Islands.

The genus name is derived from the Greek *xanthos*, a reference to yellow stamens in the type species, while the specific epithet is derived from the Greek *melas*, black and *xylo,* wood, in reference to the distinctive hard, dark heartwood. *Xanthostemon melanoxylon* is one of the few red-flowered species in the genus and is considered most closely related to the western New Guinean species, *X. novo-guineensis*, due to its red stamens and lack of a vesiculate hypanthium. Both the flowers and leaves of *X. melanoxylon* bear a superficial resemblance to those of some species of *Metrosideros*, including *M. excelsa* and *M. collina*.
Common names: *tubi* (Isabel province, Solomon Islands); *rie* (Choiseul province, Solomon Islands)

Flowering specimen (Photo: S. Tutua)

Summary of attributes and why diversity matters

Xanthostemon melanoxylon is adapted to highly acidic ultramafic soil types and has great potential for environmental restoration and/or to produce a highly valuable, ebony-like timber in these extremely challenging edaphic environments.

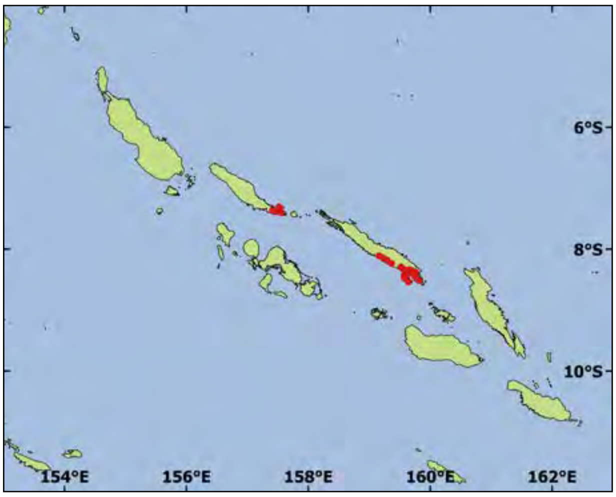
Intraspecific variation within *X. melanoxylon* has still to be studied and there are conservation concerns due to mining and logging activities and indiscriminate burning practices. There is an urgent requirement for in situ conservation of representative populations across the islands and range-wide seed collections. Seed collections will allow planting of provenance/progeny trials and demonstration plantings designed to provide information on genetic variation in the species and also serve an ex situ conservation purpose.

Description

Habit typically a medium-size tree to 35 m tall and 80 cm dbh, but can develop into a very large tree >40 m tall and >120 cm dbh on Santa Isabel, Solomon Islands. ***Bark*** shortly fibrous to scaly, brownish-orange. ***Leaves*** spirally arranged, obovate to elliptic, typically 5–9 cm long, 2.0–4.5 cm wide, discolorous and somewhat leathery, with numerous and conspicuous oil glands; secondary venation especially prominent, branching at 50–60° to primary vein. ***Inflorescences*** showy, brilliant red (rarely white), terminal corymbs. ***Flowers*** each flower has about 30 stamens arranged in a single series around the rim of the hypanthium (or floral cup). ***Fruit*** broad-ovoid, 5–7 mm long, 7–10 mm diameter, with hypanthium initially partly enclosing the base of the fruit. ***Seed*** deltoid, about 3 mm long.

Distribution

Xanthostemon melanoxylon is endemic to Solomon Islands with a restricted natural distribution, mainly on ultramafic-derived soils, in nine populations in Choiseul province (south-eastern part of Choiseul Island) and southern Isabel province (San Jorge Island and the southern part of Santa Isabel Island). There are unconfirmed reports that *X. melanoxylon* may occur inland at Arara, New Georgia, and Wanderer Bay in West Guadalcanal.



Uses

Wood—*X. melanoxylon* has an extremely hard, durable and almost black heartwood that resembles ebony. It is of great traditional importance, being used for walking sticks and, particularly, carved posts used to decorate buildings.

Cut stump showing black colour of heartwood (Photo: B. Gua)

Squared logs of the ebony-like timber of *X. melanoxylon*; Santa Isabel, Solomon Islands (Photo: B. Gua)

Non-wood—this species has great potential for environmental restoration in these extremely challenging edaphic environments.

Diversity and its importance

There have been no studies on intraspecific variation within *X. melanoxylon*. A white-flowered form has been reported from Choiseul. The most economically and environmentally important variation is likely to be in its adaptability to different soil types, including extreme edaphic environments; notably, ultramafic soils. Ultramafic soils are highly acidic with low exchangeable bases, low cation exchange capacity and elevated exchangeable aluminium, nickel and chromium. They also have low levels of nitrogen and phosphorus, and a low calcium to magnesium ratio, which is believed to be the main limiting factor for plant growth.

Four-year-old trial planting of *X. melanoxylon* on ultramafic soils, Sumitomo Metal Mining Solomons Ltd; Santa Isabel, Solomon Islands (Photo: S. Tutua)

Conservation of genetic resources (including threats and needs)

There are reasonable stocking levels of *X. melanoxylon* in most of the identified nine populations but these are vulnerable to various threats, particularly selective logging, fire and mining. Fire is listed as a threat since past burning of the vegetation on ultramafic sites has reportedly resulted in exposure of the soil surface over large areas and loss of upper soil horizons by sheet erosion. This loss may then lead to replacement of forest by open heath vegetation.

Most populations showed a good spread of age classes but fire damage at some sites had resulted in the death of all trees in affected parts of the populations. Some of these sites showed good seedling regeneration but young plants are vulnerable to repeat burning. There are substantial nickel reserves on San Jorge Island, which is almost wholly composed of ultramafic rocks and their derived sediments, and prospecting licences have been issued. Exploitation of these mineral deposits is having a significant impact on the island's remaining *X. melanoxylon* populations.

Pilot conservation and management actions are needed in order to protect remaining stands from commercial activities, such as mining, logging and indiscriminate burning. All areas with higher concentrations of *X. melanoxylon* are under customary land ownership. Therefore, it will be essential that the Solomon Islands Ministry of Forestry and Research work with the respective communities in planning and implementing *X. melanoxylon* conservation activities. Recommended sites for *X. melanoxylon* conservation are short-listed in order of priority:

- Sopleku, San Jorge, Isabel
- Huali/Hageulu, Isabel
- Havihua/Tanabosu, Isabel
- Ririe, Choiseul
- Volekana, Choiseul
- Zeleboe, Choiseul.

Priority research and conservation actions include:

- determine in situ conservation sites in Isabel and Choiseul
- establish demonstration plots, with ex situ conservation function, in other parts of Solomon Islands
- undertake representative seed collections followed by provenance/progeny trials
- establish regeneration plots at Huali/Hageulu burnt sites
- engage the community in further development of conservation and management plans.

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Appendix 2. Seed and propagation information

The table includes information on a range of factors relevant to propagating the species covered in this book—from seed and vegetatively. Numbered sources are included below the table.

Species (source)	Average no. seed/fruit	Fruit/kg	Seed storage behaviour	Viable seed/kg	Viability (%)	Average germination range (days)	Recommended seed pre-treatment	Candidate for vegetative propagation	Seed storage
Acacia auriculiformis (#1; #4; #7; #22; #23)	12 #23	12 #23	Orthodox	30,000–60,000 #4	95	4–26	Pour boiling water (10–20× seed volume) onto seed and soak overnight or immerse in boiling water (100 °C) for 1–2 minutes and soak in cold water overnight. #1	Marcotting effective for older specimens. Stem cuttings best from 6–12-month-old stock plants, rooting % declines with older stock plants. #22 Successful micropropagation technique has also been developed, including for hybrids with *A. mangium* in Malaysia. #22	Store in dry, cool conditions at a constant temperature. Will store at 18 °C for many years but refrigerated (2–4 °C) is better. #7 Constant temperature is important for longevity.
Acacia colei (#3; #4; #7; #22)	8–10 #22		Orthodox	57,000–90,000 #4	>90	5–21	Immerse in boiling water for 1 minute before sowing. #4	Variable coppicing ability; does best when cut ≥50 cm from ground level and at onset of rainy season. #3	Store in dry, cool conditions at a constant temperature. Will store at 18 °C for many years but refrigerated (2–4 °C) is better. #7 Constant temperature is important for longevity.
Acacia crassicarpa (#2; #7; #22; #23)	12 #23		Orthodox	31,000–50,000	>85	5–25	Immerse in hot water at 85 °C for 5 minutes or 80 °C for 10 minutes #22, or boiling water for 1–2 minutes. Alternatively, pour boiling water onto seed and soak until cold (water volume 10× seed volume). #2	Cuttings successful from plants ≤3 years old; older trees difficult to root. Marcotting effective for older specimens. See #2 for more details.	Store in dry, cool conditions at a constant temperature. Will store at 18 °C for many years but refrigerated (2–4 °C) is better. #7 Constant temperature is important for longevity.

Species (source)	Average no. seed/fruit	Fruit/kg	Seed storage behaviour	Viable seed/kg	Viability (%)	Average germination range (days)	Recommended seed pre-treatment	Candidate for vegetative propagation	Seed storage
Acacia koa (#4; #5)	6–12		Orthodox	5,500–16,500		5–20 #4	Hot water treatment: pour near-boiling water (90 °C) over the seed and soak for 1–3 minutes (water volume 5× seed volume), then cool seed in tepid water. As seed coat impermeability varies, a test of proposed method on small amount of seed is advisable.	Success of vegetative propagation methods, such as marcotting, rooted cuttings and tissue culture, has been limited.	Store in dry, cool conditions at a constant temperature. Will store at room temperature for 12–24 months but for many years if refrigerated (2–4 °C). #5 Constant temperature is important for longevity.
Acacia mangium (#7; #22; #23)	15 #23	Highly variable #7	Orthodox	50,000–78,000	>95	5–25	Immerse in boiling water (100 °C) for 1–2 minutes. #22 Follow with overnight soak in ambient temperature water at 20× seed volume. #7	Stem cuttings best from 6–12-month-old stock plants; rooting % declines with older stock plants. A successful micropropagation technique has also been developed.	Store in dry, cool conditions at a constant temperature. Will store at 18 °C for many years but refrigerated (2–4 °C) is better. #7 Constant temperature is important for longevity.
Acacia torulosa (#4; #7; #22)	8–10 #22		Orthodox	11,000–33,800	>75	5–21	Immerse in constantly boiling water for 1 minute. #4 Ensure enough water for seed to move freely.	Likely only to be successfully propagated vegetatively from seedling cuttings. #22	Store in dry, cool conditions at a constant temperature. Will store at 18 °C for many years but refrigerated (2–4 °C) is better. #7 Constant temperature is important for longevity.
Acacia tumida (#4; #7; #22)	8 #22		Orthodox	12,400–21,400	75	5–20	Immerse in constantly boiling water for 1 minute. #4 Ensure enough water for seed to move freely.	Some forms, e.g. Western Australian pindan sand plains, root sucker readily and are amenable to vegetative propagation. #22	Store in dry, cool conditions at a constant temperature. Will store at 18 °C for many years but refrigerated (2–4 °C) is better. #7 Constant temperature is important for longevity.
Agathis macrophylla (#8; #24)			Intermediate	5,000–6,000		7–21	No pre-treatment required. It is recommended that de-winged seed be sown immediately followed collection. #8	Vegetative propagation using both main stem and lateral cuttings from 12-month-old nursery-raised seedlings has been successful; however, the latter tend to retain plagiotropic growth habit. #24	Sensitive to chilling damage, carbon dioxide/oxygen balance and moisture content (MC)/temperature/drying rate balance. For long-term storage, most successful regime to date is to dry seed to around 9–13% MC and keep at –13 °C. Drying below 7% MC reduces viability. #8

Appendix 2. Seed and propagation information

Species (source)	Average no. seed/fruit	Fruit/kg	Seed storage behaviour	Viable seed/kg	Viability (%)	Average germination range (days)	Recommended seed pre-treatment	Candidate for vegetative propagation	Seed storage
Araucaria cunninghamii (#6; #8; #15; #39)	260 #6	~5 #6	Orthodox	2,400–4,000 #8 4,000–5,000 #6	75–80 #6		Soak in water for 4 hours to stimulate germination. #15	Easily propagated vegetatively. #6 Cuttings must be taken from upright-growing shoots toward top of tree due to the plagiotropic growth habit of side branches. #39	Can be dried to 2% moisture content (MC) without damage. #6 MC below 8% used by Queensland Forestry for long-term storage. #15 Long-term storage requires a freezer. Seed can be stored for ≤6 years in PNG and perhaps longer in other places (~8 years) at –18 °C. #6; #8
Artocarpus altilis (#5; #6; #11)	Highly variable: eastern Pacific varieties are mainly seedless #5	Depends on fruit weight (range 0.25–6 kg) #5	Recalcitrant	200 #6	90–95 for fresh seed #6; #11	21–28	No pre-treatment required. Seed is rarely grown because it does not grow or develop true to type. #11	Vegetative propagation is preferred for both seeded and seedless varieties, using root shoots or root cuttings. Can also be propagated by marcotting branches and grafting, but success rate for marcots varies considerably depending on variety. #11	No dormant period, germinates immediately and is unable to withstand desiccation. Loses viability within a few weeks and cannot be stored in a refrigerator. Fresh seed moisture content 60%. #6
Barringtonia edulis (#10)	1		Recalcitrant		>95 for fresh seed		No pre-treatment required. Flowers and fruits very quickly after cyclones.	Sometimes propagation from cuttings and marcotting has been used in Maewo, Vanuatu, for interesting forms.	
Barringtonia procera (#5)	1	10–30	Recalcitrant		>95 for fresh seed	60–90 (if sowing ripe fruit); from 7 days (if sowing seed extracted from ripe fruit)	No pre-treatment required; commonly propagated by planting whole fruit but germination time is longer than for seed with mesocarp removed. Sow in a vertical position with the basal end down.	Can be grown from cuttings taken from stumps or coppiced trees, seedlings, wildlings or managed stock plants or hedges. Marcotting useful for propagating mature shoots from pollarded trees that are difficult to root as stem cuttings.	Does not withstand drying and will only retain viability for a short period in dry storage: keep mesocarp intact and in shady, cool (19–25 °C) and low humidity (c. 50%) conditions.
Calophyllum inophyllum (#5; #8)	1	100– 200	Intermediate #5 Recalcitrant #8		>90 for fresh seed	From 22 days if fully shelled; from 38 days for cracked shells; ≥57 days for seed in its shell	Crack shells or shell seed entirely using a mallet, pliers or hammer; seed germination is slow if the entire fruit is planted.	Tissue culture protocols have been developed for other *Calophyllum* spp.	Fresh seed may keep for a few months if stored in cool and dry conditions (usually with the husk removed).

Species (source)	Average no. seed/fruit	Fruit/kg	Seed storage behaviour	Viable seed/kg	Viability (%)	Average germination range (days)	Recommended seed pre-treatment	Candidate for vegetative propagation	Seed storage
Canarium indicum (#5; #6)	1–3	50–200 seed/kg (nut-in-shell)	Recalcitrant				Soak seed in fresh water for 24 hours before sowing and discard any nuts that float or do not sink to the bottom completely. #5 Remove the outer fleshy mesocarp by wetting and/or rotting. #5	Attempts at root cuttings in PNG have been unsuccessful. #6	If seed needs to be stored for a few weeks, outer flesh should be removed and nut-in-shell stored in a shady, cool dry place (e.g. 15–25 °C). #5 Refrigeration at 3–5 °C in airtight container may retain viability for up to 6 months, after which it will rapidly drop. #6.
Casuarina equisetifolia (#4; #5; #9)	1–4		Orthodox	100,000–400,000		Between (4–)6–15 (–22) days #9 (#4) but can take ≤11 weeks #9	No pre-treatment required but soaking for 24 hours in water or in 1.5% potassium nitrate (KNO) or 7.5% calcium oxychloride ($CaOCl_2$) sometimes used to stimulate germination. #5 Soaking in running water for 24 hours also said to improve germination. #9	Can be grown from stem or root cuttings. #5	Short viability in the wild but dried seed can be stored at 3–4 °C or –18 °C for several months to 1 year (several years at Australian Tree Seed Centre). #9
Cocos nucifera (#5)	1	Highly variable depending on variety, e.g. 0.6–0.8 whole brown nuts/kg or 1.0–1.2 husked nuts/kg	Recalcitrant			Dependent on variety; some seed germinates while still on the palm but most Pacific populations take up to 6 weeks	No pre-treatment required. The seed has no dormancy.	Does not multiply vegetatively (only rarely are vegetative shoots produced), so is not a candidate for vegetative propagation. Tissue culture attempts have had limited success. Embryo culture has been used for country-to-country exchange of planting material for breeding purposes.	It is not advisable to store early-germinating types for any length of time. Slow germinators can be stored for ≤1 month as long as water in the nut cavity does not dry out. To store for longer, it is advised to pick at 11 months of age, when epicarp is starting to turn brown, and store in a cool dry place.
Corymbia citriodora (#4; #12)			Orthodox	70,000–200,000 #4		5–14	No pre-treatment required but seed/chaff contains inhibitors. Due to inhibitors, to germinate, use free-draining seed germination potting mix and do not allow pots to sit in water.	Not amenable to propagation from rooted cuttings with a success rate of <3.6%. #12	Dried seed (4–8% moisture content) can be stored for ≥10 years in cool dry conditions.

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Species (source)	Average no. seed/fruit	Fruit/kg	Seed storage behaviour	Viable seed/kg	Viability (%)	Average germination range (days)	Recommended seed pre-treatment	Candidate for vegetative propagation	Seed storage
Endospermum medullosum (#4; #5; #6; #22)	1	9,000–9,600 #5	Recalcitrant	35,000–50,000 #4	35–50 for fresh seed #6	14–35	No pre-treatment required for fresh seed sown within several days of collection. Initial viability highly variable and often low due to wasp larvae damage; wasp-infested fruit float in water and it is essential that these be discarded at collection. #5 Collection of immature seed can also be a factor in low viability of seed. #4	Can be propagated from vegetative cuttings #5 Rooting success falls quickly with age; seedlings and young stock plants preferred. Induction of coppice shoots from partial girdling and cuttings success drops after 3 years. #22	Cannot be stored for long but source #5 suggests storage in moist, well-aerated medium (e.g. slightly moistened peat moss, sawdust or plain cotton or open plastic bag at 10–15 °C). Rigid, sealed storage container should be used where there is a risk of seed loss from insect pests and vermin. #5
Eucalyptus camaldulensis (#3; #4; #14)			Orthodox	480,000–1 million #4		5–10	No pre-treatment required.	Very amenable to propagation by rooted cuttings from coppice shoots. #14	Relatively easy to store. Mature seed remains viable for ≥10 years when stored at <10% moisture content in sealed container at 1–4 °C. #3
Eucalyptus cloeziana (#3; #4; #16)			Orthodox	100,000–400,000		7–28	No pre-treatment required but seed/chaff contain inhibitors. #4 Due to inhibitors and susceptibility to damping off diseases, to germinate, use free-draining seed germination potting mix and do not allow pots to sit in water.	Difficult to propagate from cuttings. #16	Relatively easy to store. Mature seed remains viable for ≥10 years when stored at <10% moisture content in sealed container at 1–4 °C. #3
Eucalyptus deglupta (#4; #13; #14)			Orthodox; short lived at room temperature	2 million #13		5–14	No pre-treatment required but seed/chaff do contain inhibitors. #4 Due to inhibitors, to germinate, use free-draining seed germination potting mix and do not allow pots to sit in water.	Easiest of the *Eucalyptus* spp. to propagate from rooted cuttings; even adult tissue can be propagated this way, unlike other eucalypts. #14	Short lived at room temperature but viability can be extended by storing in airtight container at <10% moisture content at 3–5 °C for 3 years or at –20 °C for 5 years. #4; #13
Eucalyptus pellita (#3; #4; #17)			Orthodox	190,000–460,000 #4		5–21	No pre-treatment required.	Relatively easy to propagate stem cuttings taken from basal coppice shoots. #17	Relatively easy to store. Mature seed remains viable for ≥10 years when stored at <10% moisture content in sealed container at 1–4 °C. #3
Eucalyptus urophylla (#3; #4; #16)			Orthodox	250,000–540,000 #4		5–14	No pre-treatment required.	Can be propagated from rooted cuttings. #16	Relatively easy to store. Mature seed remains viable for ≥10 years when stored at <10% moisture content in sealed container at 1–4 °C. #3

Species (source)	Average no. seed/fruit	Fruit/kg	Seed storage behaviour	Viable seed/kg	Viability (%)	Average germination range (days)	Recommended seed pre-treatment	Candidate for vegetative propagation	Seed storage
Falcataria moluccana (#4; #13; #35; #36)	20 #35		Orthodox #36	38,000–44,000 (total seed/kg) #13	>90	3–10 #4; #36	Pre-treat by boiling in water for 1–3 minutes and then soaking in water at ambient temperature for 12–18 hours. #4; #36	Coppices, although coppicing vigour is highly variable. It has been successfully propagated from stump cuttings. #13	Air-dry and store in airtight container at 4–8 °C. #13; #36
Flueggea flexuosa (#5; #22)	4–6	3,000–8,000 #5	Orthodox (some seed collections may lose viability rapidly in storage #22)	300,000 (total seed/kg) #5		14–35 #5	No pre-treatment required.	Unknown but likely to be able to propagate cuttings from seedlings. #22	May keep for many years if stored in airtight container at 3–5 °C. #5 Ripe fruit should be soaked in water overnight, then de-pulped by rubbing and washing over a fine mesh sieve, followed by drying to <10% moisture content before storage.
Garcinia sessilis (#22)	6–13		Recalcitrant				No pre-treatment required. (Note: germination quickened if ripe fruit are placed near ant nests, with ants removing flesh and mucilage around seed.)	Unknown.	Recalcitrant: must be sown immediately after collection and cleaning.
Gliricidia sepium (#5)	3–8		Orthodox	4,700–11,000 (total seed/kg)	>90	3–15	No pre-treatment required but soaking seed overnight in cool water speeds up germination.	Very easy to propagate from small and large branch cuttings.	Seed can be stored for >10 years in an airtight container at 4 °C.
Grevillea robusta (#3; #4)	2		Orthodox or Intermediate?	18,600–50,600 #4	66 (avg.) #3	10–30	No pre-treatment required.	Easy to strike cuttings from shoots of seedlings or saplings, which can also be marcotted. #3	Retains viability for ≥2 years if dried to <8% moisture content and stored in dry, cool environment (≤20 °C). #3 Australian Tree Seed Centre stores at 3–5 °C. #4
Gyrinops ledermannii & *G. caudata* (#22; #38)	1–2		Recalcitrant #22				No pre-treatment required. #22	Readily propagated from stem cuttings. #38	Fresh seed should be sown immediately. #22

Species (source)	Average no. seed/fruit	Fruit/kg	Seed storage behaviour	Viable seed/kg	Viability (%)	Average germination range (days)	Recommended seed pre-treatment	Candidate for vegetative propagation	Seed storage
Hibiscus storckii & undescribed Fijian spp. (#22)	30–40		Orthodox	c. 40,000	50–90	10–21	Soak in warm water overnight and manually nick on convex side.	Readily propagated from vegetative cuttings (both hardwood and softwood).	Dried seed will store for many years.
Inocarpus fagifer (#5)	1	10–20	Recalcitrant	20–200	>95	≥7	No pre-treatment required.	Candidate for vegetative propagation; marcotting and stem cuttings have both proven successful.	Does not withstand drying and only remains viable for a few weeks. Best stored nut-in-shell, in a shady cool (19–25 °C) area with low humidity (<20%). Protect from pests.
Intsia bijuga (#4; #5)	2–8		Orthodox	160–225 (total seed/kg)		84	Seed has hard seed coat and requires pre-treatment to achieve germination. Nick the seed coat's outer edge opposite the hilum (where it was once attached to the pod), then soak in cool water for 24 hours. #4; #5	Cuttings from mature trees have been successfully propagated, although this method is rarely used. #5	Fresh seed moisture content (MC) 10%. Dried to <10% MC, seed will remain viable for up to 3 years. Storing in an airtight container with a desiccant at 3–5 °C or freezer is likely to extend this. #5
Macadamia integrifolia & *M. tetraphylla* (#18; #19)	1					30–90 #18	No pre-treatment required. #19 Easy to grow from seed but resulting trees are too variable for commercial production of nuts. Commercially, trees are usually grafted. #18	Commonly propagated vegetatively by cuttings, marcotting and grafts. #18	Nut-in-shell can be stored for ≤12 months in a perforated plastic bag at 3–4 °C. #19
Mangifera foetida (#8)	1	Highly variable	Short-lived orthodox (largely abortive)				No pre-treatment required if used fresh.	Although normally propagated by seed, grafting is possible.	Can be stored for about a year, then germinated with slow rehydration and seed treatment (e.g. thiabendazole).
Melaleuca cajuputi (#3; #4)			Orthodox	2–7 million #4		6–15	No pre-treatment required.	Candidate for vegetative propagation; can be reliably grown from stem and branch cuttings. #3	Relatively easy to store. Mature seed remains viable for ≥10 years if stored at <10% moisture content in sealed container at 1–4 °C. #3

Species (source)	Average no. seed/fruit	Fruit/kg	Seed storage behaviour	Viable seed/kg	Viability (%)	Average germination range (days)	Recommended seed pre-treatment	Candidate for vegetative propagation	Seed storage
Melaleuca quinquenervia (#3; #4)			Orthodox	1–5 million #4		5–21	No pre-treatment required.	Many species within this genus are vegetatively propagated from cuttings or by micropropagation, and these techniques should also be successful with this species. #3	Relatively easy to store. Mature seed remains viable for ≥10 years if stored at <10% moisture content in sealed container at 1–4 °C. #3
Metrosideros excelsa (#3; #5; #20)			Orthodox		>90 #20	5–10 (fresh seed); ≤6 weeks for stored seed #5	No pre-treatment required.	Routinely propagated vegetatively, e.g. from cuttings, for ornamental selections.	Short lived at room temperature, with no viability after 12 months, but viability retained >12 months at 1 °C. #20 Mature seed of most Myrtaceae spp. remains viable for ≥10 years when stored at <10% moisture content in sealed container at 1–4 °C. #3
Metrosideros polymorpha (#3; #5; #25)			Short-lived orthodox #5	175,000 (total seed/kg)	10–75 #5 <20 #25	5–10 for fresh seed; may take ≤42 for stored seed #5	No pre-treatment required.	Can be propagated by cuttings and marcotting. #5; #25	Two authors found that viability dropped to 10% after 1 year of storage and near 0% after 3 years (storage method not clear). #5 Some seed will germinate after 3 years if stored at 3–4 °C. #25 Mature seed of most Myrtaceae spp. remains viable for ≥10 years when stored at <10% moisture content in sealed container at 1–4 °C. #3
Musa troglodytarum (*fe'i*) (#5; #34)	Highly variable						Difficult to propagate from seed and the best varieties have few or no seed, better taste and less stringy pulp. #34 Edible bananas are predominantly seedless. Seeded populations of *Fei* bananas are only known in the western Pacific.	Principally propagated vegetatively by division and also through tissue culture which provides disease-free planting material. #5 Best to use large suckers >1 m tall and plant into deep well-prepared hole.	

Species (source)	Average no. seed/fruit	Fruit/kg	Seed storage behaviour	Viable seed/kg	Viability (%)	Average germination range (days)	Recommended seed pre-treatment	Candidate for vegetative propagation	Seed storage
Ochroma pyramidale (#31; #32; #33; #37)	400–600 #31		Orthodox	150,000–170,000 #31	60–80 for fresh seed #31		Boil for 15 seconds or expose to dry heat (96 °C) for 5 minutes. #32 Alternating temperatures (20 hours at 25 °C followed by 4 hours at 45 °C) has been recorded as improving germination. #32 PNG Balsa germinates seed in the dark for 5 days then progressively increases the light over the next 2 months. #37 Seed is covered lightly with sand when sown. Care must be taken when transplanting as seedlings are easily injured. #32	Non-coppicing species. #37 No commercial success in vegetative propagation recorded. #33	Should be stored in airtight container at 3–5 °C. Has been stored for ≤6 years at room temperature, so it could be expected that under refrigeration it would last even longer. #32 The 'kapok' that the small seed is embedded in needs to be removed as it affects the viability of the seed. It can be extracted mechanically. #31
Pandanus tectorius (#5)	2–8/key		Recalcitrant			28–70	Soak in cool tap water for 5 days; change the water daily.	Predominantly propagated from branch cuttings.	Storage of clean phalanges (keys, which contain the seed) for weeks or months may be possible. Seed is probably recalcitrant, meaning that it will lose viability if dried.
Piper methysticum	N/A	N/A	N/A	N/A	N/A	N/A	Kava cultivars do not reproduce sexually and seed has never been observed.	Entirely dependent on vegetative propagation by stem cuttings.	
Pometia pinnata (#5; #6)	1	150	Recalcitrant #5	300–500 (total seed/kg)	90 for fresh seed #5; #6	7–10 #5	No pre-treatment required if seed is sown immediately after cleaning. #5	Vegetative propagation by stem cuttings is possible. #5	Fresh seed moisture content is about 35–55% so good air ventilation is required; at 10–15 °C, seed can be stored for ≤6 weeks with coat intact. #5 Seed is recalcitrant so it loses viability if dried down. #5
Pterocarpus indicus (#5; #6)	1–3	1,500–3,000 air-dry pods #5	Orthodox #5	~13,000 extracted (total seed/kg) #5	10–20 for fresh seed #6	15–30	No pre-treatment required. #5 Seed extraction is not recommended for routine sowing as it is a slow, manual process, often resulting in some damage to extracted seed which can reduce viability and/or storage life. #5	Can be propagated vegetatively by cuttings, large branch cuttings, grafting and tissue culture. #5	Store de-winged fruit at low moisture content (MC) (can be dried down to 4% MC from fresh seed MC of 16–17%) and low temperature, 3–5 °C. #5; #6

Species (source)	Average no. seed/fruit	Fruit/kg	Seed storage behaviour	Viable seed/kg	Viability (%)	Average germination range (days)	Recommended seed pre-treatment	Candidate for vegetative propagation	Seed storage
Santalum album (#22; #27)	1		Short-lived orthodox	5,000–8,000	50–95	18–168	Nick the seed coat at the pointed end of the seed using a sharp knife, soak in a solution of gibberellic acid (GA_3) at 0.1 g/L.	Very easily grafted. #22 Success with cuttings is limited to seedlings, with about 10% success. #27 Root segments, with pre-developed shoots, can be used to vegetatively propagate mature individuals through root severing. #22.	Remove flesh, store surface-dried seed in airtight container at 3–5 °C.
Santalum austrocale-donicum (#5; #22; #26; #27)	1		Short-lived orthodox	2,400–8,400 #5	80–95	14–56	Nick the seed coat at the pointed end of the seed using a sharp knife, soak in a solution of gibberellic acid (GA_3) at 0.1 g/L. #5	Very easily grafted. #22 Cuttings from seedlings have a rooting success of 25–89% depending on provenance/family. #27	Remove flesh, store surface-dried seed in airtight container at 2–4 °C. #5
Santalum insulare (#5; #22; #28)			Short-lived orthodox	15–370 #28	60–95	10–180	Nick the seed coat at the pointed end of the seed using a sharp knife, soak in a solution of gibberellic acid (GA_3) at 0.1 g/L. #5	Likely to be easy to graft like other *Santalum* spp. Likely to be difficult to strike cuttings except of young, seedling material. #22	Remove flesh, store surface-dried seed in airtight container at 2–4 °C. #5
Santalum yasi (#22; #27)			Short-lived orthodox	5,500–7,500	80–95	40–120	Nick the seed coat at the pointed end of the seed using a sharp knife, soak in a solution of gibberellic acid (GA_3) at 0.1 g/L.	Very easily grafted. #22 Cuttings from seedlings have a rooting success of 46%. #27	Remove flesh, store surface-dried seed in airtight container at 2–4 °C. #5
Swietenia macrophylla (#21; #22; #29; #30)	35–45	3	Short-lived orthodox	1,300–2,400 #29	80–90 #30	10–30	No pre-treatment required.	Potential to be grown from cuttings from seedlings and well-managed stock plants in sand-rich media. #29 Successful micropropagation protocols developed have potential for rapid propagation of pest-resistant genotypes #29 Grafted plants typically take many years (e.g. >8–10 years) to come into seed production. #22	Hydrated seed can be stored 2–12 months under refrigeration (2–5 °C and 45% relative humidity) #21. 2.5% of seed germinated following 2 years of hermetic storage of dry seed at 3–5 °C. #22

Species (source)	Average no. seed/fruit	Fruit/kg	Seed storage behaviour	Viable seed/kg	Viability (%)	Average germination range (days)	Recommended seed pre-treatment	Candidate for vegetative propagation	Seed storage
Syzygium malaccense (#5)	1–2		Recalcitrant			28–42	No pre-treatment required. Removal of most of the flesh by lightly rubbing seed together in water is suggested as it helps to minimise fungal attack.	Can be successfully propagated by marcotting and cuttings. These techniques are commonly employed to propagate superior forms.	Does not retain viability when dried or stored. It is best to plant seed out immediately if possible. May store for 2–3 weeks wrapped in a lightly moistened medium, such as paper towel, and kept in a cool, dark place.
Tectona grandis (#13)	0–4	2,000	Orthodox			60–90	Successful pre-treatments are: put seed in oven for 24 hours at 80 °C; soak fruit for 48 hours before sowing; or char (half burn) fruit by covering with a thin layer of grass or coconut leaves and lighting it.	Candidate for vegetative propagation.	Store in airtight container at 12% moisture content at 1–4 °C. Viability can be maintained for at least 7 years in hermetic, air-dry storage at room temperature or even for 10 years in hermetic-dry storage at 2 °C.
Terminalia catappa (#5; #6)	1	15–60 (fresh fruit/ kg); 70–150 (nut-in-shell/kg) #5	Short-lived orthodox #5	500–2,000 (total seed/kg) #6		21–56 #5	No pre-treatment required. It is recommended that seed is sown within 4–6 weeks after collection. #5	Candidate for vegetative propagation. #5	Storage behaviour is unknown but tends to lose viability rapidly under storage; try storing at 3–5 °C. #6
Terminalia richii (#5)	1		Short-lived orthodox	2,600 (total seed/kg)	35–40 for fresh seed	Germination slow and sporadic, occurring over several months	No pre-treatment required.	Mass vegetative propagation by rooted cuttings feasible using seedlings or basal coppice.	While the storage behaviour is likely to be orthodox, seed appears to lose viability fairly rapidly in storage. The fleshy outer covering should be removed from the seed/ nut shortly after collection.
Xanthostemon melanoxylon (#3)	8–12		Orthodox	150,000–300,000	2 (limited data)	≤2–3 months	No pre-treatment required, but soaking may hasten germination.	In other *Xanthostemon* spp., cuttings are successful using hardened, current season's growth.	Mature seed of most Myrtaceae spp. remains viable for ≥10 years when stored at <10% moisture content in sealed container at 1–4 °C.

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