MELALEUCAS

THEIR BOTANY, ESSENTIAL OILS AND USES

Joseph J. Brophy, Lyndley A. Craven
and John C. Doran

Australian Government
Australian Centre for
International Agricultural Research
Rural Industries Research and
Development Corporation

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Research & Development Corporation

2013

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Brophy J.J., Craven L.A. and Doran J.C. 2013. Melaleucas: their botany, essential oils and uses. ACIAR Monograph No. 156. Australian Centre for International Agricultural Research: Canberra. 415 pp.

ACIAR Monograph No. 156

ACIAR Monographs – ISSN 1031-8194 (print), ISSN 1447-090X (online)

ISBN 978 1 922137 51 7 (print)
ISBN 978 1 922137 52 4 (online)

Technical editing by Mary Webb, Canberra
Design and typesetting by Sam Highley, Canberra
Printing by CanPrint Communications, Canberra

Cover: The crimson bottlebrush, *Melaleuca citrina*, a common species in coastal and subcoastal eastern Australia, and widely cultivated as an ornamental shrub (Photo: Sam Highley)

Foreword

The genus *Melaleuca* currently comprises nearly 300 species distributed in Australia and South-East Asia. Melaleucas have been used for many purposes in Australia, including brushwood fencing and as ornamental trees and shrubs for gardens and street planting. They have also been used in farm shelterbelts and for rehabilitating salt-affected lands. In South-East Asia, melaleuca fuelwood is harvested from natural forests, melaleucas are planted for poles and posts on potentially acid-sulfate soils, and research is being undertaken into the suitability of their wood for fibre. Extraction of essential oils from the foliage of three species (*Melaleuca alternifolia*, *M. cajuputi* subsp. *cajuputi* and *M. quinquenervia*) is the basis of industries in Australia and elsewhere, and is a key contributor to several local economies.

The Australian Centre for International Agricultural Research (ACIAR) has previously supported collaborative research between scientists in Australia, Indonesia and Papua New Guinea to provide the basis for local essential oil industries. It is therefore appropriate that it should take the initiative to publish a comprehensive account of melaleucas to further assist development of economic uses of these species. I anticipate that this book will be very beneficial to those planning and funding research on *Melaleuca* species, especially in Australia and the Asia–Pacific region. It should also be useful to people involved in reforestation and agroforestry who require information on species that can produce economic products and are capable of reasonable growth under poor environmental conditions.

The authors of this book are leading scientists in their respective fields and ACIAR appreciates their commitment to preparing such a scholarly and comprehensive account of melaleucas. This book is the first serious attempt to compile a consolidated account of the taxonomy, essential oils, silvicultural characteristics and utilisation of melaleucas. Detailed descriptions and natural distribution maps of all the species are included in this volume, many of which are being published for the first time. The authors made extensive field collections of melaleucas and analysed their essential oils to fill large gaps in published information. As a result, several species worthy of further study of their potential to produce economically important essential oils were identified. A searchable database of the melaleuca oil profiles is provided on the ACIAR website.

Many people and organisations helped with the creation of this book, and are mentioned in the Acknowledgments section. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the University of New South Wales provided institutional support for this activity over many years. Special thanks go to the Essential Oils and Plant Extracts Program of the Rural Industries Research and Development Corporation (RIRDC) for funding a collecting expedition to Western Australia. This allowed leaves to be collected from nearly 40 species not previously sampled for analysis of their essential oils.

Nick Austin
Chief Executive Officer
ACIAR

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Melaleuca species

Melaleuca synonyms

Synonym	Accepted name
Astroloma marginatum	*Melaleuca marginata*
Callistemon acuminatus	*M. flammea*
Callistemon brachyandrus	*M. brachyandra*
Callistemon brevisepalus	*M. brevisepala*
Callistemon buseanus	*M. buseana*
Callistemon chisholmii	*M. chisholmii*
Callistemon citrinus	*M. citrina* (Curtis) Dum.-Cours.
Callistemon comboynensis	*M. comboynensis*
Callistemon flavovirens	*M. flavovirens*
Callistemon formosus	*M. formosa*
Callistemon glaucus	*M. glauca*
Callistemon gnidioides	*M. sphaerodendra*
Callistemon hemistictus	*M. hemisticta*
Callistemon lanceolatus	*M. citrina* (Curtis) Dum.-Cours.
Callistemon lazaridis	*M. lazaridis*
Callistemon linearifolius	*M. linearifolia*
Callistemon linearis	*M. linearis* var. *linearis*
Callistemon macropunctatus	*M. rugulosa*
Callistemon macropunctatus var. *laevifolius*	*M. rugulosa*
Callistemon megalongensis	*M. megalongensis*
Callistemon montanus	*M. montana*
Callistemon montis-zamia	*M. montis-zamia*
Callistemon nervosus	*M. nervosa*
Callistemon pachyphyllus	*M. pachyphylla*
Callistemon pallidus	*M. pallida*
Callistemon paludosus	*M. paludicola*

Synonym	Accepted name
Callistemon pancheri	*M. pancheri*
Callistemon pauciflorus	*M. faucicola*
Callistemon pearsonii	*M. pearsonii*
Callistemon phratra	*M. phratra*
Callistemon phoeniceus	*M. phoenicea*
Callistemon pinifolius	*M. linearis* var. *pinifolia*
Callistemon pityoides	*M. pityoides*
Callistemon polandii	*M. polandii*
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Callistemon pungens subsp. *fletcheri*	*M. williamsii* subsp. *fletcheri*
Callistemon pungens subsp. *synoriensis*	*M. williamsii* subsp. *synoriensis*
Callistemon pyramidalis	*M. pyramidalis*
Callistemon quercinus	*M. quercina*
Callistemon recurvus	*M. recurva*
Callistemon rigidus	*M. linearis* var. *linearis*
Callistemon rugulosus	*M. rugulosa*
Callistemon rugulosus var. *flavovirens*	*M. flavovirens*
Callistemon sabrina	*M. sabrina*
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Callistemon serpentinus	*M. serpentina*
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Callistemon sieberi	*M. paludicola*
Callistemon speciosus	*M. glauca*
Callistemon suberosum	*M. dawsonii*
Callistemon subulatus	*M. subulata*

Synonym	Accepted name
Callistemon teretifolius	*M. orophila*
Callistemon viminalis	*M. viminalis* subsp. *viminalis*
Callistemon viminalis subsp. *rhododendron*	*M. viminalis* subsp. *rhododendron*
Callistemon viminalis var. *minor*	*M. viminalis* subsp. *viminalis*
Callistemon viridiflorus	*M. virens*
Callistemon wimmerensis	*M. wimmerensis*
Calothamnus suberosus	*M. suberosa*
Melaleuca acacioides subsp. *alsophila*	*M. alsophila*
Melaleuca acerosa	*M. systena*
Melaleuca apodocephala subsp. *calcicola*	*M. calcicola*
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Melaleuca calycina subsp. *dempta*	*M. dempta*
Melaleuca cardiophylla var. *longistaminea*	*M. longistaminea*
Melaleuca citrina Turcz.	*M. lutea*
Melaleuca coccinea subsp. *eximia*	*M. eximia*
Melaleuca coccinea subsp. *penicula*	*M. penicula*
Melaleuca coronicarpa	*M. marginata*
Melaleuca crosslandiana	*M. nervosa*
Melaleuca cymbifolia	*M. halmaturorum*
Melaleuca densa var. *pritzelii*	*M. pritzelii*
Melaleuca halmaturorum subsp. *cymbifolia*	*M. halmaturorum*
Melaleuca lanceolata subsp. *occidentalis*	*M. lanceolata*
Melaleuca lanceolata subsp. *planifolia*	*M. lanceolata*
Melaleuca lanceolata subsp. *thaeroides*	*M. lanceolata*
Melaleuca lateriflora subsp. *acutifolia*	*M. acutifolia*
Melaleuca lateriflora var. *acutifolia*	*M. acutifolia*

Synonym	Accepted name
Melaleuca longistaminea subsp. *spectabilis*	*M. spectabilis*
Melaleuca maidenii	*M. quinquenervia*
Melaleuca minutifolia subsp. *monantha*	*M. monantha*
Melaleuca nervosa f. *latifolia*	*M. nervosa*
Melaleuca nervosa subsp. *crosslandiana*	*M. nervosa*
Melaleuca paludosa	*M. glauca*
Melaleuca smithii	*M. quinquenervia*
Melaleuca styphelioides var. *squamophloia*	*M. squamophloia*
Melaleuca tamariscina subsp. *irbyana*	*M. irbyana*
Melaleuca tamariscina subsp. *pallescens*	*M. pallescens*
Melaleuca urceolaris var. *virgata*	*M. dichroma*
Melaleuca virgata	*M. dichroma*
Melaleuca viridiflora var. *angustifolia*	*M. quinquenervia*
Melaleuca viridiflora var. β *rubriflora*	*M. quinquenervia*
Metrosideros citrina	*M. citrina* (Curtis) Dum.-Cours.
Metrosideros decora	*M. decora*
Metrosideros glauca	*M. glauca*
Metrosideros linearifolia	*M. linearifolia*
Metrosideros nodosa	*M. nodosa*
Metrosideros pinifolia	*M. linearis* var. *pinifolia*
Metrosideros quinquenervia	*M. quinquenervia*
Metrosideros rugulosa	*M. rugulosa*
Metrosideros saligna	*M. salicina*
Metrosideros viminalis	*M. viminalis* subsp. *viminalis*
Metrosideros viridiflora	*M. virens*
Myrtus leucadendra	*M. leucadendra*
Petraeomyrtus punicea	*M. punicea*
Regelia punicea	*M. punicea*

Preface

Melaleuca is the basis of several industries in Australia and elsewhere. Predominantly these industries are based on the extraction of essential oils from the foliage of three species, *Melaleuca alternifolia* (but sometimes including minor use of *M. linariifolia* and *M. dissitiflora*), *M. cajuputi* subsp. *cajuputi* and *M. quinquenervia*. An emerging industry is underway in South-East Asia, especially on potentially acid-sulfate soils, where trees are being grown primarily for roundwood, and research is being undertaken into the suitability of their wood for fibre. In view of the challenge to find novel sources of commercially significant oils, we have been collecting samples over the past three decades, and have been extracting and analysing the oils. In spite of this activity, when this book was mooted, information on the oils of about 100 species was still lacking. Dedicated fieldwork was undertaken in south-western Western Australia, where most of the unsampled species occurred, and requests were made of individuals and organisations that might have been in a position to assist. These efforts were successful and there are only one species and four infraspecific taxa for which there are still no data on their essential oils. The majority of the oils reported in this volume have not previously been described in the scientific literature. As a result of the fieldwork, several species (e.g. *M. halophila, M. hamata, M. ochroma*) have been identified as potentially valuable sources of essential oils and may warrant further investigation of their oil content and yield.

As it is presently circumscribed, *Melaleuca* consists of 290 species with 37 infraspecific taxa. Work on the systematics of the genus in recent years has indicated that *Melaleuca* may be made larger due to the inclusion of several genera presently regarded as distinct. As this work is at present incomplete, *Melaleuca* is treated in a conventional concept in this volume, although with the addition of the species previously known as *Callistemon*. Many of the species included in this volume have previously been treated only skeletally and, for these, detailed descriptions are being published for the first time. Distribution maps are included for all species, and colour photographs of the flowers are included for those we have been able to source.

Apart from essential oils, melaleucas have been used for a wide range of purposes, from making brushwood fencing, as ornamental shrubs, as shelterbelt species for farmland, for rehabilitating salt-affected lands, for street and park trees, and so on. One interesting potential use for *M. bracteata* is as a source of water-soluble betaines—compounds that act as osmoprotectants against stress in plants. These compounds may increase stress tolerance in agricultural crops which in turn would increase national income from agriculture.

A threat to the future health and genetic diversity of a substantial number of *Melaleuca* species in eastern Australia is from *Puccinia psidii* sensu lato (synonym *Uredo rangelii*). This exotic pathogen has the common name of myrtle rust in Australia but it is known as guava or eucalyptus rust elsewhere, with origins in Brazil. Myrtle rust targets species of the family Myrtaceae, including *Melaleuca*. First observed in Australia on the central coast of New South Wales in 2010, it has now spread from Victoria to northern Queensland. In susceptible plants, young spore-covered leaves and shoots become curled and distorted and severe infection can cause shoots to die, causing these plants to become stunted after repeated infections. In the worst cases, death of the whole plant can occur after repeated destruction of new growth. As this book goes to press, this disease is of concern to all with an interest in the conservation and sustainable use of Australian plants of the family Myrtaceae.

Joe Brophy, Lyn Craven, John Doran
September 2013

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Taxonomic history and systematics

Historical context

Melaleuca is almost entirely Australian in its distribution yet the first of its species to be formally described, *Melaleuca leucadendra*, was based on material from Ambon, in present-day Indonesia. Georgius Everhardus Rumphius, a merchant with the Dutch East Indies Company, compiled a detailed account of many of the plants growing in the Malesian biogeographical region but this was not published until 1741; this important work has recently been translated into English and published with annotations (Rumphius 2011). The plant we now know as *Melaleuca leucadendra* was called *Arbor alba* by Rumphius. Rumphius' 1741 publication predated the accepted starting point for the scientific botanical nomenclature of flowering plants and the formal description of the species occurred in 1754 when the Swedish botanist Carolus Linnaeus gave it the name *Myrtus leucadendra*, taking his descriptive data from Rumphius' work (Linnaeus 1754). Subsequently, Linnaeus realised that his *Myrtus leucadendra* did not have very much in common with the other species of *Myrtus* and in 1767 he described the genus *Melaleuca* to accommodate this plant (Linnaeus 1767).

The nomenclature applied to the first endemic Australian melaleucas to be described was inconsistent due to a lack of appreciation of the relationships of the species. Doubtless this was due to the limited numbers of specimens that had been collected and consequent uncertainty as to how the genera of Myrtaceae should be circumscribed. Several species, such as *M. armillaris* and *M. decora*, described in 1788 and 1796, respectively, initially were placed in *Metrosideros*. In other cases, the author recognised a relationship with Linnaeus' *Melaleuca* and the species was placed in that genus, e.g. *M. ericifolia* and *M. gibbosa*, described in 1797 and 1806, respectively. From the perspective of having a foundation on which to build new knowledge of *Melaleuca* species, George Bentham's treatment of the genus in his Australian flora (Bentham 1867) provided the first comprehensive summary of the species known, and those species that had been described in *Metrosideros* were then brought into *Melaleuca*. Bentham's important account enabled later workers to identify their materials and thus determine if there were additional species that should be described. During the next 100 years, many species were added to the genus, including two from New Caledonia (*M. brongniartii* and *M. gnidioides*) and one from Lord Howe Island (*M. howeana*).

Melaleuca was circumscribed by Bentham (1867) in part as having stamens united in bundles opposite the petals.

The related genus *Callistemon* was distinguished from *Melaleuca* by Bentham as having free stamens, although he noted that the stamens of *Callistemon speciosus* (now *M. glauca*) were often in bundles. Most of the species placed in *Callistemon* are Australian but five species were also described from New Caledonia, two of which have stamens in bundles; one wonders why these were not therefore placed in *Melaleuca*. The recognition of *Melaleuca* and *Callistemon* as separate genera had been regarded as being artificial from the time of the description of the latter. When describing *Callistemon*, Robert Brown (1814, p. 547) wrote: 'The maximum of *Melaleuca* exists in the principal parallel, but it declines less towards the south than within the tropic, where its species are chiefly of that section which gradually passes into *Callistemon*, a genus formed of those species of *Metrosideros* that have inflorescences similar to that of *Melaleuca*, and distinct elongated filaments'. Ferdinand Mueller, who was well acquainted with both genera in the field and in the herbarium, also regarded *Callistemon* as being artificial (Mueller 1864). Bentham may in fact have had his own doubts about the distinctness of *Callistemon*, for he commented in *Flora Australiensis* that *Callistemon* 'passes gradually into *Melaleuca*, with which F. Mueller proposes to reunite it' (Bentham 1867, p. 118). The majority of authors have accepted the two genera as being distinct but the nineteenth century botanist Henri Ernest Baillon included *Callistemon* and two other genera (*Conothamnus* and *Lamarchea*) in *Melaleuca*, recognising them at sectional level (Baillon 1876). In 1998, Lyn Craven and John Dawson transferred the New Caledonian *Callistemon* species to *Melaleuca*, as they considered the endemic New Caledonian species of the complex should be placed in the same genus (Craven and Dawson 1998). Craven (2006) then discussed morphological evidence relevant to the separation of the two genera and transferred all the accepted Australian species of *Callistemon* to *Melaleuca*.

Studies based on morphological evidence

Surprisingly for a genus of nearly 300 species, few revisionary-level treatments of species groups or of prescribed geographical regions within Australian *Melaleuca* have been published. Perhaps fittingly, in view of the ecological and/or economic significance of its several species, the first was an account of the broad-leaved paperbarks, the *M. leucadendra* species group, by Stan Blake (Blake 1968); these species are a common component of savannah and woodland communities in northern and north-eastern Australia, south-eastern Malesia and New Caledonia. John Carrick and Kosmyn Chorney (Czornij) published a revisionary-level account of the South Australian species of *Melaleuca* in 1979 which gave an insight into arid-zone species of the genus (Carrick and Chorney 1979). Norm Byrnes in 1984 published the first part of a concise revision of the *Melaleuca* species of northern and eastern Australia (Byrnes 1984, 1985, 1986). Several of these species were removed from *Melaleuca* in 1989 as a result of the resurrection of *Asteromyrtus* (Craven 1989). *Asteromyrtus* is related to *Agonis* and *Leptospermum* and presumably had been included in *Melaleuca* only because its stamens are in bundles. Byrnes' *M. punicea* was also removed from the genus because of its anomalous androecium, gynoecium and seed. Initially the species was placed in *Regelia* (Barlow 1987a) but it was subsequently placed in the new genus *Petraeomyrtus* (Craven 1999), as the species was as anomalous in *Regelia* as it had been in *Melaleuca*. However, following recent investigations using molecular data, *M. punicea* is treated in the present volume under *Melaleuca* (see below).

Bryan Barlow initiated revisionary studies of *Melaleuca* in Canberra in the early 1980s. In 1986, Barlow published the results of his studies of three species complexes: the *M. acacioides*, *M. tamariscina* and *M. minutifolia* complexes (Barlow 1987b). Subsequently, the *M. cuticularis* and *M. lanceolata* species groups were revised by Barlow and Kirsten Cowley (Barlow and Cowley 1988) and the *M. fulgens* and *M. laxiflora* species groups were revised by Cowley and collaborators (Cowley et al. 1990). An enumeration of the Australian species of *Melaleuca* sensu stricto was published by Craven and Brendan Lepschi in 1999; this paper included an identification key—the first key including all these species of the genus since 1867 (Craven and Lepschi 1999). Four species belonging to the *M. thymoides* species group—*M. lutea*, *M. pungens*, *M. striata* and *M. thymoides*—were not included in the 1999 enumeration, as Craven, at that time, considered the species of this group warranted separate generic status; however, in the present volume they are again included as melaleucas.

Incorporating DNA evidence in classification

Plant classification until recently has been based largely upon morphological evidence, utilising data from anatomy, cytology, chemistry (secondary metabolites) and any other sources where these have been available. The overarching objective of classification has been to group plants according to their presumed natural relationships, with putatively closely related species classified together. The technological advances that have permitted sequencing of DNA (deoxyribonucleic acid), together with development of computer programs for detecting related species, have enabled biologists to study the genetic relationships of plants in detail for the first time. The consequences of such studies for taxon delimitation, and thus classification, are varied. In some cases, generic circumscriptions are supported by analysis of DNA data and there are no changes to the classification, and hence nomenclature, of a genus. In other cases, the current classification is not supported, with part or all of the species sampled falling (or 'nesting') within one or more other genera. There is no automatic procedure to be adopted in such cases. Typically, if all the species of a genus or group of genera nest within a single genus, a decision has to be made to either combine all the genera into one or to break the original single genus into several. This clearly has implications for nomenclature. In other cases, some of the species of a genus are found to nest within another, with the remaining species still comprising a distinct group, and in those cases the nested species are transferred to the other genus. This still has implications for nomenclature, especially if the name of the genus is transferred along with the nested genus, as the remaining species will then require a new generic name.

Species of *Melaleuca* and the morphologically closely related genera *Beaufortia*, *Calothamnus*, *Conothamnus*, *Eremaea*, *Lamarchea*, *Phymatocarpus* and *Regelia*, and including *M. punicea* (*Petraeomyrtus*), the four species of the *M. thymoides* group, and several Australian and New Caledonian species of *Melaleuca* that formerly had been placed in *Callistemon*, were included by Robert Edwards and his collaborators in an analysis of chloroplast DNA data (Edwards et al. 2010). Chloroplast DNA is maternally inherited, and phylogenies derived from chloroplast DNA data give a good estimate of the maternal 'family tree'. The results of Edwards et al. (2010) showed there were three major groupings or clades, each of which contained species of *Melaleuca* sensu stricto. The whole *Melaleuca* group itself formed a well-supported clade relative to the outgroup taxa included in the analyses. In one of the three clades are species of the *M. leucadendra*, *M. acacioides*, *M. scabra* and *M. thymoides* groups, two New Caledonian species previously placed in *Callistemon*, *M. punicea*, and representative species of *Beaufortia*, *Calothamnus*, *Conothamnus*, *Eremaea*, *Lamarchea*, *Phymatocarpus* and *Regelia*. In a second clade are representatives of the *M. cuticularis*, *M. fulgens* and *M. laxiflora* groups, together with Australian species previously placed in *Callistemon* and several species not placed within a particular grouping. The third clade contains members of the *M. bracteata*, *M. cuticularis*, *M. lanceolata* and *M. minutifolia* groups, together with other species not allocated to a particular grouping and the morphologically anomalous *M. foliolosa*.

The incorporation of nuclear DNA data in phylogenetic studies enables the paternal contribution to be assessed; using only the maternal chloroplast data could give a biased result. The broad structure of the inferred chloroplast DNA phylogeny given in Edwards et al. (2010) is in agreement with the nuclear DNA phylogenies of Ladiges et al. (1999) and Brown et al. (2001); these were based upon data derived from a smaller number of species than in the study of Edwards et al. (2010) but the sampling was drawn from most of the various genera of the complex.

Current and future classification challenges

The taxonomic implications of the DNA studies are that one either includes all the related genera within *Melaleuca* or one retains the existing segregate genera and recognises many new ones, perhaps 10 or more. Given the lack of distinctive morphological features available to differentiate many of them, such new genera would not be readily recognisable. Consequently, *Melaleuca* will be enlarged to include *Beaufortia*, *Calothamnus*, *Conothamnus*, *Eremaea*, *Lamarchea*, *Phymatocarpus* and *Regelia* (L.A. Craven, R.D. Edwards and K.J. Cowley, in preparation). The species treated in the present volume are those that accord with the conventional concept of *Melaleuca* and also include *M. punicea*, the *M. thymoides* group and those species previously placed in *Callistemon*.

Morphological evidence also has been a primary source of data for developing species' concepts in *Melaleuca*. It is unlikely that this situation will change dramatically in the foreseeable future but the few studies that have been made using DNA data have shown that this will be a very powerful tool for taxonomists. Linda Broadhurst et al. (2004), utilising nuclear restriction fragment length polymorphism (RFLP) data derived from a range of Western Australian populations of the broombush (*M. uncinata*) complex (and including one South Australian population from the type locality of *M. uncinata*), found that phylogenetic analysis showed the sampled populations represented seven species of the broombush complex. The results of the phylogenetic analysis were congruent with those of a parallel morphological study that encompassed the whole of the broombush complex in Western Australia (Craven et al. 2004).

The broad-leaved paperbark group (*M. leucadendra* group) is an ecologically important component of vegetation in northern and eastern Australia. Conventionally it has been regarded as a taxonomically difficult group and, in the mid nineteenth century, it was treated by Bentham (1867) as a single species with numerous varieties. Blake, with an insight gained from studying the complex in the field, published a detailed and workable account of the group that, despite several new species being described since, remains the most useful guide to the group (Blake 1968). One of the broad-leaved paperbarks, *M. quinquenervia*, is a common wetlands tree in eastern Australia and also occurs naturally in Papua province of Indonesia, Papua New Guinea and New Caledonia, and is a major woody weed in Florida, United States of America (USA). This species is harvested for its essential oil, niaouli oil, in New Caledonia and also in Madagascar, where it is cultivated for this purpose. In a study using DNA sequence data from two chloroplast and two nuclear regions, Cook et al. (2008) found that the genome of *M. quinquenervia* contained alleles that link the species to several other broad-leaved paperbark species and that there was regional sharing of chloroplast haplotypes, indicating introgression or lineage sorting. This has significance for biological control studies of *M. quinquenervia* as it will be necessary to match the genetics of the weed populations with naturally occurring populations in Australia when seeking control agents. A significant conclusion of the Cook et al. (2008) study was that species boundaries within the complex were not clear. This work is being extended by Robert Edwards, drawing upon a comprehensive sampling of the complex across northern Australia and the results should be of interest to systematists and others.

The extent to which hybridisation has played a role in the evolution of *Melaleuca* species is not known but it may be important and occurs quite widely across the genus (Craven 2006). DNA studies may assist in clarifying species circumscriptions in the bottlebrush (*Callistemon*) group, which is at least as difficult taxonomically as the broad-leaved paperbarks. The bottlebrush *M. paludicola* and its putative close relatives *M. phratra*, *M. quercina*, *M. sabrina* and *M. wimmerensis* make up one group worthy of investigation. The red-flowered Queensland bottlebrushes *M. hemisticta*, *M. lazaridis*, *M. montis-zamia* and *M. pyramidalis* are another, as there are populations in southern Queensland that presently are not definitively identifiable to one of these species and the whole complex requires a comprehensive population genetics study of the type conducted by Broadhurst et al. (2004) on members of the broombush group. Similarly, the relationship between *M. citrina* and *M. subulata* in southern New South Wales and eastern Victoria needs investigation. Bill Molyneux has described *Callistemon forresterae*, *C. genofluvialis*, *C. kenmorisonii* and *C. nyallingensis* from this region (Molyneux 1993, 1994, 1997, 2005) but these are regarded by one of us (LAC) as being hybrids or hybrid derivatives between *M. citrina* and *M. subulata* and are not accepted as species in the conventional sense; consequently, they are not included in the present volume. Apomixis in two bottlebrush species was studied by James (1958) and this genetic process may also be a factor in the evolution and relationships of the bottlebrushes in eastern Australia (Craven 2009).

It is clear there is need for an infrageneric classification of *Melaleuca*, with closely related species being grouped together in sections and subsections etc. Already there are nearly 300 species in the genus and with the transfer of the species flagged above there will be nearly 400; this is too large a number to be left in an unstructured arrangement. A preferred classification would be one based upon morphological data alone, but in the case of *Melaleuca* these are not sufficient and it will be necessary to incorporate DNA results in the synthesis. The DNA studies that have been published to date, while sufficient to support the merger of the genera of tribe Melaleuceae into a single genus, i.e. *Melaleuca*, do not adequately resolve the clades that were found and contain too few species to permit a classification to be prepared. Research presently underway at the Australian National University, Canberra, using next-generation sequencing methods and a very much greater sampling of species across *Melaleuca* sensu lato should give information that will guide development of a robust classification (Mike Crisp and Bo Choi, pers. comm.).

Introduction to the genus *Melaleuca*

General information

Family and tribe

The genus *Melaleuca* is in the family Myrtaceae and tribe Melaleuceae.

Botanical name

The generic name is derived from the Greek *melas*, meaning black or dark, and *leucon*, meaning white—apparently alluding to the white branches and black trunk of the first named species, *M. leucadendra*, the trunks of which are often blackened by fire.

Common names

Species with thick, spongy, peeling bark comprising many papery layers are commonly referred to as 'paperbarks', with some qualifying adjective (e.g. silver-leaved paperbark, *M. argentea*). In southern Australia, the common name 'honey myrtle' is also well established for many shrub-sized species (e.g. bracelet honey myrtle, *M. armillaris*). A few have distinctive Aboriginal (e.g. winti, *M. arcana*) or locality (e.g. South Australian swamp paperbark, *M. halmaturorum*) names, while some are referred to as 'tea tree' (e.g. black tea tree, *M. bracteata*), a common name shared with many species of *Leptospermum*. As explained above, this treatment of *Melaleuca* includes species previously belonging to the genus *Callistemon*. They retain their common name of 'bottlebrush' which alludes to the resemblance of the flowers and emerging new growth to a kitchen bottlebrush (e.g. crimson bottlebrush, *M. citrina*).

Ploidy

The great majority of *Melaleuca* species are diploid with $2n = 22$ (Brighton and Ferguson 1976; Rye 1979). Polyploidy appears to be relatively infrequent in this genus, with only a few recorded instances of aneuploidy ($2n + 2 = 24$), triploidy ($3n = 33$), tetraploidy ($4n = 44$) and hexaploidy ($6n = 66$) (James 1958; Brighton and Ferguson 1976; Rye 1979) which have been linked with hybridisation and apomixis. The apomictic species, *M. linearis*, may have populations that are diploid, triploid or tetraploid (James 1958).

Number of species

Melaleuca, as circumscribed in this work, comprises 290 species (327 entities inclusive of infraspecific taxa). As such, it is the third-largest genus of Myrtaceae after *Eucalyptus* and *Syzygium* in the Australasian region.

Botanical features

Habit and size

Melaleucas range from woody, multistemmed shrubs to very large, single-stemmed trees of timber-producing value. By far the majority of species are shrubs or small trees less than 10 m tall, 40 of which do not exceed 1 m in height. These ground-hugging types are found largely in the south of Western Australia. Fifteen species have been documented as being over 10 m in height, with seven of these species exceeding 20 m. Boland et al. (2006) report that *M. cajuputi* has been recorded with heights up to 46 m in the Northern Territory and is the tallest tree in the region; similarly, *M. leucadendra* has been measured to 43 m in northern Queensland (Figure 1).

Bark

The bark of the majority of species is of the papery type. Here, the bark consists of thin, paper-like layers of cork separated by thin fibrous layers, which may reach 5 cm in thickness. The outer layers peel naturally to give a distinctive ragged, torn and unkempt appearance to the lower bole (Figure 2A). In addition, a substantial proportion (c. 20%) of *Melaleuca* species has hard, deeply furrowed, rough bark, as exemplified by *M. bracteata* (Figure 2B). There is a further 20% of species where the bark is described as fibrous. There is some overlap in bark types in some species. For example, *M. clarksonii* is variously described as displaying all three bark types in different individuals.

Foliage

Melaleucas are evergreen and usually carry abundant green, bluish-green, grey-green or silvery-grey foliage unless drought or other stresses (e.g. salt) have stimulated leaf abscission. Leaves are minute to large. In all, 60% of recognised species have short (<30 mm long) to very short (<10 mm) leaves, while the others have medium to long leaves. *Melaleuca leucadendra*, with its narrow lanceolate

Figure 1. A substantial *Melaleuca leucadendra* on a well-watered site in north-western Queensland

Figure 2. Bark types in *Melaleuca*: papery, as in (A) *M. exuvia*; and rough, as in (B) *M. bracteata*

leaves, produces leaves measuring 75–270 mm in length, representing some of the longest in the genus. Leaves are entire, dorsiventral or isobilateral, usually coriaceous, flat, concave, centric or semi-terete, sessile or petiolate. Leaf shape is also highly variable, including elliptic, cordate, falcate, lanceolate, linear, oblong, ovate, obovate, elliptic or triangular. Leaves are cordate, attenuate, cuneate, truncate or obtuse at the base. Mature leaf blades may be glabrous, pubescent or woolly. They are carried in either alternate, opposite, spiral, decussate or occasionally ternate (whorls of three leaves) arrangement. Mature leaves are without stipules and without a persistent basal meristem. *Melaleuca* leaves are usually obviously oil-gland dotted and are aromatic or without marked odour. Leaf venation is pinnate, longitudinal or longitudinal-pinnate and is frequently obscure.

Flowers

Flowers are in spikes or clusters, or sometimes solitary; the basic floral unit is a monad, dyad or triad; the calyx lobes are five or rarely may be fused into a ring of tissue; the petals are five; the hypanthium is fused to the ovary in the proximal region only, or for up to three-quarters the length of the ovary or, rarely, for almost all the length of the ovary; the stamens are few to numerous, the filaments are fused for part of their length into five bundles and inserted on a staminal ring or free and not in bundles wherein the filaments are inserted on the hypanthium apex with the staminal ring obsolete, the anthers are dorsifixed (or rarely basifixed) and versatile, with two parallel cells that open via longitudinal slits; the ovary has three locules, the placentae are peltate and axile-median to axile-basal, the ovules are few to numerous (Figures 3 and 4).

Species vary widely in flower colour, with about half of all species having filaments of white through cream to yellow or green, while the others have pink, red or mauve filaments. In many species, the contrasting yellow anthers at the ends of these brightly coloured filaments result in a spectacular floral display.

Reproductive biology

Melaleucas generally produce only morphologically bisexual (hermaphroditic) flowers but this is not universal. About 160 species are always hermaphroditic, i.e. all inflorescences have only bisexual flowers. Examples are *M. quinquenervia* and *M. viminalis*. About 90 species are always andromonoecious, i.e. there are male and hermaphroditic inflorescences on the one plant. Typically, the male inflorescences are on the outside of the plant and possibly serve as advertisements to potential pollinators, while the hermaphroditic inflorescences are within the canopy, where they may be somewhat protected from predation but are still close enough to the outside of the plant to attract a pollinator. Examples of andromonoecious species are *M. gibbosa* and *M. uncinata*. About 30 species include some plants that are hermaphroditic and others that are andromonoecious. Examples of this type are *M. hamulosa* and *M. incana*. One species, *M. cornucopiae*, is particularly interesting as some plants are monoecious (with both male and female inflorescences on the same plant) and others are gynoecious (with female inflorescences only). The above data are based on the study of herbarium specimens supplemented with observations on living plants (L.A. Craven, unpublished data) and need verification with additional field studies. However, some general statements can be made about specific groups of

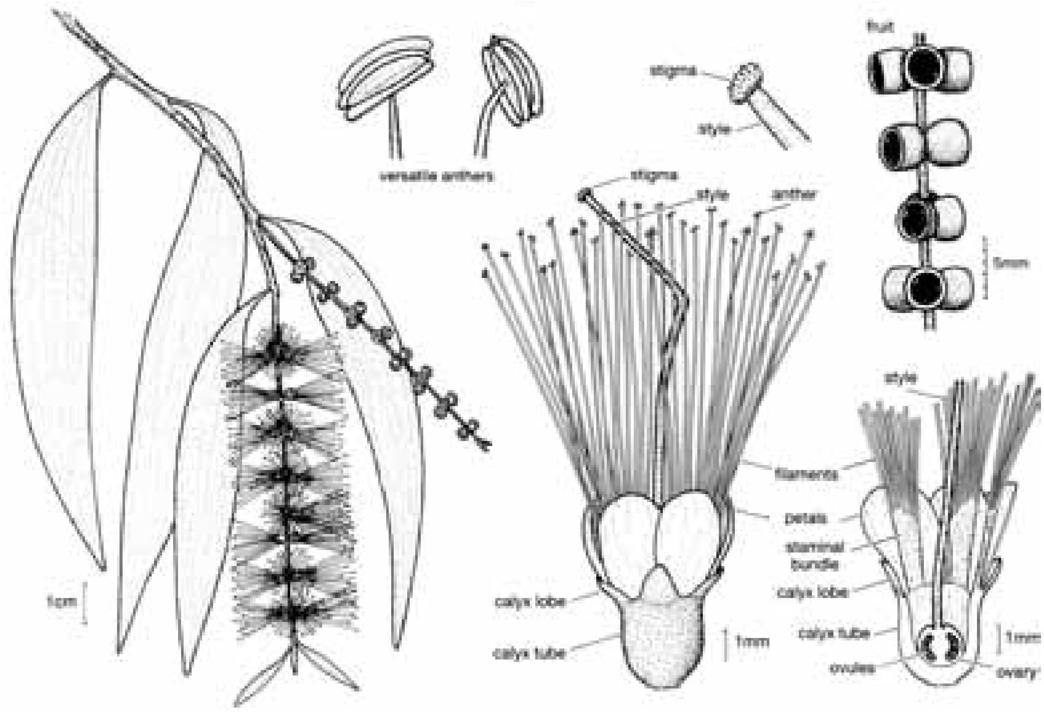

Figure 3. Flower and fruit of *Melaleuca leucadendra*, a species with its stamens in bundles (drawings by M. Fagg)

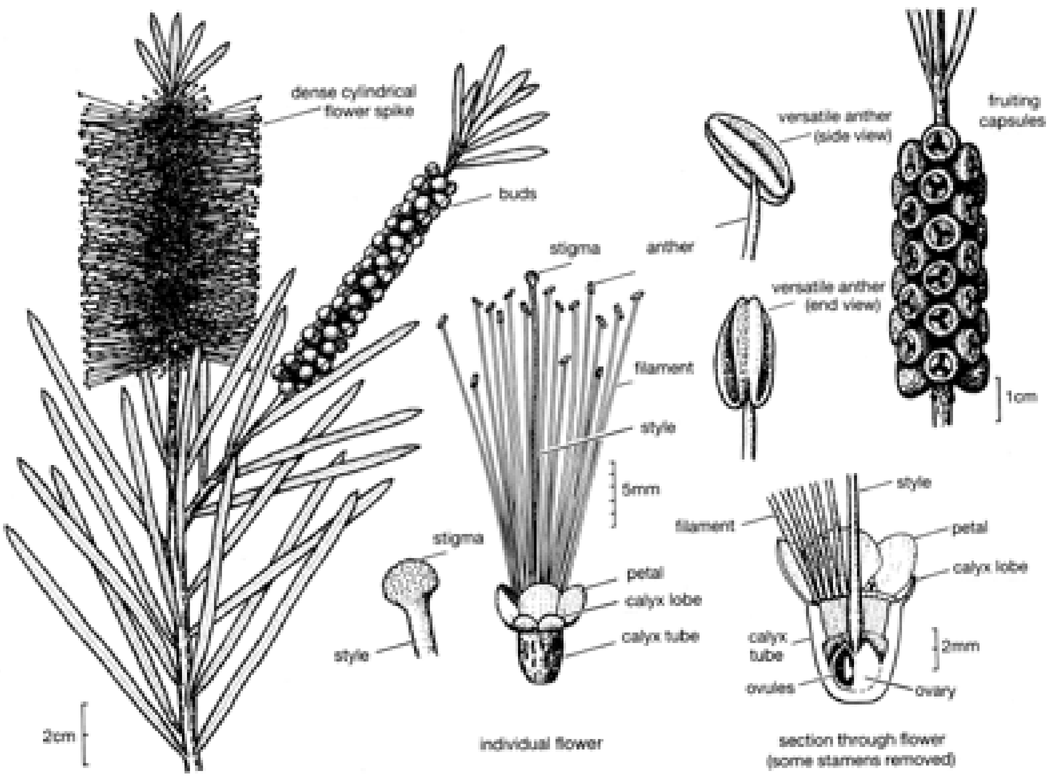

Figure 4. Flower and fruit of *Melaleuca linearis*, a species with free stamens (drawings by M. Fagg)

interest. It appears that all the species of the broad-leaved paperbark group are hermaphroditic, all of the broombush group are andromonoecious, and most of the species allied to *M. alternifolia* are hermaphroditic (*M. linophylla* may be hermaphroditic or andromonoecious but this needs verification in the field).

Baskorowati et al. (2010a, b, c) describe the reproductive biology of *M. alternifolia* (summarised in Figure 5) which is an example of floral structure and development in a hermaphroditic species.

Timing of flowering

Flowering starts early in many species. For example, *M. alternifolia* planted in breeding populations in northern New South Wales set the first flower buds as early as 2 years after planting. However, the first 'reasonable' flowering (defined as 45% of trees) did not occur until almost 4 years from plantings within the species' natural range (Doran et al. 2002). In *M. alternifolia*, a cold winter (minimum temperatures below 5 °C) appears to stimulate floral bud formation while good spring rains are needed to support a good flowering and retention of the developing fruit (Baskorowati et al. 2010a, c).

Flowering periodicity and intensity in *Melaleuca* species are highly variable between species and sites. In general, most species flower in the late winter – spring – summer period, some peak in autumn and winter, and others may flower all year round. The natural flowering pattern can be disrupted when a species is planted outside its normal range. For example, flowering of *M. alternifolia* in its region of natural occurrence is at its peak in spring (October–November) but the species flowers in winter when planted in Western Australia. The period for the morphological development of buds, flowers and fruit leading to the development of mature seed also varies between *Melaleuca* species. In *M. alternifolia*, a period of 16–18 months is required (Baskorowati et al. 2010a, c) but in summer-flowering tropical species (e.g. *M. leucadendra*), geared to shed their seed in response to the next summer's monsoonal rainfall, a shorter period of about 12 months is typical.

Pollination and pollen biology

Melaleucas are mostly insect-pollinated. Hawkeswood (1980), for example, showed that jewel beetles (*Diadoxus* spp.) were the main pollinators of *M. pauperiflora* in Western Australia and South Australia. Baskorowati et al. (2010a, b) observed a wide variety of insects visiting the flowers of *M. alternifolia* in New South Wales, including large flying insects like honey bees (*Apis mellifera*), flies and wasps (Figure 6). These authors also found that small insects like thrips (*Thrips imaginis* and *T. tabacci*) were the dominant visitors to the flowers of *M. alternifolia* and are important pollinators, as confirmed by exclusion experiments. Pollination is probably also effected by birds, notably lorikeets and honeyeaters, which are often seen visiting the flowers of bottlebrushes and broad-leaved paperbarks. Fruit bats (family Pteropodidae) also feed on flowering broad-leaved paperbarks and may be pollinators for these species.

Thornhill et al. (2012) studied the pollen morphology of 21 species of *Melaleuca* (including six species of the former genus *Callistemon*) using scanning electron and light microscopy. A general description from this work follows, combining methods and descriptions of the two relevant genera. Pollen grains were tricolporate (Figure 7), except for some pollen of *M. citrina* (as *C. citrinus*) which was tetracolporate. Pollen had a rugulate exine, except for *M. nesophila* grains that had a granulate/scabrate exine. Pollen sides were straight, or less commonly convex or concave, and the colpal morphology was consistently parasyncolpate with angular colpi, except for some grains of *M. virens* (as *C. viridiflorus*) which had arcuate colpi. Pollen ambs were round or pointed, or less commonly notched or flat. Colpal edges were smooth or occasionally rough and

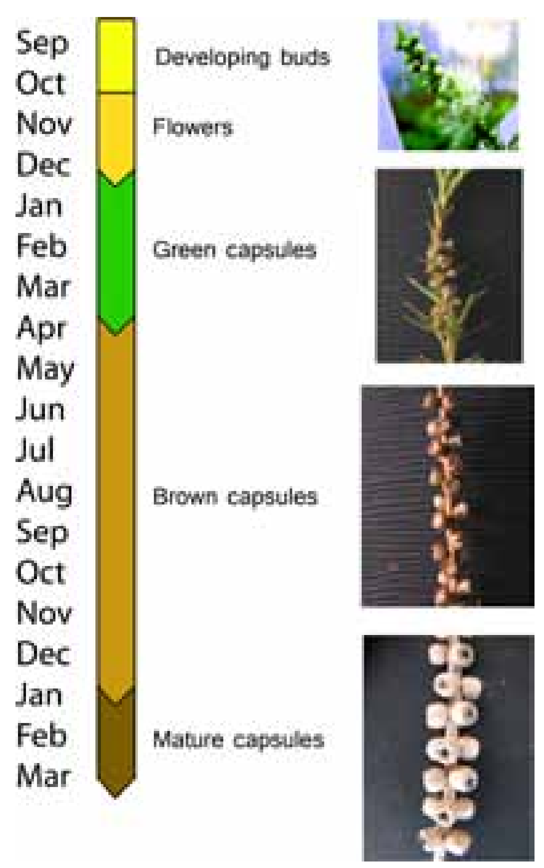

Figure 5. Monthly progress in flowering and fruit development in *Melaleuca alternifolia* (derived from Baskorowati 2006)

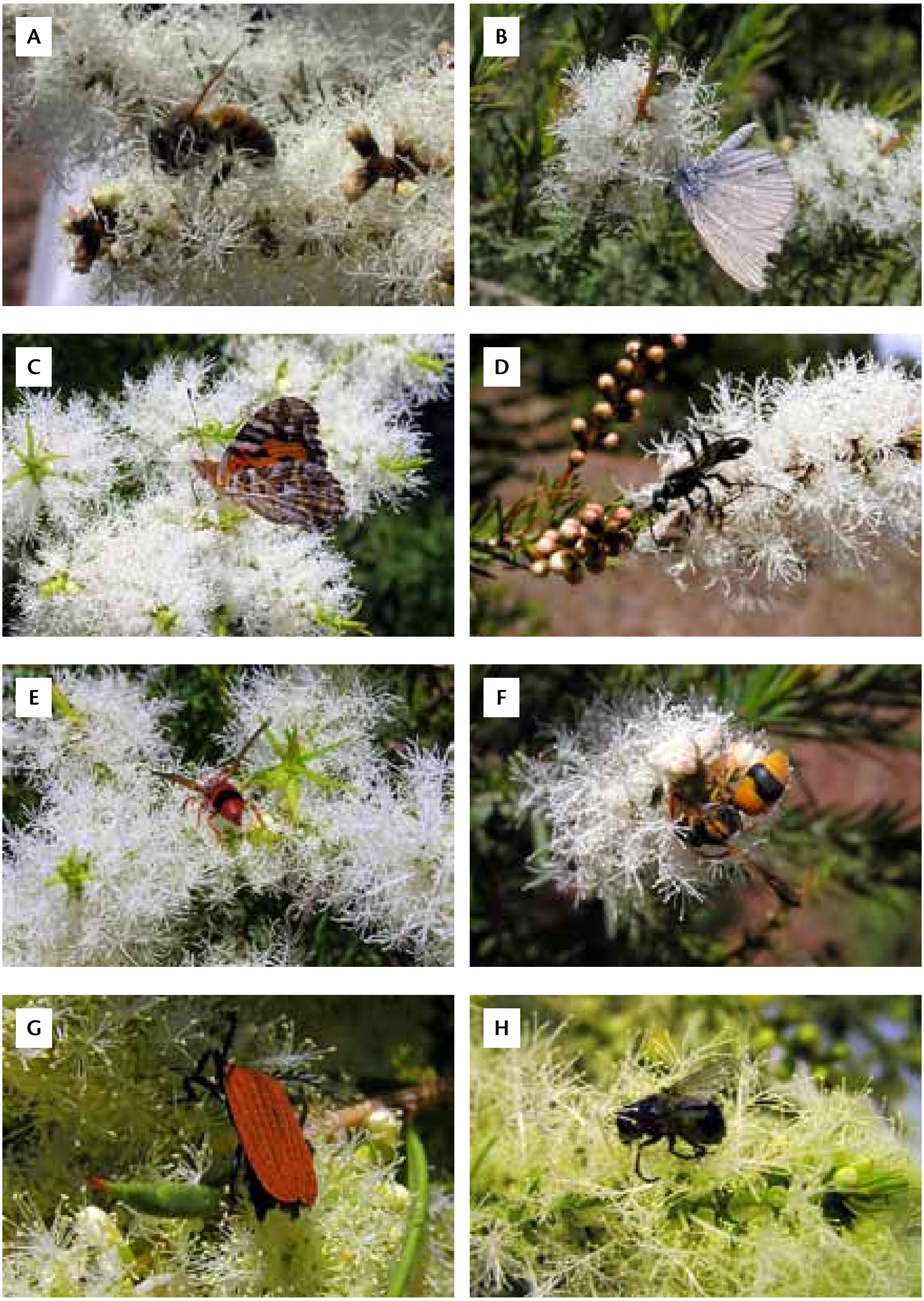

Figure 6. Some of the potential insect pollinators of *Melaleuca alternifolia*: (A) honey bee (*Apis mellifera*); (B) butterfly of family Lycaenidae; (C) butterfly of family Nymphalidae; (D, E) wasps of family Sphecidae; (F) wasp of family Vespidae; (G) beetle of family Lycidae; and (H) fly of family Calliphoridae (Source: Baskorowati 2006)

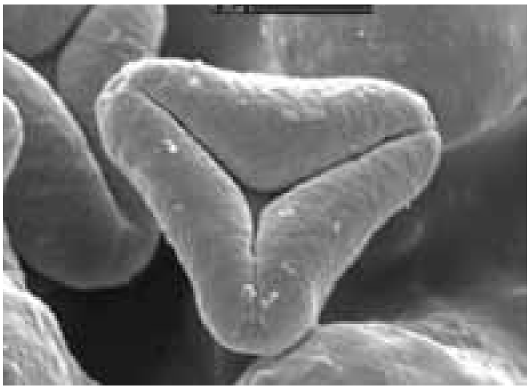

Figure 7. Scanning electron micrograph of *Melaleuca alternifolia* pollen (Source: Baskorowati 2006)

the apocolpial field was not visible or psilate. Some pollen of the former genus *Callistemon* lacked an apocolpial island or had a small irregular polar island, but all other observed species possessed closely fitting apocolpial islands. Overall, pollen length range was 11.0–29.5 µm and the colpus to length ratio range was 26.4–56.8%. Two different pollen types were observed in *Melaleuca* by these authors: those with large apocolpial islands, such as in many species of the *M. leucadendra* complex and former *Callistemon* species; and those with medium-size, syncolpate pollen with faint granulate patterning. The structure of the *Melaleuca* pollen grain, with its lack of sculpturing and its propensity for stickiness and clumping, supports the view that it is mainly dispersed by insects or flying vertebrates.

There is limited published information about pollen viability in *Melaleuca* and its longevity under different storage conditions. A report on viability of *M. cajuputi* subsp. *cajuputi* pollen using an agar medium showed that pollen was highly viable (66%) soon after collection, had 35% viability after 3 months of storage in an airtight bottle in the refrigerator (3–5 °C), but this had decreased to 4% viability after 4.5 months (Hendrati et al. 2002). Baskorowati et al. (2010a, b) found that pollen viability in *M. alternifolia* varied significantly with time (tested at 1, 14, 26, 39 and 52 weeks) and temperature (21–24 °C, 5 °C and –18 °C) of storage. Pollen of this species was still viable after 52 weeks of storage at all temperatures, with storage at –18 °C giving the best results (22%).

Most is known of the sequence of pollen release and stigma receptivity in *M. alternifolia* following the work of Baskorowati et al. (2010a, b, c). Consistent with reports on other *Melaleuca* species (e.g. Barlow and Forrester 1984), there is only slight dichogamy in individual flowers in *M. alternifolia*. The male phase, when pollen is first shed, occurs 1.5 days post anthesis, while the female phase, defined as the period of stigmatic exudate formation, occurs 3–4 days post anthesis. The synchrony of flowering within and between inflorescences on the one tree, the duration of flowering and abundant pollen provide ample opportunity for geitonogamy in the species. Despite this, *M. alternifolia* displays a breeding system that is preferentially outcrossing: Butcher et al. (1992) reported an outcrossing rate of 93% and Rosseto et al. (1999) 86% for *M. alternifolia*. Self-pollination, however, can occur, at least when manipulated. J.C. Doran and G.F. Moran (unpublished report, 2002) reported a selfing rate of up to 28% among progeny of some trees when their flowers were bagged without emasculation. A similar result was reported by Kartikawati (2005) for *M. cajuputi* subsp. *cajuputi* in a seed orchard in Yogyakarta, Indonesia, where a few individual trees in the orchard proved to be self-compatible, although most were found to be self-incompatible. Baskorowati et al. (2010a, b), reported that a self-incompatibility system operates in the style and is complemented by late-acting, self-incompatibility mechanisms discriminating against self-pollen tubes when they descend to the ovary, based on microscopic observation of pollen-tube development in *M. alternifolia* (Figure 8). Barlow and Forrester (1984) also studied self-incompatibility in various *Melaleuca* species, although not in *M. alternifolia*, and found that self-pollen tubes do not penetrate past the base of the style.

Hybridisation

Natural hybridisation in *Melaleuca* appears to be restricted to within groups of closely related species, although there has been anecdotal mention of wider crosses occurring spontaneously in cultivated melaleucas. Hybridisation occurs very widely across the genus and examples noted in both the field and the herbarium have been listed by Craven (2006). In all, over 20 examples are known. It is expected that, as comprehensive DNA studies are undertaken on species complexes within the genus, more will become known as to the extent of past and (relatively) recent hybridisation events.

Natural hybridisation between *M. alternifolia* and *M. linariifolia* has long been suspected in tea tree populations near Port Macquarie, New South Wales. This suspicion has arisen due to the intermediate leaf morphology, the occurrence of transgressive oil components in leaves of the Port Macquarie population of *M. alternifolia*, similarities in oil composition with *M. linariifolia*, and sympatry with *M. linariifolia* (Butcher 1994). Butcher et al. (1995) were able to confirm the hybrid status of the Port Macquarie populations in a study of relationships using chloroplast DNA.

Fruits

The fruit consists of a three-celled capsule within a usually woody to subwoody fruiting hypanthium, which is often cup-shaped but also frequently is described as globular, urceolate, spherical, cylindrical, barrel-shaped, or ovoid; calyx lobes persist in the fruits of some species and are a useful aid to identification. Individual capsules are usually small and not greater than 0.5 cm long × 0.5 cm in diameter, although some are larger. Fruits are subsessile to sessile (e.g. see Figure 5), persistent (partial immersion in the stem is common in southern Australian species) or shedding (fruits of some tropical species ripen and shed in rhythm with the wet season). They are dehiscent and usually many seeded. *Melaleuca alternifolia*, for example, gave from 26 to 57 viable seeds per capsule in a study of variation in this character between individual trees (Baskorowati et al. 2010a, c).

Figure 8. Fluorescence micrograph of pollen tube growth (stained with decolourised aniline blue) in the pistil of *Melaleuca alternifolia*, 4 days after cross-pollination (Source: Baskorowati et al. 2010a)

Seeds

The seed has a membranaceous or rarely coriaceous testa containing an embryo but no endosperm. It is unwinged and small—seeds of 46 largely Western Australian species had a mean length of 1 mm with a range of 0.5–2.0 mm (Sweedman 2006). Seeds are highly variable in shape and in the sculpturing and colour of the seed surface (see scanning electron micrographs in Sweedman 2006).

Typically in melaleucas, as in eucalypts and several other genera of the family Myrtaceae, the fine particles that dehisce from the fruit are a mixture of viable seed and unfertilised ovules/ovulodes commonly referred to as 'chaff'. Because of their similarity in shape, colour and small size in many *Melaleuca* species, it is almost impossible to separate the two by the naked eye and even when employing a microscope and other mechanical aids like winnowing. For this reason, *Melaleuca* seed is usually handled as this mixture where the percentage of viable seeds to chaff may be less than 10% (Rayamajhi et al. 2002). Germination rates for most species are given as viable seed per unit weight of seed and chaff mixture. For example, 27 *Melaleuca* species that have each received multiple (2–33 seed tests per species) four-replicate seed tests over time at the Commonwealth Scientific and Industrial Research Organisation's (CSIRO's) Australian Tree Seed Centre gave an overall average of 3,700 germinants/g of seed and chaff mix with a range of 1,600–6,000 germinants/g. The highest germination rate on record at the Centre was for a seedlot of *M. bracteata* that gave an average of 17,000 germinants/g of seed and chaff mix.

Cotyledons

Cotyledons are planoconvex to obvolute and are not or scarcely foliaceous.

Geographical distribution and ecology

Natural occurrence and ecology

Melaleuca principally is an Australian genus. Eight species, two of which are endemic (*M. pustulata* and *M. virens*), occur in Tasmania; one endemic species, *M. howeana*, occurs on Lord Howe Island in the Tasman Sea; and there are seven endemic species in New Caledonia (*M. brevisepala*, *M. brongniartii*, *M. buseana*, *M. dawsonii*, *M. gnidioides*, *M. pancheri* and *M. sphaerodendra*). Several species of the Australian monsoon-tropical, broad-leaved paperbarks (the *M. leucadendra* group) also occur in adjacent areas of Papua New Guinea; i.e. *M. dealbata*, *M. leucadendra, M. nervosa*, *M. stenostachya*, *M. viridiflora*, with *M. dealbata* and *M. viridiflora* also in Papua province in Indonesia and *M. leucadendra* extending as far as the Maluku Islands of Indonesia. *Melaleuca acacioides* also occurs in southern Papua New Guinea. Two species of the *M. leucadendra* group have a much broader distribution: *M. quinquenervia* extends to Papua province, Papua New Guinea and New Caledonia and *M. cajuputi* occurs from northern Australia through Malesia to South-East Asia. The indigenous western Malesian – South-East Asian populations of the latter species are referable to *M. cajuputi* subsp. *cumingiana* and represent an interesting example of dispersal across Wallacea (Barlow 1988; Lum 1994).

Within Australia, the majority of the species and the greatest phylogenetic diversity occur in the south-western region of Western Australia, especially on the leached north-western and central to southern sand plains, and in the clay soils in the drier eastern region of the south-west. The species distribution maps in the 'Species accounts' (Chapter 7) show some species are widespread within the south-west; presumably these are tolerant of variations in soils, landscapes and climates. One such species is *M. concreta* which, although restricted to the coastal plain country north of Perth, can occur on a wide range of substrates and in different parts of the landscape. Examples of other widespread species in the south-west are *M. carrii* and *M. hamulosa*. On the other hand, species such as *M. agathosmoides* and *M. venusta* are local endemics and probably have highly specific requirements as to soil type and landscape position.

Species richness is shown in Figure 9, and endemism is shown in Figure 10. The Biodiverse software version 0.17 was used to generate the maps (Laffan et al. 2010) and the calculations were based on a 100 km grid. The final maps were then generated using ESRI ArcGIS version 10.0. A continuous gradient from 1 to 72 species is shown in Figure 9 and this map depicts the lowest and highest richness. The endemism map (Figure 10) shows the unweighted endemism score for each grid cell calculated using equation (1).

$$\text{Unweighted endemism} \quad = \sum_{t \in T} \frac{1}{R_t} \tag{1}$$

where t is a taxon in the set of taxa T, and R_t is the global range of taxon t across the dataset (i.e. the number of cells in which it is found)

The number of *Melaleuca* species in south-eastern and eastern Australia is not high, although the phylogenetic diversity may not be greatly lower than that occurring in the south-west of the continent. Of particular note are the bottlebrush species (formerly *Callistemon*) of which about 30 occur in the south-east and east and only four in the remainder of Australia. A few species occur in the arid zone but, in general, *Melaleuca* has not adapted well to very dry regions. Within the monsoonal tropics, members of the broad-leaved paperbark group are often dominant and may be a characteristic feature of the landscape. Several of the larger tree species of this group (*M. argentea*, *M. leucadendra*, *M. nervosa* and *M. viridiflora*) occur across, or nearly across, the whole northern zone.

Ecological notes are provided for each species in the 'Species accounts' (Chapter 7) but a brief overview for the genus is given here. *Melaleuca* species occur in a wide range of habitats (Figure 11). Many species are found in low to tall heathlands and shrublands, and some occur as low shrubs or trees in open eucalypt forests. A few species are found in wetlands, sometimes in open water, and some commonly occur on saline soils. No species are rainforest plants, although some apparently are able to survive encroachment by tropical rainforest, notably the broad-leaved paperbark *M. leucadendra*. The south-eastern and eastern *M. pallida* can occur in wet sclerophyll forest that may be considered temperate rainforest. Because of the range of climates, landscape positions and soil types to which *Melaleuca* species have become adapted, there is good scope for selecting species for trial in many applications, e.g. saline land reclamation, mining rehabilitation and ornamental and amenity use.

Locations of planted forests

Reliable information on plantation areas worldwide by species is largely unavailable. Of the three main commercial species, *M. quinquenervia* is arguably the most widely planted. This species has been planted in numerous countries, including southern Africa, Central America (Costa Rica and Honduras), North America (southern California, Florida, Hawaii, Louisiana and in the extreme south of Texas), India, Fiji, Madagascar, Mexico, northern Nigeria, the Philippines, Puerto Rico and the West Indies (Streets 1962; NAS 1983; Turnbull 1986; Geary 1988; von Carlowitz 1991; CABI 2000; Dray et al. 2006). Two million trees have been planted on State Forest Reserve alone in Hawaii. *Melaleuca quinquenervia* was first introduced into southern Florida in the late 1800s, where it escaped cultivation on seasonally wet sites and has assumed weed status (NAS 1983). It occurs now on more than 200,000 hectares (ha) of wetlands in southern Florida (Turner et al. 1998).

Melaleuca cajuputi subsp. *cajuputi* has been planted since 1926 for oil production in central Java, Indonesia, using seed originally imported from the Maluku Islands. The extent of government-owned plantations on Java is in the order of 20,000 ha (Anto Rimbawanto, pers. comm. 2012). It has been widely planted also in Malaysia and Vietnam. *Melaleuca leucadendra* is a relatively underutilised species. Most reports of plantings of this species in Africa, America and Asia refer to arboretum or trial plantings rather than broad-scale plantations. The substantial literature on the cultivation of '*M. leucadendron*' (e.g. see

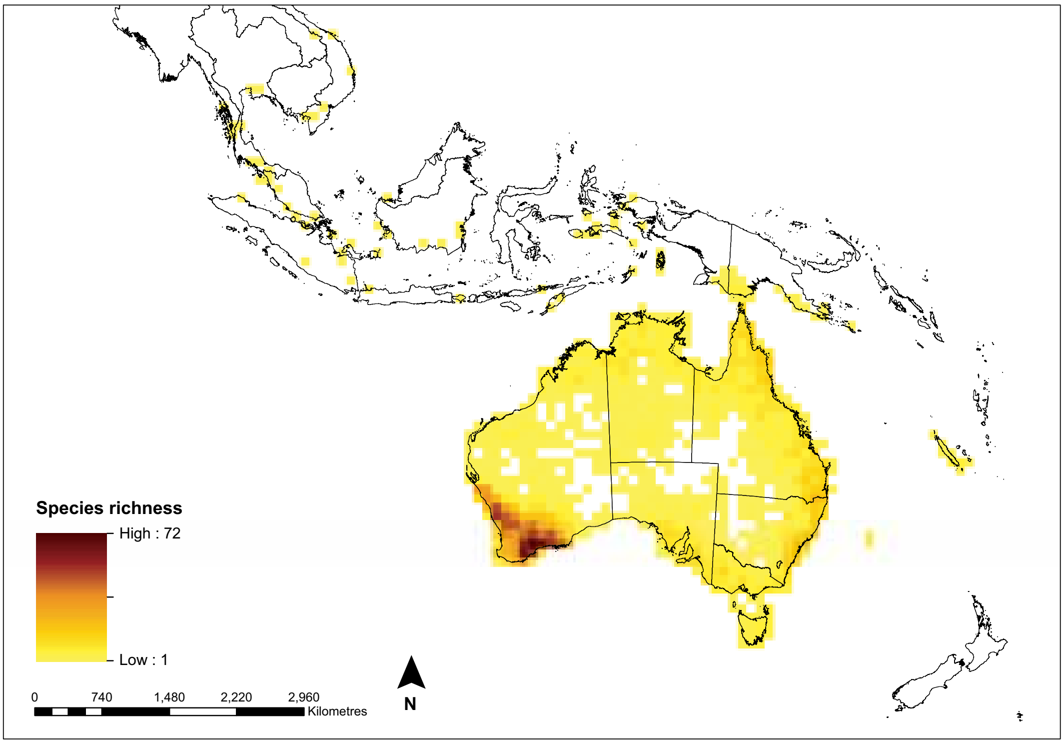

Figure 9. *Melaleuca* species richness calculated using a continuous gradient from 1 to 72 species

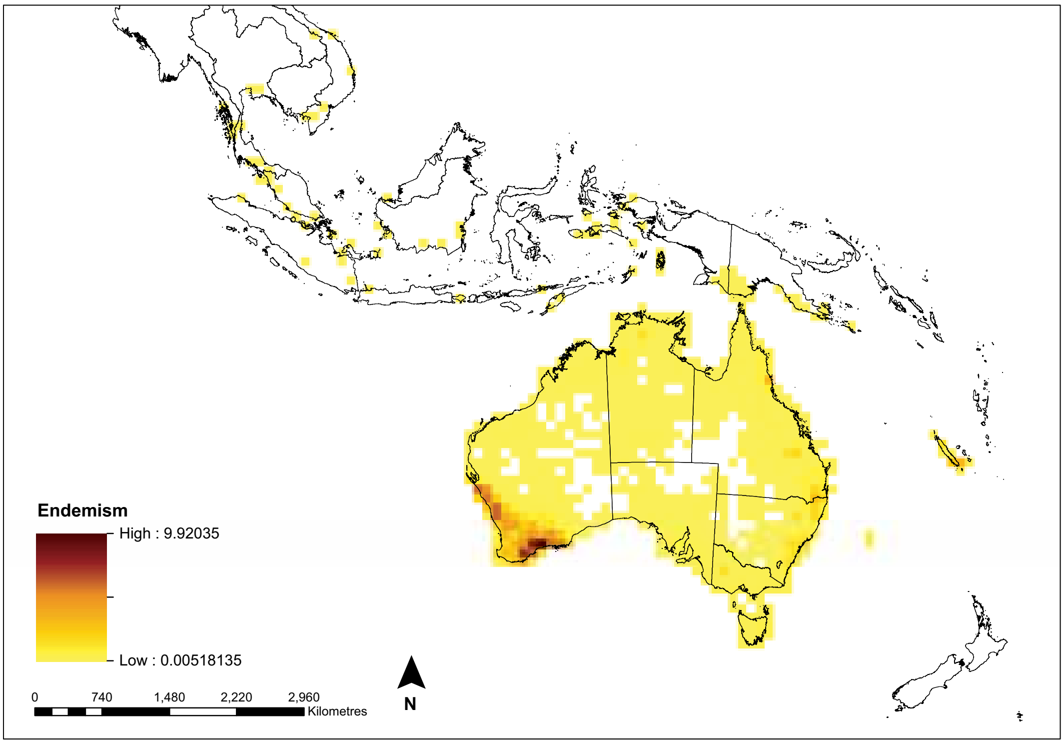

Figure 10. *Melaleuca* endemism. The greatest endemism occurs in the south-central coastal region of Western Australia with some moderately strong areas of endemism in the north-western part of the south-west. There are some lesser areas of endemism in eastern Australia.

Fenton et al. 1977), particularly in South-East Asia and USA, can be ascribed to *M. cajuputi* and *M. quinquenervia* and not *M. leucadendra*. Most current interest in the species for plantation establishment is in the Mekong Delta of Vietnam, where *M. leucadendra* outperforms the indigenous *M. cajuputi* subsp. *cumingiana* on seasonally inundated and potentially acid-sulfate sites which are very difficult for tree establishment (Hoang Chuong et al. 1996).

Melaleuca alternifolia is planted for the production of essential oil in Australia—3,000 ha producing 450–500 tonnes (t) of essential oil/year—but the total area planted and the total production worldwide is potentially twice this from plantings outside Australia in several countries, including China. Broombush (*M. uncinata* complex) plantings in Australia for brushwood fencing and related products exceed 1,000 ha.

There are extensive, but largely undocumented, plantings of melaleucas as ornamentals, street and public park trees, shelterbelts on farms and for land reclamation in Australia and elsewhere.

Tolerance of difficult conditions

As well as being tolerant of periodic (Figure 12) or even continuous waterlogging, many of the wetland melaleucas will also survive and grow in moderately to highly saline soils (e.g. *M. armillaris*, *M. bracteata*, *M. cuticularis*, *M. decussata*, *M. ericifolia, M. lanceolata*, *M. lateriflora*, *M. leucadendra*, *M. linariifolia*, *M. quinquenervia*, *M. squarrosa*, *M styphelioides* and the *M. uncinata*

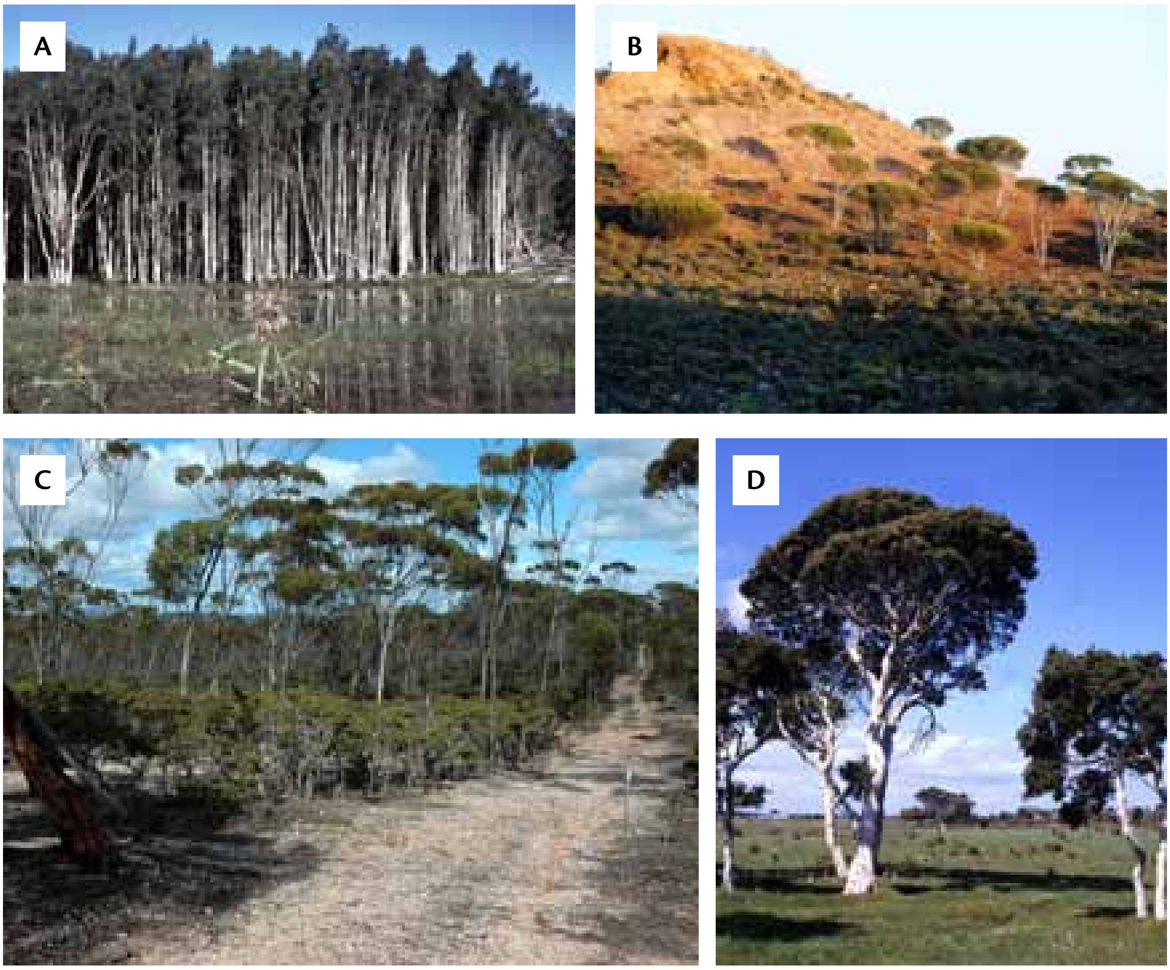

Figure 11. Some of the variable habitats occupied by *Melaleuca* species: (A) a pure stand of tree-form *M. quinquenervia* in a coastal swamp in eastern Australia; (B) the shrub *M. protrusa* on a dry stony hillside in south-western Western Australia (WA); (C) shrubby *M. sophisma* under an overstorey of mallet in south-western WA; and (D) trees of *M. cuticularis* on the edge of a wet, possibly saline area in south-western WA

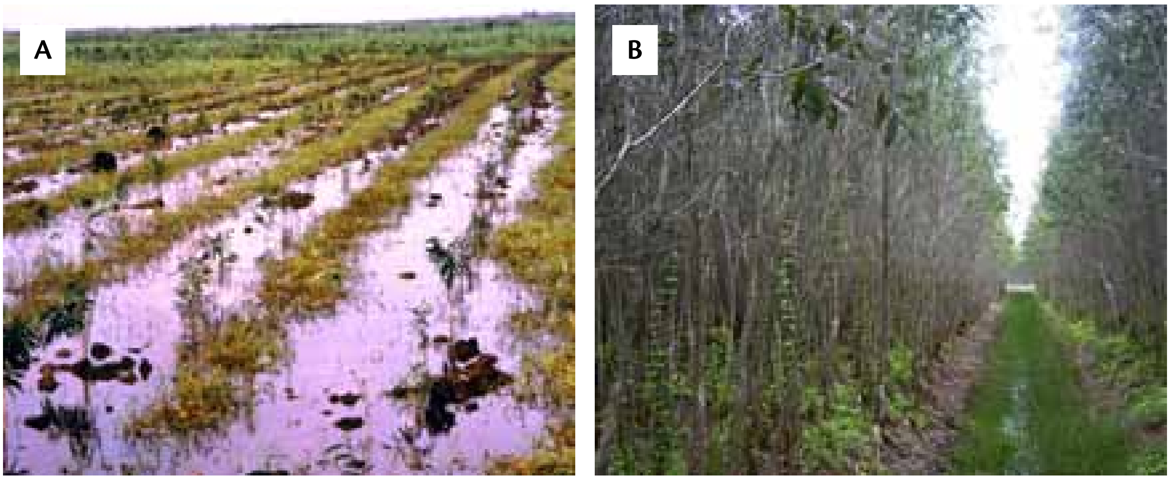

Figure 12. *Melaleuca cajuputi* surviving and growing under seasonal inundation in the Mekong Delta of Vietnam: (A) a young planting as the inundation recedes; and (B) a dense plantation nearing rotation age

complex). A few melaleucas are tolerant of extremely saline conditions (e.g. *M. halmaturorum* and *M. thyoides*). Many of these same species are also tolerant of alkaline soils, drought and frost (Marcar et al. 1995; Marcar and Crawford 2004).

Melaleucas appear to employ a diverse range of physiological strategies to adapt to difficult growing conditions. For example, Naidu et al. (2000) found that species with the capacity to accumulate one or, preferably, more of the methyl prolines in their leaves were better adapted to saline and/or sodic soils than species that accumulated only L-proline. This was the case with *M. cuticularis*: Carter et al. (2006) found that the ability of this species to tolerate saline-waterlogged conditions was related to production of methyl proline, as well as regulation of foliar sodium, chloride and potassium concentrations. Ionic stress and the differential ability of seedlings of *M. leucadendra* provenances to adjust for a declining potassium concentration in leaf sap under combined salt and aluminium stress was thought to be the main cause of variation in growth of 16 *M. leucadendra* provenances in a glasshouse trial (Nguyen et al. 2009). Mensforth and Walker (1996) found that the root dynamics of *M. halmaturorum* in response to fluctuating saline groundwater contributed to the survival of this species in saline swamps. *Melaleuca halmaturorum* accessed water from deep in the profile in late summer when salt had accumulated in the surface soils and used rainfall and shallower groundwater after winter rains had replenished the profile. The ability of this species to take up water from saline substrates through maintenance of low leaf water potentials was also a contributing factor (Mensforth and Walker 1996).

Some wetland melaleucas, like the tropical *M. leucadendra* group, develop aerial adventitious roots on their stems and within the papery bark to the height of the maximum water level during flooding (Figure 13). These are dense in aerenchyma cells which have large intracellular air spaces that improve internal root aeration and gas exchange during inundation. The fine adventitious roots on the stems of *M. quinquenervia* in a seasonally inundated forest in northern Queensland, for example, were considered an important part of the reason that transpiration in this species was unaffected by inundation of up to 24 weeks (McJannet 2008). In *M. cuticularis*, they appear to contribute to this species' enhanced tolerance to combined salinity and waterlogging (Carter et al. 2006). Tanaka et al. (2011) reported that seedlings of *M. cajuputi* in the tropical peat swamps of southern Thailand were able not only to survive complete submergence for 8 weeks but also to photosynthesise and grow during this period. This was due to the strong development in the leaves and stems of submerged seedlings of schizogenously formed aerenchyma which improved uptake of gases from the water.

Many melaleucas are highly fire-tolerant during all but the early seedling stages before a thick protective layer of bark has formed. Fire-ravaged individuals regenerate through stimulation of epicormic buds under the thick bark to sprout vigorously after fire in a process called coppicing (Figure 14). Populations may expand through fire-induced release of seed from serotinous capsules on the trees and stimulation of germination of seed in soil seedbanks.

Some melaleuca species have the ability to root sucker, and through root extension and interconnectivity form

Figure 13. Aerial adventitious roots on the stems of: (A) *Melaleuca quinquenervia* growing naturally in a seasonal swamp beside the Bensbach River, Western Province, Papua New Guinea; and (B) *M. leucadendra* planted in the Mekong Delta, Vietnam

dense clumps of single clones. This is a common adaptive characteristic of wetland plants subject to very difficult conditions for survival, growth and sexual recruitment (see review in Robinson et al. 2012). Using DNA markers, Robinson et al. (2012) showed that the large, dome-shape stands of *M. ericifolia* in Dowd Morass, Gippsland Lakes, Victoria, were individual clones that did not intermingle (phalanx growth habit) with adjacent clones. They speculate that this is also the case with other stands of this species in southern Australia. *Melaleuca viridiflora* also forms root suckers. Crowley et al. (2009) showed that population density of this species increased dramatically in grasslands and grassy woodlands in northern Queensland in the absence of fire by recruitment of suckers to the sapling layer.

Figure 14. Western Australian broombush, *Melaleuca concreta*, coppicing after fire

3 Uses

Ethnobotanical

Some *Melaleuca* species were used extensively by the Aboriginal peoples of Australia for a wide variety of cultural uses (refer to Williams 2011 for a description of 17 species used by Aboriginal communities).

The papery bark of several, mainly tropical, melaleucas (e.g. *M. argentea*, *M. dealbata*, *M. cajuputi*, *M. leucadendra* and *M. viridiflora*) had many domestic uses, including water-repellent roofing material, raft-making, in food preparation, bandages, blankets, baby slings, body wraps in burial ceremonies and for dresses denoting marriage, to name but a few (Levitt 1981; Wrigley and Fagg 1993; Yunupingu et al. 1995; Blake et al. 1998; Puruntatameri et al. 2001; Wiynjorrotj et al. 2005; Williams 2011; Wiersema and León 2013). The leaves of species such as *M. acacioides*, *M. argentea* and *M. leucadendra* were used as flavouring in cooking and *M. argentea* leaves were burnt to repel mosquitoes. The trunks of some species (e.g. *M. cajuputi*, *M. leucadendra* and *M. viridiflora*) were used for construction of canoes and shields.

'Bee bread' (produced from pollen) and honey were foods collected from native bee hives prevalent in *Melaleuca* swamp forests of *M. acacioides*, *M. lasiandra*, *M. leucadendra*, *M. minutifolia, M. nervosa* and *M. viridiflora* in northern Australia (Williams 2011). Williams (2011) also notes reports of early explorers (e.g. Leichhardt in 1847 and Mitchell in 1848) in northern Australia of the collection by Aboriginal peoples of melaleuca honey and melaleuca flowers (e.g. from *M. saligna*). The latter were soaked in water to produce a sweet-tasting drink.

Melaleucas were an important source of dry-season water for the nomadic Aboriginal peoples (and early European explorers), particularly in the wet/dry tropics of northern Australia. Bulges in the trunks of individual trees of such species as *M. argentea*, *M. cajuputi*, *M. dealbata*, *M. nervosa* and *M. viridiflora* when undercut could yield about a litre of brackish but nevertheless potable water (Yunupingu et al. 1995; Puruntatameri et al. 2001; Wiynjorrotj et al. 2005; Williams 2011).

Melaleucas played an important role in traditional Aboriginal medicines. The leaves and inner bark of *M. argentea* and others like *M. cajuputi* and *M. leucadendra* were used medicinally (coughs and colds, aches and pains, cuts and sores, ringworm, vomiting and diarrhoea and other malaises), either directly following crushing or burning (smoking medicine) and inhaling the odours or as a liniment or drink after soaking the leaves or inner bark in water and heating (Blake 1968; Levitt 1981; Aboriginal Communities of the Northern Territory 1993; Wrigley and Fagg 1993; Yunupingu et al. 1995; Puruntatameri et al. 2001; Wiynjorrotj et al. 2005; Lassak and McCarthy 2011; Williams 2011). The bark of some melaleucas was used as a poultice on wounds and for splinting broken bones, where the juice of the bark was said to penetrate the skin and aid in healing (Williams 2011). The milky extract of squashed 'bee brood' (bee pupae and larvae) collected from native beehives prevalent in melaleuca swamp forests was used as a topical antiseptic for sores, tinea and eye complaints (Williams 2011).

Ornamental, landcare, honey, bark and wood

Ornamental and amenity–horticultural use

Melaleuca species, especially the bottlebrushes, have long been popular garden subjects in Australia. The first Australian melaleucas to be cultivated, however, were grown in Europe, presumably from seed taken to England in 1771 by Joseph Banks. *Melaleuca armillaris*, *M. decora*, *M. ericifolia*, *M. hypericifolia*, *M. nodosa*, *M. styphelioides* and *M. thymifolia* were in cultivation by 1793 (Elliot and Jones 1993; Wrigley and Fagg 1993). Seed and/or transplants of the bottlebrush species *M. citrina* and *M. linearis* also were taken to Europe in the late 1700s and these species rapidly became popular conservatory plants. *Melaleuca citrina* was in fact named and described (as *Metrosideros citrina*) in 1794 from material cultivated in England and *M. linearis* was described in 1796 from material cultivated in Germany.

Many species (including cultivars derived from selection or from interspecific hybrids) are hardy in cultivation in Australia (Elliot and Jones 1982, as *Callistemon*; Elliot and Jones 1993; Wrigley and Fagg 1993, also as *Callistemon*; Holliday 2004; Stewart 2012, also as *Callistemon*). Some tolerate moderate levels of frost and others grow well in poorly drained soils. Because there are species of diverse habit, flower form and colour, and substrate preference in most of the major climatic zones within Australia, it is possible to select a species for a specific purpose, e.g. for a hedge, windbreak, specimen shrub or tree. Several species have particularly attractive papery bark and are worth cultivating for this feature. Several of the larger shrub and tree species are ideal for amenity plantings as street trees, screens for industrial sites, highway verges and so on. Many of the tree species are ideal for use in parks and large-scale landscape applications. The trees that have colourful, nectariferous flowers (Figure 15) usually attract nectar-feeding birds if these occur in the region.

There are surprisingly few melaleuca cultivars available in the horticultural industry in Australia and most, if not all, of these are selections of species. The bottlebrushes are an exception. Barriers to successful hybridisation between certain species apparently do not exist and, when grown in a common garden, bird- or insect-mediated hybridisation has resulted in the occurrence of hybrid plants. In many cases, selections have been named and propagated commercially. The following species (as *Callistemon*) have been recorded as being a parent, or putatively a parent, of named cultivars: *M. citrina*, *M. comboynensis*, *M. glauca*, *M. pachyphylla*, *M. phoenicea*, *M. polandii* (doubtfully this species and more likely to have been *M. hemisticta* or *M. pyramidalis*), *M. recurva*, *M. salicina*, *M. subulata* and *M. viminalis* (Elliot and Jones 1982; Wrigley and Fagg 1993). Much more

Figure 15. Ornamental melaleucas: (A) *Melaleuca ryeae,* a shrub with profuse pink flowerheads; and (B) *Melaleuca* cultivar 'Harkness'

work needs to be done as far as bottlebrush breeding is concerned. There is considerable opportunity for breeders to select growth and colour forms of species and cross them with an aim of obtaining a particular combination of characters. The two broad climatic zones that should be targeted for such hybridising endeavours are the tropical–subtropical and subtemperate zones in Australia and elsewhere.

As to other species groups within the genus, it seems there have been no hybridisation programs. The field is open for such programs to be initiated. The pom-pom-flowered *M. scabra* group is an obvious candidate as there is much variation within this group that could be bred into novel, improved garden plants. Although many of the species of the *M. scabra* group occur on leached, sandy soils, some of them occur on clay soils and these species may confer some degree of soil adaptability to hybrids. *Melaleuca nesophila*, an *M. scabra* group species of restricted range and habitat in the high rainfall, coastal part of south-western Western Australia, is remarkably hardy and grows well on heavier soils in the dry Western Slopes region of New South Wales. Using species such as *M. carrii*, *M. fabri*, *M. hamata*, *M. nematophylla*, *M. nesophila*, *M. oldfieldii*, *M. sapientes* and *M. systena*—and there are many others—it may be possible to develop hybrids of merit for Mediterranean and dry-temperate climates.

Another group with potential as garden plants is the *M. fulgens* group, and a hybridisation program involving such species as *M. coccinea*, *M. elliptica*, *M. eximia*, *M. fulgens*, *M. lateritia* and *M. macronychia* may result in a series of red- to orange-red-flowered, bushy plants to rival the bottlebrushes, as the species of the *M. fulgens* group also have bottlebrush inflorescences. Naturally occurring hybridisation in *Melaleuca* has been reported from a wide range of species (Craven 2006, p. 470) and it seems barriers to hybridisation within a species group or species complex are not absolute; in fact, where two or more species of the same group occur in biotic sympatry, hybridisation may be frequent.

An interesting application is the use of melaleucas as bonsai (known as *penjing* in China and *cay canh* in Vietnam). Bark texture, small leaves and flowering propensity are some of the criteria by which species are rated. Over 60 species, varieties and cultivars of *Melaleuca* have been recorded by the Australian Plants as Bonsai Study Group as being grown in bonsai within Australia (Roger Hnatiuk, pers. comm.). Early use of melaleucas tended to mimic the styling of classic Japanese trees but in recent years bonsai artists are exploring the beauty of branches and crowns of old mature trees of the species found growing in nature. Bonsai, inspired by such forms, are beginning to be seen in public displays (Figure 16).

Notes on species of particular, or potential, value for ornamental and amenity–horticultural use are provided in the 'Species accounts' (Chapter 7). The main impediment to their wider use within Australia and elsewhere is the difficulty in obtaining planting material of superior colour and growth forms of the species, or forms from particular soil types.

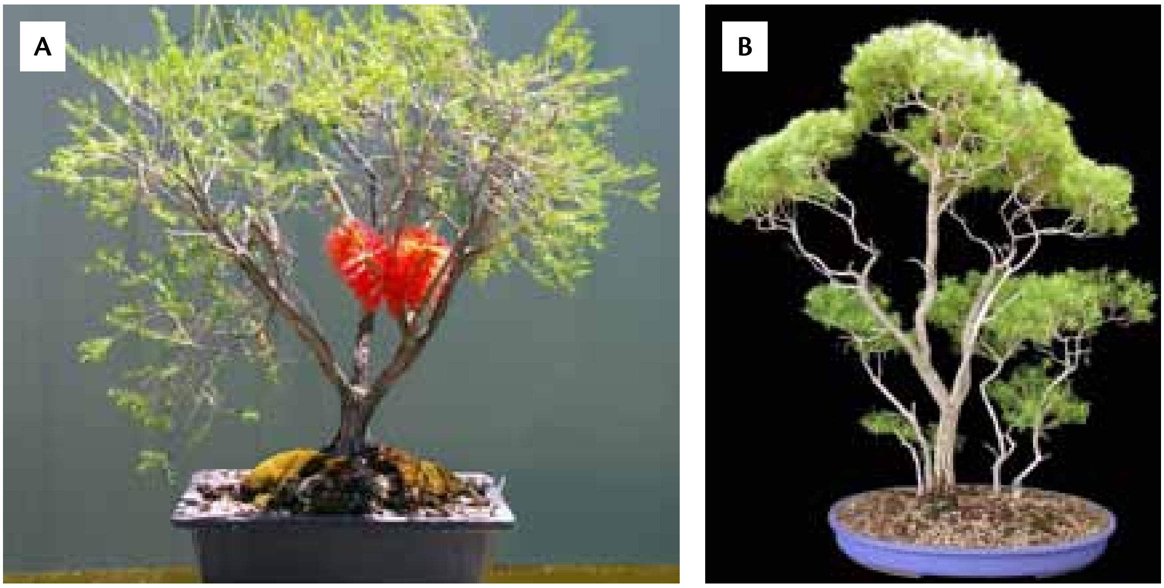

Figure 16. Examples of bonsai melaleucas: (A) *Melaleuca lateritia,* usually a 2–3 m tall shrub from south-western Western Australia; and (B) *M. bracteata,* usually a medium-size tree up to 22 m tall from inland and coastal northern Australia

Land rehabilitation

Melaleuca comprises many species of trees and shrubs that are hardy and adaptable to a wide range of habitats and soils. They regularly occupy sites that are very challenging for tree survival and growth (Figure 17), as discussed in other sections of this volume. Their diversity in form, adaptability and utility sees them listed prominently among candidate species for planting for land reclamation, with natural resource benefits including mitigation of salinity, waterlogging, and water and wind erosion. Biodiversity improvements, carbon sequestration and potential to increase farm income (e.g. through production of brushwood fencing, essential oils and bioenergy) are among other commonly stated benefits of planting melaleucas on degraded lands.

Highly topical at present is the increasing problem of saline landscapes in Australia and elsewhere. There are over 4 million ha of secondary or human-induced saline soils in Australia, in addition to 29 million ha of naturally

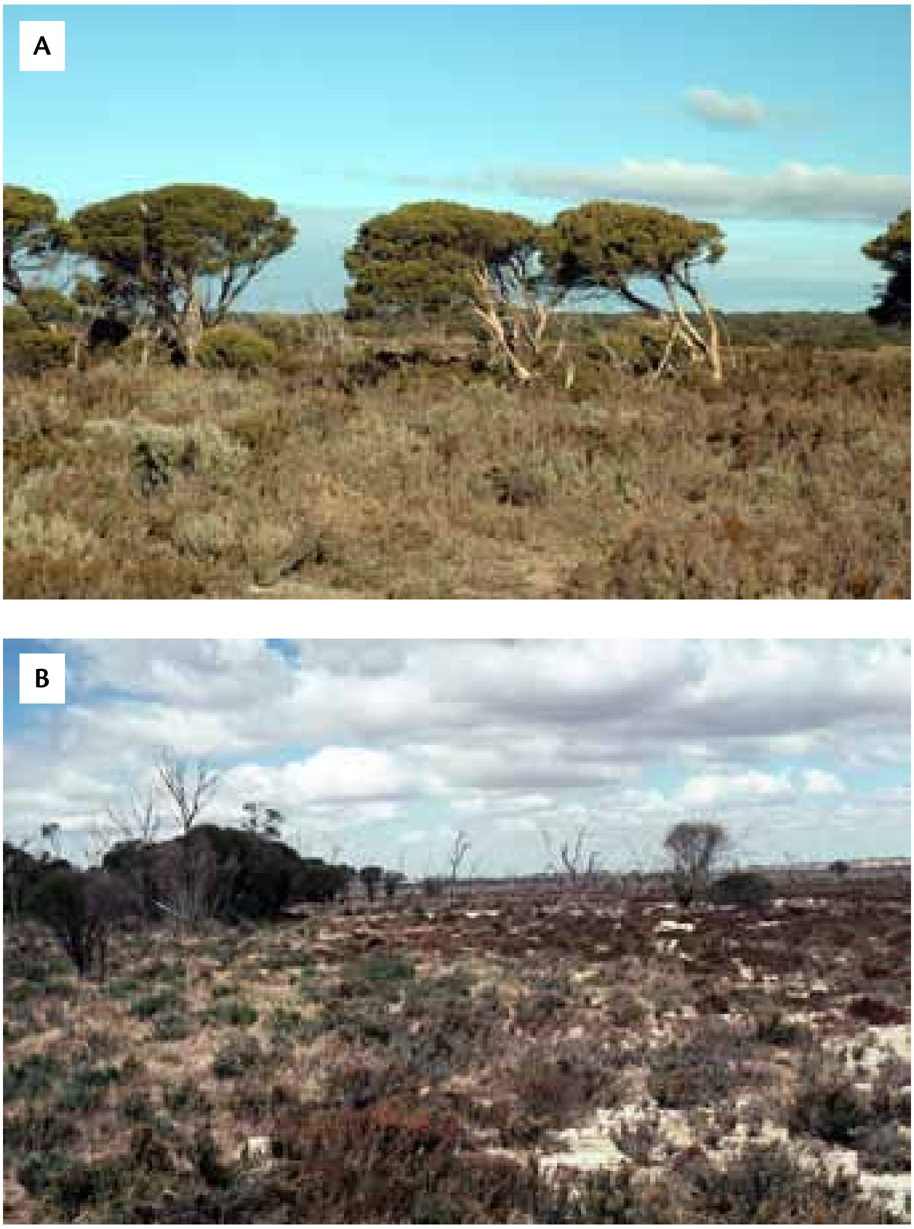

Figure 17. Salt-tolerant melaleucas: (A) *Melaleuca halmaturorum* on a saline site in southern Australia; and (B) *M. atroviridis* surviving on the margin of an area severely affected by secondary salinity in south-western Western Australia

occurring salt-affected lands (Marcar and Crawford 2004). The removal of native vegetation and development of annual agricultural systems in southern Australia, leading to rising watertables carrying soil-borne salt to the surface, are major contributors to salinisation of landscapes. Restoration of deep-rooted perennial vegetation can make a significant contribution to correcting this problem but it needs to be on a large scale to control salinity (Pannell and Ewing 2004). A range of *Melaleuca* species is suitably adapted to grow on saline sites (e.g. Figure 17), ranging from moderately (4–8 dS/m ECe) to extremely saline (>16 dS/m ECe) (Marcar et al. 1995; Department of Agriculture and Food Western Australia 2004; Marcar and Crawford 2004).

Melaleuca halmaturorum is an example of a temperate *Melaleuca* tree/shrub adapted to extremely saline conditions, while *M. leucadendra* is among the tropical tree-form melaleucas adapted to highly saline conditions. Both species are tolerant of waterlogging. Unfortunately, few of the presently recognised salt-tolerant melaleucas offer scope to growers for direct financial benefits, thus large-scale planting is not attractive. *Melaleuca uncinata*, one of the source species for brushwood (see below), and its relative *M. atroviridis*, are two exceptions. *Melaleuca bracteata* might have potential in the future if an industry were to develop around the production of betaines from its foliage.

Brushwood fencing and related products

Ornamental brushwood fencing comprising the grey stems, twigs and dry foliage of the *M. uncinata* complex of species (broombushes), hand-packed on wires in situ or, in more recent times, prefabricated in panels, has been in use in Australia for more than 80 years (McKelvie et al. 1994) (Figure 18). It represents an important market for melaleucas, despite its small size compared with alternative fencing materials (e.g. 1% of the fencing market in Western Australia). Other uses of brushwood include manufacture of garden furniture, gazebos, pergolas, gates, hanging baskets and decorative bird feeders (Robinson and Emmott, no date). McKelvie et al. (1994) indicated that about 600,000 bundles of brushwood (each c. 25 kg, consisting of stems with foliage of 1.4–1.8 m in length and 7–15 mm in diameter) were used in Australia each year, with predicted annual market growth of 5.5%.

Melaleuca uncinata is the most common broombush used for brushwood fencing. It is widespread in southern Australia, mainly south of the Tropic of Capricorn. *Melaleuca uncinata* is a hardy, bushy shrub to 7 m in height with multiple long, thin, woody erect stems topped with foliage (broom-like). It is adapted to a wide diversity of habitats and soils, mainly in semi-arid and arid Australia (see range given in its species description). Other broombushes in the *M. uncinata* complex having potential for brushwood fencing are the Western Australian endemics *M. atroviridis*, *M. concreta*, *M. hamata* and *M. osullivanii* (Robinson and Emmott, no date). *Melaleuca acuminata* and *M. hamulosa* are also worth trialling as alternative species as they have similar physical characteristics to the traditionally used *M. uncinata* (Peter White, pers. comm. 2012).

Until recent times, all harvesting of brushwood has been in native stands and producers are licensed by the various state governments. Overall, 50–70% of plants are harvested manually of which 90% can be expected to coppice in a typical bush operation based on a broombush population of about 3,000 plants/ha. This yields between 3–6 t product/ ha. The interval between harvests is 10–14 years (Wrigley and Fagg 1993). Concerns about adverse environmental effects have seen the gradual withdrawal of public lands from resources available for harvesting and concerns have arisen about the sustainability of brushwood supply from native stands. The likely direct economic benefits, complemented by the indirect benefits of establishing broombush on private lands for purposes such as shelter, salinity control, soil erosion control, biodiversity and diversification of farm income, have led to interest among some landholders in the drier regions of the southern states in developing commercial plantations of broombush. It is estimated that a total plantation area in the order of 2,000–2,500 ha would be required to fully meet demand on a sustainable basis (Cameron 2003; AVONGRO 2007). The total area planted is not known but about 900 ha had been planted in the Avon catchment area of Western Australia alone by 2007 (AVONGRO 2007).

Various landcare agencies in Western Australia, South Australia and Victoria have published informative ‘fact sheets’ on growing broombush by either direct seeding or planting tube stock and readers interested in this topic are directed to these for detailed information (e.g. Bulman et al. 1998; Cameron 2003; Robinson and Emmott, no date). Until recently, broombush was regarded as being a single species, *M. uncinata*. It is now known that there are several species involved (Craven et al. 2004), a number of which are suitable for brushwood production as mentioned above.

Honey

Most melaleucas do not provide major honey crops. Clemson (1985), however, pointed out that many species assist indirectly with honey production by providing nectar and pollen, especially nectar, in sufficient quantities to stimulate brood-rearing and sometimes for use as stores. In this way, colonies are maintained and built up for subsequent major honey flows in other taxa.

Those which are important honey producers include the broad-leaved melaleucas. *Melaleuca quinquenervia* is a major source of honey in Australia and Florida (Blake and Roff 1972; Robinson 1981; Clemson 1985; Geary 1988) and similarly *M. cajuputi* in northern Australia and Vietnam (Brock 1988; Mulder 1992). *Melaleuca leucadendra* is also said to be an important source of honey in its area of natural occurrence (Roff 1966; Anderson 1993). The honeys from these species are variously described as light to dark amber in colour, with strong flavour and odour and of low density so they granulate readily. Their pollens are universally described as being a good source of protein utilised by bees in building up colonies.

Bark

The bark of *Melaleuca* species is still used today in the construction of traditional houses in Papua New Guinea. It is used to line fernery baskets, for making bark paintings and the cork from the bark has been used in infants' pillows and mattresses (Bootle 1983). The bark of *M. cajuputi* is used in parts of Malaysia as a luting material in boatbuilding (Lum 1994; Lim and Midon 2001).

Wood

Fuelwood

There is little reported on the fuelwood value of individual species in the genus *Melaleuca*. Apart from the statement in Maiden (1889) that *M. linariifolia* wood made

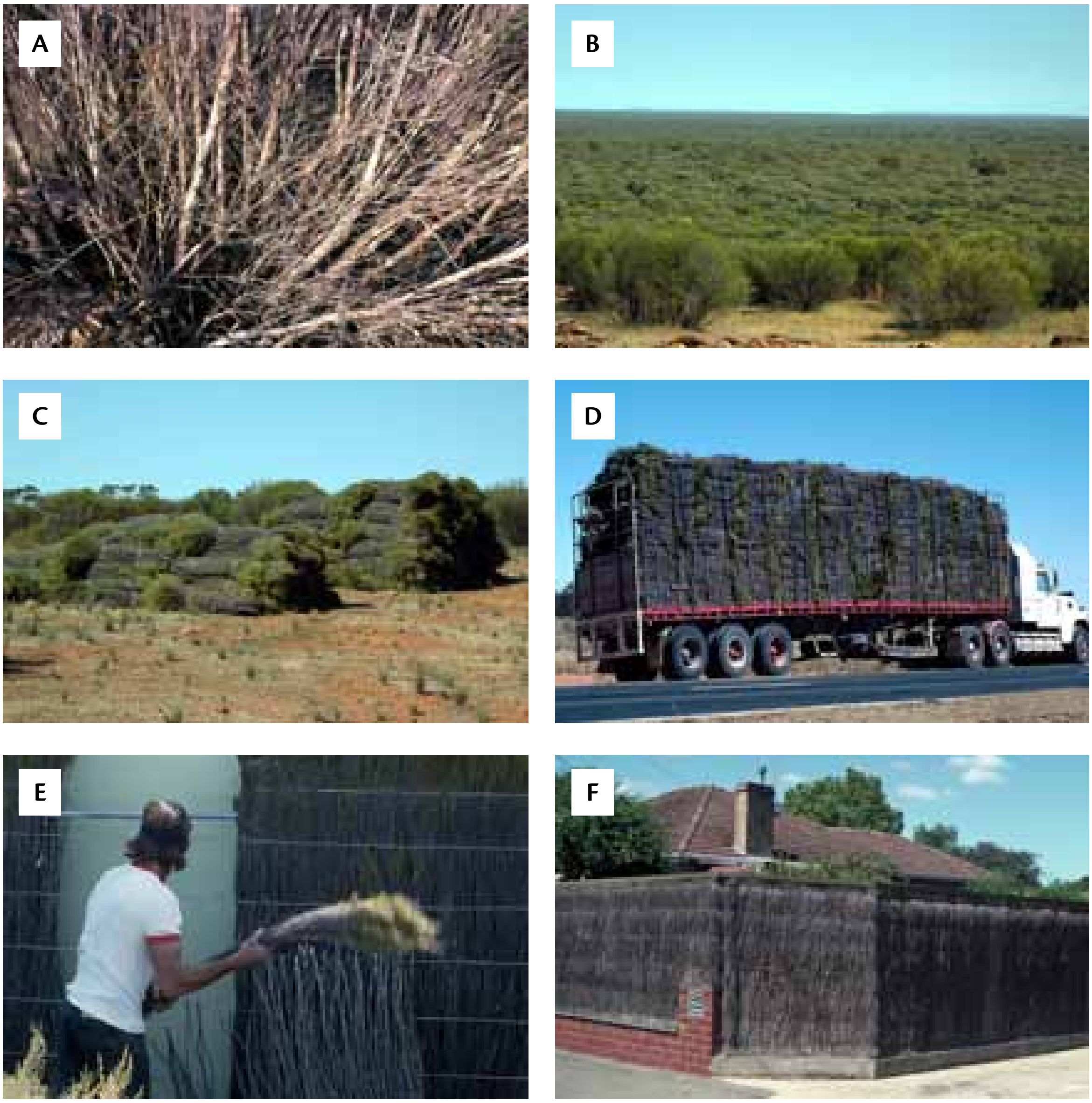

Figure 18. Facets of the brushwood fencing industry: (A) the multistemmed habit of species in the broombush complex (this is *Melaleuca stereophloia*); (B) a native broombush (*M. uncinata*) population; (C) broombush bundles in the field ready for transport; (D) transporting the bundles to market; (E) constructing a brushwood fence in situ; and (F) a typical brushwood fence

a first-class fuel, most published reports of the fuelwood value of melaleucas refer to the larger-growing species in the tropical broad-leaved *M. leucadendra* group. The wood of *M. quinquenervia*, for example, is reported to be an excellent fuel and converts into good-quality charcoal. The reported calorific values for the wood and bark of this species are around 18,400 and 25,800 kJ/kg (4,400 and 6,160 kcal/kg), respectively (Wang et al. 1981), but there is great variability in these values between trees (Wang and Littell 1983). The uniquely high heat of combustion of *M. quinquenervia* bark (equivalent to some coals) is due to the presence of a great amount of fatty substances in the bark (Wang et al. 1982). Keating and Bolza (1982) rated *M. cajuputi* and *M. leucadendra* as good fuelwoods, although often difficult to split because of interlocking grain. Gough et al. (1989) reported that the light wood of *M. leucadendra* was quick to ignite, with sooty acrid smoke initially produced from the burning bark.

Posts, poles, stakes and sticks

The stems of the larger melaleucas like *M. cajuputi*, *M. leucadendra, M. quinquenervia* and many other species were regularly used in the round or roughly fashioned for use as posts, poles, piles, mine timbers and general construction materials (e.g. rafters for huts, fencing rails) in the early days of settlement in Australia (Maiden 1889). Posts were said to be durable in contact with fresh or salt water (e.g. *M. cajuputi*, Blake 1968), although Cherrier (1981) reported that durability of untreated *M. quinquenervia* posts in the ground was high for 1 year but declined thereafter, and replacement was necessary after about 3 years. In present-day Vietnam, there is widespread use of the roundwood of the indigenous *M. cajuputi* and the introduced *M. leucadendra* for piles, poles and general construction materials (Figure 19).

A specialised industry exists in Western Australia to supply sticks for use in the lobster-fishing and vegetable-growing industries (Peter White, pers. comm. 2012). Although other myrtaceous species may be used, such as *Kunzea* sp., sticks derived from natural stands of *M. viminea* are preferred due to their greater durability. It is believed that lobsters enter pots made from natural materials more readily than they do pots made from synthetic substances. In recent years, about 1.2 million *M. viminea* sticks/year have been used in making lobster pots. Additionally, large numbers of *M. viminea* stakes are used each year in the vegetable-growing areas of the Gascoyne region for supporting climbing beans. Presently, these markets are supplied from natural stands but it may be that, in the future, the supply of sticks and stakes could be augmented from plantation sources.

Sawn wood

The wood of the broad-leaved paperbarks *M. cajuputi*, *M. leucadendra*, *M. quinquenervia* and *M. viridiflora* has yellowish sapwood, merging gradually into pinkish-brown/red/grey heartwood. It has a high silica content (0.2–1.0%) which blunts saws and planes. It is hard, heavy and of moderate strength, with wood from native trees giving a green density of c. 1,070 kg/m^3 and an air-dry density of c. 750–800 kg/m^3 (Keating and Bolza 1982; Bootle 1983). Florida-grown wood of *M. quinquenervia* has a basic specific gravity of 0.49, a density of 1,070 kg/m^3 (green), 640 kg/m^3 (air-dry) and 620 kg/m^3 (oven-dry) (Huffman 1981). Collapse is slight, with shrinkage about 3.5% radial and 7% tangential (Bootle 1983). Sawn timber tends to check and warp but, if carefully seasoned, it is suitable for general construction and flooring. Boards are difficult to plane and mortice due to interlocking grain but glue well and are good for joinery. Boat knees can be cut from branches using their natural shape.

Figure 19. Production and marketing *Melaleuca* poles and piles in Long An province, Vietnam: (A) harvesting and loading poles onto a barge for transport to market; and (B) stacks of melaleuca poles at a roadside market

Woodchips

Vietnam is the main producer of *Melaleuca* woodchips for use in fibreboard production. In 2010, 100,000 t (bone-dry) of *Melaleuca* woodchips were exported from Vietnam to China, presumably for this purpose. Presently, there are well-advanced plans to establish a medium-density fibreboard (MDF) plant in the Mekong Delta of Vietnam to utilise the *Melaleuca* resource directly (Stephen Midgley, pers. comm. 2012).

The 'kraft' pulping potentials of 2-year-old paperbark wood from Vietnamese plantations were reported by Chen and Su (1998, as *M. leucadendron*). The low pulp yield and high chemical consumption were unfavourable pulping characteristics but the strength index was adequate and bleachability excellent. The authors indicated that older trees might have better pulp qualities.

Extractives

Organic chemicals produced and stored naturally in plant tissues are numerous and chemically complex. By definition, extractives are the organic chemicals that can be removed from plant tissues by the action of water, including steam, other inert solvents such as alcohol and by mechanically crushing the source materials. The types of extractive from selected *Melaleuca* species that are of economic importance or have commercial potential fall into two classes: non-volatile (e.g. betaines) extractives and volatile (foliar essential oils).

Non-volatile extractives

The foliage of a range of *Melaleuca* species produces commercial levels (>2% fresh weight) of betaine (Naidu and Cameron 1999). Betaines are non-volatile, water-soluble compounds and comprise three methylated prolines: N-methylproline, trans-4-hydroxy-N-methylproline and trans-4-hydroxy-N,N-dimethylproline. They are osmoprotectants against stress (e.g. unfavourable temperatures, drought, soil salinity) in tolerant plants and on application (foliar and seed treatment) to stress-susceptible plants can create acquired tolerance. Naidu (2003) believes that the use of betaines to increase stress tolerance in Australian agricultural crops would stabilise and even increase the national income from agriculture.

Glycine betaine, a by-product of the sugar-beet industry, is currently sourced from Finland and a worldwide shortage is predicted for this solute. Australian melaleucas are a good alternative source of osmoprotectants. Naidu (2003) found that *M. bracteata*, which accumulates a proline analogue, trans-4-hydroxy-N-methyl proline, had the greatest potential of the melaleucas tested for commercial development, because of its adaptability, vigorous growth and high yields. Despite this potential, there have been no recent reports of further development of this opportunity.

Research has also shown *Melaleuca* bark and leaves to be a rich source of phenolic extractives (tannins) (Huffman 1981; Hussein et al. 2007) but no commercial exploitation of phenolics from melaleucas for uses such as wood adhesives, leather tanning and as antimicrobial agents has been reported.

Novel flavonoids have been identified in the leaf waxes, seeds and honey of several *Melaleuca* species (e.g. Courtney et al. 1983; Wollenweber et al. 2000; El-Toumy et al. 2001; Yao et al. 2004; Yoshimura et al. 2008). Similarly, various triterpenes, some previously undescribed, have been extracted from the leaves, bark, wood and seed of various melaleucas (e.g. Ahmad et al. 1997; Lee and Chang 1999; Vieira et al. 2004; Bar et al. 2008). Habila et al. (2010), for example, have reported the extraction of a triterpene, betulinic acid, from the wood of *M. bracteata*. They tested this compound, which they state is known for its anti-HIV and cytotoxic activity against malignant versus non-malignant cancer cell lines, and against a number of pathogenic organisms from the genera *Trichophyton, Candida* and *Microsporum*. They found that it had 'great potential' as an antifungal drug.

Foliar essential oils

An essential oil is the (usually) hydrophobic liquid containing the volatile compounds that are found in the oil glands or trichomes of a plant. These glands are usually associated with the leaves, although bark, wood or roots of plants may also contain essential oil. The oil is usually obtained by steam distillation, although the expressed oil (as in the case of citrus peel) can also be used. Essential oils are usually associated with species in the families Myrtaceae and Rutaceae, although they do occur in some other families.

Commercially important oils

Relatively few *Melaleuca* species have essential oils of commercial interest. One of the first species to be exploited commercially for its foliar oil was *M. cajuputi* subsp. *cajuputi* in the Maluku archipelago of Indonesia, probably in the first part of the eighteenth century. It was one of the first products imported to Europe from South-East Asia by the Dutch (Gildemeister and Hoffman 1961, cited in Lowry 1973), because of its reputation as a panacea in the treatment of all kinds of diseases. **Cajuput oil** is produced currently in South-East Asian countries including Indonesia, Cambodia and Vietnam and annual production potentially exceeds 600 t (Doran 1999a, b). This oil is rich in 1,8-cineole (typically 40–60% of total oil) (Doran 1999a, b; Pujiarti et al. 2011), as is medicinal *Eucalyptus* oil but at slightly higher proportions (70% or more). Cajuput oil acts as a mild antiseptic and is especially useful for treating respiratory ailments, but also finds use in a wide range of personal-care (e.g. ointments and liniments) and household products (Doran 1999a, b; Lassak and McCarthy 2011). **Niaouli oil** from the 1,8-cineole-rich form of *M. quinquenervia* (40–80% 1,8-cineole) was, until recently, produced in Madagascar from plantations yielding 1.5–2.0 t of oil/year. This oil was used for similar purposes to cajuput oil (Ramanoelina et al. 2008; Lassak and McCarthy 2011). Production of niaouli oil in New Caledonia from natural stands of *M. quinquenervia* (Trilles et al. 1999, 2006) has now also ceased after many years of exploitation, although there is new interest in producing this oil type in Vietnam (Le Dinh Kha, pers. comm. 2012).

The basis for the commercial interest in, and development of, the **Australian tea tree oil** industry—utilising mainly plantations of *M. alternifolia* established in northern New South Wales and northern Queensland and plantings made outside Australia—can be traced back to the 1920s. It was then that the medicinal properties of the oil were first studied and reported (Penfold and Grant 1925). The terpinen-4-ol-rich oil produced from *M. alternifolia* was found to be a powerful antimicrobial agent. It has demonstrated its ability to serve as an antiseptic, antifungal, antiviral, antibacterial and anti-inflammatory agent in multiple studies and is relatively safe for topical applications (Southwell and Lowe 1999; RIRDC 2007; Lassak and McCarthy 2011). It is incorporated into many personal-care and household products and is seeing increasing use in products designed for agricultural and animal-husbandry purposes (Figure 20). Annual production in Australia of Australian tea tree oil is estimated to be in the order of 400–500 t, worth approximately A$15–20 million at the farm gate.

The three abovementioned species/chemotypes provide the bulk of the commercial production of essential oils from the genus at present. In addition, there is sporadic interest in the following oils.

Linalool-rich oil is sourced from specific provenances of *M. ericifolia*. Linalool, with its fruity notes, is of value to the flavour and fragrance industries and, although it can be produced synthetically, there remains a market in aromatherapy where natural linalool is preferred (Coppen 1995).

E-nerolidol-rich oil can be extracted from the appropriate chemotype of *M. quinquenervia*. This compound, presently sourced from a diminishing world supply of cabreuva oil (Erich Lassak, pers. comm. 2007), has an established market in perfumery where it is used as a base note in many delicate, flowery odour complexes (Bauer et al. 1997). *Melaleuca quinquenervia* was shown to yield and coppice well in plantations in northern Queensland (Doran et al. 2007) before the recent arrival of myrtle rust to Australia (see Chapter 5).

E-methyl cinnamate has been derived from a northern Queensland form of *M. viridiflora* (Hellyer and Lassak 1968; Brophy and Doran 1996). Methyl cinnamate is a colourless, crystalline solid with a fruity, sweet-balsamic

Figure 20. A sample of the many products that utilise Australian tea tree oil

odour and its uses include as a flavour enhancer and in perfumery (Bauer et al. 1997). A small market exists for the natural product, but it can be produced artificially at relatively little cost and there is strong competition from other natural sources.

Platyphyllol, a β-triketone, is found in *M. cajuputi*. It has been identified as having ultraviolet-blocking attributes and insecticidal properties but it is not being produced commercially at this time (Yaacob et al. 1989; Brophy and Doran 1996; Doran 1999a, b).

Citral-rich oil is extracted from *M. teretifolia* (Southwell et al. 2003, 2005). A small production of this oil has commenced from natural stands and plantations in Western Australia. The producer claims the oil has perfumery and therapeutic properties.

An objective of work undertaken for this book was, if possible, to identify other species/chemotypes of melaleuca with commercial potential. The results of this work are summarised in the 'Species accounts' (Chapter 7) and in Appendix 1, which provides a quick reference to the oil type(s) present in individual species.

Inter- and intra-specific variation

Essential oils from a plant species are not necessarily chemically uniform. There can be, and usually is, variation in the compounds contained in the oil and their relative percentages. For this reason, chemists studying the essential oils of plants try to examine samples of the oils from a number of plants, preferably from many different sites.

Variation in the essential oils may be continuous over a geographical region, or it can be quite discrete. This latter occurrence leads to the finding of different chemotypes of the plant, i.e. plants which, though morphologically the same, produce different essential oils. It is possible, because of inadequate sampling, to find two different oil compositions within a species (i.e. two chemotypes) when, in fact, they just represent the extremes of a continuous variation. Examples of both types of variation as they apply to the main (*M. quinquenervia*, *M. alternifolia* and *M. cajuputi*) and one minor (*M. ericifolia*) commercial oil-producing species are discussed below. The possible presence within a species of these types of variation should be borne in mind when interpreting the results given in the following sections.

The essential oil of *M. ericifolia* has been studied for over 50 years. A 2004 study examined its essential oil content over its natural geographical range, which extends from coastal regions near Newcastle, New South Wales, in the north to Tasmania in the south (Brophy and Doran 2004). The study looked particularly at the amount of 1,8-cineole and linalool in the oils and the results are shown in Figure 21. Generally, the amount of 1,8-cineole increases from Newcastle southwards to Tasmania, and the amount of linalool decreases concomitantly. As the essential oil of *M. ericifolia* is important because of its linalool content, it is important to source the oil from plants in the north of its range. But there is a continuous variation in oil contents so, in this case, it is not correct to refer to a cineole chemotype or a linalool chemotype.

Melaleuca quinquenervia, in contrast, is a species known to contain chemotypes. There are two distinct chemotypes of this species; chemotype I contains E-nerolidol as the major component (in amounts of up to 95%) of the oil, while chemotype II contains major amounts of either 1,8-cineole or viridiflorol (or both), as well as lesser amounts of other terpenes. There is no plant producing an oil containing significant amounts of all three oils (E-nerolidol, 1,8-cineole and viridiflorol). Viridiflorol production is catalysed by terpene synthase enzymes. The genes coding for these enzymes are present in the genome of all plants of the species, but are expressed only in the viridiflorol chemotype (Padovan et al. 2010). The Australian distribution of the two chemotypes has been mapped and is shown in Figure 22 (Ireland et al. 2002). The chemotype containing major amounts of 1,8-cineole is the basis of the niaouli oil industry.

Melaleuca alternifolia exists in several chemical forms (chemotypes), although among them there are only three principal forms (Butcher et al. 1994; Homer et al. 2000). These three chemotypes contain terpinen-4-ol (up to 50%), the chemotype on which the tea tree oil industry is based, 1,8-cineole (up to 60%) and terpinolene (up to 50%). Production of the oils of these three chemotypes is controlled by three different enzymes (Keszei et al. 2010a, b). The 1,8-cineole chemotype is not used commercially, and the oil presents a similar oil profile to a eucalyptus or niaouli oil. This particular type of oil is very common in species of *Melaleuca* (see Appendix 1). The terpinolene chemotype found in *M. alternifolia* (Southwell et al. 1992) also occurs in *M. trichostachya* (Brophy 1999).

Melaleuca cajuputi subsp. *cajuputi*, the basis of the cajuput oil industry in South-East Asia, contains up to approximately 60% of 1,8-cineole, together with lesser amounts (approximately 10%) of limonene, α-terpineol and viridiflorene, and spathulenol (up to 30% in some cases). There are, however, a few isolated cases of this species, from northern Western Australia, producing an oil containing large amounts of E-nerolidol and virtually no 1,8-cineole (J.J. Brophy et al., unpublished data).

Species by oil type

With 290 species in the genus *Melaleuca*, it is not surprising that their leaf oils have much variation, resulting in many different types of oils. In this short section, we will review this variation and show what a wide range of chemicals is contained in *Melaleuca* leaf oils. The full data from the analyses are provided on the internet, accessible at **<http://aciar.gov.au/publication/MN156>**.

Species producing aromatic (in the chemical sense) oils

So far, only five species (*M. bracteata, M. halmaturorum, M. leucadendra, M. squamophloia* and *M. viridiflora*) produce chemotypes whose oils contain a preponderance of aromatic chemicals. *Melaleuca bracteata* gives four chemotypes in which methyl eugenol, E-methyl isoeugenol, elemicin and E-isoelemicin are the principal components of the oils. In a large collection survey in southern and central Queensland, several collections (from Rolleston) did not contain any aromatic components but were composed entirely of terpenoid components (Masunga 1998). *Melaleuca squamophloia*, a species with a limited distribution, also produces oils containing either elemicin or E-isoelemicin as the principal component (Brophy et al. 1999). *Melaleuca leucadendra* from the eastern part of its range produces oil in which the principal components are either methyl eugenol or E-methyl isoeugenol. The methyl

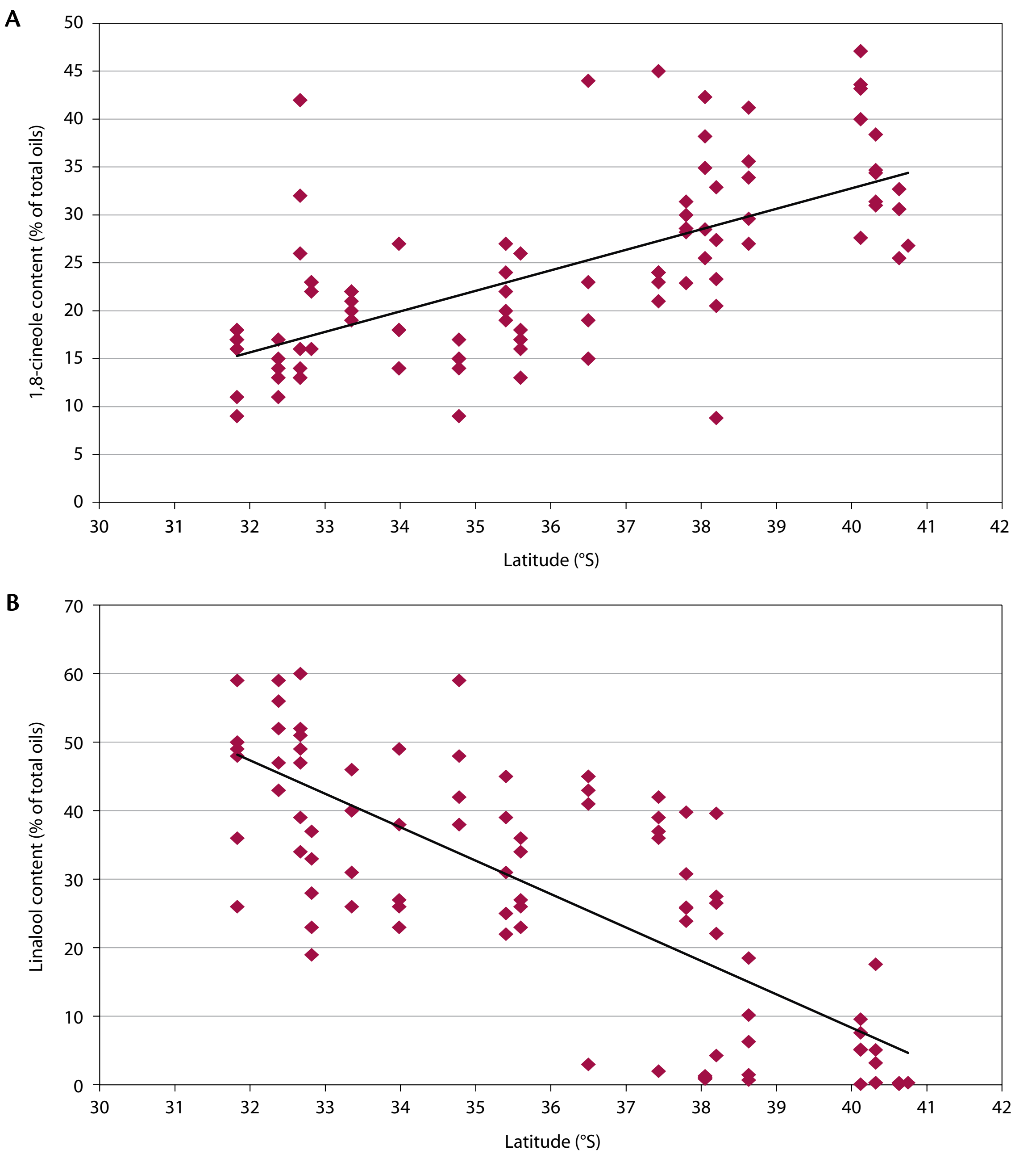

Figure 21. Variation in the proportions of (A) 1,8-cineole and (B) linalool (% of total oils) in the essential oil of *Melaleuca ericifolia* with latitude of occurrence (derived from Brophy and Doran 2004)

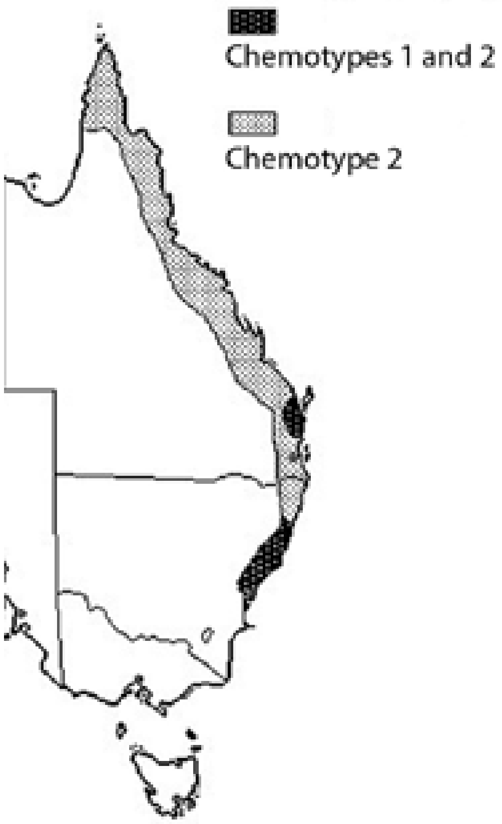

Figure 22. Chemotypes of *Melaleuca quinquenervia* in Australia (Source: Ireland et al. 2002)

eugenol chemotype bred true, while the methyl isoeugenol chemotype produced these two compounds in an approximate ratio of 3:1 (Brophy and Lassak 1988). The mix of aromatic chemotypes occurs from Flying Fox Creek in the Northern Territory eastward to Queensland. Westward of Flying Fox Creek the oil is entirely terpenoid in content with no aromatic compounds present (Brophy 1999).

Melaleuca halmaturorum produces an oil which, although mainly terpenoid, contains about 30% of 2,4,6-trimethoxy-1-isobutyrophenone and small amounts of other aromatic ketones (J.J. Brophy et al., unpublished data). *Melaleuca viridiflora* has two chemotypes, one of which has three terpene variants, while the other chemotype contains E-methyl cinnamate (82%) as its principal component. The remainder of this oil is composed of 2,4,6-trimethoxy-1-isobutyrophenone (5%), a monoterpene, E-β-ocimene (12%), and other terpenoid compounds (Hellyer and Lassak 1968; Brophy 1999).

Related to aromatic compounds are β-di-or β-triketones, and several species produce these in significant amounts in their leaf oils. *Melaleuca triumphalis* contains a novel β-diketone, triumphalone, and its thermal rearrangement product, as by far the major component of its leaf oil (Brophy et al. 2006a). *Melaleuca nanophylla* contains a β-triketone, flavesone (44%), as a principal component of its leaf oil, while *M. deanei* contains a homologous β-triketone, leptospermone, in small amounts.

Species producing lemon-scented oils

There are only four *Melaleuca* species known to produce lemon-scented oils, namely *M. alsophila, M. citrolens, M. stipitata* and *M. teretifolia. Melaleuca alsophila* exists in several chemical forms, but one form contains geranial as a major component. In this oil there is a significant amount of terpinen-4-ol.

Melaleuca citrolens, so named after the lemon scent of the crushed leaves, exists in six chemical forms, three of which have this lemon scent. These lemon-scented forms contain (a) citronellal, as well as 1,8-cineole and isopulegol, (b) 1,8-cineole, neral, geranial and citronellic acid in significant amounts, and (c) neral, geranial and methyl cinnamate. There is also a form that contains citronellol (21–47%) and methyl citronellate (9–31%) which has a pleasant fruity (but not necessarily lemon-scented) odour. *Melaleuca stipitata* also contains neral and geranial (totalling over 40%) as well as terpinen-4-ol (10%) in its lemon-scented leaf oil, while one chemotype of *M. teretifolia* contains neral (29%) and geranial (39%) as principal components of its oil.

Species producing oils with significant amounts of linalool

So far, about 10 species have been found to produce leaf oils containing significant amounts of linalool. They can contain up to 55% of linalool in their oils, sometimes within a particular chemotype of that species. The main species is *M. ericifolia* which, in the northern extent of is range, produces an oil containing up to 55% of linalool and, more importantly, in yields of 1–2%, based on fresh leaf. In the other part of its range, its oil contains 1,8-cineole as the major component (Brophy and Doran 2004, and references therein).

Other species containing linalool in significant amounts are: *M. bisulcata*, 55% (0.5% yield); *M. depressa*, 37% (0.3% yield); *M. exuvia*, 16–26% (2% yield); *M. hamata*, 28–34% (0.6–1.0% yield); *M. parviceps*, 41% (0.2% yield); *M. spicigera*, 39% (0.1% yield); *M. systena*, 30% (0.2% yield); and *M. tuberculata* subsp. *tuberculata*, 57% (0.4% yield)—all yields are based on fresh weight of leaf. For any of these species to be useful commercially, they would have to produce the oil at reasonable concentrations in the leaves (say >1%, weight for weight [w/w] fresh weight), have a high percentage of linalool (say 50% and above) in their oils and produce high yields of leafy biomass from which to extract the oil. These constraints rule out most of the above species except *M. ericifolia*. It is probable that, in most of them, examination of more samples would show a range of linalool concentrations and the existence of chemotypes within the species, so some might be potentially useful.

Species producing oils with significant amounts of terpinen-4-ol

Melaleuca alternifolia, and to a minor extent *M. linariifolia* and *M. dissitiflora*, are used commercially for the production of Australian tea tree oil because of their high percentage of terpinen-4-ol and good oil yield. Several other species also produce terpinen-4-ol oils: *M. alsophila*, 15–28% (0.1–0.3% yield); *M. arcana*, 23–31% (0.6–1.0% yield); *M. calcicola*, 33% (0.3% yield); *M. concreta*, 35% (1–2% yield); *M. exuvia*, 22–28% (2.0–2.3% yield); *M. foliolosa*, 23–40% (<0.1% yield); *M. halophila*, 44% (1.7% yield); *M. hamata*, 24–42% (0.7–2.0% yield); *M. nodosa*, 18–20% (0.8–1.3% yield); *M. ochroma*, 44% (0.6% yield); and *M. uncinata*, 27–31% (0.3–0.5% yield)—all yields being based on fresh weight of leaf.

As with the species rich in linalool mentioned above, there would have to be a significant reason to consider using these species to produce a tea tree oil. A reason could be that the species grows in saline soils, e.g. *M. hamata*, or contains other useful components, e.g. *M. alsophila* (12–19% geranial) and *M. exuvia* (16–26% linalool).

Groundbreaking work on gene control of terpene biosynthesis in melaleucas

Over the past decade, there has been a revolution in understanding the genes that control the production of essential oils. Researchers at the Australian National University (ANU) have been using new technologies developed originally in the family Lamiaceae, and especially in mint, to study the genes controlling both the profile and quantity of essential oils in *M. alternifolia*. The primary objective of this work is to improve efficiencies in the breeding of *M. alternifolia* for better oil quality and greater in-leaf oil concentrations (Keszei et al. 2010b). The latter has a direct influence on off-paddock yields and the economics of production in this commercially important essential oil–producing species (Zhang et al. 2011).

Several conclusions can be drawn from the ANU work on the genes controlling terpene synthesis in *M. alternifolia* that might be broadly applicable throughout the genus. Six chemotypes described previously (e.g. Butcher et al. 1994; Homer et al. 2000), and one additional intermediate chemotype, were identified from a reanalysis of existing chemical data on the composition of *M. alternifolia* leaf oils. It was confirmed that, as suggested by the chemotypes present, as few as three terpene synthase genes produce most of the monoterpenoid compounds in *M. alternifolia* oil.

Keszei et al. (2010b) found that the gene that makes the commercially important compound, terpinen-4-ol, likely arose from a chance gene duplication event to an existing gene that made 1,8-cineole, followed by a small number of mutations. Thus, oil quality (high proportions of terpinen-4-ol accompanied by low proportions of 1,8-cineole) in this species, as demanded by industry, is based on a very small number of genetic variants. These genes have been characterised, thus allowing screening of seedlings at an early age to indicate the chemotype of the mature plant. The oil profiles of other species of *Melaleuca* (e.g. *M. quinquenervia*) are produced similarly (Padovan et al. 2010).

In contrast, the yield of oil in *M. alternifolia* is determined by the flux of precursor metabolites that are made available for the terpene synthase enzymes. These precursors are produced by a complex series of enzymes in the plant cell and, in high-yielding plants, nearly all of these are up-regulated (Webb et al. 2013). Ongoing work aims to identify the genetic variants that are associated significantly with foliar oil concentration, raising the exciting possibility of being able to efficiently screen plants at a young age for their oil-producing capacity (Külheim et al. 2011).

Readers are directed to texts such as Sell (2010) for general information on basic biosynthetic pathways for terpenoid compounds in plants and to Southwell and Lowe (1999) for information specific to *Melaleuca* oil biogenesis.

4 Propagation, silviculture and management

Propagation

There are many texts available on the propagation of Australian Myrtaceae, including *Melaleuca* species, and readers embarking on a major propagating and planting of melaleucas are directed to these for detailed information. Available texts include Doran (1990, 1997); Wrigley and Fagg (1993, 2007) and Venning (1988).

Propagation by seed

Mass propagation of melaleucas is usually by seed, which germinate readily in moist, warm conditions with no pretreatment. Seed should be sown under shade (optimum temperature for germination is 25–30 °C) on a free-draining and sterilised medium and covered very sparingly with inert material (e.g. sand). Germination should be complete after 15 days and then shade can be reduced. After germination, the tiny seedlings can be slow to develop at first, presumably while the roots establish. Once underway, however, they grow quickly and the 3–6 months it takes for seedlings to reach plantable size is similar to other fast-growing species such as eucalypts.

Young seedlings are easily damaged by overhead watering or rain, or may be killed if the sowing mix dries. Growers in Vietnam have adopted the 'bog' technique of watering to avoid these problems in propagating *M. cajuputi* (Figure 23). This involves standing the base of the germination tray permanently in water so that moisture soaks up to the surface which is constantly moist but not flooded. Seed is sown evenly over the surface at a density of about 7,000 viable seeds/m². An inflated plastic bag is fitted over the germination tray to maintain a moist environment. Once the seedlings are sturdy enough to withstand overhead watering (c. 4 weeks), the container is removed from the water and handled normally. The risk of fungal disease is high, so good hygiene is essential.

Open-rooted seedlings are sometimes used in establishment of *M. alternifolia* plantations in northern Queensland. Successful establishment of open-rooted seedlings is very dependent on the weather at planting time and/or the availability of irrigation. Container-grown seedlings, although more expensive to produce than open-rooted seedlings, suffer much less planting shock and are less susceptible to the vagaries of the weather (Colton et al. 2000).

There are two ways of producing container-grown seedlings commonly applied in the propagation of melaleucas:

Figure 23. *Melaleuca* propagation in Vietnam using the 'bog' technique for germinating the fine seeds

(1) the two-stage system where seeds are first sown into germination trays or germination beds and the seedlings later transplanted (an operation called pricking out); or (2) the direct-to-container system where seeds (usually an average of three per container) are sown directly into individual containers and thinned down to one per container after germination is completed.

In the two-stage system, seedlings are transplanted from the germination trays or beds at the second leaf-pair stage (usually 2–3 cm tall at 4–8 weeks after sowing) to containers (commonly tubes, bags or pots of about 550 cm^3 filled volume, e.g. tubes of 65 mm diameter and 160 mm depth) filled with sterilised potting mix (e.g. 1:1:1 coarse river sand, perlite and cocopeat with the addition of a slow-release fertiliser). Extreme care must be taken during transplanting not to 'J'-root (bend roots upward in a too-shallow planting hole) seedlings as this will cause retarded growth and instability of the seedling after planting. Shade cover is needed for the first week after transplanting after which time plants should be fully exposed. This technique is usually applied when only a relatively small number of plants are required and/or seed is in short supply and efficient capture of all available seedlings is a requirement. Where very large numbers of seedlings are required, as in the establishment of *M. alternifolia* plantations for oil production with stocking levels commonly in the order of 30,000 plants/ha, the direct-to-container system is widely applied. Cell-type trays of small individual cell volume (c. 20 cm^3) (e.g. 'speedling' trays) are commonly used in this system. A relatively sophisticated nursery infrastructure, including potting mix and sowing equipment, plastic igloos or glasshouses, shadehouses and automated watering systems, is usually employed to produce high-quality planting stock at competitive prices for mechanical planting. Seedlings are routinely topped at about 15 cm to stop them becoming too tall and spindly and to encourage a woody stem. Nursery duration under this system is in the order of 12–20 weeks.

Melaleucas form symbiotic mycorrhizal associations between the roots and various fungi. The roots of *M. quinquenervia* trees growing on stream banks, or in fresh or brackish waters in swamps and seepage areas of New South Wales, Australia, were found to possess both vesicular-arbuscular (VA) mycorrhizas and ectomycorrhizas (Khan 1993). Nurseries growing melaleucas, especially where the soils are deficient in phosphorus, should attempt to introduce appropriate mycorrhizas to the nursery soil. Various delivery systems, including soil, spores, sporocarps and vegetative mycelium, are described by Brundrett et al. (1996) and Doran (1997).

Vegetative propagation

Many melaleucas can be propagated vegetatively from stem cuttings (Figure 24) and grafts (Wrigley and Fagg 1993) and some have been successfully tissue cultured (e.g. *M. alternifolia*; de Oliveira et al. 2010). To ensure the genetic integrity of cultivars, it is essential that they be propagated vegetatively.

Prastyono et al. (2011) highlighted the potential of clones in improving oil yields and qualities and, in turn, the financial returns to producers of essential oil from *M. alternifolia* plantations. Readers interested in the mass vegetative propagation of melaleucas are directed to Chapter 22 in Eldridge et al. (1993) and Chapter 11 in Evans and Turnbull (2004). Although mass vegetative propagation of tropical eucalypts is the focus of these detailed descriptions, the methods are directly transferable to the related genus *Melaleuca*.

The same principles used in mass vegetative propagation can be applied on a much smaller scale. Readers interested in the small-scale vegetative propagation of melaleuca cultivars are directed to the treatments by Wrigley and Fagg (1993, 2007).

Silviculture and management

Melaleucas are used for a range of landcare, wood and non-wood purposes. The silvicultural system adopted will depend very much on the end use of the planting, although it is clear from the lack of literature on the subject that little is known about optimal stand establishment, tending and management systems for melaleucas.

Plantations for wood production

Most interest in growing melaleucas for wood production is in the tropics on difficult sites for tree growth where the adaptive traits of the melaleucas give them a competitive advantage over other, higher value tree crops. It is mainly the broad-leaved species of the *M. leucadendra* complex, such as *M. cajuputi*, *M. leucadendra* and *M. quinquenervia*, that are grown for this purpose in places such as the Mekong Delta of Vietnam. An important advantage of the broad-leaved melaleucas over other tree crops under cultivation in this harsh environment for tree growth is that they can be established successfully without expensive and environmentally damaging soil mounding. Mounding is required to cultivate alternative species and this exposes the acid-sulfate soils. Species of the *M. leucadendra* complex are able to survive a fluctuating watertable, including prolonged seasonal inundation and severe acidity. Other important advantages in this environment are abilities to withstand strong weed competition and dry-season fire.

Typically, these species are grown in plantations on relatively short coppice rotations that maximise the production of small-size logs suitable for posts, piles, poles and fuelwood. Conventional plantation spacings, such as those used in trial plantings in Queensland, Australia (1.5 × 3 m and 2 × 3 m; Ryan and Bell 1989), Thailand (2 × 2 m; Pinyopusarerk 1989), Vietnam (1.5 × 2 m and 2 × 2 m; Hoang Chuong et al. 1996) and Florida, USA (1 × 1 m; Geary 1988), appear appropriate for these end uses. Wider spacings (e.g. 3 × 3 m up to 6 × 6 m) might be employed where agroforestry is being practised or on sites where very poor soils are being reforested (Geary 1988).

Practices that include good site preparation, fertilisation when required and intensive weed control pay dividends in the cultivation of melaleucas, as with other tree crops like eucalypts. For example, intensive site preparation by ploughing to a depth of 20 cm, addition of a nitrogen/phorphorus/potassium (NPK) fertiliser and manual tending have been found to be beneficial to establishment and early growth of *Melaleuca* plantations in the Mekong Delta region (Simpson 1995). Although pruning is not usually applied in *Melaleuca* plantations, form pruning has been advocated for garden specimens of *M. leucadendra* (Hearne 1975).

Reported growth rates are reasonable without being exceptional, even on good sites. For example, *M. quinquenervia* trees in Hawaiian plantations on good sites average 18 m in height and 50 cm in diameter at 40 years (NAS 1983). Annual increments in height of 1–2 m and in basal diameter of 1–3 cm are typical of young plantations of the broad-leaved melaleucas over a wide range of site

Figure 24. Stem cuttings of *Melaleuca alternifolia* displaying excellent rooting characteristics

types (Morton 1966; Lamb 1975; Ryan and Bell 1989; P.A. Ryan and R.E. Bell, unpublished report, 1991; Gwaze 1989; Pinyopusarerk 1989; Sun and Dickinson 1995; Hoang Chuong et al. 1996). Rotation lengths as short as 3–5 years are typical in Vietnam.

Plantations for production of essential oils

The silvicultural systems employed for the production of essential oils from plantations fall broadly into two categories as highlighted in the two case studies given here. The first case study is that of *M. alternifolia* plantations in northern New South Wales and northern Queensland, Australia, which represents an intensive, high-cost but high-return system. The second case study is that of *M. cajuputi* subsp. *cajuputi* in Java, Indonesia, which is a less intensive, lower cost but also lower return system. This second case is representative of silvicultural systems used in developing countries where *Melaleuca* plantations must provide a multitude of services for sustainable development, such as inter-row cropping, rather than oil production alone, as is the case with *M. alternifolia* in Australia.

Australian tea tree oil

Principal source: Plantations of *Melaleuca alternifolia* (Maiden & Betche) Cheel (Figure 25) are the main source of tea tree oil in Australia.

Species description: The mature plant is a shrub or tree, 2.5–14 m tall. Its reddish-brown bark is papery, peeling in long flakes; adult leaves are alternate, linear, 10–32 mm long, 0.4–1 mm wide and short-petiolate to subsessile, with glabrescent blades and dense oil glands, more or less in rows (see the *M. alternifolia* species account [Chapter 7] for more details).

Natural occurrence: The species occurs from the Stanthorpe district in Queensland, south and east into New South Wales to the Lismore and Grafton areas, with a southernmost disjunction near Port Macquarie. It is found at elevations ranging from near sea level to 800 m.

Climate: *Melaleuca alternifolia* occurs in warm subhumid climates, with mean maximum temperatures of hottest and mean minimum of coldest months of 25–30 °C and 1–9 °C, respectively; frost incidence, low to moderate (up to 50 at high elevation sites); and rainfall of 750–1,600 mm per year, with a summer maximum.

Topography and soils: The species is found on coastal plains and adjacent ranges, where it grows on seasonally inundated swamps and along watercourses. It grows in soils that are mainly alluvial silty loams while, in Queensland, soils are sandy loams derived from granite (soil pH 4.5–5.5).

Essential oils: Six or more chemotypes have been identified in the foliar oils of *M. alternifolia* of which only one, a terpinen-4-ol–rich (30–48%) type with more than 100 components, qualifies commercially as Australian tea tree oil (ISO standard no. 4730; see ISO 2004). Leaf oil concentration is in the range of 3–6% (fresh weight).

Uses: Efficacy, stability, oxidation and toxicity of terpinen-4-ol-rich tea tree oil have been closely studied for many years. It is an effective antiseptic, antibacterial, antiviral, antifungal and anti-inflammatory agent and is used in a wide range of antimicrobials and cosmetics. It is also sold as pure oil or in 10–15% tea tree oil solutions.

Quality and prices: Contaminant-free oils with terpinen-4-ol levels of 40% or more in combination with low levels of 1,8-cineole (i.e. <3%) are demanded by the principal markets. Oil prices have fluctuated widely in recent years but in 2013 are around A$30/kg, recovering from a low of A$12/kg in 2005.

Production and markets: Total annual world production of this oil type is in excess of 600 t (Australia c. 400 t; China c. 200 t; and others). The main markets are North America and Europe.

Plantations for tea tree oil production: North-eastern New South Wales and the Atherton Tablelands of Queensland are hubs for production of Australian tea tree oil from plantations totalling around 3,000 ha. A typical Australian plantation will be established on weed-free, level ground at a stocking rate of 30,000–35,000 plants/ha at row spacings that suit available machinery. Row spacing of 1 m and 30 cm between plants within rows is commonly applied. Managing weeds, insect pests/diseases and crop nutrition, combined with use of carefully developed, higher yielding seed lines, are paramount to optimising production.

Harvesting, distillation and oil storage: Mechanical harvesting is used in Australian plantations, with the first harvest taking place at 18 months and annually thereafter. The best oil yields are in spring and summer. Steam distillation is used to extract the foliar oils. Typical distillation times are 1.5–2 hours after condensate starts to flow. Oil should be stored in cool, dark, dry, air-free conditions to minimise the rate of oxidation.

Yields: Oil yield is determined by three components: yield of biomass harvested; proportion of leaf in the total biomass; and oil concentration in the leaves. Typically, the first harvest of 18-month-old seedlings will give 50%, second harvest of 12-month-old coppice 75% and third harvest of 12-month-old coppice 100% of the mature plantation yield. There is wide disparity between growers in oil yields achieved in practice due to the many interacting factors involved. Overall, the average yield from mature coppice plantations in Australia using unselected seed lines is an estimated 150 kg/ha. Selected seed lines now available from an Australian industry breeding program have yielded about 270 kg/ha and further substantial increases are anticipated through breeding.

Further reading: Southwell and Lowe (1999); Colton et al. (2000); Davis (2003); ISO (2004); Doran et al. (2006); RIRDC (2007).

Figure 25. Steps in the production of Australian tea tree oil from *Melaleuca alternifolia*: (A) seedlings grown in cell-type trays to produce plants well suited to mechanical planting; (B) mechanical planting into a cultivated, weed-free, drained area; (C) newly planted seedlings being irrigated at establishment; (D) a plantation ready for harvest; (E) mechanical harvesting into bins; and (F) oil separators in a modern distillery

Indonesian cajuput oil

Principal source: Plantations of *Melaleuca cajuputi* Powell subsp. *cajuputi* (Figure 26) are the main source of this oil in Indonesia.

Species description: The mature plant is a shrub or typically an erect tree, (2–)25(–46 m) tall. Its bark is grey to white and papery; adult leaves are alternate, mainly narrowly elliptic, 40–140 mm long, 7–26 mm wide and petiolate, with glabrescent blades but silky-hairy on the branchlets and silvery new growth, and moderately dense, obscure oil glands (see the *M. cajuputi* species account [Chapter 7] for more details).

Natural occurrence: The subspecies occurs in Indonesia (islands of Buru, Seram, Ambon, Tanimbar in Maluku province and West Timor) and Australia (Top End of the Northern Territory and north-western Western Australia). It is found at elevations ranging from near sea level to 400 m.

Figure 26. Steps in the production of Indonesian cajuput oil from *Melaleuca cajuputi* subsp. *cajuputi* plantations in Java: (A) seedlings grown in polyethylene bags; (B) plantation in Central Java; (C) leafy branches delivered to a distillery; (D) four of the eight 1-t capacity pots in a cajuput oil distillery at Gundih; (E) a portion of the dry, spent biomass being bundled for fuelling the distillery boiler; and (F) oil separators in a distillery run by Perum Perhutani (Forestry Department)

Climate: *Melaleuca cajuputi* subsp. *cajuputi* occurs in hot, humid climates, with mean maximum temperatures of hottest and mean minimum of coldest months of 31–33 °C and 17–22 °C, respectively; frost free; and rainfall of 600–4,000 mm/year, monsoonal with up to an 8-month dry season.

Topography and soils: The subspecies is found mainly on low swampy coastal plains but, in Maluku, mostly pure stands extend inland on infertile gravelly ridges. Soils are often highly organic alluvial clays of poor drainage and low fertility.

Essential oils: There is wide variation in the chemical composition of cajuput oil. The commercial oil usually contains substantial amounts of 1,8-cineole (c. 40–60%). Leaf oil concentration is in the range of 0.4–1.2% (fresh weight).

Uses: Cajuput oil is classified as non-toxic and non-sensitising. It is a common household medicine throughout South-East Asia and is used internally for treatment of coughs and colds and externally for relief of pain, often in the form of ointments and liniments. The oil is useful in treating roundworm and infections of the genito-urinary system. It is used as a fragrance and freshening agent in soaps, cosmetics, detergents and perfumes.

Quality and prices: Contaminant- and adulterant-free oils with 1,8-cineole levels of 55–65% are preferred by the principal markets. Oil prices at Indonesian Government distilleries in 2013 are around A$15/kg.

Production and markets: Total world production of 1,8-cineole-rich cajuput oil is estimated to be c. 600 t/year, with most oil produced in Indonesia (300 t from plantations and 90 t from natural stands) and Vietnam (100 t from natural stands). The main markets are in South-East Asia.

Plantations for cajuput oil production: The main source of oil in Indonesia is from 20,000 ha of plantation established on degraded lands on the main island of Java. Plantations are established at an average stocking rate of 2,000 seedlings/ha. Since 2002, genetically improved seed from a government breeding program has been deployed to improve oil yields and quality. Plantations are intercropped with cassava, maize and peanuts and participating farmers are required to weed the cajuput trees when weeding their crops. There are no major pests or diseases and fertiliser is not routinely applied.

Harvesting, distillation and oil storage: At 4 years of age, plants are pollarded at 1.1 m above ground during the first harvest of essential oils. Thereafter, plants are visited annually, when coppice shoots of greater than 1 cm diameter are selectively harvested and leaves and twigs stripped into hessian bags for transport to the distillery. Peak production in Java is from June to October when oil yields are highest. Steam distillation is used to extract the foliar oils. Distillation time is usually 4 hours. Oil should be stored in cool, dark, dry, air-free conditions to minimise the rate of oxidation.

Yields: A plantation of 1 ha established using unimproved seed produces about 7.5 t of cajuput leaves annually which in turn produces about 60–65 kg of oil. Through use of the improved seed available since 2002, future yields are expected to improve by more than 20%.

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Further reading: Doran (1999a, b); Susanto et al. (2003, 2010).

Pests, diseases and other limitations

Pests and diseases

A wide range of insects causing damage to leaves, stems and roots of various *Melaleuca* species—including suckers (e.g. bugs, psyllids, froghoppers, scales, galls and thrips) and chewing pests (e.g. sawflies, caterpillars, beetles and borers)—has been described by Elliot and Jones (1982, 1983), Elliot et al. (1998) and Jones and Elliot (1986), who also give methods of control.

Over 400 herbivorous insects were found in association with *M. quinquenervia* and its close allies in Australia (Balciunas et al. 1993a, b; Burrows et al. 1994) but damage was reported as localised. Coreid bugs attacked the growing tips of coppice growth of *M. quinquenervia* in trials in northern Queensland, reducing yields of essential oil and requiring application of insecticidal sprays (Doran et al. 2007). This species was reported as suffering slight damage from sawflies (Marcar et al. 1995) and possessing heartwood that lacked resistance to damage by termites, marine borers and fungi (Bultman et al. 1983). Damage to *M. leucadendra* by grasshoppers and leaf-rolling caterpillars can be severe during the dry season in northern Australia (Hearne 1975).

Of the more than 100 insect species identified in native stands and plantations of *M. alternifolia* in Australia, five have emerged as significant pests in commercial essential oil–producing plantations. They are pyrgo beetles (*Paropsisterna tigrina*), psyllids (*Trioza* spp.), mites (*Eriophyoid* spp.), pasture scarabs (*Diphucephala lineata*) and leafhoppers (including *Erythroneura* spp.) (Colton et al. 2000). All eat flush new leaves or suck their sap and can cause extensive damage. The sap-sucking leafhoppers also attract ants which in turn promote infestation by black sooty mould. Economic losses through attack of *M. alternifolia* plantations by African black beetle, mole crickets, cutworms and a wide range of other minor insect pests have also been reported.

Myrtaceae tip blight and leaf spots can attack melaleucas (Jones and Elliot 1986) and powdery mildew and grey mould (*Botrytris* sp.) can develop on cultivated, ornamental melaleucas, especially when dry-region species are cultivated in humid, subtropical climates.

An introduced disease of Australian plants of the family Myrtaceae, *Puccinia psidii* sensu lato (synonym *Uredo rangelii*), or myrtle rust as it is commonly called in Australia, was first observed on the central coast of New South Wales in April 2010 (Morin et al. 2012). This exotic pathogen (native to South America) has now spread from Victoria to the Daintree River, north of Cairns in northern Queensland. Myrtle rust is a form of guava/eucalyptus rust which has had severe impacts on eucalypt plantations in Brazil and has spread to other parts of the Americas (South, Central and North), China and Japan. *Melaleuca quinquenervia*, an invasive pest in the Florida Everglades, is highly susceptible to guava rust in Florida and Hawaii (see following section on 'Weediness/biological control') and also highly susceptible to the rust in Australia. This disease has so far been observed on 107 host species in 30 genera, including *Angophora*, *Asteromyrtus*, *Backhousia*, *Eucalyptus, Leptospermum* and *Melaleuca* (Carnegie and Lidbetter 2012). There are expectations that many more species will be found susceptible and this is causing much concern. The young leaves and shoots of seedlings, the outer growing tips of the crowns of saplings and, in some cases, adult trees (e.g. *M. quinquenervia*) and coppice from stumps or damaged trees are most vulnerable to attack by myrtle rust. The rust causes spots or lesions on young leaves and shoots that spread and develop masses of yellow powdery spores (Figure 27). The rust can also infect floral buds and young fruit, depending on the host. Infected leaves become curled and distorted and severe infection can kill shoots, causing these plants to become stunted after repeated infections. In the worst cases, death of the whole plant can occur after repeated destruction of new growth.

Melaleuca alternifolia in plantations in northern New South Wales that at first appeared to be resisting the spread of myrtle rust are now showing signs of greater damage with the rust-induced death of flush growth and upper stems becoming more common (Peter Entwistle, pers. comm. 2012). Other fungal pathogens of *M. alternifolia* plantations include stem blight (*Dothiorella* sp.), with pink disease (*Cylindrocladium* sp.) that causes leaf drop, charcoal root disease (*Macrophemena phaeseolina* or *Diplodia* sp.) and leaf scab (*Elsinoe* sp.) also causing damage (Colton et al. 2000). These authors also reported grey mould (*Botrytis cinerea*), anthracnose (*Colletotrichum* sp.), rhizoctonia (*Rhizoctonia* sp.) and damping off (*Pythium* sp.) to be important diseases in nurseries growing *M. alternifolia* seedlings. Some Western Australian melaleucas are prone to the rootrot fungus *Phytophthora cinnamomi* (Wrigley and Fagg 1993). Colton et al. (2000) reported that no bacterial or viral diseases of economic importance have been identified in *M. alternifolia* plantations.

Other limitations

Weediness/biological control

Melaleuca species can seed profusely and there are instances in Australia where they have escaped cultivation and naturalised to become invasive and troublesome weeds, especially where periodic fires provide a suitable seedbed. Species that are reported to have naturalised include *M. armillaris*, *M. bracteata*, *M. decussata*, *M diosmifolia*, *M. ericifolia* (per root suckers), *M. halmaturorum*, *M. hypericifolia*, *M. incana*, *M. lanceolata*, *M. leucadendra*, *M. linariifolia*, *M. microphylla*, *M. nesophila*, *M. parvistaminea*, *M. pentagona*, *M. quinquenervia*, *M. styphelioides*, *M. viminalis* and *M. viminea* (Lazarides et al. 1997; Randall 2002; Richardson et al. 2011; Wiersema and León 2013).

Beyond Australia, *M. quinquenervia* has become a United States federally listed noxious weed in southern Florida and is also moderately invasive in the Caribbean (Bahamas and Puerto Rico) and Hawaii (Dray et al. 2006). *Melaleuca quinquenervia* was first introduced into Florida as an ornamental and agroforestry species from Australian and exotic sources. Dray et al. (2006) have traced the earliest introduction back to 1886 in Sarasota County, with the species becoming naturalised in southern Florida during the 1920s and spreading rapidly from there. Since its introduction, the tree has invaded more than 200,000 ha of Florida wetlands, including portions of Everglades National Park (Turner et al. 1998). With its prolific seed production, *M. quinquenervia* rapidly invades moist, open habitats, both disturbed and undisturbed, and forms dense, impenetrable monocultures. Unmanaged stands may have stocking densities of 7,000–20,000 stems/ha, thus crowding out native vegetation and wildlife habitats (Geiger 1981; Loope et al. 1994). Serbesoff-King (2003) reported that public agencies in Florida had spent US$25 million in control efforts between 1989 and 1999. Serbesoff-King (2003) also gave estimates of economic impacts of the invasive *Melaleuca* populations on recreation, tourism, fires, loss of endangered species and more. These ranged from US$168 million annually to US$2 billion over a period of 20 years. It is currently being suppressed using manual, mechanical, herbicidal and biological control management strategies (Martin et al. 2011).

A classical weed biological control program targeting *M. quinquenervia* in Florida was initiated in the late 1980s. Surveys in Australia for potential biological control agents of *M. quinquenervia* for possible release in Florida revealed several promising insect species (Center 1992; Balciunas and Burrows 1993; Balciunas et al. 1993a, b; Purcell and Balciunas 1994). One herbivore established for biological control of *M. quinquenervia* in Florida is a weevil, *Oxyops vitiosa*. It was introduced into Florida in 1997 (Christensen et al. 2011) and prefers to feed on the nerolidol chemotype. Another is a psyllid, *Boreioglycaspis melaleucae*, which was released in 2002 and prefers the viridiflorol chemotype. Predation of *M. quinquenervia* by these insects eventually results in partial defoliation of mature trees, loss of reproductive ability and mortality of seedlings (Martin et al. 2011; Pratt and Arakelian 2011). Tipping et al. (2009), in a 5-year study of a cypress pine wetland in the West Everglades invaded by *M. quinquenervia* after a destructive crown fire, reported a 48% decline in *Melaleuca* density over 5 years due to biological control agents. Annual mortality ranged from 11% to 25% and mean tree height declined by 31%. Rayamajhi et al. (2009) found rapid reduction in *Melaleuca* density and canopy cover, attributed to self-thinning accelerated by the negative impact of the introduced insect pests, positively influenced native plant diversity (two- to fourfold increases in plant diversity) and facilitated the partial rehabilitation of degraded habitats.

Fungi are also under investigation as potential biological control agents of *M. quinquenervia* in Florida (Rayachhetry et al. 1996a, b). *Puccinia psidii*, as detailed in the previous section on 'Pests and diseases', is one possibility. In the early 2000s, *P. psidii* was observed on *M. quinquenervia* in Florida (Rayachhetry et al. 2001). It has now joined the introduced herbivores as effective biological control agents

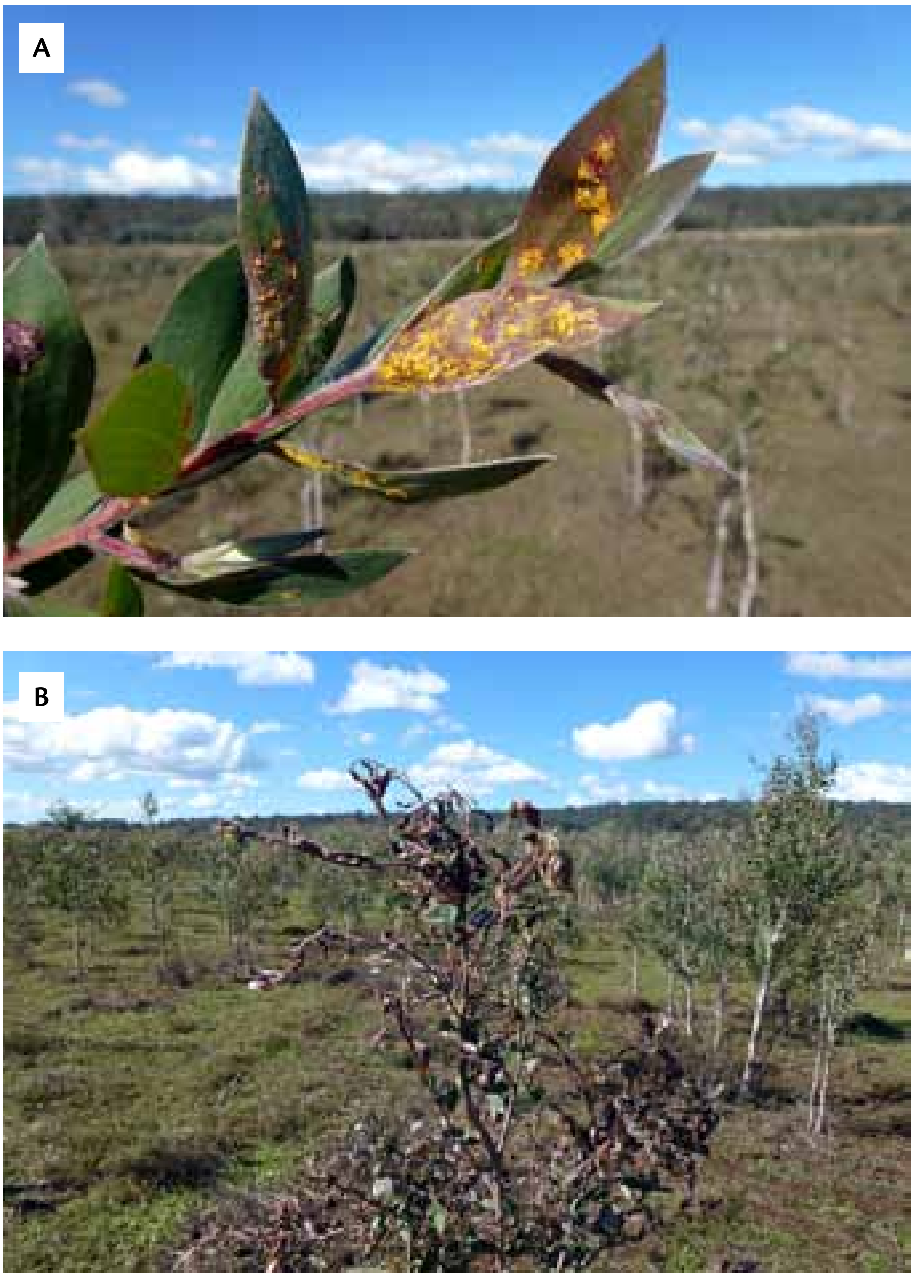

Figure 27. *Puccinia psidii* sensu lato (synonym *Uredo rangelii*) (myrtle rust) spores on *Melaleuca quinquenervia* in northern New South Wales: (A) yellow spores on a leafy shoot; and (B) a badly deformed and stunt young plant after rust attack of its growing tips

of *M. quinquenervia* in Florida although there are resistant individuals (Rayamajhi et al. 2010a, b). Regrettably, it has been found to also attack some native American species, including a threatened species.

Source of allergens

Earlier reports implicating *M. quinquenervia* in southern Florida as the cause of serious allergic reactions and acute respiratory problems in humans (Geary 1988) have been shown to be false in a detailed medical study involving more than 1,000 subjects (Stablein et al. 2002).

6 Conservation and prospects

Conservation status

An estimated 100 million ha of the Australian landscape have been cleared for agriculture, urban development, mining and other pursuits. In addition to clearing of forests and woodlands, drainage and flood mitigation measures, waterlogging from irrigation and increased salinity have all adversely affected the extent of natural populations of *Melaleuca*. Australia accounts for 20% of the world's flora that has been classified as 'presumed extinct' and 15% of the world's flora that has been recognised as 'threatened' (Briggs and Leigh 1995). It is somewhat surprising, therefore, to report that apparently no species within this large plant genus have been classified as 'presumed extinct'. Wrigley and Fagg (1993) reported that *M. arenaria*, a species described in 1923 from a specimen collected in the Western Australian wheatbelt in an area subject to much clearing, was 'presumed extinct', but this species is now considered to be a variety of the widespread *M. tuberculata* (see 'Species accounts' [Chapter 7]).

Briggs and Leigh (1995) listed 48 *Melaleuca* taxa (including *Callistemon*) in their compendium of rare and threatened Australian plants. *Melaleuca kunzeoides*, from central southern Queensland, *M. sciotostyla*, from south-western Western Australia, and *Callistemon* sp. 1 (Boulia, L.Pedley 5297)—now classified within the widespread *M. viminalis* subsp. *viminalis*—were listed as 'vulnerable'; with only one of these species, *M. sciotostyla*, protected in reserves in 1995. Eighteen species, 15 of which were in reserves or National Parks in 1995, were classed as 'rare' (*Callistemon acuminatus* [= *M. flammea*], *M. basicephala, M. cheelii, M. chisholmii, M. cliffortioides*, *M. corrugata* [= *M. fulgens* subsp. *corrugata*], *M. deanei*, *M. fissurata*, *M. flavovirens, M. formosa, M. groveana*, *M. linearifolia*, *M. pauciflora, M. pearsonii*, *M. pungens*, *M. pustulata*, *M. shiressii* and *M. tortifolia*); and the remaining taxa were placed in category 'K'. Category 'K' is for species known to be limited in distribution but whose conservation status cannot be reliably determined, either because the species has been seldom collected or there is uncertainty about the level of threat. The list of rare or threatened Australian melaleucas needs to be revised, as many very localised and/or rare species have been described since 1995.

Outside Australia, there have been concerns about the decline of *Melaleuca* forests and woodlands of *M. cajuputi* subsp. *cumingiana* in the wetlands of South-East Asia. Clearing and draining of the *Melaleuca* forests for rice production and other crops in places such as the Mekong Delta region of Vietnam have led to environmental degradation, loss of biodiversity and social consequences for local peoples (Safford et al. 2009). While not to the extent yet of endangering the survival of the species in these wetlands, there are, nevertheless, compelling reasons to rehabilitate selected areas of these forests and woodlands. This has been a priority in Vietnam's forest policy since the mid 1990s.

Prospects

Opportunities for wider use

Reasonable growth rates in the face of extremely poor environmental conditions for plant growth and a broad range of uses are among the desirable attributes of the *Melaleuca* species regularly deployed in reforestation, land reclamation, amenity and ornamental plantings and for production of essential oils. With a predominance of species occurring in arid and semi-arid regions, but with a range from the humid tropics to cool temperate southern Australia and on highly variable soils and topography, it is possible to select species that are tolerant of a wide range of unfavourable conditions (infertile soils, poorly drained sites, continuous and periodic inundation, coastal exposure, fire, frost, salinity and both high and low soil pH). Uses, depending on species/provenances or cultivars, include ornamental and amenity planting, essential oils, fuelwood, woodchips, sawn timber, posts, poles, rails, brushwood fencing, shade and shelter, honey, land reclamation and improvement in biodiversity values. In Appendix 2, we have endeavoured to highlight by end use, best-bet species for planting/trialling in two broad climatic zones: (A) subtemperate and (B) tropical and subtropical.

Melaleucas are largely outbreeding, often with heritable and highly variable commercial traits (e.g. foliar oil concentrations and various growth characteristics, including inflorescence shape and flower colour). This provides a huge opportunity for the tree breeder, whose main task is to exploit this variability through exploration, evaluation, selection and breeding. Nowhere is this more so than with the ornamental *Melaleuca* cultivars that after manipulation by controlled pollination, either within or between species, must be propagated vegetatively to capture desired characteristics (e.g. inflorescence shape and colour). There is also great opportunity for selection and breeding to improve oil yields and oil qualities in the established essential oil–producing species *M. alternifolia*, *M. cajuputi* subsp. *cajuputi* and *M. quinquenervia*. These species all have distinctly different chemical variants of which only one (or two in the case of *M. quinquenervia*) of several types found in nature is suitable for commercial exploitation. So it is very important to select the provenance(s) within species that will reliably provide the required oil as well as the ability to grow rapidly and coppice well so that oil yields are maximised.

Once the best natural provenances are identified, further economic gains can be achieved by selection between and within families established in progeny trials and development of clonal or seedling seed orchards to provide improved seed. This is well demonstrated by a traditional, relatively low-cost, seed-based breeding program for *M. alternifolia* in Australia (Figure 28). This program has delivered to industry realised genetic gains in oil yield from improvements in foliar oil concentration and leaf biomass per ha in one generation of breeding: 55% from selections within the best natural provenance; 43% from a culled, broadly based seedling seed orchard; and 83% from a clonal seed orchard established by stem cuttings from selected individuals within the best provenances in a progeny trial (Doran et al. 2006). Even greater genetic gains are expected to be realised from the second generation of selection and breeding in this species. Similar results have been achieved in the breeding of *M. cajuputi* subsp. *cajuputi* in Indonesia where gains in oil yield in excess of 20% are anticipated from the first generation of selection and breeding in open-pollinated seedling seed orchards (A. Rimbawanto, 'Indonesian cajuput oil' section in Chapter 4).

Caution

High on the list of undesirable traits, particularly when introducing melaleucas to a new environment, is the potential for their spread from cultivation to become noxious weeds. This occurs through distribution of seed by wind and water from canopies that hold a store of mature fruit, often for many years, awaiting the right conditions to stimulate release (e.g. fire) and also root suckering which is a feature of some melaleucas with extensive root systems (e.g. *M. ericifolia*, *M. viridiflora*). The experience with the *M. quinquenervia* invasion of the Florida Everglades is a classic example of an inappropriate species introduction that has gone horribly wrong, with the aggressive, fast-growing invader crowding out regeneration of native species and destroying wildlife habitat. Thus, extreme caution is warranted when introducing a *Melaleuca* to a new environment for the first time, and particularly, it seems, in swampy conditions. Another disadvantage is the susceptibility of certain of the more tropical species, such as *M. leucadendra* and *M. quinquenervia*, to fungal attack at a young age by the rust, *Puccinia psidii* sensu lato. Insect pests are also an impediment to the successful establishment and growth of some species (e.g. in the cultivation of *M. alternifolia* for essential oil production), requiring use of chemical sprays. Despite these disadvantages, there will be localities where the genus *Melaleuca* can provide the species-of-choice for the prevailing conditions and intended end use.

Figure 28. Progeny trials (A, B), a young seedling seed orchard (C) and controlled crossing activities (D–F) as part of a tree breeding project aimed at improving oil yields in *Melaleuca alternifolia* in Australia

Advice is at hand

Prospects for wider exploitation of carefully selected germplasm of *Melaleuca* species appropriate for intended end use(s) both within and beyond their zones of natural occurrence appear promising. When considering introduction of a *Melaleuca* species to a location for the first time, plant risk analysis procedures should be applied and the species rejected if the weediness risk is unacceptable. The Australian Tree Seed Centre, CSIRO Plant Industry, Canberra, holds seed stocks of a wide range of mainly tree-form melaleucas and is a source of both seed and information on cultivating species in the genus.