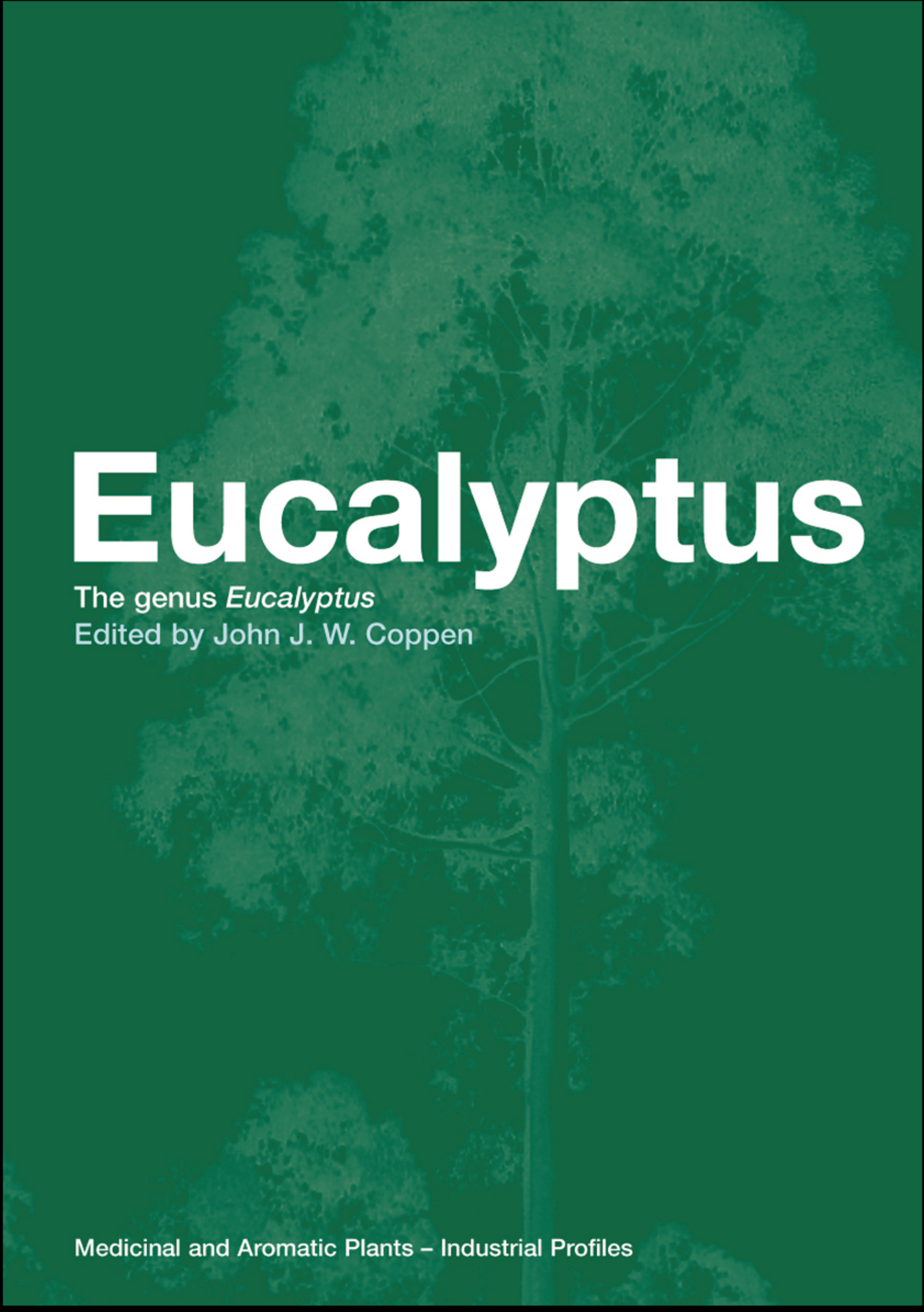

Eucalyptus

The genus *Eucalyptus*

Edited by John J. W. Coppen

Medicinal and Aromatic Plants – Industrial Profiles

Also available as a printed book see title verso for ISBN details

Eucalyptus

Medicinal and aromatic plants – industrial profiles

Individual volumes in this series provide both industry and academia with in-depth coverage of one major medicinal or aromatic plant of industrial importance.

Edited by Dr Roland Hardman

Volume 1
Valerian
Edited by Peter J. Houghton

Volume 2
Perilla
Edited by He-ci Yu, Kenichi Kosuna and Megumi Haga

Volume 3
Poppy
Edited by Jenö Bernáth

Volume 4
Cannabis
Edited by David T. Brown

Volume 5
Neem
Edited by H.S. Puri

Volume 6
Ergot
Edited by Vladimír Křen and Ladislav Cvak

Volume 7
Caraway
Edited by Éva Németh

Volume 8
Saffron
Edited by Moshe Negbi

Volume 9
Tea Tree
Edited by Ian Southwell and Robert Lowe

Volume 10
Basil
Edited by Raimo Hiltunen and Yvonne Holm

Volume 11
Fenugreek
Edited by Georgios Petropoulos

Volume 12
Gingko biloba
Edited by Teris A. Van Beek

Volume 13
Black Pepper
Edited by P.N. Ravindran

Volume 14
Sage
Edited by Spiridon E. Kintzios

Volume 15
Ginseng
Edited by W.E. Court

Volume 16
Mistletoe
Edited by Arndt Büssing

Volume 17
Tea
Edited by Yong-su Zhen

Volume 18
Artemisia
Edited by Colin W. Wright

Volume 19
Stevia
Edited by A. Douglas Kinghorn

Volume 20
Vetiveria
Edited by Massimo Maffei

Volume 21
Narcissus and Daffodil
Edited by Gordon R. Hanks

Volume 22
Eucalyptus
Edited by John J.W. Coppen

Eucalyptus

The Genus *Eucalyptus*

Edited by

John J.W. Coppen

London and New York

First published 2002
by Taylor & Francis
11 New Fetter Lane, London EC4P 4EE

Simultaneously published in the USA and Canada
by Taylor & Francis Inc,
29 West 35th Street, New York, NY 10001

Taylor & Francis is an imprint of the Taylor & Francis Group

This edition published in the Taylor & Francis e-Library, 2005.

“To purchase your own copy of this or any of Taylor & Francis or Routledge’s collection of thousands of eBooks please go to www.eBookstore.tandf.co.uk.”

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging in Publication Data
A catalog record for this book has been requested

ISBN 0-203-21943-0 Master e-book ISBN

ISBN 0-203-27451-2 (Adobe eReader Format)
ISBN 0-415-27879-1 (Print Edition)

Contents

Contributors

S.G. Agarwal, Regional Research Laboratory, Jammu-Tawi 180 001, India.

Judi Beerling, Quest International, Kennington Road, Ashford, Kent TN24 0LT, UK.

Trevor H. Booth, CSIRO Forestry and Forest Products, PO Box E4008, Kingston ACT 2604, Australia.

Ian Brooker, Centre for Plant Biodiversity Research, CSIRO Plant Industry, GPO Box 1600, Canberra ACT 2601, Australia.

Joseph J. Brophy, Department of Chemistry, University of New South Wales, Kensington, NSW 2033, Australia.

Ian R. Calder, Centre for Land Use and Water Resources Research, Porter Building, University of Newcastle, Newcastle-upon-Tyne NE1 7RU, UK.

Shaoxiong Chen, China Eucalypt Research Centre, Renmin Dadao Zhong 30, Zhanjiang, Guangdong 524022, P.R. China.

John J.W. Coppen, 12 Devon Close, Rainham, Kent ME8 7LG, UK.

Laércio Couto, Departamento de Engenharia Florestal, Universidade Federal de Viçosa, 36571 Viçosa, MG, Brazil.

Geoffrey R. Davis, G.R. Davis Pty Ltd, PO Box 123, 29-31 Princes Street, Riverstone NSW 2765, Australia.

Stanley G. Deans, Aromatic & Medicinal Plant Group, Food Systems Division, SAC Auchincruive, South Ayrshire KA6 5HW, UK.

E.F.K. Denny, Denny, McKenzie Associates, PO Box 42, Lilydale, Tasmania 7268, Australia.

John C. Doran, CSIRO Forestry and Forest Products, PO Box E4008, Kingston ACT 2604, Australia.

William J. Foley, Division of Botany and Zoology, Australian National University, Canberra 0200, Australia.

Peter Golob, Food Security Department, Natural Resources Institute, University of Greenwich, Chatham Maritime, Kent ME4 4TB, UK.

S.S. Handa, Regional Research Laboratory, Jammu-Tawi 180 001, India.

Paul A. Jacovelli, 6 Clive Road, Preston, Lancs PR1 0AT, UK.

Takao Konoshima, Kyoto Pharmaceutical University, Misasagi, Yamashina-ku, Kyoto 607, Japan.

Erich V. Lassak, Phytochemical Services, 254 Quarter Sessions Road, Westleigh, NSW 2120, Australia.

Ivan R. Lawler, School of Tropical Environment Studies and Geography, James Cook University of Queensland, Douglas Q 4811, Australia.

Steve Meakins, Quest International, Kennington Road, Ashford, Kent TN24 0LT, UK.

Hiroyuki Nishimura, Department of Bioscience and Technology, School of Engineering, Hokkaido Tokai University, Sapporo 005-8601, Japan.

Atsushi Satoh, Department of Bioscience and Technology, School of Engineering, Hokkaido Tokai University, Sapporo 005-8601, Japan.

Les Small, Quest International, Kennington Road, Ashford, Kent TN24 0LT, UK.

Ian A. Southwell, NSW Agriculture, Wollongbar Agricultural Institute, Wollongbar, NSW 2477, Australia.

Midori Takasaki, Kyoto Pharmaceutical University, Misasagi, Yamashina-ku, Kyoto 607, Japan.

R.K. Thappa, Regional Research Laboratory, Jammu-Tawi 180 001, India.

John W. Turnbull, CSIRO Forestry and Forest Products, PO Box E4008, Kingston ACT 2604, Australia.

Preface to the series

There is increasing interest in industry, academia and the health sciences in medicinal and aromatic plants. In passing from plant production to the eventual product used by the public, many sciences are involved. This series brings together information which is currently scattered through an ever increasing number of journals. Each volume gives an in-depth look at one plant genus, about which an area specialist has assembled information ranging from the production of the plant to market trends and quality control.

Many industries are involved such as forestry, agriculture, chemical, food, flavour, beverage, pharmaceutical, cosmetic and fragrance. The plant raw materials are roots, rhizomes, bulbs, leaves, stems, barks, wood, flowers, fruits and seeds. These yield gums, resins, essential (volatile) oils, fixed oils, waxes, juices, extracts and spices for medicinal and aromatic purposes. All these commodities are traded worldwide. A dealer's market report for an item may say 'Drought in the country of origin has forced up prices'.

Natural products do not mean safe products and account of this has to be taken by the above industries; which are subject to regulation. For example, a number of plants which are approved for use in medicine must not be used in cosmetic products.

The assessment of safe to use starts with the harvested plant material which has to comply with an official monograph. This may require absence of, or prescribed limits of, radioactive material, heavy metals, aflatoxin, pesticide residue, as well as the required level of active principle. This analytical control is costly and tends to exclude small batches of plant material. Large scale contracted mechanised cultivation with designated seed or plantlets is now preferable.

Today, plant selection is not only for the yield of active principle, but for the plant's ability to overcome disease, climatic stress and the hazards caused by mankind. Such methods as *in vitro* fertilization, meristem cultures and somatic embryogenesis are used. The transfer of sections of DNA is giving rise to controversy in the case of some end-uses of the plant material.

Some suppliers of plant raw material are now able to certify that they are supplying organically-farmed medicinal plants, herbs and spices. The European Union directive (CVO/EU No. 2092/91) details the specifications for the *obligatory* quality controls to be carried out at all stages of production and processing of organic products.

Fascinating plant folklore and ethnopharmacology leads to medicinal potential. Examples are the muscle relaxants based on the arrow poison, curare, from species of *Chondrodendron*, and the anti-malarials derived from species of *Cinchona* and *Artemisia*. The methods of detection of pharmacological activity have become increasingly reliable and specific, frequently involving enzymes in bioassays and avoiding the use of laboratory animals. By using bioassay linked fractionation of crude plant juices or extracts, compounds can be specifically targeted which, for example, inhibit blood platelet aggregation, or have anti-tumour, or anti-viral, or any other required activity. With the assistance of robotic devices, all the members of a genus may be readily screened. However, the plant material must be *fully* authenticated by a specialist.

The medicinal traditions of ancient civilisations such as those of China and India have a large armamentaria of plants in their pharmacopoeias which are used throughout South-East Asia. A similar situation exists in Africa and South America. Thus, a very high percentage of the World's population relies on medicinal and aromatic plants for their medicine. Western medicine is also responding. Already in Germany all medical practitioners have to pass an examination in phytotherapy before being allowed to practise. It is noticeable that throughout Europe and the USA, medical, pharmacy and health related schools are increasingly offering training in phytotherapy.

Multinational pharmaceutical companies have become less enamoured of the single compound magic bullet cure. The high costs of such ventures and the endless competition from 'me too' compounds from rival companies often discourage the attempt. Independent phytomedicine companies have been very strong in Germany. However, by the end of 1995, eleven (almost all) had been acquired by the multinational pharmaceutical firms, acknowledging the lay public's growing demand for phytomedicines in the Western World.

The business of dietary supplements in the Western World has expanded from the health store to the pharmacy. Alternative medicine includes plant-based products. Appropriate measures to ensure the quality, safety and efficacy of these either already exist or are being answered by greater legislative control by such bodies as the Food and Drug Administration of the USA and the recently created European Agency for the Evaluation of Medicinal Products, based in London.

In the USA, the Dietary Supplement and Health Education Act of 1994 recognised the class of phytotherapeutic agents derived from medicinal and aromatic plants. Furthermore, under public pressure, the US Congress set up an Office of Alternative Medicine and this office in 1994 assisted the filing of several Investigational New Drug (IND) applications, required for clinical trials of some Chinese herbal preparations. The significance of these applications was that each Chinese preparation involved several plants and yet was handled as a *single* IND. A demonstration of the contribution to efficacy, of *each* ingredient of *each* plant, was not required. This was a major step forward towards more sensible regulations in regard to phytomedicines.

My thanks are due to the staffs of Harwood Academic Publishers and Taylor & Francis who have made this series possible and especially to the volume editors and their chapter contributors for the authoritative information.

Roland Hardman

Preface

The eucalypt, or gum tree, is such an established feature of the Australian landscape that it has left its mark in that most well-loved of Australian institutions, Waltzing Matilda, penned by 'Banjo' Patterson towards the end of the nineteenth century:

> Once a jolly swagman camped by a billabong,
> Under the shade of a coolibah tree[1] …

For those for whom the association between coolibah tree and eucalyptus goes unrecognised the latter word may, instead, conjure up pictures of koala bears munching contentedly on the leaves of gum trees. And for yet others, eucalyptus may have medicinal connotations – whether through the use of eucalyptus-flavoured throat lozenges or chest rubs or through eucalyptus oil and the increasingly popular practice of aromatherapy. In truth, all these associations are genuine but the single, simple word 'eucalyptus' does not convey the complexity and diversity of all that it embraces, whether measured in terms of the uses to which it is put or the number of species to which it refers. Nor does it convey to the man or woman in the street the international nature of eucalyptus. Australia may be its natural home but its progeny have spread far and wide and the industries associated with it now span the globe. Whether cultivated as narrow tracts alongside roads, railways and canals in China and India, or as vast blocks of monoculture in Brazil and elsewhere, no continent, outside of Antarctica, has failed to be smitten by the lure of eucalyptus.

The genus *Eucalyptus*, which is native to Australia and some islands to the north of it, consists of over 800 species of trees.[2] This number continues to grow as new taxa are described. The trees grow under a wide range of climatic and edaphic conditions in their natural habitat and the very large and varied gene pool which can be drawn upon for planting purposes is one reason for the successful introduction of *Eucalyptus* into so many other countries in the world. Another reason is the fast-growing nature of eucalypts which makes them ideally suited to obtaining an economic return within a relatively short period of time. With the advantages have come some perceived disadvantages, however, and a fair measure of controversy. Not least the effects of eucalypts on the soil in terms of water and nutrient abstraction. Calder (Chapter 2) demonstrates that proper scientific research is now distinguishing between myth and reality and dispelling some of the misconceptions surrounding eucalyptus and the environment.

1 *Eucalyptus coolabah* or *E. microtheca*.

2 *Corymbia*, previously a sub-genus of *Eucalyptus*, has been elevated to the rank of a separate genus by Hill and Johnson. However, since at least one well-known species (*Corymbia citriodora*) is the source of a commercially important oil, which will continue to be traded under the name *Eucalyptus citriodora*, the original classification is retained in this book to facilitate the discussion.

The multipurpose nature of *Eucalyptus* and its cultivation for such end-uses as timber, pulp and fuelwood is generally well described and documented. Information on the medicinal and aromatic properties of eucalyptus, however, although well known, generally resides in the primary research literature or is scattered, much of it superficially, in a number of different media forms. This is particularly true of the commercial and practical aspects of production, both of the trees themselves and of the pharmaceutical and perfumery products which reach the marketplace (either the primary extractives, such as eucalyptus oil, or end-use products). It is these aspects, embracing everything from the land preparation and fertiliser prescriptions used in Africa and China for the cultivation of oil-bearing species to the chemistry and composition of eucalyptus oils, from an examination of world trade and prices for the oils and the increasingly burdensome demands being placed on producers and exporters by legislation and quality specifications to formulations used to make bath foams and hair conditioners, that are described and discussed in this book. Everything, in short, which should constitute an industrial profile. Some things, such as distillation, are taken for granted by their practitioners but, as Denny shows (Chapter 6), commercial practice is not always best practice and there is ample scope for improvement. Koalas (and possums) are not left out and what we learn about their eating habits and preferences (Chapter 15) may enable us to determine the role of essential oils and related compounds in conferring resistance to herbivores – with considerable economic consequences.

The use of eucalyptus as a commercial source of volatile oil forms the basis for much of the content of the book, but not all of it. The relative ease with which plant essential oils are distilled and analysed made them primary targets for early investigation and exploitation. It remains the case today that they are by far the largest group of eucalyptus extractives to be exploited for medicinal and fragrance or flavour purposes. However, research in recent years has uncovered a large number of pharmacologically active non-volatile compounds unique to eucalyptus, many of which – such as the euglobals and macrocarpals – form groups of structurally similar compounds. Their potential for use in the treatment of AIDS and cancer, amongst other things, ensures that they will be the subject of much more research in the years to come. Results to date, and an indication of the species of *Eucalyptus* which contain the most promising groups of compounds, are described in some detail.

The native Australian aborigines had long used eucalyptus. Not only its wood and bark for the fabrication of canoes, spears and boomerangs, and domestic items such as bowls and dishes, but its leaves, roots and other parts for medicinal purposes. The crushed leaves would inevitably have disclosed the presence of fragrant oils but it was not until 1788, the year of white settlement in Australia, that the first recorded distillation of eucalyptus oil was made. In 1852 a still was set up for its commercial production. Joseph Bosisto, who had emigrated from England four years earlier, established his still on Dandenong Creek, about 40 km southeast of Melbourne, with the encouragement of Ferdinand von Mueller, then Government Botanist in Victoria. The rest, as they say, is history.

Today, of the hundreds of species of *Eucalyptus* that have been shown to contain volatile oil in their leaves, only about a dozen are utilised, of which six account for the greater part of world oil production: *E. globulus*, *E. exserta*, *E. polybractea*, *E. smithii*, *E. citriodora* and *E. dives*. Australia is no longer the main producer of eucalyptus oil – this distinction belongs to China, by a long way – but it has maintained a highly efficient industry in the face of competition from more than a dozen countries. Medicinal-type eucalyptus oil – or its main constituent, 1,8-cineole (eucalyptol) – is an ingredient of many hundreds of pharmaceutical products and used for the treatment of ailments ranging from colds, coughs and congestion to sports injuries and muscle and joint pain, from insect bites to skin disorders. It is also used in an array of personal care products such as shampoos, bath foams, soaps and body lotions, not to mention cleaning agents. All this in addition to use of the neat oil, again in many and varied ways, around the home. Complementary to the medicinal oils are the perfumery eucalyptus oils, exemplified by the familiar lemon-scented oil of *E. citriodora*, used directly for fragrance purposes or as a source of citronellal.

The existence of chemical variants within the same species of *Eucalyptus* creates potential pitfalls for the analyst and producer alike but it also offers prospective benefits arising from plant selection and breeding. Continued screening of *Eucalyptus* species, together with research into aspects such as optimum species and provenance selection for locations outside their natural distribution, vegetative propagation, improved farm management practices and new applications, indicates that eucalyptus oil will continue to be an essential oil of major importance in world trade and usage and to the economy of many countries and communities in both the developed and developing world. Together with new avenues of research opened up by the discovery of pharmacologically active non-volatile constituents, and the prospect of treating or preventing a variety of important human diseases and ailments, eucalyptus may not yet have exhausted its capacity for surprising us at its multifarious nature.

Finally, I should like to thank all the contributors to this volume for their efforts and expertise, Dr Roland Hardman, Series Editor, for his support and encouragement throughout, and, not least, my family, particularly Eve, for their patience and understanding.

John J.W. Coppen

Part 1

General aspects

1 Botany of the eucalypts

Ian Brooker

Introduction

There are probably few tree genera that have had as much written about them as the eucalypts. Indigenous to the Australasian region, they are now among the most widely cultivated of all plants, particularly in tropical and subtropical parts of the world. The multiple uses to which eucalypts are put, from construction timber to fuel and pulp, and from oils to amenity planting, make this plant genus one of the most valuable and widely used in the world.

To the average Australian they are a natural feature of the environment, where vast forests have been exploited for commercial purposes, often in the expectation that natural regeneration will sustain an industry more or less permanently. In the last thirty years, however, an awareness of the need to preserve the forests has become as much a political as a silvicultural necessity.

The perspective in many other countries, where the eucalypt is known as an alien plant, is different. But after generations of planting the eucalypt may be seen as almost part of the landscape, providing fuel, timber and ornamentation in places where the original forests have been razed beyond the possibility of natural regeneration. In a few countries the eucalypt is the dominant tree in plantations where vast numbers of even-aged trees of more or less identical habit and size occupy great areas. Their uniformity is often due to the surprisingly small choice of species, many subsequently cloned or produced by manipulated crossing to package the most desired characters for site adaptation and specific end use.

When it is considered that relatively few species of eucalypt form the basis of plantation industries, it may be questioned to what extent this large and greatly variable genus has been tested. It occurs in a vast assortment of forms and in sites which range from rainforest to alpine to desert. There is no doubt that among the 800 species of eucalypt which have now been described, species as yet untried will prove to be successful for a multitude of reasons, whether for their fuel, timber, fibre, oils or other chemicals, or merely for shelter and amenity.

The discovery of the eucalypts

The popular conception of the discovery of *Eucalyptus* relates to the voyages of Captain James Cook in the Endeavour in the 1770s. Following the naming and exploration of New Zealand on his first voyage, the party arrived on the eastern coast of Australia. From their first principal landfall which Cook named Botany Bay, they sailed northwards, making plant collections under the guidance of Sir Joseph Banks. There are several extant eucalypt specimens from this first voyage, one of which from Botany Bay was described, but not recognised as a new genus, and was placed in the established genus *Metrosideros* by the botanist Joseph Gaertner in 1788.

On Cook's third voyage to the south seas, the botanist of the party, David Nelson, collected a specimen on Bruny Island to the south of the Tasmanian landmass. Taken back to England it was studied by the French botanist, Charles Louis L'Héritier de Brutelle, working at the British Museum, Natural History, where the specimen remains. He published it in 1788 as the single species of a new genus which he named *Eucalyptus*, from the Greek, *eu*, well, and *calyptos*, covered, alluding to the cap (operculum) that covered the stamens in the bud before anthesis. In the fifty years following Cook's voyages many more eucalypt species were discovered. These were found by settlers radiating from the new settlements on Port Jackson (Sydney), Hobart, Melbourne and Adelaide, and by naturalists on exploration trips around the continent, of which the best known are those of Labillardière in 1792, Robert Brown in 1801–1803, and that of the surveyor Allan Cunningham (1817–1822).

By 1867, when the first substantial classification of the genus *Eucalyptus* was published by George Bentham, 135 species were known. Since then hundreds more have been discovered, with periods of activity coinciding with the efforts of the principal eucalypt botanists operating at the various times. Notable eras of *Eucalyptus* publication have been the latter half of the nineteenth century (Ferdinand von Mueller), 1903–1933 (Joseph Henry Maiden) and 1934 (William Faris Blakely). An indication of the accumulation of named eucalypts is given in Figure 1.1, where periods of intensive activity can be seen. Considering that eucalypts are now recognised to number about 800, it appears that, on average, for every species published a synonym has also been published.

While eucalypts were largely brought to public awareness from the early nineteenth century onwards, there can be no doubt that eucalypts were known to Europeans well before that time. In 1699, the English navigator William Dampier landed on the west coast of Australia and made plant collections which are extant and held at Cambridge, England. There are no eucalypts among them (A.S. George pers. comm.) but it is unlikely that Dampier or his party could not have come across them, even though they landed in a very arid part of the continent. The earliest collected eucalypt is believed to have come from Ceram, an island of eastern Indonesia. It was probably *Eucalyptus deglupta* Blume, one of the few *Eucalyptus* species not indigenous to the Australian landmass but occurring in New Guinea, Indonesia and the southern Philippines. The

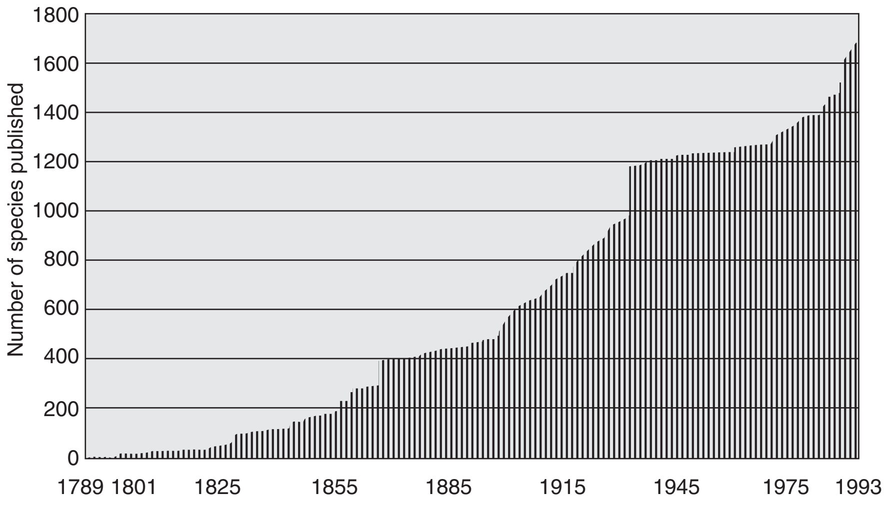

Figure 1.1 Numbers of *Eucalyptus* species published by year.

specimen was not described and published at the time and its history remains a curiosity. The species was, however, formally described in 1849 by Carl Blume from a sterile specimen earlier given the manuscript name 'Populus deglubata'.

There is a possibility that a eucalypt species was reasonably well known before the Ceram specimen. *E. alba* Reinw. and *E. urophylla* Blake, the latter only described in 1977, are indigenous to Timor and some Indonesian islands and it is likely that these species were encountered and used by the colonising Portuguese, as well as the local people. Seed may also have been taken to Brazil, another colony of the Portuguese, from the early 1600s.

The origins of *Eucalyptus*

Australia is the most arid of continents. Nevertheless, there are significant regions of very high rainfall along the eastern coast and in southwestern Tasmania. These areas support the remaining rainforests which, floristically, are in great contrast to the far more widely distributed 'typical' Australian landscapes dominated by *Eucalyptus* and *Acacia*. It was once assumed that the sclerophyll vegetation of most of the land surface was the autochthonous flora and that the rainforest was a later invader, probably from the north, across land bridges which were manifest at times of low sea level. The more recent theories of plate tectonics, supported by fossil evidence, show that the present landmass was once part of a single super-continent, Gondwana (Barlow 1981) comprising what is now known as New Guinea, Antarctica, India, Arabia, Africa, Madagascar and South America.

As Gondwana broke up in the Tertiary period, the Australian landmass drifted northwards from Antarctica. It is believed that in the early part of this drift the continent experienced high rainfall and was characterised by a relatively uniform rainforest vegetation. The landmass gradually became drier and the ancient soils lost their fertility. The new land environments became totally unsuited to rainforest and it contracted, largely to the eastern seaboard. However, by the evolution of new adaptable forms some plant families were able to occupy the areas of less certain rainfall and soils of diminishing fertility. Notable examples are *Myrtaceae*, which spawned the eucalypts, and *Mimosaceae*, the distinctive phyllodinous acacias. Both plant groups required morphological and physiological modifications to enable them to thrive. This may be seen in *Acacia* in the dominance among the hundreds of dryland species of the phyllode, a modification of the soft divided leaves of the probable rainforest precursors.

In the case of the eucalypts, the most conspicuous change for the survival of plants in the harsher environments of the open forests and shrublands can be seen in the leaves and inflorescences. In the closed forests there would have been far more competition for sunlight and the leaves are necessarily dorsiventral, held more or less horizontally, with the photosynthetic tissues facing upwards and stomata on the underside. For the most successful reproduction of primarily entomophilous plants, it is likely that the inflorescences should be presented as conspicuously as possible. This requires that the inflorescence be large and terminal on the crown (e.g. *E. calophylla* R. Br. ex Lindley, Figure 1.2). We cannot know what the precursor or precursors of *Eucalyptus* were, but from an analysis of the present rainforest and of the sclerophyllous vegetation of the majority of the Australian environment, *Protoeucalyptus* may have had the characters given in Table 1.1.

The contrast between the shadowy environment beneath the crowns of the rainforest and the intense light of the open forests and shrublands is immense in terms of available sunlight. An essential adaptation was the development of the isobilateral leaf which, in addition, tended to be held vertically, often presenting an edge to the sun with the stomata on both sides, a style of leaf that minimises the effects of direct sunlight and protects the stomata as much as possible.

Figure 1.2 Terminal inflorescences (*E. calophylla*).

Table 1.1 Suggested characters in *Protoeucalyptus*

Character	*Protoeucalyptus*
Habit	Tree
Bark	Rough
Cotyledons	Reniform
Juvenile leaf phase	Short
Adult leaves	Dorsiventral
Leaf oil glands	Few and small
Inflorescences	Terminal
Sepals	Present
Petals	Present
Anthers	Versatile
Fruit	Slightly fleshy
Seeds	Hemitropous

It is interesting to observe in leaf characters, however, the present day relationships between the current species of the more humid forests and their related taxa in the more arid lands. In the emergence of *Eucalyptus* and its development of a hierarchy of infra-generic forms, many taxonomic series have present-day species in the humid forests, with unmistakably related species that have been modified to adapt to the drier environments. This is notable in the bloodwoods, which have radiated over most of the continent. All the bloodwood species currently in the humid east and far southwest have dorsiventral leaves. None of the numerous species of the arid lands in this group has dorsiventral leaves. The situation of the northern tropics, with their short, very wet season and long dry one, is somewhat different, with predominantly dorsiventral species and some isobilateral ones. Examples of humid-climate, dorsiventrally-leaved species and dry-climate, isobilaterally-leaved species of the same taxonomic groups are shown in Table 1.2.

The situation with the inflorescence is somewhat different. While there has been an apparent retreat of the inflorescence from the outside of the crown to the leaf axils in most taxonomic groups (e.g. *E. pyrocarpa* L. Johnson & Blaxell, Figure 1.3), the bloodwood species in particular have retained the terminal inflorescence in all arid zone species. All bloodwood species, whether

Table 1.2 Examples of related pairs of *Eucalyptus* species showing advance from the primitive dorsiventral leaf to the isobilateral leaf

Taxonomic group	*Dorsiventral leaves (humid regions)*	*Isobilateral leaves (dry regions)*
Red bloodwoods	*E. polycarpa*	*E. terminalis*
Yellow bloodwoods	*E. leptoloma*	*E. eximia*
Swamp gums	*E. brookeriana*	*E. ovata*
Apple boxes	*E. angophoroides*	*E. bridgesiana*
Boxes	*E. rummeryi*	*E. microtheca*
Ironbarks	*E. paniculata*	*E. beyeri*
White mahoganies	*E. acmenoides*	*E. apothalassica*
Stringybarks	*E. muelleriana*	*E. macrorhyncha*

Figure 1.3 Axillary inflorescences (*E. pyrocarpa*).

of the humid forests or of the inland arid regions, have the primitive terminal inflorescence (Figure 1.2). However, several hundred species of the other taxonomic groups which have radiated across the continent, and which occur in myriad environments, have the derived axillary inflorescence.

The bark of *Protoeucalyptus* was probably rough. This has been retained without exception in the eastern bloodwood species occupying humid regions. Desert species provide a contrast and the rough bark may vary from nil to rough over part or most of the trunk. The adaptive nature of rough bark is open to much speculation. It may appear to be protective but is scarcely a necessity as rough and smooth-barked species grow in association in many varying environments. The form of the bark, whether rough or smooth, remains a powerful aid in identifying taxonomic groups within the genus, although experience is required to distinguish the different types.

Classification in the genus *Eucalyptus*

The genus *Eucalyptus*, which began in formal botanical terms as a single species, *E. obliqua* L'Hérit., in 1788, has now been recognised to comprise about 800 species, in numbers second only in Australia to *Acacia*. By 1800 only a few species had been described. These were, as expected, all from around the new colony at Port Jackson (Sydney). Most were named by Joseph Smith working at the British Museum. They include many of the most valuable timber species which, then as now, must have been the most important in a pioneer settlement for construction and fuel, namely, *E. saligna* Smith, *E. resinifera* Smith, *E. pilularis* Smith, *E. capitellata* Smith and *E. paniculata* Smith.

In the first half of the nineteenth century, land and sea-based expeditions resulted in the discovery of many more new eucalypts. Groups of related species soon became evident, e.g. the stringybarks and the ironbarks. Consequently, a comprehensive classification of the 135 known species into these recognisable categories, as formal series and subseries, was published in 1867 by George Bentham of the Royal Botanic Gardens, Kew, England. He did not visit Australia but was greatly assisted by the endeavours of the great scientist Ferdinand von Mueller, working from Melbourne, who sent Bentham plant material on which to base his studies.

Bentham devised a system that divided the eucalypts into five taxonomic series based on stamen characters. For each group he further discussed other characters such as bark, habit, etc., although these latter appear not to be essentially diagnostic. His largest series was divided into subseries based on the structure of the inflorescence and, to a lesser extent, the leaves. Overall, Bentham's system of classification was a brave attempt to order the eucalypts but his groupings have little relevance today.

The sixty years following Bentham saw the major researches in *Eucalyptus* of Joseph Henry Maiden and William Faris Blakely working at the Royal Botanic Gardens, Sydney. Their collaboration culminated in the monumental 'A Critical Revision of the genus *Eucalyptus*' by Maiden (1903–1933) which was a descriptive and historical treatment of all eucalypt species known to the time, together with detailed analyses of certain organs, e.g. the anthers, cotyledons and seeds. Maiden produced no comprehensive classification but this was remedied by his co-worker, Blakely, who published in 1934 his 'Key to the Eucalypts' – an intricately constructed system treating 606 species and varieties, bearing some resemblance to Bentham's classification but improved by the reference to many more characters, such as ontogenic development of the leaves, the inflorescences, buds, fruits and habit.

Blakely's work marks the high point of the discipline of purely comparative morphology, although his stated aim was to place species 'in the most natural position to each other and kindred genera'. With no instruction as to his methodology, it is not possible to determine if his estimations of similarities were unquestionable and intentional expressions of homology to indicate natural affinities. There has been no formal, comprehensive classification since Blakely's Key.

Few new eucalypt species were published immediately following Blakely and in the twenty-five years after World War II, and a period of stability in numbers appeared to have set in. It was about this time that a new, but not formalised, classification was published by Lindsay Pryor of the Australian National University, Canberra, and Lawrie Johnson of the Royal Botanic Gardens, Sydney (Pryor and Johnson 1971). Pryor was a strong advocate of the importance of breeding barriers in assessing natural affinities. The authors stated that 'there are several completely reproductively isolated groups within *Eucalyptus* and these conform to the subgenera of our system'. Pryor and Johnson's system is explicitly phylogenetic and divided the genus into seven subgenera (Table 1.3). Their taxonomic sections, series, subseries and superspecies were not qualified by diagnostic data but the classification became the benchmark for a host of subsequent eucalypt studies.

Pryor and Johnson's classification was deliberately extracodical (informal and outside the Code of Botanical Nomenclature). The system was hierarchical (sections, series, etc.) and contrasts with

Table 1.3 The classification of Pryor and Johnson (1971) with examples of well-known species in the taxa

Subgenera (Pryor and Johnson 1971)	*Well-known species and species groups*
Blakella	Ghost gums (e.g. *E. tessellaris*)
Corymbia	Bloodwoods (e.g. *E. citriodora*)
Eudesmia	Includes *E. miniata* and *E. baileyana*
Gaubaea	Comprises *E. curtisii* and *E. tenuipes*
Idiogenes	*E. cloeziana* only
Monocalyptus	White mahoganies (e.g. *E. acmenoides*), stringybarks (e.g. *E. globoidea*), blackbutts (e.g. *E. pilularis*), ashes (e.g. *E. obliqua*), peppermints (e.g. *E. dives*, *E. radiata*)
Symphyomyrtus	Red mahoganies (e.g. *E. robusta*), red gums (e.g. *E. camaldulensis*), mallees (e.g. *E. polybractea*), gums (e.g. *E. globulus*), boxes (e.g. *E. polybractea*), ironbarks (e.g. *E. staigeriana*)

Table 1.4 Proposed new classification of the genus *Eucalyptus* (Brooker unpubl.)

Subgenus *Angophora*
Subgenus *Corymbia* sensu Pryor and Johnson 1971
Subgenus *Blakella* sensu Pryor and Johnson 1971
Subgenus (*E. curtisii*)
Subgenus (*E. guilfoylei*)
Subgenus *Eudesmia* sensu Pryor and Johnson 1971
Subgenus *Symphyomyrtus* sensu Pryor and Johnson 1971
Subgenus (*E. raveretiana*, *E. brachyandra*, *E. howittiana*, *E. deglupta*)
Subgenus (*E. microcorys*)
Subgenus (*E. tenuipes*)
Subgenus *Idiogenes* sensu Pryor and Johnson 1971 (*E. cloeziana*)
Subgenus (*E. rubiginosa*)
Subgenus *Eucalyptus* (= *Monocalyptus* in Pryor and Johnson 1971)

the formal classification used by Chippendale (1988), where only one infra-generic rank (series) was used. This latter work, however, made possible the formal reference of all species published up to 1988 to taxonomic series, which is generally required in systematic papers.

The most recent major contribution to classification in the genus *Eucalyptus* was made by Hill and Johnson (1995) who formally published a new genus, *Corymbia*, comprising two of the subgenera of the Pryor and Johnson classification (1971), namely, *Corymbia* and *Blakella*. The rationale for this step was based on cladistic analyses of all the traditional eucalypt components at the general 'subgenus' level and is corroborated by molecular studies of Udovicic *et al*. (1995).

Some ambiguity, however, remains over the relationship of the closely related genus *Angophora* Cav. A recent study on the relationships within *Eucalyptus* concluded that *Angophora*, *Corymbia* and *Blakella* form a monophyletic group (Sale *et al*. 1996). Perhaps all these recent studies should be considered merely as hypotheses that will contribute ultimately to an optimum system with further researches. My current preference is for a single genus consisting of thirteen subgenera (Table 1.4), namely, the five major subgenera of Pryor and Johnson (1971), the genus *Angophora*, a subgenus comprising the four tropical species with the small fruit, and six single-species subgenera – a system embracing demonstrable morphological distinctions.

While comparative morphology is the basis for estimating natural affinities and resulting classification, the value of characters used varies greatly. Features such as bark in eucalypts have been traditionally used in keys and descriptions, but bark as a character is only of medium reliability as its constant exposure to the elements results in attrition and change of colour. Internal characters protected from outside influences are of higher reliability. In this respect, essential oils have been considered as possible aids to testing natural affinities. Little success has been achieved and it may be concluded that the developmental pathways for morphology and for essential oils are not closely associated within the eucalypt plant.

In contrast, essential oils have been useful in distinguishing related species. This is easily demonstrated in the distinctive lemon-scented *E. citriodora* Hook. when compared with the closely related *E. maculata* Hook. The latter species does not contain citronellal and so lacks the lemon fragrance. Another instance is the distinction between *E. ovata* Labill., which has a very low oil content, and the related *E. brookeriana* A. Gray, which is rich in oil, particularly 1,8-cineole (Brooker and Lassak 1981).

Complicating the situation is the well known phenomenon in eucalypts of the variation in essential oil composition between individual trees and races of trees. In the 1920s, Penfold and Morrison reported the existence of several races in the broad-leaved peppermint which they named *E. dives* Schau. 'Type', *E. dives* 'var. A', 'var. B' and 'var. C', according to their broad chemical groupings (e.g. Penfold and Morrison 1929; see also Penfold and Willis 1961). The latter variety was of greatest commercial importance since it was particularly high in 1,8-cineole. Today, these different types are regarded simply as examples of what may be a wide range of possible chemical variants or chemotypes and not given formal names, although the old nomenclature sometimes still persists.

The eucalypt plant

Habit

The plantation eucalypt is notably a fast-growing tree of good form (e.g. *E. maculata*, Figure 1.4), suitable for modern harvesting practices and intended ultimately for use as pole timber or a source of fibre. The species used for these purposes are remarkably few in number. They mostly originate in the wetter forests of the eastern seaboard of the Australian continent, e.g. *E. grandis* W. Hill ex Maiden, *E. saligna*, *E. globulus* Labill., *E. tereticornis* Smith, *E. nitens* (Deane & Maiden) Maiden, *E. dunnii* Maiden and *E. smithii* R. Baker. These species are tall trees from the natural forested areas and altogether number about fifty, and include some from the far southwest of Western Australia, namely, *E. marginata* Donn ex Smith and *E. diversicolor* F. Muell.

In drier regions, and often on less fertile soils, smaller trees of woodland habit and habitat dominate (e.g. *E. kumarlensis* Brooker, Figure 1.5). There are about 250 species of predominantly woodland form and they occupy the hills, slopes, plateaus and mountains, and the heavier soils of the plains. Notable among these is the widespread river red gum, *E. camaldulensis* Dehnh., which is a large spreading tree of freshwater streams across most of the continent. Its adaptability to many differing habitats has made it one of the most widely planted trees in other countries, where it is chosen for its fast growth, hard timber and excellent fuel.

Most of the interior of Australia is arid, and *Acacia* is the dominant genus, but eucalypt species are usually to be found in these regions along the seasonal streams and in the rocky hills. In the south, particularly, there are extensive sandplains of low fertility. These support the very

Figure 1.4 Forest tree with long bole and small terminal crown (*E. maculata*).

Figure 1.5 Woodland tree with short bole and large spreading crown (*E. kumarlensis*).

numerous mallee species (about 180 in all) although a few occur in eastern uplands, e.g. *E. approximans* Maiden and *E. gregsoniana* L. Johnson & Blaxell. The mallee is the dominant form over wide areas of tall shrubland. As a mature plant it is easily recognised by the multi-stemmed habit (e.g. *E. livida* Brooker & Hopper, Figure 1.6) and the presence of a lignotuber which is either buried just below the soil surface or is exposed through weathering of the soil.

Figure 1.6 Mallee with multiple stems (*E. livida*).

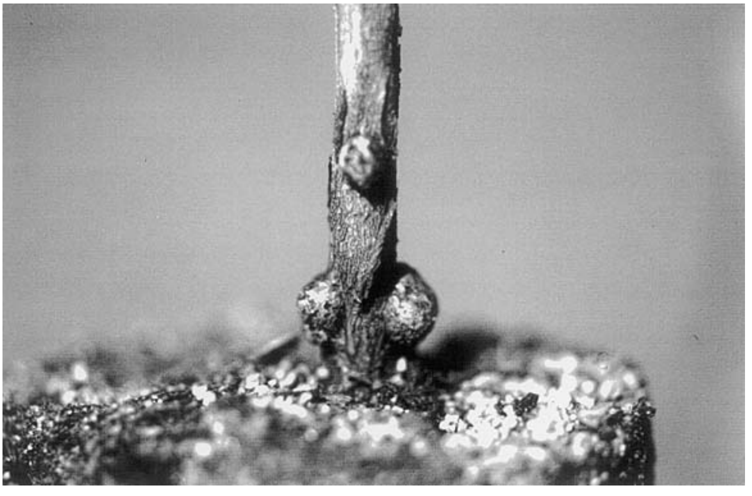

Figure 1.7 Seedling of *E. dwyeri* showing small lignotubers which have formed in the axils of fallen cotyledons.

The lignotuber

Most *Eucalyptus* species develop lignotubers. They begin as swellings in the axils of the cotyledons (e.g. *E. dwyeri* Maiden & Blakely, Figure 1.7). As the seedling gets older the swellings form in the axils of several of the lower leaf pairs. They are usually conspicuous on the young stem as they necessarily form decussately. The swellings coalesce and often engulf the upper part of the root. The whole bulbous mass becomes lignified and is a store of dormant shoots which develop and produce new stem structures when the upper part of the plant is lost through cutting, fire, grazing, etc. In very old eucalypts the lignotuber may be massive.

The lignotuber is a vital organ in the regeneration of trees or mallees and its evolution may be a particular response to ancient and constant fire regimes. Not all eucalypts form lignotubers and the regenerative capacity of the plant is an important factor in the choice of species for plantations in which repeated harvests for oil-bearing foliage are the requirement. Species best suited to a plantation and harvesting programme are those which are lignotuberous and guarantee coppice regeneration. Because of the large number of *Eucalyptus* species and the task required to detect lignotubers in all taxa and provenances, there is no comprehensive list of species which form lignotubers.

Most eucalypts form lignotubers, yet many of the best known commercial species are non-lignotuberous, e.g. *E. regnans* F. Muell., *E. delegatensis* Smith, *E. pilularis*, *E. grandis* and *E. nitens* (Jacobs 1955). These are species of wet forests of southeastern Australia which regenerate prolifically from seed, especially after site disturbance. In these species the base of the stem or trunk becomes swollen and is a store of dormant buds which respond much like the true lignotuber and result in coppice regrowth from a felled tree base. *E. diversicolor*, also non-lignotuberous, occupies high rainfall country of southwestern Australia, but the same regenerative process occurs in species of the much drier country of Western Australia, e.g. *E. astringens* (Maiden) Maiden. This species is one of several that are both non-lignotuberous and of distinctive 'mallett' habit, in which the trunk branches low and produces a characteristic crown of steep branches (Brooker and Kleinig 1990).

E. camaldulensis, which has the widest natural distribution of all eucalypt species, is variable in lignotuber formation. Populations in the northern half of the Australian continent are reported to be lignotuberous while southern populations are non-lignotuberous (Pryor and Byrne 1969), although recent seedling studies (CSIRO unpubl.) indicate that stress on the young plant is as important a stimulus for lignotuber formation as genetic predisposition.

Bark

The bark character in *Eucalyptus* is one of the most difficult to assess and describe. It has long been recognised that many species shed their outer bark each year and that others retain the dead bark. The eucalypt tree puts on an annual increment of bark tissue. Regular decortication results in smooth bark, while retention of dead bark results in rough bark, but the colour, form and thickness of the bark types varies conspicuously with the taxonomic grouping and with the age of the tree, its health, the season, etc. Recognition of the various bark types can only be achieved by regular field experience but, when learnt, it provides the botanist, naturalist and forester with a powerful tool in the recognition of species and taxonomic categories.

It is also important to bear in mind that most of the bark descriptions in texts have been made from trees growing in their natural environments, and that different conditions, particularly in other countries where eucalypts are planted, may result in different responses of colour and texture.

Smooth bark

The outer dead bark of some species and species groups sheds in slabs at a particular time of the year. This results in the sudden exposure of the underbark which is a different colour and soon changes with weathering until the trunk is an even grey or pale pink (e.g. *E. citriodora*, Figure 1.8). Such a trunk contrasts strongly with a rough-barked species (e.g. *E. macrorhyncha* F. Muell., Figure 1.9).

In the red gums (e.g. *E. camaldulensis*, Figure 1.10), and the grey gums, the outer bark sheds in irregular patches at different times during the year. The freshly-exposed underbark is usually

Figure 1.8 Bark completely shed leaving a smooth bole (*E. citriodora*).

Figure 1.9 Bark retained forming a rough bole (*E. macrorhyncha*).

Figure 1.10 Mottled smooth bark (*E. camaldulensis*).

brightly coloured yellow or coppery, which fades to light grey and then weathers to dark grey. The trunks can be spectacular immediately after decortication, and even over a whole year a mottled effect of three colours can be seen. Other species shed their bark in ribbons, e.g. *E. viminalis* Labill. and *E. globulus*, and some of these species hold the partly shed ribbons hanging in the crown, where they accumulate season after season and give rise to the name 'ribbon gums' (Figure 1.11).

Rough bark

When the dead bark accumulates year by year it dries by the loss of soft tissue and the fibres remain. The resulting rough bark has many forms. The outer layers usually weather to grey overlying the red-brown unexposed inner rough bark, which will be exposed later by the attrition of the outer fibres. The fibres may form long strings that can be pulled off, as in the stringybarks (e.g. *E. macrorhyncha*, Figure 1.9). The rough bark may break into flakes or 'squares' so characteristic of the bloodwoods (e.g. *E. calophylla*, Figure 1.12). In a large group of species the rough bark becomes infused with kino, a natural exudate, resulting in extremely hard bark that is usually deeply furrowed, as in the ironbarks (e.g. *E. cullenii* Cambage, Figure 1.13). A few species have hardened rough bark but, unlike the ironbarks, lack the characteristic deep furrowing over the whole trunk. These are the compact bark species, e.g. *E. fraxinoides* Deane & Maiden.

It is not possible to summarise adequately the rough bark types in *Eucalyptus* in so short a space, as it is too difficult to treat each form for which the conventional terms do not apply, e.g. in the many mallee species with some rough bark, and the red gums, swamp gums and mountain gums which are mostly smooth-barked but which have varying amounts of rough bark which has accumulated at the base of the trunk or stems.

Figure 1.11 Ribbons of bark (*E. globulus*).

Figure 1.12 Tessellated bark (*E. calophylla*).

Figure 1.13 Ironbark (*E. cullenii*).

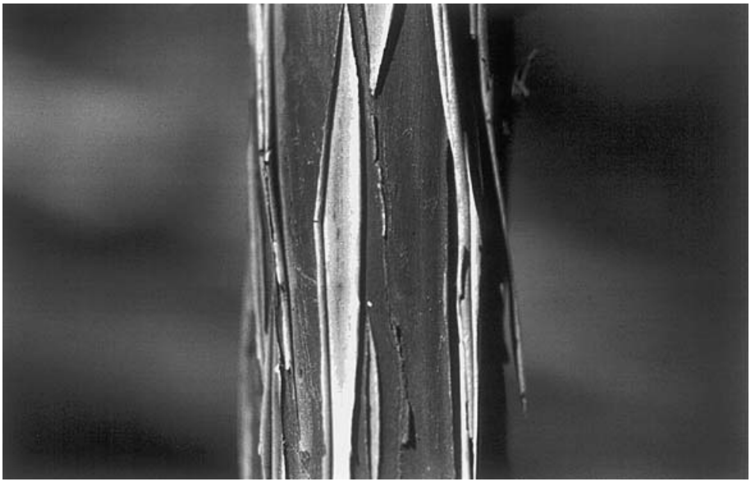

Figure 1.14 Minniritchi bark (*E. caesia*).

A small group of species has probably the most beautiful rough bark of all. These are the minniritchi group in which the thin, outer, dark red-brown bark only partly sheds longitudinally (e.g. *E. caesia* Benth., Figure 1.14). The edges curl and expose fresh green bark, providing partly rough, partly smooth bark on the green and rich red-coloured stems.

Seeds and germination

The seed morphology of eucalypts is extremely variable. Shape, size, colour and surface ornamentation are strongly inherited traits and indicative of taxonomic groups (Boland *et al*. 1991). Perhaps the most distinctive seed is that of most of the bloodwoods in which the body of the seed is basal and subtends a terminal wing. The seed of most species is flattened-ellipsoidal with a ventral hilum although in some large groups the seed has a terminal hilum. This occurs in all 'subgenus *Eucalyptus*', e.g. *E. obliqua*, and parts of 'subgenus *Symphyomyrtus*', namely, series *Annulares*, e.g. *E. pellita*, series *Fimbriatae-lepidotae*, e.g. *E. propinqua*, and series *Exsertae*, e.g. *E. tereticornis*.

There is no endosperm and the bulk of the seed is the embryo, dominated by the cotyledons, which are flat and appressed in ghost gums (*Blakella*, Pryor and Johnson 1971) but in all other species are variously folded across each other. The germinant consists of a radical, root collar, hypocotyl, cotyledons, epicotyl and terminal growth meristem. Germination is epigeal.

Seedlings and leaf ontogeny

The primitive cotyledon shape is reniform and this form of cotyledon occurs widely in the genus (Maiden 1933). The extreme modification is the bisected cotyledon formed by emargination, resulting in a Y-shaped structure. A large number of species have cotyledons shaped between these extremes and are usually described as bilobed, although the distinction between the bilobed and the reniform is often blurred.

The normal pattern throughout the life of a eucalypt is to form leaves decussately and this arrangement is seen most characteristically in the seedling. The leaves are formed in pairs on opposite sides of the four-sided stem. Successive pairs, as assessed by the axes from the leaf tips of a pair through the stem, are at right angles to each other. Exceptions are the trigonous stems and resultant simple spiral leaf pattern in *E. lehmannii* (Schauer) Benth. and related species (Carr and Carr 1980) and the spirally-leaved seedlings, based on a five-sided stem, of several mallee species, e.g. *E. oleosa* F. Muell. ex Miq. (Brooker 1968).

While opposite leaf pairs continue to be formed at the growth tips of the adult plant, the leaf arrangement is modified in all species which develop adult leaves, apart from the exceptions above. The leaf-bearing axis elongates unequally on opposite sides such that the leaf pairs become separated and the arrangement appears to be alternate (Jacobs 1955). The leaves are usually petiolate and pendulous and therefore able to become positioned for optimum use of light. This false alternation may be a simpler way of producing the same effect as a true spiral.

The eucalypt plant is notably heterophyllous and the seedling leaves usually contrast with the adult leaves in terms of shape, petiolation, disposition in relation to the axis, colour, etc. Blake (1953) suggested a somewhat arbitrary set of categories to describe the progression of the leaf forms through the life cycle of the plant, namely, seedling, juvenile, intermediate and adult leaves. Some species seldom progress beyond the juvenile phase and are reproductively mature without advancing to the adult phase. Hence the flower buds, flowers and fruit form in the axils of juvenile leaves which exclusively make up the crown of a mature tree (e.g. *E. cinerea* F. Muell. ex Benth.). Most species in this category may form intermediate and adult leaves. A few species have never been seen in the adult phase, e.g. *E. crenulata* Blakely ex Beuzev. and *E. kruseana* F. Muell., although both of these rare and isolated species hybridise with co-occurring species, *E. ovata* DC. and *E. loxophleba* Benth., respectively, and produce offspring with leaves advanced from the juvenile state.

The adult leaves

Leaf form and coloredness

The mature crown of most eucalypts consists of adult leaves. These are usually petiolate, pendulous and lanceolate. Those of most species are concolorous (isobilateral). The truly pendulous leaf is frequently asymmetrical, being oblique at the base on the underside of the vertically hanging blade. Discolorous (dorsiventral) leaves occur in about fifty species and tend to be held more horizontally. The discolorous leaf is seen most prominently in the bloodwood species of humid regions, e.g. *E. polycarpa* F. Muell., and all of the eastern blue gums, e.g. *E. grandis*, red mahoganies, e.g. *E. pellita* F. Muell., and the grey gums, e.g. *E. propinqua* Deane & Maiden. An anomalous species of obscure affinity, but widely planted, is *E. cladocalyx* F. Muell. It occurs in relatively dry regions of South Australia and is strongly discolorous in the leaf. The fact that no species with dorsiventral leaves has formed the basis of an essential oil industry indicates that the increase in oil content and the changes in oil composition have proceeded in the evolutionary advance of the genus.

The distinction between the two leaf types is a strong diagnostic feature, but a few species may be difficult to categorise in this respect, e.g. most stringybarks are slightly discolorous. *E. muelleriana* A. Howitt., which grows in mesic areas, is the most distinctive of them.

Leaf venation

Leaf venation can be a strong character for the identification of eucalypts. Basically, the midrib subtends the side veins, between which varying densities of further reticulation occur, i.e. in the form of tertiary and quaternary veining. The primitive pattern appears to be the strongly pinnate form in which the side veins leave the midrib at a wide angle. This is seen in all bloodwoods (e.g. *E. calophylla*, Figure 1.15). The most modified form of venation is that seen in snow gums, e.g. *E. pauciflora* Sieber ex Spreng. and one or two peppermint species, e.g. *E. willisii* Ladiges,

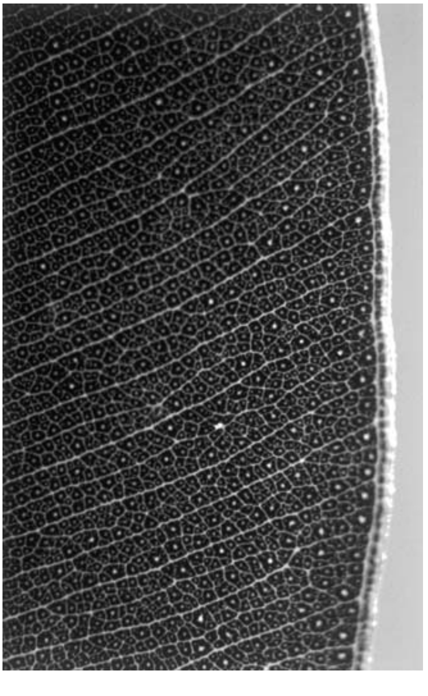

Figure 1.15 Bloodwood leaf (*E. calophylla*) showing wide-angled side veins and oil glands, mostly one per areole.

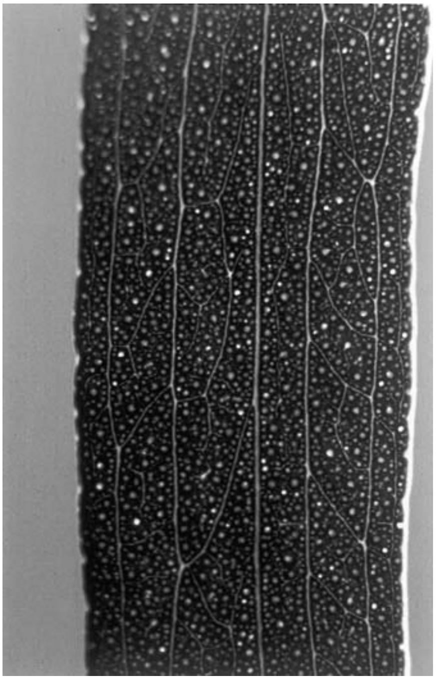

Figure 1.16 Leaf of peppermint (*E. willisii*) showing parallel side veins.

Humphries & Brooker (Figure 1.16). A great variety of patterns occurs between these extremes. In a very few species, particularly narrow-leaved species, the side veins cannot be seen at all (e.g. *E. approximans*).

Oil glands

Eucalyptus leaves are well known for their aromatic oils. Most texts refer to the invariable presence of oil glands in the leaves although some species are reported as having obscure glands. In fact many species have no visible glands at all. This situation occurs most commonly in the dryland and desert bloodwood species, e.g. *E. terminalis* F. Muell., and ghost gums, e.g. *E. tessellaris* F. Muell. Bloodwood species in more humid regions have oil glands, which are usually small and appear discretely situated in the middle of the very small areoles. Only one bloodwood of high rainfall areas, *E. ficifolia* F. Muell. of far southwestern Western Australia, appears to lack glands. It can occur sympatrically with *E. calophylla*, which is always glandular, making the presence or absence of glands a useful key character for these species, which are often held to be difficult to distinguish when not in flower. Outside the bloodwood and ghost gum groups, very few species in wetter areas consistently lack visible leaf glands, although *E. fasciculosa* F. Muell. (Figure 1.17) is an exception. The great majority of eucalypt species have conspicuous oil glands in the leaves.

The formation and development of oil glands in the eucalypt leaf has been discussed by Boland *et al*. (1991) on the basis of the studies of Carr and Carr (1970) on the formation of glands in the cotyledon or hypocotyl of the embryo. The process of gland formation begins from an epidermal cell which, on division, forms casing and epithelial cells for the gland. The cavity that becomes the oil gland itself derives from the development of an intercellular space that

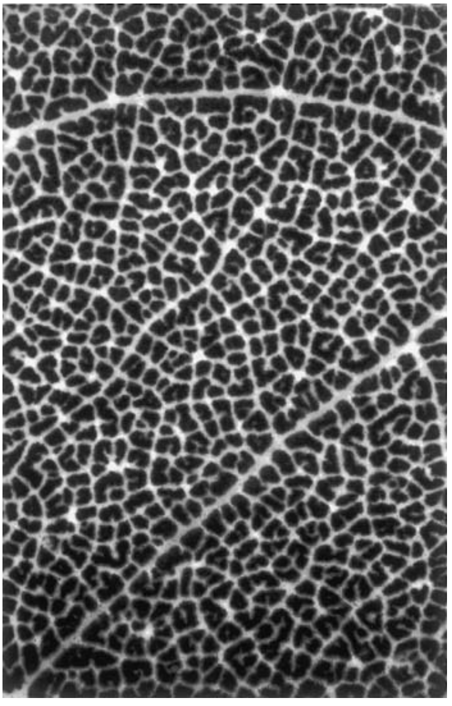

Figure 1.17 Part of a leaf of *E. fasciculosa* showing dense reticulation without visible oil glands.

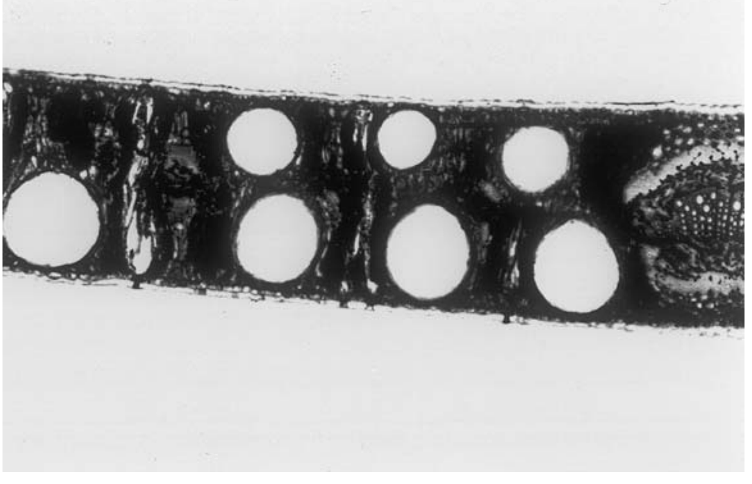

Figure 1.18 Section of a leaf of *E. kochii* showing oil glands close under both epidermises.

increases in volume and matures as an ovoid or globular cavity (e.g. *E. kochii* Maiden & Blakely, Figure 1.18). The epidermal origin of the glands is reflected in the mature leaf, and in a leaf cross-section the glands are seen to occupy a zone just under the current epidermal layer of one or both surfaces.

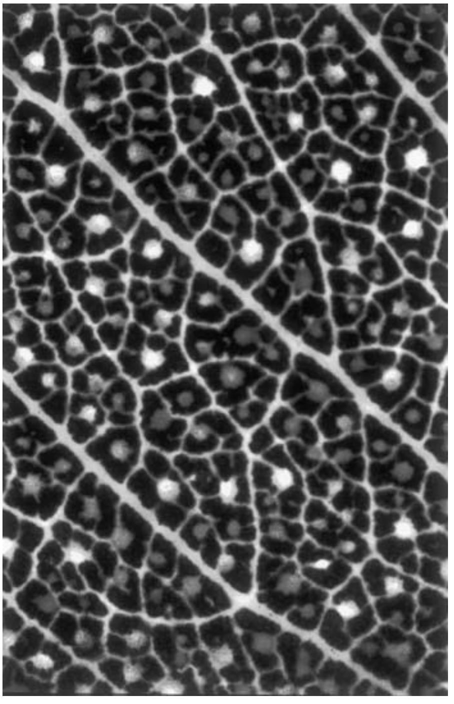

Figure 1.19 Part of a leaf of *E. kochii* showing dense reticulation and intersectional oil glands.

In the mature adult leaf of most species the oil glands are very conspicuous. Their size, shape and colour, and their apparent spatial association with veinlets, result in a multitude of patterns which are useful in the identification of species. The glands may appear to be at the intersections of veinlets (e.g. *E. kochii*, Figure 1.19), situated singly in the areoles (e.g. *E. calophylla*, Figure 1.15) or few to many within the areoles (e.g. *E. microcorys* F. Muell., Figure 1.20), or a combination of both. In a few species they are so numerous and dense that they obscure the leaf venation completely (e.g. *E. mimica* Brooker & Hopper unpubl., Figure 1.21). Within a species, while the leaf venation pattern remains unaltered and is the more fundamental diagnostic feature, gland presence and density can vary. For the purposes of field estimation, oil gland density estimated by visual inspection is no certain indicator of total oil content.

The eucalyptus oil industry in Australia

The English began a settlement at Port Jackson in 1788. Among the settlers' first objectives would have been the need to provide shelter and fuel. For these purposes trees of the native forests were felled in great numbers for their timber. It would not have taken long for the aromatic nature of the leaves to be noticed. The oil was loosely referred to as peppermint because of the supposed resemblance to that of the English peppermint, but the two oils are now known to be quite different chemically.

In 1789 a sample of oil was sent to England. It is believed to have been steam-distilled from the Sydney Peppermint, *Eucalyptus piperita* Smith, and there was obviously a presumed association of the effective medicinal properties of the *E. piperita* oil with those of the peppermint herb

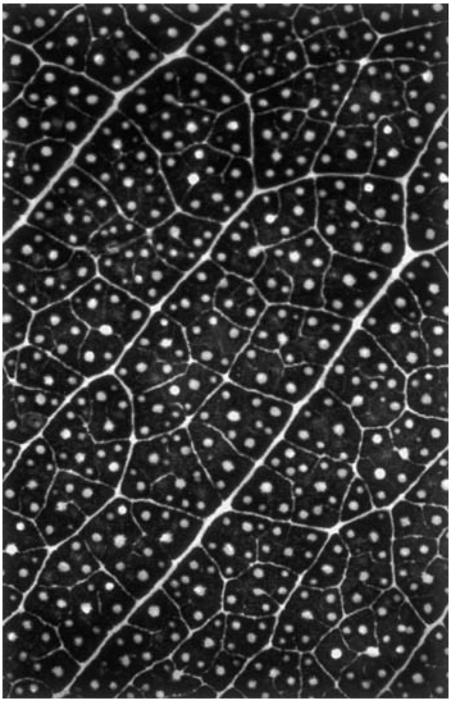

Figure 1.20 Part of a leaf of *E. microcorys* showing moderate to sparse reticulation and numerous island oil glands.

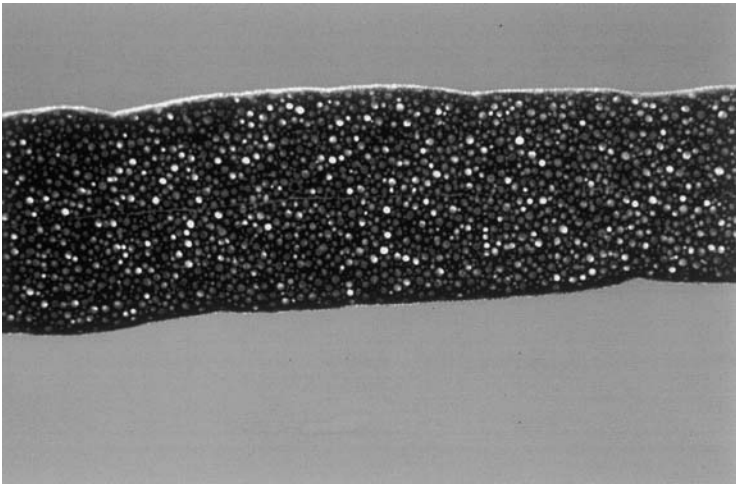

Figure 1.21 Leaf of *E. mimica* showing very numerous oil glands obscuring side veins.

of England. A naval surgeon of the First Fleet, Denis Considen, considered that eucalyptus oil was 'much more efficacious in removing all cholicky complaints' (Boland *et al*. 1991).

As European occupation of the new colony extended further north, west and south, numerous new eucalypts were found, many of which were much richer in oils than the Sydney Peppermint.

Taxonomically the name 'peppermint' became traditionally used for a different group of species, also in 'subgenus *Eucalyptus*', and it was on these that the first eucalyptus oil industry was founded.

Around 1852 or 1854, a distillation plant was established near Dandenong, east of Melbourne, using the narrow-leaved peppermint, *E. radiata* Sieber ex Spreng. (Boland *et al.* 1991). This species is one of a small group of eucalypts noted for their oils and which have been exploited for commercial purposes. They still form the basis of small industries in tableland and mountain country of southeastern Australia. For optimum exploitation of the various species it was recognised that provenance was important in the choice of leaf material for distillation. This is now known to be due to the existence of different chemotypes within a species. There are notable phellandrene and cineole-rich forms of *E. radiata*, and piperitone and cineole-rich forms of *E. dives*. Despite the early successful use of these peppermint species, the industry is now largely based on entirely unrelated species.

Settlement progressed beyond the mountains and tablelands of southeastern Australia in the early nineteenth century and onto the inland plains, now mostly cleared and used for agriculture. Pockets of these new lands were unsuitable for cropping because of their infertility or stony soils but large areas of mallee species were available for exploitation. One in particular, blue mallee, *E. polybractea* R. Baker, was found to be rich in cineole and eucalyptus oil industries were founded on this species over 100 years ago in New South Wales and Victoria.

The mallee plant is peculiarly suited for 'agricultural' practice. It is small, becoming mature after a few years growth at about 1–2 m height, although old uncut or unburnt specimens can exceed 10 m. Its size and precocious maturity makes it ideally suited to mechanical harvesting. The propensity for regeneration from the lignotuber allows the virtual perpetual regrowth of the same biotype and it is harvested at approximately eighteen-month intervals. The ideal species will have a dense crown for high biomass, high cineole yield, strong regeneration capacity and fast growth. Selection and cloning will maximise these advantages for plantation industries.

A new and interesting development in oil mallee farming is being tested in southern Western Australia. There, vast areas of wheatland have become unproductive through salination, following extensive clearing of the natural vegetation. A few eucalypt species are being tested for growth on affected sites as a means of lowering the water table and, hence, reducing salinity. As a bonus, it is hoped to harvest the plants at suitable intervals and extract the essential oils. The species in question, *E. kochii*, *E. horistes* L. Johnson & K. Hill, *E. polybractea* and *E. loxophleba* Benth. subsp. *lissophloia* L. Johnson & K. Hill, have been chosen for their high oil content and expected adaptation to saline soils (Bartle 1997).

Mallee species seldom grow naturally in pure stands. They usually occur in association with one or more other eucalypt species of similar habit, but quite unrelated. Where natural stands were harvested, as in the early years of the industry, the value of these was enhanced by the culling of the less useful species. The most successful oil-producing centres are now going over to plantations, particularly of *E. polybractea*, established either from seed or from vegetatively reproduced high-yielding individuals.

Few species have been tested for the heritability of eucalyptus oil composition and yield. A trial of a high-yielding species from Western Australia, *E. kochii*, had a family heritability index of 0.83 based on $2\frac{1}{2}$-year-old progeny (Barton *et al.* 1991). Another trial on the commercially valuable and widely planted *E. camaldulensis* from Petford in northern Queensland had a family heritability of 0.62 (Doran and Matheson 1994), indicating that for these two species of widely differing affinities, growth habits and environments, heritability for essential oil factors is high.

In contrast to the Australian experience, eucalyptus oil industries in other countries have often begun as byproducts of eucalypt plantations established for other purposes, e.g. timber or pulp production, where large volumes of oil-bearing leaf material are available which would otherwise go to waste. This is the case in Spain and Portugal. Mallees have received little attention as commercial trees outside Australia because of their unpromising size and unsuitability for pole timber.

Eucalyptus species used in oil production

In the following digests, arranged alphabetically, *Eucalyptus* species that are currently exploited for oil production are described. The first group comprises those species of modest or major current commercial significance, while the second group are those of lesser economic importance or those which have significant potential but which are, as yet, not fully exploited.

A number of other species have been used for oil production in the past but are not described in detail here. Neither are those few which are still very occasionally distilled. None are likely to assume greater importance in the future. Such species include the following:

1 *E. cneorifolia* DC., a mallee of Kangaroo Island off South Australia, which is still used for local cottage industries in the production of 1,8-cineole.
2 *E. elata* Dehnh., a peppermint common along streams in high rainfall country from west of Sydney, southwards in the subcoastal ranges to eastern Victoria, which contains high but variable amounts of piperitone.
3 *E. leucoxylon* F. Muell., a taxon with several subspecies which occurs in southern South Australia and western and central parts of Victoria and usually contains 1,8-cineole.
4 *E. macarthurii* Deane & Maiden, a tree of the Southern Tablelands of New South Wales which was once harvested for geranyl acetate.
5 *E. nicholii* Maiden & Blakely, a favourite ornamental tree of the Northern Tablelands of New South Wales harvested for 1,8-cineole.
6 *E. salmonophloia* F. Muell., a handsome tree of relatively dry country of southern Western Australia also harvested for 1,8-cineole.
7 *E. sideroxylon* Cunn. ex Woolls, an ironbark widespread on the drier slopes and plains associated with the Great Dividing Range in southeast Queensland and New South Wales which contains a cineole-rich oil. A distinctive form of *E. sideroxylon* from coastal New South Wales and eastern Victoria, once regarded as subsp. *tricarpa*, is now recognised as a separate species, *E. tricarpa* (L. Johnson) L. Johnson & Hill.
8 *E. viridis* R. Baker, a mallee of the wheatlands of western New South Wales and northern Victoria which grows with or near *E. polybractea*, and which contains a similar oil and is often harvested indiscriminately with it (Weiss 1997).

Remarkably few species are used worldwide as a commercial source of eucalyptus oil. Boland *et al.* (1991) state that of the 'more than 600 species of *Eucalyptus* probably fewer than twenty have ever been exploited commercially'. Coppen and Hone (1992) state that 'about a dozen species are utilised in different parts of the world, of which six account for the greater part of world production of eucalyptus oils'. Inventory surveys in the last fifteen years, however, have revealed several untried species that could be exploited. It is likely that a compromise may be sought between industries relying on high biomass availability in relatively low-yield tree species and those based on species with higher biomass per plant, high yield of desired oils and ease of mechanical harvesting. Spontaneous regeneration from lignotubers will be an important property of a desirable species.

Species of commercial significance in essential oil production

E. citriodora *Hook. – Lemon-scented Gum*

This species is one of the best known eucalypts, widely planted in Australia and elsewhere. It is unusual among eucalypts of subtropical origin in that it thrives in southern Australia among winter rainfall regimes. The trees are notably tall and erect with completely smooth bark of uniform colour, which contrasts with the closely related *E. maculata*, with its spotted, smooth bark and southern distribution. The juvenile leaves are typical of the bloodwood group in being large, alternate, peltate and hairy. The adult leaves of lemon-scented gum are narrowly lanceolate and on crushing reveal their most conspicuous character, the lemon scent.

E. citriodora belongs to a large taxonomic group, the bloodwoods (subgenus *Corymbia*), which are notable for the comparatively large, thick-walled, urceolate fruits. Within this group it is closely related to only two other species, *E. maculata* and *E. henryi* Blake, and together they are distinguished by the axillary, elongated, compound inflorescences, usually confined to the axils of the upper leaves, and by the flattened-ellipsoidal, red-black seeds with a cracked seedcoat and ventral hilum. This smooth-barked group is closest to the yellow bloodwoods, e.g. *E. peltata* Benth., which differ by the completely rough bark and the early loss of the outer operculum of the flower bud.

The leaves of bloodwood species are distinguished by the great number of secondary (side) veins and their wide angle to the midrib, which approaches 85 degrees. The side veins terminate at the intramarginal vein beyond which, as is typical in narrow-leaved bloodwoods, there is a single line of areoles parallel to the leaf margin. In *E. citriodora* the next degree of veining between the side veins occurs in about 2–4 rows, making a very clear, densely reticulate pattern. The oil glands occur spatially isolated within the areoles, usually single.

The main constituent of the oil of *E. citriodora* is citronellal, which gives the characteristic lemon scent. Although the oil has recently found commercial application as the active ingredient of some mosquito repellents (J. Coppen pers. comm.), it is used mainly for perfumery purposes. It is produced mainly in China, India and Brazil. Only one other *Eucalyptus* species has a lemon-scented oil, the citral-rich *E. staigeriana* F. Muell. ex Bailey (Lemon-scented Ironbark). This is unrelated to the Lemon-scented Gum and is easily distinguished from it by the completely coarse rough bark.

E. dives *Schau. – Broad-leaved Peppermint*

This species is a small to medium-sized tree of relatively dry sites for peppermints, often occurring on sunny, northern slopes of hills with shallow, often stony soils. Its natural distribution is on the tablelands and lower mountains of southeastern Australia. The bark is typical peppermint, i.e. finely fibrous, not coarse and stringy, and is indistinguishable from that of *E. radiata*. The juvenile leaves are the most conspicuous element of the species. *E. dives* regrows readily on roadsides from lignotubers and the young plants produce many pairs of opposite, ovate, glaucous, juvenile leaves. The adult leaves are the broadest for the peppermint group and are lanceolate to broadly lanceolate, glossy green.

E. dives belongs to the monocalypts ('subgenus *Eucalyptus*'), a large subgenus distinguished by the axillary inflorescences, buds with a single operculum and seeds that are cuboid, pyramidal or elongate with a terminal hilum. The peppermints are characterised in the monocalypts by the many pairs of opposite leaves of the seedling. The buds and fruit are probably the largest for the peppermints of mainland Australia. The non-glaucous *E. nitida* J.D. Hook. of Tasmania has larger buds and fruit.

The secondary venation of the leaves of *E. dives* is conspicuous and terminates at a distinct intramarginal vein which is well removed from the edge. A minor, less distinct, intramarginal vein runs between the principal intramarginal vein and the edge. The reticulation is sparsely to only moderately dense through lack of tertiary and further veining, the areoles in the broader leaf being correspondingly larger than those in *E. radiata*. The oil glands are numerous per areole and do not appear to be associated with veinlets when the leaf is viewed fresh with transmitted light. They are approximately circular in outline and mostly green with some white in colour.

Several chemotypes occur in *E. dives* and there are 1,8-cineole, phellandrene and piperitone variants. In South Africa, around 150–180 t of the piperitone-rich oil was produced annually in the late 1980s (Coppen and Hone 1992) and although it is no longer used for the production of menthol, as it once was, it continues to be distilled for flavour and fragrance applications (J. Coppen pers. comm.).

E. exserta *F. Muell. – Queensland Peppermint*

This is a small to medium-sized tree or mallee belonging to the red gum group. It is notable for the linear juvenile leaves and hard rough bark. The fruit of the entire red gum group are recognised by the hemispherical base and very prominent raised disc and exserted valves. The seeds of *E. exserta* are typical of most of the red gums, e.g. *E. tereticornis*, in being elongated, black, toothed around the edges and with a terminal hilum. They contrast strongly with those of the widely planted red gum, *E. camaldulensis*, which are yellow and double-coated.

E. exserta is widespread in eastern Queensland, particularly on low stony rises. The red gums divide into four taxonomic groups distinguished by seed, juvenile leaf, fruit and bark characters. To the north of its natural distribution the related *E. brassiana* Blake occurs as far as New Guinea, while to the south another related species, *E. morrisii* R. Baker, is endemic to low rocky hills of western New South Wales.

The leaves of *E. exserta* are slightly glossy, green to greyish green, and have the typical red gum pattern of moderately dense reticulation. Tertiary venation is fine with fairly large areoles and numerous oil glands per areole. Most glands appear round and green when the leaf is viewed fresh with transmitted light.

E. exserta has been planted in China for many years for its timber and leaf oils.

E. globulus *Labill. (four subspecies) – Southern Blue Gums*

This is one of the most widely cultivated species around the world. Typically, it is a tall, erect forest tree with mostly smooth bark. The characteristic prolonged juvenile leaf phase is one of its most notable features, making it one of the easiest eucalypts to identify. In this phase the leaf pairs remain opposite and sessile to the sapling stage and are conspicuously broad and glaucous. The adult leaves are strikingly different in being long, falcate, glossy green. The juvenile leaves are often seen in clear contrast to the adult leaves when they appear as new growth on old branches within the crown.

E. globulus sens. lat. occurs disjunctly over a wide area of relatively high rainfall parts of south-eastern Australia. It has created considerable confusion taxonomically, having been variably split into four or five species. It belongs to the large section *Maidenaria*, which may be diagnosed by the concolorous leaves, axillary inflorescences, juvenile leaves sessile and opposite for many pairs, and seeds prominently lacunose with a ventral hilum. Currently, *E. globulus* is regarded as four subspecies, one of which, subsp. *globulus* from Tasmania and southern, coastal Victoria, is the principal form grown in other countries.

Tasmanian Blue Gum (subsp. *globulus*) is one of the few eucalypt species with a single bud to the inflorescence. The buds are large, sessile, warty and glaucous. The other subspecies are subsp. *bicostata* (Maiden, Blakely and J. Simm.) Kirkpatr., which has three buds to the inflorescence and is distributed in high country from northern New South Wales to southern Victoria, subsp. *pseudoglobulus* (Naudin ex Maiden) Kirkpatr., which has three buds to the inflorescence and occurs in east coastal Victoria and possibly the northern end of Flinders Island in Bass Strait, and subsp. *maidenii* (F. Muell.) Kirkpatr., which has seven buds and occurs in coastal hills of eastern Victoria and far southeastern New South Wales.

The leaves have a moderately dense, fairly distinct reticulation formed by the tertiary and fine quaternary veinlets between the side veins. The oil glands occur singly or in twos and threes within the areoles and can be seen with transmitted light through a fresh leaf. The glands are roughly circular in outline and are mostly green with some white. Some glands touch veinlets or appear to terminate ultimate veinlets within an areole.

E. globulus is the principal source of eucalyptus oil in the world. It is utilised for such purposes in China, Spain, Portugal, India, Argentina, Brazil and Chile. The major constituent of the oil is 1,8-cineole.

E. polybractea *R. Baker (syn.* E. fruticetorum *(F. Muell. ex Miq.) R. Baker) – Blue-leaved Mallee*

This is the principal species used in Australia for essential oil production. It is a mallee, naturally adapted to relatively low rainfall and infertile soils on plains and low hills inland from the Great Dividing Range in Victoria and New South Wales. As a mallee it matures as a tall, multi-stemmed shrub. It has fibrous rough bark over the lower part of the stems and the leaves are bluish or greyish green. The juvenile leaves are opposite for a few pairs, then alternate, shortly petiolate, lanceolate to linear, green or greyish green in colour. Adult leaves are notably bluish. The inflorescences are terminal panicles.

E. polybractea belongs to the box group of eucalypts, most of which are characteristically rough-barked and have terminal inflorescences. The boxes divide into tree forms and mallees. Among the latter, *E. polybractea* is closest to Green Mallee, *E. viridis*, which occurs over a similar distributional range. Green Mallee is distinguished by the green, glossy leaves, which are linear and held erect.

The leaf venation of Blue-leaved Mallee is common to many box species and quite different from monocalypts and *Maidenaria* species. The side veins are very acute, particularly towards the base of the leaf. Intramarginal veins are present while tertiary veining is dense, somewhat obscure and erose, resulting in elongated, oblique areoles which accommodate many discrete oil glands (Figure 1.22). There is no clear reticulation outside the intramarginal veins. The glands are large and very irregular in outline.

Australia is the only country which utilises *E. polybractea* for oil production, relying as it does mainly on 'cleaned' areas of natural stands, supplemented by modest areas of plantations. The centres of production are at West Wyalong in western New South Wales and near Inglewood in northern Victoria.

E. radiata *Sieber ex Spreng. (syn.* E. australiana *Baker & Smith,* E. phellandra *Baker & Smith) – Narrow-leaved Peppermint*

This species is typically a small to medium-sized tree of relatively dry forests and woodlands. The bark is rough over the whole trunk, fibrous and interlaced, though not as coarse as in the

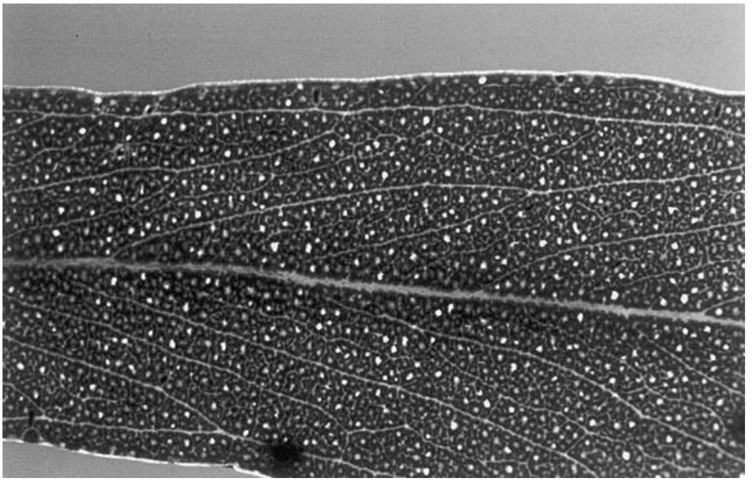

Figure 1.22 Leaf of *E. polybractea* showing dense, obscure reticulation and numerous, very irregular oil glands, both features typical of the mallee boxes.

stringybarks. The juvenile leaves remain opposite for many pairs, are sessile, lanceolate and green. In morphology the young plants resemble *E. viminalis*, which may grow naturally in the vicinity, but the two species can be distinguished by the stronger fragrance, emanating from the more abundant oil glands, and by the reduced amount of leaf reticulation in *E. radiata*. The mature crown is usually dense and attractive with small, narrow leaves which are green to dark green and glossy.

Narrow-leaved Peppermint is a monocalypt ('subgenus *Eucalyptus*') and belongs to one of the taxonomically most difficult groups in this subgenus. Most peppermints are relatively narrow-leaved and the common name mainly has relevance to the contrasting, broader-leaved, *E. dives*. Baker and Smith (1915) published a new species, *E. australiana*, which they considered was a mainland form of the otherwise Tasmanian endemic, *E. amygdalina* Labill. They were apparently unaware that the long established name, *E. radiata*, accounted for their new species in conventional morphological terms. Blakely (1934) stated that *E. australiana* 'yields an excellent pharmaceutical oil far superior to that of *E. radiata*, due mainly to the presence of a large amount of cineole'. This nomenclatural anomaly illustrates the problem of trying to establish taxa from differences in their chemistry alone. While the 'chemical' species may be disregarded from the purely taxonomic point of view, it emphasises that provenance is an important aspect in assessing the value of a species for oil production. *E. phellandra*, another mainland taxon, is similarly regarded now as a high-phellandrene form of *E. radiata*.

One other accepted taxon has been conventionally associated with *E. radiata*, namely, *E. robertsonii* Blakely. Over the relatively wide natural distribution of *E. radiata*, populations extend from the typical tableland regions to the mountains of far southeastern New South Wales. Here, the species takes on a taller habit, the leaves are somewhat bluish and the buds are slightly glaucous. This form was reduced to a subspecies of *E. radiata* (Johnson and Blaxell 1973) but later reinstated as a species in its own right (Johnson and Hill 1990). In the latter paper Johnson and Hill split typical *E. radiata* and erected the northern form as *E. radiata* subsp. *sejuncta*. The new taxon differs from subsp. *radiata* by the broader juvenile leaves and appears to be richer in α-pinene than 1,8-cineole (Brophy unpubl.).

The inflorescences of the peppermints invariably have more, often many more, than seven buds. These are pedicellate, clavate, and minutely warty. The fruits usually have a thick rim and a conspicuous reddish brown disc. A peppermint species with which *E. radiata* may be confused is *E. elata*, the River Peppermint, which has only the basal part of the trunk rough and has very numerous buds such that the flowers are a characteristic ball of white. A peppermint species with notably narrower leaves, and a favoured ornamental, is *E. pulchella* Desf., which is a Tasmanian endemic and mostly smooth-barked.

The leaf reticulation in *E. radiata* is sparse with the side veins at a prominently acute angle (<30° to the midrib). There is usually an inner strong and outer weak intramarginal vein. This overall pattern is typical of the peppermints, although *E. willisii* from southern, coastal Victoria can have side veins parallel to the midrib, as seen in snow gums, e.g. *E. pauciflora*. The oil glands occur many to an areole without obvious association with the veinlets. The glands are roughly circular in outline and a mixture of green and white in colour when viewed fresh with transmitted light.

E. radiata was once exploited in Australia for oil production, and still is to a small extent. It is also grown for this purpose in a small way in South Africa and has shown promise in other parts of Africa such as Tanzania (J. Coppen pers. comm.). There are several recognised chemotypes. Boland *et al*. (1991) cite two, one being rich in 1,8-cineole and the other in phellandrene/piperitone. Recent commercial interest has focused on the cineole-rich form.

E. smithii *R. Baker – Gully Gum*

This is a medium-sized to tall, erect forest tree of southeastern Australia, where it occurs on the coastal plains and in valleys of the eastern fall of the Southern Tablelands of New South Wales. Small mallee forms are found on very rocky crags of mountain country of far eastern Victoria. In habit and bark the trees are easily confused with the unrelated *E. badjensis* Beuzev. & Welch and *E. elata* in that all three are tall trees with basal, compacted, brown-black rough bark. Juvenile leaves are also similar, being sessile, opposite, lanceolate and green for many pairs. However, inflorescences clearly differentiate the three: *E. smithii* is 7-flowered, *E. badjensis* is 3-flowered and *E. elata* has many more than 7 flowers.

E. smithii is classified in the section *Maidenaria* which divides into two large groups, one 3-flowered and the other 7-flowered. It is difficult to associate it taxonomically with any other species to establish natural affinity, although it has superficial similarities to the two mentioned above.

The leaves of Gully Gum are usually long and narrow. Side veins are clear with lesser side veins running more or less between. The intra-veinal zone is broken by relatively weak tertiary veinlets and some even less distinct quaternary veinlets. Oil glands are fairly numerous, one to few per areole, without giving the immediate impression that the leaves are highly glandular. The glands are green and yellowish.

E. smithii is widely grown in South Africa for timber purposes and in the eastern Transvaal it is harvested for cineole-rich leaf oil (Coppen and Hone 1992).

E. staigeriana *F. Muell. ex Bailey – Lemon-scented Ironbark*

This is a small to medium-sized tree, usually of poor form in its natural habitat which is granite or sandstone hills of Cape York Peninsula in far northern Queensland. The bark is typical ironbark, i.e. hard, black and furrowed. The crown is conspicuously bluish due to the blue-green to glaucous, usually broad, adult leaves. The inflorescences are terminal panicles. Buds and fruit are small and inconspicuous.

The numerous ironbark species belong to three taxonomic groups. *E. staigeriana* is in the largest group which is distinguished by the early loss of the outer operculum and stamens which are all fertile. Both of these characters contrast with the buds of the better known ironbark species, *E. sideroxylon*.

The adult leaves are relatively small with very dense reticulation formed by the tertiary and quaternary veining. The oil glands are of two types, either small, green and single in the areoles (some areoles lacking glands) or fewer, larger and whitish, occurring at the intersections of quaternary veinlets.

E. staigeriana is one of two eucalypt species that are notable for their lemon-scented oils (see *E. citriodora* above) and is cultivated for the production of citral-rich oil, chiefly in Brazil. Weiss (1997) states that it is also grown for such purposes in Guatemala, the Seychelles and the former Zaire (now the Democratic Republic of the Congo).

Species of lesser importance or with potential for essential oil production

E. camaldulensis *Dehnh. – River Red Gum*

This is the most widespread species in Australia and one that is cultivated throughout the world in tropical and subtropical regions. It is notably a species of freshwater stream banks, whether of the major rivers or the inland rivers which only flow after heavy rain. It frequently has a heavy butt and widely spreading crown. Basically a smooth-barked species, it usually has an accumulation of unshed or imperfectly shed rough slab bark on the bottom 1 m of the trunk. As with all the red gums, the juvenile leaves are petiolate and only the first 4 or 5 pairs remain opposite. In River Red Gum the juvenile leaves are lanceolate, which contrast with the ovate leaves of most of the related species. The adult leaves are mid-green, slightly bluish green or yellowish green and vary from dull to slightly glossy.

E. camaldulensis belongs to the large series *Exsertae* and, as might be expected in a species of such widespread natural distribution, there is considerable variation in morphological characters. This has been recognised in the taxonomic treatment which has resulted in many named varieties. The principal split, which is recognised today more for convenience than any fixed morphological distinction, is into two varieties, var. *camaldulensis*, which is the form of the Murray-Darling river systems of southeastern Australia, most easily distinguished by the strongly beaked operculum, and var. *obtusa* Blakely, which is the name loosely applied to all other provenances, the name referring to the obtuse operculum. The seeds are distinctive in being yellow to yellow-brown, cuboid and having a double seedcoat and terminal hilum.

The leaf reticulation in River Red Gum is moderately dense in southern Australian occurrences while the northern River Red Gums have a denser, more closed pattern. The quaternary veining is relatively weak and ultimate fine veinlets may appear to end within an areole, such that the overall pattern is not finite. Oil glands are usually numerous and conspicuous and may be several per areole in leaves of southern provenances, becoming fewer per areole in northern specimens. The glands are approximately circular in outline and are usually a mixture of green, yellow and white when viewed fresh with transmitted light (Figure 1.23). Very rarely do the leaves appear glandless.

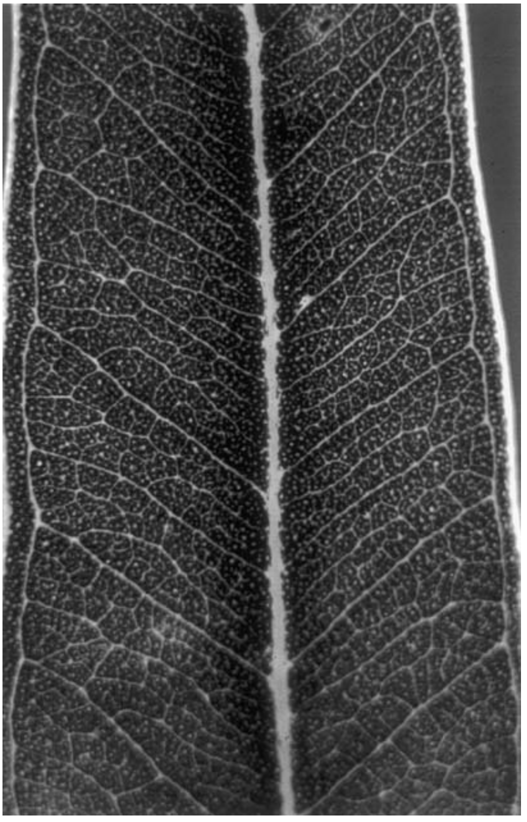

Figure 1.23 Leaf of *E. camaldulensis* showing dense reticulation and island oil glands, both features typical of the red gums.

It is likely that there are many chemotypes. One well-known provenance, Petford in northern Queensland, for example, has two forms, one rich in 1,8-cineole and the other in sesquiterpenes. Because of its widespread cultivation it may well become a future source of eucalyptus oil.

E. cinerea *F. Muell. ex Benth. – Argyle Apple*

This is one of the most widely planted ornamental eucalypts in southern Australia. It is considered highly attractive for its mature crown of glaucous, ovate juvenile leaves, and is also much favoured in dried flower arrangements. It is only one of several species, however, that are reproductively mature in the juvenile leaf phase. It is one of the mostly easily recognised eucalypt species by the combination of the grey crown and thick, reddish brown, completely rough bark. It is further distinguished by its 3-flowered inflorescences and funnel-shaped fruits.

Argyle Apple belongs to the large section *Maidenaria*, many species of which are 3-flowered. From a distance it could only be confused among species of southern Australia with *E. risdonii* J.D. Hook., one of the completely unrelated monocalypts ('subgenus *Eucalyptus*') which is easily distinguished on closer inspection by the connate leaf pairs. Species of northern Australia may