Eucalyptus oils: a review of production and markets (NRI Bulletin 56)

Natural Resources Institute

EUCALYPTUS OILS
A REVIEW OF PRODUCTION AND MARKETS

Bulletin 56

Overseas Development Administration

EUCALYPTUS OILS
A REVIEW OF PRODUCTION AND MARKETS

J. J. W. Coppen and G. A. Hone

Bulletin 56

NRI
Natural Resources Institute

The scientific arm of the
Overseas Development Administration

The Natural Resources Institute (NRI) is an internationally recognized centre of expertise on the natural resources sector in developing countries. It forms an integral part of the British Government's overseas aid programme. Its principal aim is to alleviate poverty and hardship in developing countries by increasing the productivity of their renewable natural resources. NRI's main fields of expertise are resource assessment and farming systems, integrated pest management, food science and crop utilization.

NRI carries out research and surveys; develops pilot-scale plant, machinery and processes; identifies, prepares, manages and executes projects; provides advice and training; and publishes scientific and development material.

Price £7.50

No charge is made for single copies of this publication sent to governmental and educational establishments, research institutions and non-profit-making organizations working in countries eligible for British Government Aid. Free copies cannot normally be addressed to individuals by name but only under their official titles.

Natural Resources Institute
ISBN: 0-85954-308-0
ISSN: 0952-8245

Contents

ACKNOWLEDGEMENTS

In addition to United Kingdom sources, much of the information for this bulletin was obtained from fieldwork carried out in Western Europe, Southern Africa, South America and Australia. The authors gratefully acknowledge the assistance and advice given to them by the many individuals, companies and other organizations contacted.

NOTES

The following conventions apply in all tables:

– nil or negligible

... not available

Any apparent minor errors in the 'Totals' or 'Other countries' categories are due to rounding.

In some cases it will be found that export figures and corresponding import figures do not equate. Such discrepancies are due, in part, to time lags in recording or in methods of recording re-exports. They may also be due to deficiencies in the recording systems operating in some countries. Unless otherwise stated, commodity definitions from which trade statistics have been extracted correspond to 'eucalyptus oil' or similar.

All prices and costs are quoted in United States dollars.

Summaries

SUMMARY

The bulletin provides information on the technical and economic aspects of the production of steam-volatile oils from eucalyptus leaf, including the collection or harvesting of the leaf and its distillation. It also reviews recent trends in the world market for eucalyptus oils. It is intended for prospective new producers of eucalyptus oil as well as organizations and individuals appraising projects involving its production. It is particularly intended for those in developing countries.

Three types of eucalyptus oil are produced and marketed: medicinal (cineole-containing) oils, perfumery oils and industrial oils. The medicinal type of oil is the most important in volume and value terms. In 1991 total world production is estimated to have been about 2800 t, of which Chinese production accounted for approximately 70%. Other producers include Portugal, Spain, Australia, South Africa, Swaziland, India and Chile. The People's Republic of China also dominates world trade in cineole oils (estimated at about 2000 t of exports, excluding re-exports). Although present (January 1992) prices of eucalyptus oils are the lowest they have been in recent years, fluctuations are often experienced in the essential oil market and prices may be expected, in due course, to recover. The extent to which this may happen, and the period over which it may occur, cannot be predicted with any certainty.

The People's Republic of China is also the leading supplier of *Eucalyptus citriodora* oil, a perfumery type of oil. Brazil and, to a much lesser extent, India are the only other producers of any significance of this oil.

Prospects appear to be poorest for the piperitone-containing oil from *E.dives*, a so-called industrial oil, of which South Africa is the world's largest supplier.

Eucalyptus leaf for the production of volatile oil is obtained commercially by one of three methods: recovery of 'waste' leaf from felled trees which are grown primarily for pulp, timber, fuelwood or other purposes; short-rotation harvesting using a system of coppicing of plantations established specifically for oil production; and regular harvesting of coppiced natural stands (peculiar to Australia). Systems of leaf production and harvesting used in different parts of the world are described, including the use of 'waste' leaf from *E.globulus* in Portugal and Spain and *E.smithii* and *E.dives* in southern Africa; short-rotation coppicing of *E.smithii* in Swaziland and Zimbabwe, *E.dives* in South Africa and some other species in Brazil; and mechanical harvesting of *E.polybractea* in Australia.

An indication of the costs involved in producing oil from trees that are planted, maintained and harvested specifically for oil under a coppice system of management is given for two instances. One is a recently established operation in Zimbabwe which is yielding 10 t/a of crude cineole-type oil. The other is in Swaziland, in which approximately 55 t/a of crude cineole oil are produced.

The principal components of a distillery for the production of crude oil from eucalyptus leaf are described and factors which affect the yield and quality of oil obtained from eucalyptus leaf discussed. The need for a prospective producer wishing to establish eucalypts specifically for oil production to identify the best planting stock at an early stage is emphasized. Ways in which extra revenue may be generated from 'waste' by-products of oil production are noted.

RESUME

Le présent bulletin fournit des informations concernant les questions technico-économiques de la production d'huiles volatiles en phase vapeur provenant de la feuille de l'eucalyptus, y compris la collecte ou la récolte de la feuille et sa distillation. Il passe également en revue les tendances récentes observées sur le marché mondial des huiles d'eucalyptus. Il est destiné aux nouveaux producteurs potentiels d'huile d'eucalyptus tout autant qu'aux organismes et personnes individuelles évaluant des projets faisant intervenir sa production. Il est particulièrement destiné à ceux intervenant dans les pays en voie de développement. Il est produit et commercialisé trois types d'huile d'eucalyptus, à savoir les huiles médicinales (contenant du cinéol), les huiles essentielles et les huiles industrielles. L'huile de type médicinal est la plus importante aussi bien au plan du volume que de la valeur. En 1991, on estime que la production mondiale totale s'élevait à 2800 t, dont la production d'origine chinoise représentait environ 70%. Parmi les autres pays producteurs, citons le Portugal, l'Espagne, l'Australie, l'Afrique du Sud, le Swaziland, l'Inde et le Chili. La

République Populaire de Chine domine également le commerce mondial des huiles d'eucalyptol (estimée à environ 2000 t d'exportations, à l'exclusion des réexportations). Bien que les prix actuels (Janvier 1992) d'huiles d'eucalyptus soient les plus faibles observés au cours des dernières années, l'on observe fréquemment des variations sur le marché des huiles essentielles et l'on peut s'attendre à un rétablissement des prix en temps utile. Il n'est pas possible de prévoir avec une certitude quelconque la mesure dans laquelle ce rétablissement pourra avoir lieu et le temps qui sera nécessaire. La République Populaire de Chine est aussi le principal fournisseur d'huile *Eucalyptus citriodora*, un type d'huile essentielle. Le Brésil et, dans une bien moins grande mesure, l'Inde sont les seuls autres producteurs notables de cette huile.

Les perspectives sont les plus médiocres pour l'huile contenant de la piperitone dérivée d'*E. dives*, une soi-disant huile industrielle, dont l'Afrique du Sud est le plus important fournisseur du monde.

La feuille d'eucalyptus pour la production d'huile volatile est commercialement obtenue au moyen d'une de trois méthodes: récupération de la feuille 'de déchet' des arbres abattus cultivés principalement pour la pulpe, le bois d'oeuvre, le bois de chauffage ou autre but; la récolte à courte rotation, faisant appel à un régime de taillis des plantations établies spécialement pour la production d'huile et enfin la récolte systématique de coupes naturelles en taillis (particulière à l'Australie). Il est décrit les systèmes de production et de récolte de la feuille mis en oeuvre dans diverses régions du globe, ainsi que l'emploi de la feuille 'de déchet' d'*E. globulus* au Portugal et en Espagne et *E. smithii* et *E. dives* en Afrique du Sud; le régime de taillis à courte rotation d'*E. smithii* au Swaziland et au Zimbabwe, *E. dives* en Afrique du Sud et quelques autres espèces au Brésil, ainsi que la récolte mécanique d'*E.polybractea* en Australie.

Une indication des coûts applicables à la production d'huile dérivée d'arbres qui sont plantés, entretenus et récoltés spécialement pour l'huile au titre d'un régime de gestion de taillis est fournie pour deux cas. L'un d'eux est une unité récemment établie au Zimbabwe, produisant 10 tonnes/an d'huile brute de type eucalyptol. L'autre est une unité au Swaziland dans laquelle il est produit quelque 55 tonnes/an d'huile d'eucalyptol.

Il est décrit les principaux éléments d'une distillerie de production d'huile brute de feuille d'eucalyptus, ainsi que les facteurs ayant une incidence sur le rendement et la qualité de l'huile d'obtenue de la feuille, d'eucalyptus étudiée. Il est fait ressortir la nécessité, pour un producteur potentiel souhaitant établir des eucalyptus spécialement pour la production d'huile, d'identifier le plus tôt possible la race de plantage optimale. Il est noté les moyens selon lesquels des revenus complémentaires peuvent être générés à partir des sous-produits 'de déchets' de la production d'huile.

RESUMEN

El boletín proporciona información sobre los aspectos técnicos y económicos de la producción de aceites esenciales a partir de las hojas del eucalipto, incluyendo su recolección o cosecha y su destilación. También se pasa revista a las tendencias recientemente observadas en el mercado mundial con relación a los aceites de eucalipto. Este estudio está dirigido a posibles nuevos productores de aceite de eucalipto y a organizaciones e individuos interesados en la evaluación de proyectos relacionados con su producción, particularmente en países en desarrollo.

Tres don los tipos de aceite de eucalipto producidos y comercializados: aceites medicinales (que contienen cineola), aceites de perfumeria y aceite industriales. El aceite medicinal es el tipo más importante, tanto por su volumen como por su valor. Durante 1991, la producción mundial total ascendió a unas 2800 toneladas, de las que la producción china representó un 70%, aproximadamente. Otros productores son Portugal, Espana, Australia, Suráfrica, Swazilandia, India y Chile. La República Popular China es asimismo la fuerza dominante en el mercado mundial de aceites de cineola, con exportaciones de unas 2000 toneladas, excluyendo reexportaciones. Si bien los precios actuales de los aceites de eucalipto (enero de 1992) se encuentran en el punto más bajo de los últimos años, las fluctuaciones en el mercado de los aceites esenciales son frecuentes. Y aunque es de esperar que, en su día, se producirá una recuperación de los precios, no nos es posible predecir con certidumbre ni el grado ni el período sobre el que tal vez tenga lugar dicha recuperación.

La República Popular China es también el principal proveedor de aceite de *Eucalyptus citriodora*, utilizado en perfumeria. Otros productores de cierta importancia son Brasil y, en mucho menor grado, la india.

La panorámica menos optimista es la relativa al aceite del *E. dives* aceite industrial con contenido de piperitona, cuyo principal proveedor mundial es Suráfrica.

Las hojas de eucalipto para la producción de aceites esenciales se obtienen comercialmente por uno de los tres métodos siguientes: recuperación de hojas de 'desecho', procedentes de árboles talados, principalmente cultivados para la producción de pasta de madera, madera, leña y otros fines; recolección de rotación corta, utilizando un sistema de corte de plantaciones establecidas específicamente para la producción de aceite; y recolección regular de bosques naturales cortados (específico de Australia). También se presenta una descripción de los sistemas de recolección y producción de hojas utilizados en distintas partes del mundo, incluyendo el

empleo de hojas de 'desecho' del *E. globulus* en Portugal y España y del *E. smithii* y *E. dives* en Suráfrica; corte de rotación reducida del *E. smithii* en Swazilandia y Zimbabwe, *E. dives* en Suráfrica y algunas otras especies en Brasil; y recolección mecánica del *E. polybractea* en Australia.

También se presentan los costes de la producción para dos empresas dedicadas a la producción de aceite a partir de árboles plantados, mantenidos y cosechados específicamente para dicho fin, dentro de un sistema de gestión de sotos. Una de ellas es una empresa, recientemente establecida en Zimbabwe, que produce 10 toneladas anuales de aceite bruto tipo cineola. La segunda empresa, ubicada en Swazilandia, produce unas 55 toneladas anuales de aceite bruto de cineola.

Se presenta una descripción de los principales elementos de una destilería para la producción de aceite bruto, a partir de hojas de eucalipto, y se indican los factores que afectan el rendimiento y calidad del aceite obtenido de dichas hojas. El estudio subraya la necesidad de que el futuro productor que desee establecer eucaliptos especificamente para la producción de aceite identifique, en una etapa temprana, el mejor material de plantío posible. El estudio concluye apuntando métodos que permitan obtener beneficios adicionales, mediante el empleo de subproductos de 'desecho' de la producción de aceites.

Section 1

Introduction

The genus *Eucalyptus*, which is native to Australia and some islands to the north of it, consists of over 500 species of trees. These grow under a wide range of climatic and edaphic conditions in their natural habitat. This very large and varied gene pool can be drawn upon for planting purposes, and is one reason for the successful introduction of *Eucalyptus* into so many other countries in the world. Together with *Pinus*, the two genera account for the larger part of exotic plantations in the Americas, Europe, Africa and Asia.

Like pines, the eucalypts* are grown primarily for timber or pulp. The major advantage of the latter over pines, however, and another reason for them being so widely planted, is their fast growth rate. Pulp rotations of 10-12 years for eucalypts compare with 20-30 years for pines. The fast-growing nature of eucalypts also makes them ideally suited as a fuelwood crop, whether grown on a large scale or as small, village-scale or communal woodlots.

This multipurpose facet of *Eucalyptus* extends further to its use as a source of essential oils; it is this aspect that forms the subject of the bulletin. The leaves of most species of eucalypt, when steam-distilled, yield an essential oil which is known in the trade as eucalyptus oil. Only a few species, however, produce an oil in sufficient amounts and of such a quality as to make its distillation practicable and economic. Where eucalypts are used for such purposes, recovery of the oil is often a secondary activity, with the 'waste' leaf from the felled tree being collected and distilled by someone quite unconnected with the utilization of the wood. In other cases, the leaf may be obtained from trees grown specifically for oil production: leaves are harvested periodically from the same trees at intervals of between 4 months and 20 months. The ability of many eucalypts to regenerate after such coppicing obviates the need to replant after each harvest and the unproductive establishment phase is kept to a minimum.

The aim of this bulletin is to provide the basic information that a prospective new producer of eucalyptus oil requires in order to make a considered judgement on whether or not to proceed with investment. It is particularly intended for those in developing countries, be they prospective producers themselves, or government bodies, financial institutions or donor agencies appraising projects involving eucalyptus oil production. It is hoped, also, that it will assist existing producers, traders and consumers of eucalyptus oil by increasing their awareness of production methods and quality requirements in other parts of the world, and their knowledge of market demands, trends and preferences.

The text is presented in six sections. In Section 2 the different types of eucalyptus oil are described and the main aspects of production, trade and markets summarized; the emphasis is on an analysis of the trends, outlook and prospects for new producers of cineole-rich medicinal oils. In Section 3 there are brief descriptions of the methods used to harvest both 'waste' leaf and that produced by cultivation and coppicing of eucalypts specifically for oil production. Reference is made to current practice in Spain and Portugal, Southern

*The terms '*Eucalyptus*' and 'eucalypt' are both used in this bulletin. The former denotes the genus, the first part of the Latin binomial which, together with the species name, forms the basis of botanical classification for all plants and animals. The word 'eucalypt' is a simple noun used to describe those species within the genus *Eucalyptus*.

Africa – including Swaziland, Zimbabwe and South Africa – Brazil and Australia. In Section 4 the methods of distillation used to recover the oil from the leaf are reviewed, and a brief description of the way in which the crude cineole-rich oils may be upgraded to higher quality, value-added forms is included. Ways in which the spent leaf remaining after distillation can be utilized are considered.

Section 5 contains analyses in some detail of the financial costs involved in the cultivation, harvesting and distillation of leaf for the production of eucalyptus oils. Two sites and scales are chosen, both in Southern Africa: an established estate in Swaziland with an annual production potential of 50-100 t/a and a new, smaller-scale unit with a potential of 10-20 t/a in Zimbabwe. It is possible to distil eucalyptus oil on a smaller scale than this, but this bulletin does not address the economics of small-farmer, village-scale production, although this is a feasible option with considerable potential in a number of countries (as it is for many other essential oils). In the final section, Section 6, the most important technical and economic aspects which must be considered when undertaking a project study for a new eucalyptus oil operation are indicated as well as earlier discussions being summarized.

The appendices contain references and further reading; information on sources of supply of *Eucalyptus* seed for planting; a discussion of the factors influencing oil yield and composition; quality criteria and specifications for the different types of eucalyptus oil; advice on packaging and labelling requirements; and the names and addresses of a number of processors of eucalyptus oils to whom a new producer might first turn for sales.

Section 2

Production, trade and markets

DESCRIPTION, USES AND PRINCIPAL SOURCES

Eucalyptus oils are clear liquids with aromas characteristic of the particular species from which they are obtained. The oils are colourless when refined, but usually slightly yellow when first distilled from the leaf. Like other essential oils they are mixtures of organic compounds – mainly terpenes – the individual components of which, and their proportions, determine the chemical and olfactory characteristics of the oil and, therefore, its value. The composition of the oil is dependent, mainly, on genetic rather than environmental factors. The species of *Eucalyptus* from which the oil is obtained is, therefore, the most important factor determining its quality and the use, if any, to which it is put. Within a species, there may still be significant quality differences according to the provenance of the seed, and even between individual trees within a provenance. These aspects are discussed in more detail in Appendix 3.

Over 300 species of *Eucalyptus* have been shown to contain volatile oil in their leaves, but probably fewer than 20 of these have ever been exploited commercially for oil production. About a dozen species are utilized in different parts of the world, of which six account for the greater part of world production of eucalyptus oils. The oils of these exploited species are classified in the trade into three broad types according to their composition and main end-use: medicinal (cineole-rich), perfumery and industrial. Of these, the most important in terms of volume of production and trade is the medicinal type.

Those species currently exploited, and the countries in which they are utilized, are listed in Table 1 according to the type of oil they yield.

Other species used in the past include *E.cneorifolia* (medicinal), *E.macarthurii* (perfumery) and *E.radiata* (industrial; phellandrene variant, syn. *E.phellandra*).

Medicinal oils

The medicinal properties of eucalyptus oil were known to the aborigines of Australia thousands of years ago, but were first exploited commercially by Bosisto. He began production in Australia in 1852, extolling the oil's virtues for the treatment of a wide range of ailments. Since then, medicinal eucalyptus oil has remained the most important of the three types of oil, although Australia is no longer the dominant producer that it was.

The value of eucalyptus oil for medicinal purposes lies in its cineole* content. This largely determines, also, the price that it fetches. While many other essential oils are referred to simply by name in the trade or in manufacturers' or dealers' product and price lists, medicinal eucalyptus oil is invariably specified in terms of cineole content. 'Eucalyptus oil China 80%', 'eucalyptus oil 70/75% Spain/Portugal' and 'eucalyptus oil 80/85% Spain/Portugal' are typical descriptions. The higher grades are usually rectified forms of the crude oil and essentially pure cineole (about 98%+), which always commands the highest price, is known as 'eucalyptol'.

*Strictly, 1,8-cineole, to distinguish it from the alternative 1,4-cineole, but the term 'cineole' is commonly applied to the former and is used here and throughout the text. The terms 'medicinal oil', 'cineole oil', 'cineole-type oil' and 'cineole-rich oil' are also used interchangeably throughout.

Table 1 Commercially exploited sources of eucalyptus oil: plant species and country of production

Species[a]	Producing country[b]
Medicinal	
Eucalyptus globulus Labill.[c]	China, People's Republic of, Portugal, Spain, India, Brazil, Chile, (Bolivia, Uruguay, Paraguay)
E.smithii R. Baker	South Africa, Swaziland, (Zimbabwe)
E.polybractea R. Baker[d]	Australia
E.exserta F. Muell.	China, People's Republic of,
E.radiata Sieber ex DC.[e]	(South Africa, Australia)
E.viridis R. Baker	(Australia)
E.dives Schauer (cineole variant)	(Australia)
E.camaldulensis Dehnh.[f]	(Nepal)
Perfumery	
E.citriodora Hook.	China, People's Republic of, Brazil, India
E.staigeriana F. Muell. ex Bailey	Brazil
Industrial	
E.dives Schauer (piperitone variant)	South Africa, (Australia)
Eucalyptus sp. nov. aff. *campanulata*	Australia

Notes:
[a] Botanical nomenclature is that used by Chippendale (1988).
[b] Parentheses indicate a minor producer. The list of countries is not intended to be exhaustive.
[c] Subspecies *globulus*.
[d] The name *E.fruticetorum* F. Muell. ex Miq. has been misapplied to this species.
[e] Subspecies *radiata*. Synonyms: *E.australiana*, *E.radiata* var. *australiana*.
[f] Synonym: *E.rostrata* Schldl.

Details of national and international standards for eucalyptus oil, including the medicinal type, are given in Appendix 4. However, the general norm for cineole content, typified by the international standard (ISO) for 'oil of *Eucalyptus globulus*' and the British Pharmacopoeia (BP) specification for 'eucalyptus oil', is a minimum of 70%. Only those species of *Eucalyptus* which yield an oil rich in cineole, therefore, are worth considering for distillation. Anything containing less than about 60-65% cineole in the crude oil would probably not be of interest to a buyer and rectifier of such oils. Blending of rectified oils obtained from more than one source may be carried out by the largest producers or importers.

Providing a medicinal oil satisfies the appropriate pharmacopoeial requirements it may be sold as such, neat, in pharmacies and other retail outlets. In the home, eucalyptus oil is used in liquid form as an inhalant or chest rub to ease breathing difficulties, as a mouthwash in water to refresh or ease the throat, and as a skin rub to provide relief from aches and pains. The more common form of consumption in developed countries is after formulation in sprays, lozenges, cough sweets, ointments and other oils. Anti-plaque solutions are a more recent application. Menthol is often an added ingredient and camphor, peppermint oil and clove oil, also, in some products. Levels of incorporation of eucalyptus oil range from 1-2% to about 10% or more. In some products eucalyptol is preferred, and in these cases much smaller amounts may be used – of the order of 0.01-0.1%.

The oil is also used as an antiseptic for treating cuts and abrasions and as a general disinfectant, cleaner and deodorizer about the house. Again, it may be sold in liquid form or as formulated products for these purposes.

Other, non-medicinal applications of cineole-containing eucalyptus oil include use as a solvent for cleaning and removing oil-soluble stains, inks, paints, etc. In Australia, particularly, it is used in a well-known wool wash recipe. Its fragrant properties make it attractive to use in certain soaps and bath oils.

Some research has been carried out in Australia and Japan on the use of cineole-containing eucalyptus oil as a fuel additive for petrol-alcohol mixtures, but any widespread application of this nature must remain uncertain and speculative.

Perfumery oils

Of the two perfumery oils listed in Table 1, that from *Eucalyptus citriodora* is produced in the greatest volume. It differs from the medicinal oils in containing citronellal as the major component – usually about 65-85% – rather than cineole. The oil is employed in whole form for fragrance purposes, usually in the lower-cost soaps, perfumes and disinfectants, but its main use is as a source of citronellal for the chemical industry. The citronellal obtained by fractionation of the crude oil may be employed as such as an aroma chemical or converted to hydroxycitronellal. The latter compound finds major usage as a perfumery material. Other, minor constituents of the oil, such as citronellol, are recovered during fractionation for subsequent use by the fragrance industry.

Both citronellal and the derived hydroxycitronellal are produced from two other sources, citronella oil and turpentine. To some extent, therefore, there is competition between these sources and *E.citriodora* oil. Price and slight odour differences caused by accompanying minor constituents in the chemical isolates determine customer preference. 'Natural' citronellal derived from eucalyptus or citronella oils may have some marketing advantage over 'synthetic', turpentine-derived citronellal in flavour applications.

Eucalyptus staigeriana oil, produced only in Brazil, is believed to be utilized solely in whole form for fragrance purposes. It has a lemon-type character. No single chemical predominates, as it does in the other eucalyptus oils, although limonene and the higher-boiling citral (neral + geranial) together account for about 50-60% of the total terpenes.

Oil from *Eucalyptus macarthurii*, which has only ever been available in very small quantities, appears no longer to be produced. It is a rich source of geranyl acetate.

Industrial oils

The term 'industrial' oil is commonly used to denote usage of the oil as a raw material for isolation of individual chemical constituents. The isolates may then be used in their own right for some applications, or further processed into marketable derivatives. (In this sense, *E.citriodora* oil might also be termed an industrial oil).

The piperitone variant* of *Eucalyptus dives* is one which yields an oil rich in piperitone and phellandrene (in contrast to the cineole variant of the same species, which produces a medicinal-type oil). Since the mid-1960s, most of the world's supply of this oil has originated in South Africa, although the bulk of it has then been shipped to Australia for fractionation. The lower-boiling 'phellandrene' fraction (comprising alpha-phellandrene and other monoterpenes) is recovered and sold, mainly for use as a cheap fragrance source. Piperitone, which accounts for about 40% of the oil, is recovered for use as a starting material for the production of menthol. Menthol is a major flavour ingredient, but its production via eucalyptus-derived piperitone is in competition with natural menthol obtained directly from 'Japanese' mint (*Mentha arvensis*) and that obtained synthetically from petroleum-based raw materials.

A newly exploited source of eucalyptus oil is the recently discovered species *Eucalyptus* sp. nov. aff. *campanulata*. Oil distilled from leaf of this eucalypt has been found to contain about 98% E-methyl cinnamate, a chemical of value as a

*The meaning and origin of the term 'variant', which refers to the fact that quite different types of oil may sometimes be produced by the same species of *Eucalyptus*, is explained in Appendix C.

flavour and fragrance material. Commercial production of E-methyl cinnamate began in Australia in the late 1980s and to date this remains the sole source, a fact unlikely to change in the foreseeable future.

WORLD PRODUCTION, TRADE AND OUTLOOK

World production and trade in eucalyptus oils is dominated by the People's Republic of China, which is the largest producer of cineole-rich medicinal oils (65-75% of global output and at least 70% of world trade). The People's Republic of China is also a significant supplier to the world market of *E.citriodora* oil. Total Chinese production of eucalyptus oils is certainly in excess of 3000 tonnes, with exports of some 1300-1500 tonnes of medicinal oils and 300-500 tonnes of perfumery oil. It is suggested that changes and disruptions in the Chinese market since 1989 have caused a fall in domestic market offtake of eucalyptus oils – particularly the medicinal type – in the period 1989-91. This, together with changing trading practices in 1990 and 1991, and disruption of past trade patterns and networks, combined with the world recession in 1991-92 forced the sharp fall in prices for the standard grade Chinese 80% medicinal oil from the $ 6/kg level to the January 1992 $ 4.60-4.75/kg. These price and volume changes have coincided with overstocking in 1991 by the major European processors and distillers, and the development of significant new eucalyptol producers such as Singapore. As a consequence, there has been sharply reduced production since 1990 in countries such as Portugal and Spain, who are shipping much less of the lower cineole eucalyptus oils, although they continue to manufacture the higher grades, including eucalyptol. From 1988 to 1990, both countries continued to increase their imports of Chinese oil for further processing.

The biggest markets importing eucalyptus oils apart from Portugal, Spain and Australia – who also have their own production – are France, Germany, the United Kingdom (UK) and the United States (US). Globally, the European Community (EC) is the biggest importer, processor and consumer, for whom the People's Republic of China is by far the biggest supplier.

All trade statistics, including those showing EC imports, are of limited real value for analytical purposes because of the impossibility of separating medicinal and perfumery oils. An estimate for 1988 EC imports from the People's Republic of China might include 900-1000 tonnes of medicinal oil and 200 tonnes of *E.citriodora* oil, but it is known that in 1989 and 1990 the volumes of both rose strongly. The total of medicinal oils imported by the EC from the People's Republic of China in 1990 was probably as high as 1300-1500 tonnes, but even this high level implies a large volume of *E.citriodora* oil. Only the Brazilian imports of 200 t/a are known to be almost entirely *E.citriodora* oil.

A second difficulty is that processed products of eucalyptus oil (often including eucalyptol) enter a category of 'other chemicals' or become manufactured goods and cannot be traced through the tariff numbers for eucalyptus oil.

A further problem is caused by the weakness of production statistics and of domestic consumption statistics in the producing country markets. Without such data, especially for the People's Republic of China, it is impossible to know how far usage is rising or falling in the importing markets of Western Europe, the US and South-East Asia.

Finally, the statistical problems are compounded by the lack of any significant trade data for 1991.

The market outlook (at January 1992) for cineole-containing eucalyptus oils has deteriorated significantly from the second half of 1990. End-of-year prices for the period 1987-91 for eucalyptol and cineole oils from different sources (as well as *E.citriodora* oil) are given in Table 7A of Appendix 7. January 1992 prices of

Chinese 80% oil of $ 4.60-4.75/kg have fallen from $ 7.70/kg at the end of 1987, $ 9.50 at the end of 1988 and about $ 6 during 1989 and 1990. The fall in price from $ 6.00 has taken place against a background of dollar weakness. The dollar has fallen by up to 10% against the European currencies (linked through the Exchange Rate Mechanism). It is the French, German and UK markets which remain the major markets for eucalyptus oil-based products, excluding the traditional Chinese remedies produced in the People's Republic of China, Hong Kong and Singapore.

The price fall for Chinese oil accelerated in 1991, and into 1992, because the world recession, accompanied by rising interest rates in Europe and the Far East, reduced buyers' interest and stockholding activities. During 1990 increased shipments of Chinese oil to Europe took place, which led in 1991 to sharp cuts in both Portuguese and Spanish production of oil. Iberian producers of eucalyptol continue to manufacture using both imported Chinese oil and locally produced oil, but exports of the traditional 80-85% eucalyptus oils have been reduced to very small tonnages. Production of oil in Portugal in 1990 is estimated to have been 300-400 t and in Spain 50-100 t. By the end of 1991 output levels were only 150-200 t in Portugal and perhaps 50 t or less in Spain. Even this estimated fall of 150-250 t has not been sufficient to stabilize the markets for either the 80% oil or eucalyptol.

There has been little additional non-Chinese eucalyptus oil entering the market. Chile probably ships 60-100 t. The bulk of Swazi production of cineole-type oil, some 80 t/a, is exported to Australia for further processing. Most South African cineole oil goes to Australia and Spain.

Additional Chinese selling in 1991 took place in a European market which is not growing rapidly. No major new uses for eucalyptus oil have developed which could absorb the increased selling pressure from the People's Republic of China.

Chinese patterns of trade and domestic usage were apparently disrupted throughout the period from mid-1989. The number of export corporations expanded at the provincial level and, with less experience, began to trade through Hong Kong middlemen. They also became responsible for their own profits and losses early in 1990. The fall in domestic offtake of oil in both 1990 and 1991 was worsened by a change in local usage of traditional flavours and fragrances in products such as toothpastes and mouthwashes. Multinational companies are now actively manufacturing and marketing with the People's Republic of China, particularly in the southern Chinese area adjoining Canton and Hong Kong, and this has led to a reduced demand for traditional flavours such as eucalyptus. These developments resulted in heavy stocks being shipped to Europe and the Far East in 1990. These were absorbed by the market, but in 1991 the release of some additional 300-400 t of oil coincided with a downturn on the demand side caused by recession, the cutback in world trade and loss of confidence experienced during the Gulf War. The result has been a steady and relentless fall in prices, even though eucalyptus oil continues to be priced in depreciating dollars.

The present analysis assumes that in 1991 demand and stocks were reduced by 100-200 t and Chinese shipments rose by 300-400 t. It is suggested that even a 150-250 t reduction in Portuguese and Spanish output of oil was insufficient to prevent the market receiving surplus exports of Chinese 80% oil of about 200-400 t. It is not suggested that all this oil has been shipped, but the extent of the price cuts at the Canton Fair in October 1991, and since then in December 1991 and January 1992, shows that extra volumes are still being offered to overstocked traders and manufacturers.

It is possible that the period 1992-95 will see reduced Chinese export sales, a slow recovery in demand and a gradual rebuilding of stocks, but there is a danger that oversupply will persist through 1992-93 as a result of continued surpluses as the Chinese domestic market contracts. Depressed prices for Chinese 80% oil would then remain for several years more, making the task for any new producer very difficult. A medium-term recovery of prices will be dependent on reduced production and shipment of the standard Chinese 80% cineole eucalyptus oil or a revival of domestic demand.

The next sections attempt to estimate the production, trade and domestic offtake of the major producing countries and regions.

People's Republic of China

Until very recently, when areas of eucalypt have been established specifically for oil production, most Chinese eucalyptus oil has come from plantations intended for timber and pulp production. *Eucalyptus* has been planted extensively in southern areas of the People's Republic of China. More than 100 000 ha of *E.globulus* occur in the south-western area, mainly in Yunnan province, and this is the chief source of Chinese eucalyptus oil. *E.globulus* is also grown in southern Sichuan province and parts of Guangxi and Guangdong. *E.citriodora* and *E.exserta* oils are produced from plantations growing in Guangxi and Guangdong and, additionally, from those on the Leizhou Peninsular and Hainan Island. Some of the oil-bearing eucalypts are grown, also, as sources of fuelwood or for inter-cropping in agroforestry.

Current opinion is divided on how much so-called Chinese eucalyptus oil is derived genuinely from *Eucalyptus* and how much is 'ex camphor'. The camphor tree, *Cinnamomum camphora*, yields an oil which, on fractionation, furnishes a cineole-rich fraction. This material is difficult to distinguish chemically from genuine eucalyptus oil* and has undoubtedly been traded in the past. One recent Chinese source has suggested that *C.camphora* has been overlogged and is no longer used as a source of medicinal 'eucalyptus oil'. Others in the trade, although unable to estimate how much, express the view that it is still used.

A recent Chinese source (Wang Huoran and Green, 1990) puts annual production of all types of eucalyptus oils in the People's Republic of China at about 3000 t. It also states that over 1000 t are exported, but this seems to be an under-estimate, given that recorded imports into the EC and the US alone were over 1300 t in 1989 and 2000 t in 1990. Reasons for the sharp rise in 1990 and the subsequent low price of Chinese oil, which still prevails, have been given earlier. The bulk of exports are of the cineole type but several hundred tonnes of *E.citriodora* oil are also known to be exported. It is estimated that the People's Republic of China produces up to 2000 t/a of cineole-rich oil, with exports of 1300-1500 t and domestic offtake of 500-700 t. The fall in domestic offtake and expansion of exports that has been discussed earlier probably placed an additional 300-400 t of oil on the world market in both 1990 and 1991.

Portugal and Spain

In Portugal, the extensive planting of *Eucalyptus* has been motivated by the desire to meet the needs of the large and expanding domestic pulp industry. About 0.5 million ha of eucalypts exist, distributed mainly along the Atlantic coast north of Lisbon and the Tagus valley. The vast majority, and sole source of oil, is *E.globulus*. The main concentrations of eucalypt plantings in Spain are in the south of the country, in the forests of Huelva, where the main species is again *E.globulus*. In both cases, oil production is from the 'waste' leaf remaining after the trees have been felled. The main distillery groups, in addition to producing crude oil themselves, buy oil from a number of small, independent distilleries.

In the period 1988-90, Portuguese output of oil from the three major distillery groups was some 300-400 t/a. It is estimated that current production has fallen to 150-200 t/a and one of the groups is understood to have ceased production. Indigenous Spanish production in 1990 was about 50-100 t and it is estimated that this has now declined to 50 t or less. The fall in Portuguese and Spanish

*Eucalyptus oil 'ex camphor' is said to have a different odour from genuine eucalyptus oil. It also has a slightly negative optical rotation that excludes it from direct pharmaceutical use under the requirements of the BP.

output has been a partial response to high labour costs, particularly those incurred in the collection and transportation to the distillery of the 'waste' leaf. It is even more critically related, however, to the extra volumes of Chinese oil being exported and increased price pressure in the second half of 1991.

Portugal and Spain remain significant exporters of eucalyptus oil products, including eucalyptol, but an increasingly larger share of the starting oil is imported from the People's Republic of China and South Africa. Spain also imports crude oil from Portugal.

Africa

Southern Africa is a major producing region for eucalyptus oil. Most comes from South Africa, but a significant proportion originates from Swaziland. Zimbabwe has recently commenced production, albeit on a small scale.

With the exception of a small amount of medicinal oil produced from *E.radiata* in Cape Province, South African production of eucalyptus oil is centred in the eastern Transvaal, close to the border with Swaziland. Approximately half of the oil produced there, 150-180 t, is the cineole type distilled mainly from *E.smithii*, but with a small contribution from *E.radiata*. Although large areas of *E.smithii* have been planted in the south-eastern Transvaal and Natal for timber purposes, and could be utilized for oil production should there be a wish to do so, existing production of oil from this species is derived entirely from short-rotation coppiced trees of which oil is the sole product. The remainder of South African production, also estimated at 150-180 t, is of the piperitone-containing oil produced from *E.dives*. This species, too, is grown specifically for oil under a coppicing regime.

In Swaziland, the greater part of oil production is of medicinal oil, from short-rotation, coppiced *E.smithii*. A proportion, however, is derived from *E.smithii* grown on an 8-10 year rotation in which wood suitable for use as mining timber is produced, as well as oil. A total of some 80 t/a of medicinal oil is produced. A little piperitone oil from *E.dives* is produced, also under the longer rotation system of dual-purpose management.

The bulk of Swazi and a proportion of South African cineole oil is exported to Australia for further processing. Spain is also a significant importer of South African oil. In addition, a South African rectification plant processes about 40-50 t/a of the crude 70% oil; this supplies some 15 t of 85% cineole oil and eucalyptol to the domestic market, the balance being exported.

All South African and Swazi *E.dives* oil is exported, most of it to Australia and France.

Zimbabwean production, which began in 1989, amounts to 10 t of cineole-rich oil annually. It is based mainly on coppiced *E.smithii* with a little from *E.cinerea*. Zaire, which once produced small amounts of oil, appears no longer to do so. In Tanzania, plans are being considered for production of oil from *E.smithii*.

Australia

After the first large-scale commercial operations began towards the latter part of the last century, Australian production of eucalyptus oil reached a peak in the late 1940s and has since declined. However, in the face of increasing production elsewhere in the world, the introduction of mechanized harvesting enabled the Australian industry to become more efficient and it has consolidated in two main geographical areas: near West Wyalong, New South Wales, and the Inglewood area of Victoria. In both cases, 'cleaned' natural stands of *E.polybractea*, a high quality source of medicinal oil, are utilized. A little oil is produced from *E.radiata* and *E.dives* (both cineole and piperitone variants) growing in south-eastern New South Wales, around Canberra. Small quantities of E-methyl cinnamate are produced from *Eucalyptus* sp. nov. aff. *campanulata*.

Domestic production of oil is believed to be about 150 t/a, but is supplemented by imports of lower-quality cineole-containing oils from Swaziland and South Africa (about 80-100 t/a), as well as the People's Republic of China, which are rectified and then blended with locally produced oils for subsequent re-export. Smaller quantities of piperitone-containing *E.dives* oil are imported from South Africa for menthol production.

South America

Brazil has about 5 million ha of eucalypts – more than any other country in the world – but most of this is not of oil-bearing species. Brazil is, however, a major source of *E.citriodora* oil, with production taking place in São Paulo, Minais Gerais and Bahia States. Leaf is harvested either from trees grown specifically for oil on a coppice system, or by collection as 'waste' leaf from plantations established for other purposes (as a source of fuelwood for use by the steel industry, for example). *E.globulus* oil is also produced, again either from coppiced trees or 'waste' leaf. Smaller amounts of *E.staigeriana* oil are produced from coppiced leaf.

Brazilian production of *E.citriodora* oil is difficult to estimate but may be about 400-600 t/a. This level may decline in the future as steel companies replace *E.citriodora* with faster growing species of *Eucalyptus* to meet their fuel needs. Several hundred tonnes are exported to the EC, with France prominent among the importing countries. Much less cineole oil and perfumery oil from *E.staigeriana* is produced.

In recent years, Chile has emerged as a significant producer of eucalyptus oil (including eucalyptol) from *E.globulus*, which is widely planted in Chile. The main areas of *E.globulus* are in the Valparaiso and Bio-Bio Administrative Regions in the centre of the country. Annual production is about 80-100 t of oil, most of which is exported.

Other smaller producing countries include Uruguay, Paraguay and Bolivia. *E.globulus* is the main source of leaf, although Paraguay distills a little *E.citriodora.*

India

Eucalypts have been planted on a large scale in India – mainly for fuelwood, pulp, pole and afforestation purposes – but the dominant species is *E.tereticornis* ('Mysore hybrid'), which is not suitable for oil production. Both *E.globulus* (mainly in southern India) and *E.citriodora*, however, have also been planted, and these two species form the basis for Indian eucalyptus oil production.

E.citriodora has been much promoted within the country as a crop suitable for small-scale cultivation for oil production, but it still remains the lesser of the two species in oil volume terms. Reliable estimates of production are not easy to come by, but it seems likely that something of the order of 50 t of *E.citriodora* oil and 150-200 t of cineole-rich *E.globulus* oil are produced annually. In addition to domestic production, imports of oil have been used in the past for conversion into toothpaste flavours and soap fragrances for the markets of the former Soviet Union, which were sold through bilateral rupee/rouble trade.

ESTIMATES OF WORLD PRODUCTION AND EXPORTS

The best estimates for production and exports of the three types of eucalyptus oil are now given. Estimates of production of medicinal oils for 1991 are based on known 1988-90 figures which have been adjusted to reflect the changes of the last year. Figures for exports, which are necessarily more tentative, exclude re-exports.

Medicinal oils

Production and export data for cineole-rich oils are given in Table 2. It must be noted that the lower figure for production includes a figure for the People's Republic of China which is only possible if significant portions of 1990 exports were made from stocks. The downward adjustment in Portuguese and Spanish domestic output is also severe. Overall production of cineole-rich oils in 1991 is likely to have been around 2800 t. International trade in the same year (excluding re-exports) is estimated at about 2000 t.

Table 2 World production and exports (excluding re-exports) of cineole-type eucalyptus oil – 1991 estimate

	Production (tonnes)	Exports (tonnes)
Total	2480-3130	1870-2070
of which:		
China, People's Rep. of	1600-2000	1300-1500
Portugal	150- 200	150
India	150- 200	ne
South Africa	150- 180	120
Australia	120- 150	100
Swaziland	80- 100	80
Chile	80- 100	70
Spain	50- 100	50
Others	100	ne

Source: NRI and trade estimates. **Note:** ne indicates 'not estimated'.

Perfumery oils

Chinese production of *E.citriodora* oil is estimated at 900-1100 t and Brazilian production at 400-600 t. India, with about 50 t, is the only other producer of this oil of any significance. Total world output is therefore about 1350-1750 t. Exports from the People's Republic of China and Brazil amount to some 300-500 t and 200-300 t respectively.

Production of *E.staigeriana* oil in Brazil was probably about 60-80 t.

Industrial oils

South Africa is the world's largest supplier of piperitone-containing oil from *E.dives.* A best estimate for 1991 production is 150-180 t, all of which was intended for export, although actual sales were probably less than this.

The volume of Australian production of E-methyl cinnamate is not known, but it is probably of the order of 10 t/a or less – very small in comparison with the internationally traded oils.

Section 3

Leaf production and harvesting

Eucalyptus leaf destined for production of essential oil is obtained commercially by one of three methods:

- recovery of 'waste' leaf from felled trees which have been grown primarily for their timber;
- short-rotation harvesting of plantations established specifically for oil production. Under such a system of coppicing, plants are allowed to grow for no more than about 20 months before cutting; and
- regular harvesting (coppicing) of wild stands; peculiar to Australia.

Each of these operations is described below.

UTILIZATION OF 'WASTE' LEAF FROM TIMBER OPERATIONS

Where eucalypts have been planted on a large scale for pulp, timber, fuelwood or other purposes in which the stem is the primary product of harvesting, an inevitable by-product is the foliage which is trimmed from the tree. This includes shoots and side stems derived from pruning operations, as well as the branches lopped off from the main stem after felling. In most circumstances this 'waste' material is treated as such and simply left in the field or burnt. A few countries – notably the People's Republic of China, Portugal and Spain, which have large areas of *E.globulus* planted – have been able to make use of this 'waste' resource to produce oil.

In Portugal, *E.globulus* is grown on a type of coppice system for pulp and normal management involves three or four rotations of 10-12 years each. After the first felling, two or three stems are allowed to grow and the remaining shoots pruned. The felled trees are de-barked and the branches removed. When the foliage is to be used subsequently for oil production it is tied into bundles in the field by the distiller's work-force before transportation to the distillery. According to the practice of the distiller the bundles of leaf material may be left for some days before removal, in order to reduce the moisture content prior to distillation. The bundles should not be left too long, however, or there is a risk of losing valuable volatile oil.

In Swaziland, one producer grows *E.smithii* and *E.dives* (piperitone variant) for both oil and timber production. The trees, again, are grown under a long-interval coppice type of system with a rotation of 8-10 years. One year after the first felling, the coppice regrowth is thinned down to two stems. A year later one of them is removed to leave one stem which is allowed to grow. Removal of side shoots continues for 3-4 years. The whole cycle may be repeated three or four times. 'Waste' leaf is therefore available from both the final felling and the intermediate pruning.

It should be noted that both yield and composition of the oil are likely to be slightly different according to whether the adult leaf or the side shoots are distilled. This is discussed more fully in Appendix 3.

It is very difficult to give figures for biomass production on a 'per hectare' basis from which meaningful estimates of oil yields can be made. The amount of 'waste' leaf potentially available from a given area clearly depends on the species of *Eucalyptus* planted, stocking density of the trees, rate of growth under prevailing climatic and edaphic conditions and age at felling. Use of the term 'leaf' in the context of oil production is also rather imprecise and misleading: leaf material that is collected and which goes into the still for distillation (whether it is 'waste' leaf or material harvested from coppiced trees grown specifically for oil production) always includes the small branches to which the leaves are attached. In the case of 'waste' leaf these branches may be up to 10 mm or more in thickness. The meagre data available on individual biomass components, on the other hand, do separate leaves from branches. For *E.globulus* intended for pulpwood, and growing under Portuguese conditions, one source of information has estimated the above-ground biomass at the felling age of 12 years (first rotation) to comprise 5% leaf and 7% branches, yielding 6 t and 9 t of dry matter per hectare, respectively. Assuming a combined fresh weight equivalent of 30 t and a yield of 1% oil, this corresponds to 300 kg of oil per hectare, a figure which is almost certainly too high. Another source has given an estimate of 8-10 t for the quantity of 'waste' leaf per hectare available for oil production from *E.globulus* in Chile. This corresponds to about 100 kg of oil per hectare.

Although the landowners where the trees are grown may be happy to be rid of the foliage and not impose any great price on its removal, it should not be regarded as a near zero-cost raw material for the distiller. Labour costs for collection and the cost of transporting leaf to the distillery have to be met. If distances are great, transport costs will not be insignificant. Any prospective producer of eucalyptus oil who is contemplating the utilization of 'waste' leaf needs to ensure that the logistics of collection are adequately considered:

- are the areas where trees are to be felled readily accessible by road?
- is the felling (and planting) programme such that there will be continuity in supply of leaf within a reasonable distance of the distillery to maintain similar continuity of production of oil?

COPPICE MANAGEMENT OF PLANTATIONS SPECIFICALLY FOR OIL PRODUCTION

Many species of *Eucalyptus* respond to coppicing, that is, they produce shoots from the stump when the tree is felled. The ease with which coppicing occurs varies from species to species, and some coppice poorly or not at all. Most of the oil-bearing eucalypts listed in Table 1 do coppice. It is possible, therefore, to manage them in such a way that regular and repeated harvests of leaf are made as a means of supplying a distillery with material for oil production. Management of eucalypts on 8-12 year coppice rotations has already been discussed in connection with 'waste' leaf utilization. Harvesting leaf on a much shorter cycle, between 6 months and 20 months, and illustration of the way this is achieved for various *Eucalyptus* species, forms the basis of the remainder of this section.

It is not intended, here, to give detailed silvicultural advice on propagation, establishment and maintenance of eucalypts. This information is available from other sources. Where particular points are worth making, however, in the context of oil production, then these aspects are briefly referred to. Neither is it the intention to present an annotated list of preferred species. There are insufficient published data on oil and biomass yields to make any comparison of species meaningful and ranges of values can be misleading. General information on climatic and cultural preferences, again, is available elsewhere and the prospective producer of eucalyptus oil may have locally acquired data from species or provenance trials which he can turn to for guidance.

Notwithstanding the above comments, a few species have characteristics that have made them favoured ones for oil production. In trials of medicinal-type oil-bearing eucalypts in southern Africa, *E.smithii* has performed consistently well in terms of growth and biomass production. Results in Zimbabwe, for example, have shown it to be superior to *E.radiata*, *E.dives* (cineole variant), *E.polybractea*, and *E.bakeri*. Similar results have been obtained in the People's Republic of China. This, together with the fact that it gives a reasonable oil yield, has made *E.smithii* the most widely planted species in southern Africa for the production of medicinal eucalyptus oil. *E.radiata*, however, does appear to give higher yields of oil from the leaf than *E.smithii* and some provenances tested in southern Africa have shown sufficient promise in terms of biomass production as to encourage their planting for oil extraction purposes. The variability of oil yield (and composition) within and between species is discussed in more detail in Appendix 3.

It should be noted that although most crude medicinal oils are rectified before final use so as to increase their cineole content, rectification of the oil from *E.smithii* is necessary, also, to remove small amounts (1-2%) of isovaleraldehyde which would otherwise exclude it from use for pharmaceutical purposes.

Propagation and field management

Eucalypts are usually propagated by seed and guidance on sources of supply of seed for planting is given in Appendix 2. A few species are shy to produce seed away from their native habitat and seed may need to continue to be imported for some years after initial establishment of the crop. *E.smithii* is such an example in southern Africa, and in Brazil *E.globulus*, which is grown specifically for oil production, fails to seed. Another problem with seed propagation is the resulting heterogeneous population. As discussed in Appendix 3, individual trees within a provenance can vary considerably in oil yield and oil composition. Vegetative systems of propagation would lead to greater homogeneity and allow more rapid gains in productivity through breeding programmes. However, despite the advances that have been made in developing such systems, there are some major problems yet to be overcome before they are likely to be exploited commercially for oil-bearing eucalypts. These include the problems of obtaining good root formation which will ensure survival of the plant in the field, and the disposition of the plants to respond favourably to subsequent coppicing.

When planting out the eucalypt seedlings in the field, the spacing that is employed is something of a balance between high stocking density – to maximize oil yields on a 'per hectare' basis – and allowing the seedlings sufficient room to grow and flourish in the time available between harvests. Stocking should not be too open, however, because natural shading from adjacent plants is important as a means of suppressing weed growth. In the first year, before the plants are able to provide this, weeding – whether mechanical, by hand, or by use of chemicals – is necessary to avoid competition. The planting scheme should allow for subsequent access, during the harvesting period, by tractor-trailers or trucks. It is important that they have room to move within the stands without damaging the newly formed stools.

Harvesting

After establishment of the crop, practice in Swaziland is to make the first cut of *E.smithii* at 20-24 months. Subsequent cuts of the coppice regrowth are made at approximately 16-month intervals, at which time the plants are about 5-6 m tall. Yields of fresh leaf are about 15 t/ha at this age. Corresponding yields of oil are approximately 150 l/ha. Harvesting may continue for many years and in Swaziland some areas of *E.smithii* are still being harvested 20 years or more after the first cut. In Zimbabwe, harvesting of *E.smithii* is carried out at 12-month intervals and timed so that it is completed shortly before the period in the year when there is maximum growth of the plants; coppice growth is then established before weeds can compete. Care should be taken to cut the stems cleanly so as to encourage and maximize coppicing and they should not be cut too close to the ground to avoid stool mortality; about 15 cm above the ground is typical.

In South Africa, the practice of one producer of *E.dives* (piperitone variant) is to cut the stem at knee height 4-5 years after planting. Re-growth, in the form of six or more main shoots, is then allowed to continue and the whole of the aerial parts above the stump are harvested at 15-18 month intervals thereafter.

In Brazil, where one producer grows *E.citriodora*, *E.globulus* and *E.staigeriana*, a slightly different system of harvesting is adopted. Eighteen months after planting the smaller branches are cut from the stem. This process is repeated every 6 months (*E.citriodora*) or 4 months (*E.globulus* and *E.staigeriana*) until the branches are too high to be reached (a period of about 3 years). The stem is then cut at about knee height and two or three stems allowed to grow over a period of about 12 months, when the harvesting cycle is repeated.

The harvesting operation is undertaken by teams of workers, each member of a team having an assigned task. A separate person may organize and co-ordinate the teams. In Swaziland, each team consists of 12 persons. For the first (seedling) cut, two people are responsible for felling the trees (using chain saws), six trim the branches from the stems and four tie the branches into bundles. Each team aims to have produced a given amount of foliage within the working day. Separate teams follow behind the harvesters to load the cut material onto trailers: six loaders, three people to clear up foliage that has not been tied into bundles and one driver per team. In Zimbabwe, where the stocking density is greater, three men with knives first cut off the lower branches; these are followed by three more who use bow saws to cut the stems. A team of six women then moves the foliage into lines where it can be loaded onto a trailer, with three more women clearing up behind.

Circumstances will dictate whether use is made of the stems from which the branches are trimmed and, therefore, whether this operation is carried out in the field or at the distillery. In some cases, the economics will not be favourable for the collection and sale of the stem wood as fuel, in which case it is simply left in the field. In Zimbabwe, trimming is carried out at the distillery and the stems used both as a source of fuel for the boiler and for sale locally as fuelwood.

Use of fertilizer

Whether or not the application of fertilizer after harvesting is beneficial to the promotion of biomass production – or, more importantly, oil production – is still the subject of research. It cannot be assumed that increased biomass will result in proportionate increases in oil yield. Even if proven, any increase needs to be weighed against the cost of the fertilizer and its application. Consideration of whether to apply fertilizer is not related solely to its possible value in improving productivity through gains in oil yield. Continual harvesting and removal of plant material without any return to the soil of nutrients may lead to deficiencies which ultimately result in declining yields. Occasionally, some effort is made to return the spent leaf remaining after distillation to the field (in Brazil, for example, and in Australia, where it is intended more as a mulch to conserve water) but this does not appear to be common practice.

MECHANICAL HARVESTING OF COPPICED NATURAL STANDS OF *EUCALYPTUS POLYBRACTEA* IN AUSTRALIA

In contrast to coppicing of plantations of the species discussed above, the Australian system for *E.polybractea* offers an alternative means of leaf collection that is not labour intensive: mechanical harvesting. *E.polybractea* is one of a group of eucalypts of the 'mallee' type. Mallees are multi-stemmed from ground level and rarely exceed 10 m in height when mature. The coppice regrowth after cutting has a shrubby form that makes it amenable to mechanical harvesting. The system of harvesting that has been developed in Australia has an added advantage. Just as with the system used to harvest mint in the US, the mobile 'bin' into which the cut foliage is placed functions not only as a means of transportation for taking it back to the distillery, but also as the distillation vessel. By such means, double handling by way of unloading and re-loading of the leaf into a separate still is avoided*. A brief description of the use of this type of arrangement for distillation is given in Section 4.

The areas in Australia where *E.polybractea* is harvested are predominantly 'cleaned' natural stands which have had other eucalypt and non-eucalypt species removed, as well as rocks and other obstacles which would impede movement of the harvester. Coppice regrowth of the cut trees gives them the appearance of shrubs of about 1 m in height at harvesting. Although *E.polybractea* remains the dominant species, a few other plants survive and these are also entrained during the harvesting. Fortunately, their presence does not impair the quality of the distilled oil. The frequency of harvesting is anywhere between about 18 months and 24 months, the exact time being dependent on weather conditions. Areas of natural stands that have been repeatedly harvested for 20 years are claimed to have suffered no apparent loss of vigour or reduction in oil yield over this time.

On a much more limited scale *E.polybractea* has been planted as a crop. Harvesting of plantation-grown *E.polybractea* may begin after 12-15 months but the first commercial harvest is usually made after three years, cutting down the single stem and then cutting the multi-stem regrowth at about 18-month intervals as usual.

In the field, a forage harvester is towed by a tractor, and a series of rotating 'hammers' with cutting edges slice through the shrubby plants at ground level. The chopped pieces are blown up and into the separate 3-t capacity rectangular, box-shaped 'bin' trailed behind. It takes approximately one hour to fill a bin and two to two and a half bin loads to harvest one hectare of land. When harvesting areas near to the distillery, pairs of bins are towed to and from the site by tractor. If the distances involved preclude this then each pair is transported by low loader. One man is able to undertake the harvesting operation at each site on his own.

*This system was developed in the early 1970s by GR Davis Pty Ltd and is used by them and the other major producer of eucalyptus oil in Australia.

Section 4

Distillation and processing

INTRODUCTION

Most essential oils, including eucalyptus oils, are obtained from the plant material by a process known as steam distillation. Both the theory and practice of steam distillation are complex issues and it is not intended, here, to write at length on either aspect or to give detailed plans for the construction of distillation units. After indicating the different types of steam distillation, a general description of the design and workings of the distillery and its various items of equipment is given, highlighting particular points which relate to systems used by eucalyptus oil producers. The reader is referred to Appendix 1 for references to other, more comprehensive descriptions, especially those of Ames and Matthews (1968) and Denny (1991). The latter author, in particular, discusses equipment needs, distillery layout and methods at some length and includes eucalyptus leaf distillation amongst the examples given.

Oil is contained in eucalyptus leaves within glands below the surface of the leaf, which may be seen as tiny transparent 'windows' of light if the leaf is held up to a bright source of light. In order to recover the oil the leaves are subjected to a process of steam distillation. The fundamental nature of steam distillation is that it enables a compound or mixture of compounds to be distilled (and subsequently recovered) at a temperature substantially below that of the boiling point(s) of the individual constituent(s). Eucalyptus oils contain substances with boiling points in the range 150°-200°C and higher, including some that are solids at normal temperatures. In the presence of steam or boiling water, however, these substances are volatilized at a temperature close to 100°C at atmospheric pressure. The mixture of hot vapours will, if allowed to pass through a cooling system, condense to form a liquid in which the oil and water comprise two distinct layers. Eucalyptus oils, in common with many other (but not all) essential oils, are lighter than water and form the top layer. The solubility of the major, commercial eucalyptus oils in water at ambient temperature is sufficiently small as to be regarded as negligible.

In practical terms, the steam that is used for the distillation is generated either within the still that contains the leaf (by boiling water contained at the base) or by an external boiler.

Water-and-steam distillation

The use of steam generated within the still requires that the leaf be supported above some boiling water by a grid. The water is heated either directly using a fire or by heat exchanger coils. The simplicity of the method makes it suitable for small-scale distillation of essential oils and it is used by some eucalyptus oil producers. Apart from the need for containment of the water in the still below the charge of leaf, the design and function of the still and condensing system is largely the same as that for the externally generated steam method described below.

Steam distillation

As with the water-and-steam distillation, the plant charge is held on a grid within the still vessel. The steam generated from an external boiler is introduced at the base of the still via an open coil, jets or similar device(s). The advantages of this type of distillation are that it is relatively rapid and capable of greater control by the operator. The still can be emptied and recharged quickly and with the immediate reintroduction of steam there is no unnecessary delay in the commencement of the distillation process. Oils produced by this means are more likely to be of acceptable quality than those produced using the water-and-steam method of distillation.

LEAF PREPARATION

The harvesting of the leaf and its subsequent distillation are usually closely matched so that there are no more than a few days between the two operations. Leaf brought to the distillery in the morning is often distilled by the end of the day. In most cases, the leaf is loaded into the stills in the form that it is received, that is, as bundles of foliage. Occasionally, some other operation is first performed. This may entail putting the foliage through a chipper so that after distillation it is in a physical form that facilitates its use for other purposes (see below); or the leaf and twigs may be stripped from the main stem (if this is not done in the field) so that the latter can be sold for use as firewood.

THE DISTILLERY AND ITS COMPONENTS

A schematic flow diagram indicating the essential components of a commercial distillery employing steam from an external boiler is shown in Figure 1. The layout of the distillery is largely a matter of convenience for the particular site. It is usual to operate the stills at two levels: loading and unloading takes place at the higher level, while oil collection at the separator(s) occurs at the lower level. Australian practice is rather different (since there is no direct handling of the leaf at the distillery) and is discussed separately.

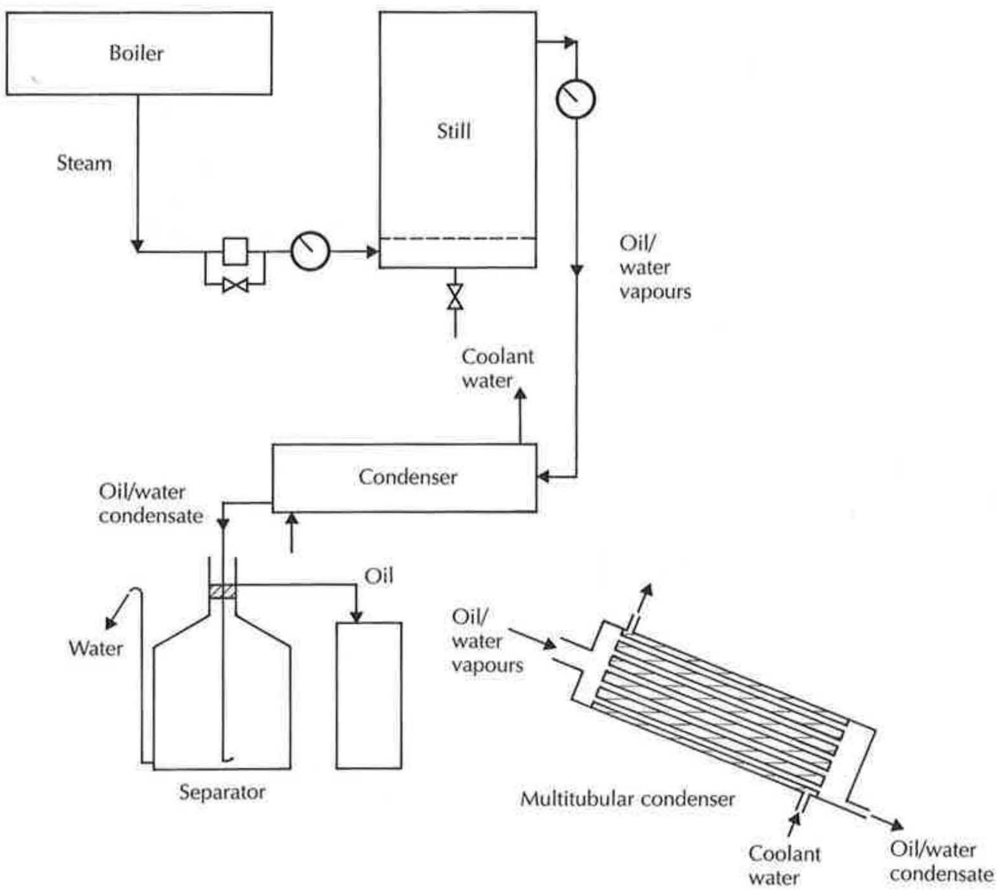

Figure 1 Schematic flow diagram (not to scale) showing the principal components of a eucalyptus oil distillery and details of a multi-tubular condenser

The boiler

The performance of the boiler used to generate the steam is critical to the efficient production of oil. Furthermore, the rate at which it is able to supply steam is more important in determining processing capacity than the number or size of stills alone. At the distillery design stage a prospective producer should, through the services of a competent engineer, calculate the boiler load necessary to supply steam at the rate required, given the number of charges of leaf that need to be distilled per day to meet the target oil output. A steam pressure somewhere in the range 300-500 kPa (3.0-5.0 kg/cm^2; 45-70 psi) measured at the boiler is likely to be necessary for charges of about 2-3 t.

Producers in Portugal, Spain and southern Africa have cited distillation times of between 2 h and 5 h for charges of 1-2 t – an indication of the variable, and sometimes inadequate, steam pressures used. On the other hand, one Brazilian producer distills 2-t charges of *E.citriodora* in one hour; *E.globulus* takes approximately 1.25 h and *E.staigeriana* 1.5 h. Differences in distillation time attributable to the use of different species of *Eucalyptus* rather than operational factors are further illustrated by a comparison of *E.smithii* and *E.dives* (piperitone variant): for the same sized charge it takes one southern African producer almost three times as long to distill *E.dives* as it does *E.smithii*.

The steam supply may be used by several stills at different stages of loading and distilling. In such cases, the steam pressure will be less than if it were being supplied to only one still and the distillation time correspondingly longer. Another southern African producer of *E.dives* has changed his previous practice of splitting the steam in this way and thereby reduced the time it takes for each distillation from 6 h to 2.5 h for a single distillation.

The degree of wetness of the steam supplied by the boiler is also important. If the steam is too wet, there is a risk of refluxing, a condition where the water and oil vapours condense within the still instead of emerging from the top of it. This risk is greatest in a water-and-steam type of distillation and is one reason for the use of an external source of steam. Stills should be properly lagged to avoid refluxing.

The choice of fuel used for the boiler depends principally upon the fuel availability and its cost. Very often the spent leaf remaining after distillation of the oil is used, in which case virtually no fuel cost is incurred. In some cases, it is 'waste' wood that is available from ancillary timber operations carried out by the oil producer. Sometimes the stem wood remaining after harvesting of the leaf is utilized as fuel.

Still design

Almost universally, but with the exception of the box type of still used in Australia (see below), the still is cylindrical in shape. The lid may be detachable or hinged on one side and, in either case, may be secured by wing bolts around the circumference. A fibre gasket usually provides a seal between the lid and the body of the still. Alternatively, the lid may sit in a small trough of water constructed around the top of the still (approximately 10 cm wide and 15 cm deep) and this forms the seal. The exit point for the oil/water vapours may either be near the top of the still or from the lid itself. In the latter case, the lid, as well as the still, should be lagged to prevent premature condensation of the vapours (refluxing). With the all-in-one lid and take-off, it is often convenient to share it between a pair of stills in which one is being unloaded as the other is distilling.

Still packing

The manner in which the leaf is loaded into the still is important if the distillation is to be efficient and the recovery of oil maximized. Packing should be firm and as uniform as possible so that the steam does not follow the path of least resistance in passing upwards through the charge ('channelling'). Particular attention should be given to that part of the charge in contact with the still wall. It is good practice to line the still with foliage – and to tread it down if possible – as the bulk of the material is loaded. Some distillers see advantage in trickling steam through the leaf as it is packed, so as to reveal any uneven packing.

Condensing system

On leaving the still, the hot oil/water vapours pass through a cooling system to a device where the oil/water condensate is separated into its component parts. The simplest form of condenser is one in which a long pipe leads the vapours through a trough of water. In the days of the old Australian 'bush' stills, the pipe was commonly led through a dam or stream. A more compact form of condenser has the pipe or tubing wound into a coil or other convoluted shape which is then immersed in a water bath. These types are still seen in Portugal and Spain. If necessary, the coolant water is circulated and replenished to ensure that the condenser provides an adequate degree of cooling. If it does not, then not only may some oil be lost by evaporation, but the final separation of the oil and water layers may be impaired.

The most efficient type of condenser is the multi-tubular form illustrated in Figure 1. By passing the hot vapours through a number of parallel tubes, on the outside of which is flowing water, a very large cooling area is provided in a relatively small space. The whole system is contained within a cylindrical vessel. The number and size of tubes needed are calculated on the basis of the required heat transfer, given the rate at which distillate vapour is to be condensed and the target exit temperature. Condensers of about 2 m in length containing 30 or so tubes may be adequate to deal with a flow rate of 4-5 l/min of condensate. Denny (1991) recommends a coolant flow rate of 15-17 times that of the condensate flow. A convenient method of cooling the coolant water after exit from the condenser and prior to recycling, when it may be about 40-45°C, is to use an evaporative cooling system which discharges the water as a spray.

Oil collection and separation

The mixture of oil and water flowing from the condenser is led into a 'Florentine flask' type of receiver (illustrated diagramatically in Figure 1) in which the two liquids separate. The condensate is allowed to fall to the bottom of the separator through a vertical tube, whereupon the less dense oil separates spontaneously and rises in a stream of droplets to the surface of the water. With a separator of suitable dimensions the oil overflows continuously from a side-arm in the neck while the water discharges from the bottom. The oil is led directly into drums or into a larger holding vessel. In either case, the oil is usually held overnight to allow any entrained water to separate out and then transferred to clean drums for subsequent sale. The condensate water is led away to waste. It is unwise to return it to the boiler for re-use because of the slow, but nevertheless significant, corrosive action of the small amounts of oil and other soluble matter contained in it – this is particularly true of *E.dives* distillations.

Construction materials

The choice of material for construction of the various items of equipment is important. It is necessarily a compromise between strength and resistance to corrosion, and cost. Stainless steel is the preferred material for fabrication of the still, but it is expensive and mild steel is a cheaper alternative. In time, however, mild steel will corrode and rust. Pitting becomes evident on the inner surface of the lid and at the top of the still where the hot oil/water vapours rise above the charge during distillation. Such a still may last only about 5 years before it has to be replaced. Its life may be extended by lining the mild steel with a suitable stainless steel ('inox') or coating it with a special anti-corrosion formulation. Alternatively, the lid, at least, may be entirely stainless steel.

Apart from the inner part of the still itself, the exit pipe and all pipework up to the condenser (which is in contact with hot vapours) should be made of corrosion-resistant steel. The condenser – at least those parts which come into contact with the oil – should be made of stainless steel and also, preferably, the separator.

Labour requirements

Most of the labour force at the distillery is employed in loading and unloading the stills. Apart from this, one other person is usually responsible for the boiler (when the steam is generated externally) and another may monitor the distillations and collection of oil.

SCALE OF OPERATIONS

Distillations may be carried out in vessels as small as an oil drum. Stills of 0.5 t capacity are used by many small producers (farmers, co-operatives, etc.) for essential oils and can be used for eucalyptus oils. The remaining discussion focuses on larger operations which use stills of 1-t capacity or larger, although many of the points raised apply, equally, to the smaller scale.

Typical still sizes used by producers in Portugal, Spain and southern Africa are about 3 m (height) x 2 m (diameter), with capacities of 2-3 t of leaf. A few 1-t stills are used and occasionally larger ones of 4 t capacity or more. A distillery may have anything between two and eight stills. The potential annual production capacity of a distillery is dependent on the following:

- still capacity;
- number of stills;
- oil yield;
- number of distillations per day; and
- number of working days per year.

While the number and size of the stills can be fixed, the oil yield is dependent on many factors (*see* Appendix 3) including the intrinsic characteristics of the plant material, seasonal and environmental factors, and the efficiency of the distillation itself. The number of distillations that can be achieved in a day also depends on how efficiently the distillations are carried out (as well as the number of shifts being worked). The number of operational days in the year is dependent on the supply of leaf to the distillery (which may be seasonal or subject to disruption) and down-time due to maintenance or repair of equipment. However, assuming a yield of 1% oil from the fresh leaf* and a 250-d working year, illustrations of potential annual production for different numbers and sizes of stills are given in Table 3.

Table 3 Potential annual oil production for different numbers and sizes of stills

Still capacity (t)	Oil yield/ distillation (kg, @ 1% of leaf)	Number of stills	Number of distillations/ still/d	Oil produced/d (kg)	Oil produced/ year (t; 250 d)
1	10	2	2	40	10
1	10	2	3	60	15
1	10	2	4	80	20
2	20	2	2	80	20
2	20	2	3	120	30
2	20	4	2	160	40
2	20	4	3	240	60
3	30	2	2	120	30
3	30	2	3	180	45
3	30	4	2	240	60

*Oil yields quoted by producers during the fieldwork for this bulletin fell within the range 0.6-1.3%.

DISTILLATION OF MECHANICALLY HARVESTED LEAF IN AUSTRALIA

On arrival back at the distillery, the bin containing the harvested leaf is positioned underneath a top cover suspended from the roof. A connection is made to the bottom of the bin to allow steam from an external boiler to be introduced and the cover is then lowered onto the bin by block and tackle and fastened. A hole in the centre of the top cover allows exit of the oil/water vapours during distillation and these pass via a flexible hose to a multitubular condenser and separator. No lagging or double skinning of the bin is found to be necessary, ambient temperature being sufficiently high to prevent reflux of vapours within the bin during distillation. Once distillation commences, it is complete in approximately one hour.

The bin itself is made from mild steel, the top cover being either mild steel or stainless steel and the hose and condenser both being made of stainless steel. The whole operation is carried out in a fairly compact, enclosed area designed to accommodate two bins at a time. While one is being distilled the other, with spent leaf, is being removed and replaced by another with fresh leaf. Both the major oil producers in Australia who use this system retain part of the spent leaf (about 20%) to fuel the boiler. The remainder is used as a mulch (see below).

PACKAGING OF OIL

Oil that is to be exported is packed in new, mild steel drums of 200-l or 220-l capacity (170-200 kg net weight). Some producers use internally lacquered drums. Advice on packaging and labelling requirements for oils intended for export is given in Appendix E.

RECOVERY AND UTILIZATION OF 'WASTE' PRODUCTS

One aspect that a prospective producer of eucalyptus oil should consider is the possibility of utilizing 'waste' or by-products from the operation. The possible use of the woody material left over from harvesting as fuel – either for in-house use for steam generation, or for sale to others – has been referred to earlier. Whether or not this material is brought back from the fields is a matter of choice, given the costs of transportation and handling that will be involved.

The spent leaf, on the other hand, is necessarily a product that one is left with at the distillery and if it is not utilized then it remains to be disposed of on removal from the still. This is invariably done by burning it in the open. Use of the spent leaf as fuel for the boiler has already been mentioned, though this may consume only one-third or less of the total available. When the producer is harvesting leaf from his own plantings of eucalypts rather than purchasing 'waste' leaf he may choose to return the spent material to the fields to serve as a fertilizer. In Australia, in the semi-arid areas where *E.polybractea* is harvested, the spent leaf is used, instead, as a mulch, either by the producer himself (who returns it to an area that has recently been harvested) or by wholesale or retail sale to others. Conversion of the spent leaf into compost for subsequent sale is worth considering and a few oil producers in Portugal and Spain chop the foliage prior to distillation to facilitate this. In Spain, one distiller sells the pre-chopped spent leaf to a brick factory for use in fuelling the kilns; a Portuguese producer converts the spent leaf into charcoal before sale.

RECTIFICATION OF CRUDE MEDICINAL EUCALYPTUS OIL

For medicinal eucalyptus oil to comply with national or international requirements for pharmaceutical use (minimum 70% cineole in the case of the *British Pharmacopoeia; see* Appendix 4) it is usually necessary to increase the cineole content of the crude oil produced from the leaf. In the case of *E.smithii* oil, small amounts of isovaleraldehyde also have to be removed. Small producers of eucalyptus oils, for whom it is not economic to invest in the equipment needed to do this, sell their crude oil either to other, larger producers or to rectifiers who are not, themselves, producers of crude oil. An annual oil production of the order of 40-50 t is the minimum scale of operation that would make rectification a viable option for a producer.

Medicinal eucalyptus oil is purified in two stages, by fractional distillation (rectification) and then by a freezing process. The latter is usually carried out only if the aim is to produce eucalyptol. The height of the distillation column used for rectification and the capacity of the still will depend on the composition of the crude oil and the throughput required. Limonene, which has a boiling point close to that of cineole (178°C; cf. 176°C), is usually present at levels of about 2-7% in the crude oil. Its presence prevents eucalyptol being obtained solely by distillation without a great deal of effort and there is little to be gained in seeking to achieve very high cineole purity by having a very tall fractionating column. Distillation is usually carried out under vacuum so that the low-boiling components of the oil (the 'heads'), including water, are removed at temperatures only a little above ambient. At higher temperatures, but still usually less than about 80°C, the cineole-rich fraction (which may contain about 90% cineole) is collected. A higher-boiling fraction (the 'tails') is left behind in the still. The still itself may be fabricated from mild steel but the column, condenser and receiver are preferably made from stainless steel.

To produce eucalyptol, the cineole fraction is transferred to a number of buckets or bowls, frozen in a cold store at –30°C to –40°C for up to 24 h and the recovered mixture, which contains unfrozen limonene, centrifuged. The liquid portion rich in limonene is thus removed and the frozen part collected and warmed to furnish eucalyptol. Eucalyptol is hygroscopic and may be returned to the still for removal of water. On completion of this step the eucalyptol is transferred to new steel drums for storage and subsequent sale.

Depending on the cineole content of the crude oil, up to 50% of it may remain after rectification in the form of heads and tails and it is vital, therefore, to try and find market outlets for these. Sales to companies in the flavour and fragrance industries are possible but much will depend upon the composition of the fractions.

Section 5

Financial and economic aspects of oil production

This section provides some indication of the size and nature of the costs involved in producing eucalyptus oils from trees that are planted, maintained and harvested specifically for oil under a coppice system of management. Two instances are considered: one in which a recently established operation in Zimbabwe is yielding 10 t/a of crude cineole-type oil; and another in which approximately 55 t/a of crude cineole oil are produced in Swaziland. The indicated costs are, therefore, site-specific and in other situations there could be substantial differences, according to local circumstances.

In Tables 4 and 5 the fixed investment, annual production and delivered costs of oil are detailed for the operations in Zimbabwe and Swaziland respectively. The two operations differ significantly in several respects. In Zimbabwe, oil production is only one of several farm activities and is undertaken during the four-month period June-September. The whole of the area planted with *Eucalyptus* (approximately 50 ha) is harvested at 12-month intervals. In Swaziland, oil production is virtually a year-round activity, harvesting and distillation being

Table 4 Fixed investment, annual production and delivered costs for 10 t/a *E.smithii* oil produced in Zimbabwe[a]

		Sub-total (US $)	Total (US $)
Fixed investment costs			
Harvesting			
Tractors (4)		100 000	
Trailers (5)		11 500	
Tipping trailer[b]		3 000	
		114 500	
Cost set against eucalyptus oil operation[c]			50 000
Distillation			
Buildings and boiler:			
Steel structure		20 000	
Concrete slabs and brickwork		11 000	
Boiler and coal stoker (replacement value)		11 000	
Electrical installation		3 000	
Cooling tower		500	
Office/laboratory fitments		500	
		46 000	
Distillery equipment:			
Stills (3 x 2-t, insulated), including chain baskets		6 500	
Condensers (2; one common to two stills) + cooling water pump		4 200	
Electric hoist		1 600	
		12 300	
Laboratory equipment, including gas chromatograph		3 000	
	Sub-total	61 300	
	Rounded to		62 000
	Total		112 000

Table 4 – *continued*

		Sub-total (US $)	Total (US $)
Annual costs			
Cultivation[d]			
Rent of land		1 500	
Establishment of plants[e]		2 000	
		3 500	3 500
Harvesting and trimming[f]			
Labour (21 persons[g] x $ 1.00/d x 120 d)		2 520	
Depreciation of tractors/trailers (20%)		10 000	
		12 520	
	Rounded to		12 500
Distillation[h]			
Labour (10 persons x $ 1.50/d (2 shifts) x 120 d)		1 800	
Depreciation of buildings, boiler and equipment[i]		4 130	
		5 930	
	Rounded to		6 000
	Total		22 000
Additional costs for delivery to European buyers			
Drums (55 x 200-l coated steel)		2 750	
Sea freight ($ 125/t x 11 t gross)		1 375	
		4 125	
	Rounded to		4 000
	Total delivered cost		26 000

Notes:
[a] All costs converted to US $ at Zimbabwe $ 5 = US $1.
[b] For use at distillery.
[c] Tractors and trailers are used in other farm activities.
[d] 50 ha; land previously under cultivation so no land preparation necessary.
[e] Total cost written off over 10 years.
[f] Harvesting carried out on a 12-month rotation over a 120-d period.
[g] 12 fieldworkers responsible for cutting and loading, 3 tractor drivers and 6 workers at distillery trimming branches from stems.
[h] Target oil production 85 kg/d (5 distillations) for 120 d = 10 t/a. Fuel costs for boiler are negligible; dried woody stems from harvesting leaf are used.
[i] Charged at 5% for buildings and boiler, 10% for distillery equipment and 20% for laboratory equipment.

carried out for 10 months of the year. Foliage is cut at 14-16 month intervals and so a greater area is planted (about 660 ha) than is harvested in any one year (about 400 ha). It is important to note that in neither example has a charge been made for management or supervision or for the cost of capital.

The Zimbabwean distillery was built at very low cost and it would only be possible in 1992 to construct a similar one at a cost 80-125% higher than the level shown. For any similar-sized operation in southern Africa, labour costs may vary and the volume of leaf processed may be greater, but the major cost will remain the harvesting and distillation equipment.

The Zimbabwean example gives a delivered cost of $ 26,000 for 10 t of 70% cineole oil, i.e. $ 2.60/kg. Given that this oil would have to be offered at a discount to compete with Chinese 80% oil selling (January 1992) at $ 4.50-4.75/kg and the rather higher capital costs, as indicated above, that a new producer might incur in establishing a similar-sized operation in 1992, the profitability of such a venture is clearly very dependent on Chinese oil prices.

The Swazi example gives a delivered cost of approximately $ 254,000 for 55 t of 70-75% cineole oil, equivalent to $ 4.60/kg. At a landed price close to $ 5.00/kg this operation, too, is under pressure from Chinese oil prices.

It should be repeated that there are specific circumstances pertaining to each of the above examples and in order to arrive at an investment decision any prospective producer will need to undertake a detailed feasibility study. No consideration has been given to additional revenue that might be generated from the sale of 'waste' products such as wood (for fuel) or spent leaf (for compost or mulch). In addition, profitability increases sharply if extra oil is produced from the same plantation area by improved yields, or from the same distillation equipment by increased efficiency.

Table 5 Fixed investment, annual production and delivered costs for 55 t/a *E.smithii* oil produced in Swaziland[a]

		Sub-total (US $)	Total (US $)
Fixed investment costs			
Distillation			
Buildings and boilers:			
Structure, concrete and brickwork		54 000	
Boilers (2, second-hand)		70 000	
Steam reticulation		6 000	
Water system		18 000	
Stand-by generator		13 000	
		161 000	
Distillery equipment:			
Stills (4 x 3.5-t, insulated)		29 000	
Condensers and separators (2)		7 000	
Electric hoists (2)		12 000	
Tanks		9 000	
		57 000	
	Total		218 000
Cultivation costs (/ha)			
Land clearance		220	
Ripping and ridging		140	
Planting, including fertilizer application[b]		220	
Maintenance[c]		115	
		695	
	Rounded to	700	
	Total for 660 ha		460 000
Annual costs			
Cultivation			
Depreciation of total cost (12.5%)			57 000
Harvesting[d]			
Labour (50 persons)[e]		45 000	
Maintenance and fuel for tractors/trailers		33 000	
Depreciation of tractors/trailers		25 000	
Chain saws		2 300	
		105 300	
	Rounded to		105 500
Distillation[f]			
Labour (16 persons, 2 shifts)		18 000	
Depreciation of buildings, boiler and equipment[g]		21 000	
Repairs, maintenance and protective clothing		11 000	
Electricity and boiler fuel[h]		4,000	
		54 000	54 000
Other, unspecified costs			3 500
	Total		220 000

Table 5 – *continued*

		Sub-total (US $)	Total (US $)
Additional costs for delivery to Australian buyer			
Drums (285 x 210-l coated steel)		10 000	
Sea freight ($ 400/t x 60 t gross)		24 000	
		34 000	34 000
	Total delivered cost		254 000

Notes:

[a] All costs converted to US $ at Rand 2.80 = US $1.

[b] 2,800 plants/ha; fertilizer 75 g/plant.

[c] Weeding 1st and 2nd years, then every 2 years, together with application of herbicide.

[d] Harvesting of 400 ha carried out on a 14-16 month rotation for 10 months (200 d) of the year; target leaf production 2 ha/d.

[e] 3 teams of 12 persons cutting and bundling + 2 teams of 7 persons loading and transporting leaf to distillery.

[f] Target oil production 300 l/d (7-8 distillations) for 200 d = 60,000 l (55 t)/a.

[g] Charged at 5% for buildings, water system and tanks, 10% for boilers and most other equipment and 20% for stills.

[h] Mainly coal (200-250 t) @ $ 15/t, together with some sawmill waste wood.

Section 6

Conclusions and advice to a new producer

From the foregoing discussion it will have become evident that there are three broad categories of eucalyptus oil which a new producer might consider supplying to the market: medicinal, perfumery and industrial. There are also two basic ways in which the leaf raw material needed for production of the oil might be obtained. It may be available as 'waste' from an operation in which eucalypts are being grown for some purpose other than oil production. Alternatively, the trees may be grown specifically for oil and the leaf repeatedly harvested under a short-rotation coppice system of management.

Before undertaking a detailed technical and financial appraisal, the intending producer needs to decide upon the type(s) of oil to be produced. This will require an up-to-date assessment of the domestic, regional and international markets for eucalyptus oils. The cineole-containing, medicinal type of oil is the most important one in volume and value terms. Although present (January 1992) prices of Chinese 80% oil (with which any new producer will effectively have to compete) are the lowest they have been in recent years, this is not atypical of the fluctuations that occur in the essential oil market and they may be expected, in due course, to recover. Prospects appear to be poorest for the piperitone-containing oil from *E.dives*. Outlets for this type of oil are limited and South African production is capable of meeting existing requirements.

Someone contemplating production of eucalyptus oil in a developing country may be prompted to do so by the existence of a ready source of suitable 'waste' leaf. *E.globulus*, which yields a medicinal type of oil, and *E.citriodora*, which gives a perfumery oil, are examples of eucalypts which are utilized in this way. It is vital to the success of this type of operation that the distillery is not sited too distant from the source of leaf and that the security and continuity of supply of leaf is assured. Leaf collection and transportation costs are a major part of the overall costs of such an enterprise.

If intending producers do not wish to be dependent on others for 'waste' leaf then they may decide to grow their own, multipurpose trees. Besides having control over the supply of leaf to the distillery, such a situation means that they are not reliant on one product only for a source of income. *E.smithii* and *E.radiata* in southern Africa are examples of dual-purpose eucalypts which are grown for timber and oil production.

Rather than utilize 'waste' leaf, a prospective producer may wish to establish eucalypts specifically for oil production. Harvesting of the leaf on a 12-20 month cycle may provide a year-round supply of material for distillation. Intensive cultivation is necessary, and a combination of high biomass (leaf) production and high oil yield from the leaf is desirable. Correct species (and provenance) selection is, therefore, vitally important. Having particular (but not necessarily exclusive) regard to the species of oil-bearing eucalypts used by others – and referred to elsewhere in this bulletin – information should be sought on their suitability for local conditions. Field trials should then be established to determine growth and oil characteristics for a number of them, including different provenances, if possible. It is only by such means that a reasonable idea of oil yield on a 'per hectare per year' basis can be obtained and, therefore, the likely returns on investment. *E.smithii* and (more recently) *E.radiata* are utilized in this way in southern Africa. *E.globulus, E.citriodora* and a few other species are farmed elsewhere. The mechanical harvesting of *E.polybractea* in Australia is a rather special case.

The advantages to be gained from giving adequate attention to selection of seed for planting cannot be over-emphasized. Over-hasty planting of a species or provenance which is unsuited to local conditions, or does not produce an oil of acceptable quality or yield, will result in failure.

The distillery, too, is important and due regard should be given to its design, construction and operation if, and when, a decision is made by the intending producer to commence investment. Hard-won gains in oil yield in selection of planting stock may be lost by poorly designed equipment or bad distillation practice.

The possibility of generating extra revenue from the oil production process by making use of 'waste' by-products should not be ignored. Wood left over from the harvesting of the leaf, as well as the spent leaf from distillation, are potential sources of such income.

Oil quality (composition) should be determined by a public analyst or other competent organization before sending samples out to the trade for evaluation. For medicinal oils, the crude oil is usually rectified before sale to the consumer and it is to the rectifier that the producer should turn first for an opinion on his oil. A cineole content of 65% or higher will probably be necessary for the rectifier to consider purchasing it. In the case of *E.citriodora* oil, it should contain at least 65% citronellal.

Ennever (1967) has described the problems and pitfalls associated with marketing essential oils, either new ones or existing ones being offered by new producers. The advice he gave then is still relevant today. He observed that:

> The production of essential oils calls for the utmost patience and the closest possible supervision at all stages....General merchant houses, banks, agents, brokers, dealers, public warehouses and public analysts have all, to a greater or lesser extent, become participants in the marketing and distribution of essential oils. In theory, all these may appear unnecessary, but, in well proven practice, all have a valuable function in the process of channelling the established oils from the point of production to the point of use....Marketing, as well as producing, essential oils is likely to prove very trying for the new producer and much patience, understanding and confidence will be needed for both. Given these, the production of some essential oils can be profitable and there is abundant evidence to support this claim.

Appendices

APPENDIX 1: REFERENCES AND FURTHER READING

AMES, G.R. and MATTHEWS, W.S.A. (1968) The distillation of essential oils. *Tropical Science*, **10**: 136-148.

BOLAND, D.J., BROPHY, J.J. and HOUSE, A.P.N. (eds) (1991) *Eucalyptus Leaf Oils*. Melbourne/Sydney: Inkata Press.

BROOKER, M.I.H. and KLEINIG, D.A. (1990) *Field Guide to Eucalypts*, Vol. I and Vol. II. Melbourne/Sydney: Inkata Press.

CHIPPENDALE, G.M. (1988) *Flora of Australia*, Vol. XIX, *Myrtaceae – Eucalyptus, Angophora*. Canberra: Australian Government Publishing Service.

DENNY, E.F.K. (1991) *Field Distillation for Herbaceous Oils*. Lilydale, Tasmania: Published by the author (PO Box 42).

ENNEVER, W.A. (1967) Marketing essential oils. *Tropical Science*, **9**: 136-143.

GUENTHER, E. (1950) *The Essential Oils*, Vol. IV. London/New York/Toronto: D. Van Nostrand Co.

IFEAT (1989) *Guide Line for Classification and Labelling of Essential Oils for Transport and Handling*. Protzen, K.-D. (ed.). London: IFEAT (Kemp House, 152-160 City Road, EC1V 2NP).

PENFOLD, A.R. and WILLIS, J.L. (1961) *The Eucalypts*. London: Leonard Hill.

POORE, M.E.D. and FRIES, C. (1985) The ecological effects of eucalyptus. *FAO Forestry Paper*, No. 59. Rome: Food and Agriculture Organization of the United Nations.

ROBBINS, S.R.J. (1983) Selected markets for the essential oils of lemongrass, citronella and eucalyptus. *Report of the Tropical Products Institute* [now Natural Resources Institute], G171.

WANG HUORAN and GREEN, C.L. (1990) A review of eucalyptus oil: production, market and its prospect in the world. *World Forestry Research*, **3** (2): 71-76.

ZOBEL, B.J., VAN WYK, G. and STAHL, P. (1987) *Growing Exotic Forests*. New York: John Wiley & Sons.

APPENDIX 2: SOURCES OF EUCALYPTUS SEED

A leaflet giving details of 40 Australian private seed suppliers is available from the Australian Tree Seed Centre in Canberra:

Australian Tree Seed Centre
CSIRO Division of Forestry and Forest Products
PO Box 4008
Queen Victoria Terrace
Canberra
ACT 2600

(Tel. Canberra 281 8211
Fax Canberra 281 8266
Telex AA62751)

Many of the suppliers listed specialize in eucalypts and some offer bulk or individual tree collections from specified provenances. Catalogues and price lists are available from suppliers on request. The Centre points out that there is no tree seed certification scheme in Australia and recommend that:

> the purchaser ascertain details of the seed origins before entering into any purchase agreement. The minimum details which might be expected are the precise locality of collection including latitude and longitude co-ordinates, altitude of the collecting site, year of harvesting and number of trees sampled.

The leaflet also gives details of three State Government seed sources (Queensland, Tasmania and Western Australia). The Australian Tree Seed Centre itself supplies authenticated seed for research and tree improvement programmes.

APPENDIX 3: FACTORS INFLUENCING OIL COMPOSITION AND YIELDS

Oil composition

The composition and, hence, quality and marketability of an oil is largely determined by the species of *Eucalyptus* that is distilled. Correct choice, according to the type of oil to be produced and the suitability of the species to local conditions, is therefore vital to the success of any eucalyptus oil operation. For some eucalypts, oil composition is fairly consistent within a species, not only in terms of the particular constituents present, but also in their relative proportions. Thus, oil distilled from *E.polybractea* (in Australia) has a cineole content of about 80-85%*, while the cineole content of *E.smithii* oil (southern Africa) is in the range 70-75%; for *E.globulus* (Portugal/Spain) it is approximately 60-65%. Sometimes, however, there are intrinsic differences in oil composition within a species according to the provenance origin of the seed – that is, the particular area of collection within the natural populations. *E.camaldulensis*, for example, has a very wide distribution in Australia, but only certain northern Queensland provenances (Petford, in particular) yield an oil which makes the species attractive as a source of medicinal oil.

Consistency of composition, whether within a species or within a provenance, is only approximately true, however, when dealing with bulked samples of oil, derived from a number of trees. If individual trees are examined then more significant differences in the cineole content (of medicinal oils) become apparent. Although having disadvantages, this fact does give some scope for improvement in oil quality through élite germplasm selection. Having established at the outset that he is using the best planting stock available in terms of species and provenance, a new (or, indeed, existing) producer of eucalyptus oil should bear this in mind as a longer-term goal.

---

*Cineole values reported in this section are from NRI analyses of commercial samples of crude oil obtained from source.

In extreme cases, the oil produced from some trees in their natural habitat is completely different from that produced from others of the same species, even when the two types of tree are physically quite close to each other. This may extend to a third or fourth type of oil, all of which come from trees that are morphologically indistinguishable. The groups of trees from which these different oils come from are referred to as chemotypes or chemical variants. *E.dives* is a well-known example of a species that exhibits such behaviour, the two often-quoted types being the piperitone variant (grown and distilled commercially in South Africa) and the cineole variant (now only harvested in small areas in Australia)*.

Oil yields

Not only quality (composition) but quantity (yield) of oil is dependent on the species of *Eucalyptus* that is distilled. As with composition, it is possible to make certain generalizations (for example, that *E.radiata* is a high oil-yielding eucalypt) to which exceptions are increasingly found as one proceeds from the species to provenance level and then to individual trees. A breeding programme, therefore, can pay dividends in terms of productivity as well as quality improvement by identifying high-yielding provenances or trees.

When evaluating and comparing data on oil yields, it is essential that a fair comparison be made. Leaf must be compared with leaf, and not leaf plus twigs, and the moisture content must be consistent or known so that results can be expressed on a moisture-free basis. Only when oil yields are determined in the laboratory are these variables likely to be fixed or known. In commercial practice, the leaf that is distilled has woody material present that contains no oil and the proportion of wood in the charge can only be guessed at. The moisture content of the leaf is also unknown and variable. Even oil yields reported in the scientific literature are sometimes deficient in not stating the basis for their calculation. Evaluation of reported yield data is therefore subject to these uncertainties and for this reason, and others discussed below, although some figures that have been provided by commercial producers have been cited earlier, no attempt is made in this bulletin to meticulously list oil yields for individual eucalypts. Ranges of values, too, can be equally unhelpful.

Variability due to differences in leaf type

In addition to intrinsic, genetic sources of variation, there are other factors that may affect the quality and quantity of oil that is distilled from a particular group of trees. Firstly, the type of leaf that is distilled may have some effect. Eucalypts are characterized by having different types of leaf present on the tree at different stages of their development. The most distinct types are the juvenile and adult leaves. The former are often rounder and more glaucous than the latter, with sessile, opposite pairs of leaves on the branchlet which become petiolate and alternate in the adult form. Sometimes the progression from juvenile to adult leaves is apparent on the same tree and sometimes it is not. These types of leaf, which are different morphologically, are not to be confused with those that are of different physiological age. Both juvenile and adult leaves may be young (at and near the tips of the branchlets) or old.

Although yields of oil and (to a lesser extent) composition may be different according to the type of leaf distilled and its age, it is not always possible to predict which is the better. Individual producers of eucalyptus oil may also have different perceptions of which is best†. In practice, even if differences are known to exist they may be relatively small and circumstances or needs may not make it possible to discriminate between them in the harvesting/collection process.

*These two variants are still sometimes referred to using the older terminology: '*E.dives* (Type)' for the piperitone variant and '*E.dives* (Var. C)' for the cineole variant. The terms 'Type', 'Variety A', 'Variety B', 'Variety C', etc., were introduced in the 1920s and applied chronologically within a species as each distinct type of oil was enumerated.

†Of four producers interviewed in Portugal and Spain during the fieldwork for this bulletin, two stated that juvenile leaves and shoots collected from pruning operations of *E.globulus* yielded more oil (with lower cineole content) than adult leaf from felled trees. The other two producers affirmed that the opposite was true.

Environmental effects

Another source of variability is that caused by environmental factors. Climate might be expected to have some effect, although seasonal variation due to flushes of growth at certain times of the year may serve to confuse the issue. Evidence based on large-scale distillation may also be unreliable if, for example, apparent differences in oil yield are not recognized as being caused by differences in moisture content of the feedstock leaf at different times of year, or differences in oil recovery caused by variable still performance. In Portugal and Spain there is some consensus that *E.globulus* gives higher yields in the spring and autumn months than in the summer ones. In southern Africa, coppiced *E.smithii* and *E.dives* are said by some producers to afford higher yields in the wetter, warmer season than the dry season. Claims are also made that a combination of sun and rain is conducive to high yields, but that within a week or two of overcast weather yields decline. Producers of long standing in Australia admit to being unable to see any clear correlation between oil yields and season from one year to another, even with the benefit of many years' data.

The dependence, if any, of oil yield on soil type is equally uncertain and the views of some producers in Portugal and Spain that sandy soils produce higher yields than clay ones is contradicted by others who claim that the reverse is true.

One may conclude that while there are many factors that influence oil yields to a greater or lesser extent, the ways in which these combine are, as yet, only poorly understood. Furthermore, the timing of harvesting operations or the choice of site for planting may be necessarily determined by reasons other than consideration of possible advantages to be gained in yield terms.

APPENDIX 4: QUALITY CRITERIA AND SPECIFICATIONS

Medicinal oils

The cineole content is of prime importance in the medicinal type of eucalyptus oils. Commercial producers usually offer their own specifications for the oil, but both international and national standards exist. The producers may or may not choose to state that their product complies with the standards.

The International Organization for Standardization (ISO) is a world-wide federation of national standards institutes and has issued three standards covering different types of cineole-containing eucalyptus oil. It should be emphasized that the standards specify certain characteristics of the oils with a view to facilitating the assessment of their quality; they cannot adequately define those properties which involve a buyer's subjective judgement, such as odour. In addition to laying down a minimum cineole content (at least 70%), values, or ranges of values, of a number of physico-chemical properties are stipulated. The main requirements are shown in Table 4A. ISO 770-1980 and ISO 4732-1983 refer specifically to oil derived from *E.globulus*, while ISO 3065-1974 states simply that the oil as defined is from 'appropriate species of *Eucalyptus* of Australian origin'. The ISO standards apply to rectified rather than to crude oils.

The ISO standards may be formally approved by member bodies of individual countries and go on to be adopted as national standards. This is particularly true in Europe. The French standard for essential oil of *E.globulus*, for example, is identical to ISO 770-1980. The British Standard Specification for 'Oil of eucalyptus', BS 2999/53:1975, was very similar to ISO 770-1980 and has been superseded by adoption of the latter.

In the US, which is not a member of the ISO, the Food Chemicals Codex (1981) has laid down specifications for the use of eucalyptus oil in foods (as a flavouring agent). The main requirements are shown in Table 4B. Minimum cineole content is 70%. In addition to the requirements indicated, the oil must pass tests that demonstrate nil (or low) amounts of heavy metals and phellandrene. The specification refers to the oil as that obtained from *E. globulus* and 'other species of *Eucalyptus*'.

Table 4A Physico-chemical requirements of the International Organization for Standardization specifications for cineole-containing eucalyptus oils

	Cineole content (% m/m)	Relative density (20/20°C)	Refractive index (20°C)	Optical rotation (20°C)	Solubility in ethanol (70% v/v, 20°C)
ISO 770-1980 'Oil of *Eucalyptus globulus*'	min. 70	0.906-0.925	1.4590-1.4670	0° to +10°	soluble in 5 volumes
ISO 4732-1983 'Rectified oil of *Eucalyptus globulus* Labillardiere, Portugal':					
70/75% cineole	70.0-74.9	0.907-0.917	1.4600-1.4640	+3° to +8°	soluble in 8 volumes
75/80% cineole	75.0-79.9	0.910-0.919	1.4590-1.4630	+2° to +6°	soluble in 5 volumes
80/85% cineole	80.0-85.0	0.913-0.920	1.4590-1.4620	+2° to +4°	soluble in 3 volumes
ISO 3065-1974 'Oil of Australian eucalyptus, 80 to 85% cineole content'	80-85	0.918-0.928	1.4580-1.4650	−2° to +2°	soluble in 3 volumes

Table 4B Physico-chemical requirements of the Food Chemicals Codex (1981) specification for 'eucalyptus oil'

Cineole content (%)	Specific gravity	Refractive index (20°C)	Solubility in alcohol (70%)
Min. 70.0	0.905-0.925	1.458-1.470	soluble in 5 volumes

Although conveniently termed medicinal eucalyptus oils, the above standards make no reference to the use to which the oils are put. For strictly medicinal purposes the oils must comply with national or international pharmacopoeiae. Compliance with the British Pharmacopoeia (BP) specification is often cited by producers elsewhere in the world and its main requirements are indicated in Table 4C. The BP describes eucalyptus oil as being obtained from 'various species of eucalypts that are rich in cineole', although it then goes on to say that 'the species used are *Eucalyptus globulus* Labill., *E.fruticetorum* F. von Muell. (*E.polybractea* R.T.Baker) and *E.smithii* R.T.Baker'. In addition to stating a minimum cineole content of 70% and ranges within which certain physico-chemical properties must fall, the specification describes chemical tests that are to be carried out. These are intended to ensure that levels of aldehydes and phellandrene which might be present are below certain limits. These additional requirements distinguish the BP specification from ISO 770-1980 with which it is otherwise very similar. Crude *E.smithii* oil suffers from the disadvantage of containing 1% or 2% of isovaleraldehyde and this adversely affects its odour. The aldehyde content must be reduced by rectification if the oil is to meet BP standards.

The requirements of the European Pharmacopoeia (Volume III, 1975) for 'Eucalypti aetheroleum', eucalyptus oil, are identical to those of the BP. Other national pharmacopoeiae that lay down standards for eucalyptus oil are those of Argentina, Austria, Belgium, Czechoslovakia, Egypt, France, Germany, Hungary, India, Italy, Japan, Netherlands, the People's Republic of China, Poland, Portugal, Rumania, Spain, Switzerland and the US. These may have slightly

Table 4C Physico-chemical requirements of the British Pharmacopoeia (1988) specification for 'eucalyptus oil'

Cineole content (% m/m)	Relative density (20/20°C)	Refractive index (20°C)	Optical rotation (20°C)	Solubility in ethanol (70% v/v, 20°C)
Min. 70.0	0.906-0.925	1.458-1.470	0° to +10°	soluble in 5 volumes

Table 4D Physical property requirements of the British Pharmaceutical Codex (1973) specification for 'cineole' (eucalyptol)

Freezing point (°C)	Weight per ml (g, 20°C)	Refractive index (20°C)	Optical rotation (20°C)	Solubility in alcohol (70%, 20°C)
Min. 0°	0.922-0.924	1.456-1.460	−1° to +1°	soluble in 2 parts

different requirements to the BP. The US Pharmacopoeia/National Formulary (1985), for example, requires a minimum of 70% eucalyptol [cineole] but, additionally, has a limit of 0.004% on heavy metals. It makes no reference to optical rotation or aldehyde content. The Pharmacopoeia of India demands a minimum cineole content of 60% rather than 70%.

The British Pharmaceutical Codex (BPC), 1973, set down standard specifications for eucalyptol (cineole) which are still referred to today. The main requirements of the standard are shown in Table 4D. The purity corresponds to approximately 98%+.

Methods of determination of the various physico-chemical properties are described either in separate standards (such as ISO 1202-1981 for determination of cineole content) or in appendices attached to the pharmacopoeia. An established producer may carry out one or more, or all, of the analyses himself, particularly if he is involved in product formulation or blending, or have them carried out on his behalf by another body – a consultancy service or similar. Alternatively, if a primary producer is selling on to a larger one, and once the quality of the oil from the former has been established, the buyer may be content, or even prefer, to perform the necessary checks on quality himself.

For a new or prospective producer, or one who is contemplating eucalyptus oil production, the need to determine the best source of leaf for his operation will necessitate more extensive analytical work, of a research nature. Apart from biomass and oil yield data, cineole content will be of primary importance and, if a large number of samples are to be analysed, procedures based on gas chromatography are more rapid than the published methods involving use of *o*-cresol (e.g. ISO 1202-1981). Gas chromatography is a widely used analytical tool, capable of high accuracy, but one that may not be readily available in all developing countries. In such circumstances, outside assistance from a body such as the Natural Resources Institute, which has experience in this area going back many years, will be helpful.

Perfumery oils

Of the perfumery oils, published standards exist only for *Eucalyptus citriodora* oil. The main features of the international standard (ISO 3044-1974) are shown in Table 4E. Citronellal content is important and the oil should contain at least 70% carbonyl compounds calculated as citronellal. The British Standard Specification for 'Oil of *Eucalyptus citriodora*' (BS 2999/23:1972) has been superseded by adoption of the ISO standard. The French standard, NF T 75-247, is identical with ISO 3044-1974. The Indian standard, IS:9257-1979, is similar and has the same minimum citronellal requirement (70%).

Table 4E Physico-chemical requirements of the International Organization for Standardization specification for 'oil of *Eucalyptus citriodora*' (ISO 3044-1974)

Carbonyl compounds as citronellal (% m/m)	Relative density (20/20°C)	Refractive index (20°C)	Optical rotation (20°C)	Solubility in ethanol (80% v/v, 20°C)
Min. 70	0.858-0.877	1.4500-1.4590	−2° to +4°	soluble in 2 volumes

Table 4F Physico-chemical requirements of the Essential Oil Association (US) specification for '*Eucalyptus citriodora*' (EOA 130)

Aldehyde content as citronellal (%)	Specific gravity (25/25°C)	Refractive index (20°C)	Optical rotation	Solubility in alcohol (70%)
65-85	0.860-0.875	1.4510-1.4640	−0.5° to +2.0°	soluble in 3 volumes

Note: The Fragrance Manufacturers' Association of the US is likely to replace this standard during 1992.

The Essential Oil Association (EOA) (now subsumed by the Fragrance Manufacturers' Association (FMA) of the US) has a standard for *Eucalyptus citriodora* oil (EOA 130) which states that the aldehyde content, calculated as citronellal, should be in the range 65-85%. The main requirements of the standard are shown in Table 4F. A new FMA standard is in preparation.

Other perfumery oils, such as that from *E.staigeriana*, are traded on the basis of sample assessment by the buyer.

Industrial oils

No published standards exist for oil from *E.dives* (piperitone variant) and sales, and the price obtained, are a matter for agreement between buyer and seller. If the oil is being utilized as a source of piperitone then the content of this in the oil should be high enough to make it attractive. This is usually expected to be about 40% or more.

Oil from *E.* sp. non. aff. *campanulata* is sufficiently rich in E-methyl cinnamate that only the latter enters trade after isolation from the oil. Standards for the oil are therefore unnecessary.

APPENDIX 5: PACKAGING AND LABELLING REQUIREMENTS

It is important for new producers of eucalyptus oil to appreciate that increasing attention is being given by importing countries to packaging and labelling of 'dangerous' goods, including essential oils. This is a response to world-wide concern for adequate safety measures to ensure the safe handling and transportation of materials that are actually or potentially dangerous substances. The main risk associated with essential oils is their flammability.

Within the EC, a 1979 Council Directive (79/831/EEC), which has now become mandatory, details 'laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances'. The Directive requires every package to show the name and origin of the substance, the danger symbol (for example, a flame in a red diamond indicating a flammable liquid) and standard phrases indicating special risks (e.g. 'flammable') and safety advice. Minimum size and placement of labels are also specified. When dangerous 'substances' are transported they become 'goods' and when conveyed from one country to another they are subject to international regulations according to the means of conveyance. In the case of shipment by sea, regulations of the International Maritime Dangerous Goods (IMDG) code have to be observed. As with dangerous substances, dangerous goods have to be marked with warning labels.

Oils with a flash point of below 61°C, which include the cineole-rich eucalyptus oils, have to be shipped under a general United Nations (UN) number which defines the type of package to be used. This number has to be quoted in shipping documents. For cineole oils UN No. 1993 (flammable liquids, non-toxic, not otherwise specified) is applicable, although when rectified they may be shipped using UN No. 1197 (extracts, flavouring, liquid). Within this designation cineole oils have to be shipped in containers meeting the specification of Packing Group III. When purchasing drums from the manufacturer the producer should, therefore, specify the appropriate UN number. *E.citriodora* oil has a flash point greater than 61°C and is, therefore, not regarded as flammable.

It is the producers who are responsible for proper classification and labelling of goods. Since within the EC, for example, importers are considered to be the producers (since they supply the goods to the market), it may be tempting for producers at origin to feel that they are absolved from taking the measures indicated above when they are exporting to Europe or elsewhere. They should recognize, however, that it is in their own interests, if they wish to secure the confidence of their buyers overseas, to strive to meet the appropriate packaging requirements.

More detailed information may be obtained from national transportation authorities, trade associations or from prospective importers. The International Federation of Essential Oils and Aroma Trades (IFEAT) has issued a 'Guide Line for Classification and Labelling of Essential Oils for Transport and Handling' (*see* Appendix 1).

APPENDIX 6: NAMES AND ADDRESSES OF EUCALYPTUS OIL PROCESSORS

The following list gives the names of some companies able to rectify eucalyptus oil and who may be willing to consider making purchases of oil from a new producer. The list is not exhaustive and inclusion in the list does not imply that NRI has any knowledge of the financial standing of the company.

Australia
GR Davis Pty Ltd
21 Rosemead Road
Hornsby
NSW 2077

Brazil
Dierberger Oleos Essenciais SA
Av. Industrial 827
Caixa Postal 03
17.340 Barra Bonita, SP

Portugal
Socidestilda
Quinta da Galega
Paio Pires
2840 Seixal
Apartado 2721
1118 Lisboa

SONOL
Rua Lucinda Simoes, 1-1°
1900 Lisboa

Spain
Destilaciones Bordas Chinchurreta SA
Carretera de Carmona, 30
Apartado 11
41008 Sevilla

South Africa
Clive Teubes Pty Ltd
PO Box 4919
75 Wakis Avenue
Strydom Park
Randburg 2125

APPENDIX 7: STATISTICAL TABLES

Table 7A Eucalyptus oil: end-of-year prices for different types and grades, c.i.f. European main port, 1987-91

$/kg

	1987	1988	1989	1990	1991
Eucalyptol	10.00	14.85	10.00	10.00	9.50
Spanish/Portuguese 80/85%	8.25	10.50	9.00	10.50	9.25
Spanish/Portuguese 70/75%	7.55	9.50	8.40	8.75	8.15
Chinese 80%	7.70	9.50	5.80	5.70	5.10
Chinese *E.citriodora*	5.00	3.75	4.30	4.20	4.35

Source: London dealer.

Table 7B Eucalyptus oil: exports from Portugal, 1983-90

tonnes

	1983	1984	1985	1986	1987	1988	1989	1990
Total	257	369	352	268	282	296	297	236
70-75% cineole								
Total	170	187	202	210	223	104	127	59
of which to:								
UK	51	42	46	49	33	24	50	30
France	25	22	16	10	25	22	19	15
Germany	28	17	25	17	11	16	2	2
Belgium/Luxembourg	7	15	–	26	60	–	–	–
US	41	41	54	35	13	10	11	6
Soviet Union (former)*	–	–	17	–	14	25	37	–
Other countries	18	50	44	73	67	7	8	6
75-80% cineole								
Total	6	19	19	9	8	7	6	6
80-85% cineole								
Total	79	149	112	41	26	100	69	49
of which to:								
UK	15	9	7	12	8	6	16	19
France	9	28	14	19	7	8	10	8
Germany	42	67	66	6	7	27	9	6
Spain	–	–	–	–	1	18	23	10
Other countries	13	45	25	4	3	41	11	6
85%+ cineole								
Total	2	14	19	8	25	85	95	122
of which to:								
UK	–	–	1	–	5	24	15	19
France	–	2	3	1	5	25	15	37
Germany	–	11	15	6	13	21	9	10
Spain	–	–	–	–	–	–	23	14
Soviet Union (former)*	–	–	–	–	–	–	23	35
Other countries	2	1	–	1	2	15	10	7

Source: *Estatisticas do Comercio Externo.*

*Statistics cannot be broken down for individual countries which made up the former Soviet Union.

Table 7C Eucalyptus oil: exports from Spain, 1984-90

tonnes

	1984	1985	1986	1987	1988	1989	1990
Total	298	333	260	237	222	224	182
of which to:							
UK	39	13	2	–	3	1	–
France	36	54	26	35	34	29	16
Germany	30	39	59	46	25	23	53
Netherlands	32	28	26	31	28	38	25
Belgium	11	26	12	12	13	20	9
Italy	14	11	14	9	10	13	7
Switzerland	34	43	50	24	11	18	16
Denmark	1	4	5	4	3	7	6
Hong Kong	–	9	1	–	–	–	–
Singapore	7	18	19	20	33	23	9
Japan	14	18	19	24	11	27	10
Brazil	–	–	5	–	–	–	3
US	22	43	7	20	9	13	4
Soviet Union (former)*	–	–	–	–	33	–	–
Other countries	58	27	15	12	9	12	24

Source: *Estadistica del Comercio Exterior de España.*

Table 7D Eucalyptus oil: exports from Brazil, 1983-90

tonnes

	1983	1984	1985	1986	1987	1988	1989	1990
Total	233	339	164	119	276	285	145	158
of which to:								
UK	11	24	8	–	21	8	...	–
France	49	105	61	25	47	104	...	–
Germany	21	74	26	27	25	37	...	11
Spain	27	52	32	36	46	43	...	31
Switzerland	23	21	17	15	26	16	...	27
US	28	8	–	7	50	22	...	12
Mexico	67	50	2	5	37	46	...	37
Guatemala	–	–	–	–	5	–	...	30
Argentina	1	–	2	–	10	–	...	–
Other countries	6	5	16	4	9	9	...	10

Source: *Comercio Exterior.*

Table 7E Eucalyptus oil: exports from Australia, 1982/83-1989/90

tonnes

	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89	1989/90
Total	72	61	70	41	61	106	128[a]	71[b]
of which to:								
UK	9	–	3	–	2	16	12	1
Germany	8	4	5	3	5	11	6	3
Hong Kong	11	12	15	11	15	14	23	16
Singapore	3	8	2	2	2	3	2	1
Japan	2	–	2	4	2	7	3	–
Malaysia	12	11	10	5	15	10	11	7
Thailand	13	14	11	10	15	1	12	14
New Zealand	–	3	2	5	4	3	3	3
US	12	2	10	1	–	38	48	21
Other countries	2	7	10	1	1	3	8	5

Source: Australian Bureau of Statistics.

Notes: [a] Includes 16 tonnes of re-exports.
[b] Includes 2 tonnes of re-exports.

*Statistics cannot be broken down for individual countries which made up the former Soviet Union.

Table 7F Eucalyptus oil: imports into the UK, 1983-90

tonnes

	1983	1984	1985	1986	1987	1988	1989	1990
Total	372	320	224	317	312	362	288	433
of which from:								
China, People's Rep. of	200	200	76	159	169	250	126	328
Portugal	67	49	54	71	58	39	68	56
Spain	9	23	24	16	2	7	4	1
South Africa	...	...	...	...	...	8	13	21
Hong Kong	33	9	25	33	37	19	38	1
Other countries	63	39	45	38	46	39	39	26

Source: *UK Imports.*

Table 7G Eucalyptus oil: imports into France, 1983-90

tonnes

	1983	1984	1985	1986	1987	1988	1989	1990
Total	514	709	464	481	810	652	729	866
of which from:								
China, People's Rep. of	330	428	221	339	593	340	519	600
Portugal	31	53	30	30	38	40	41	25
Spain	26	29	59	29	30	36	33	21
Brazil	46	106	73	38	58	105	33	...
South Africa	75	67	72	32	78	100	62	105
Other countries	6	26	9	13	13	31	41	115

Sources: *Statistiques du Commerce Interieur de la France; Eurostat* (1990).

Table 7H Eucalyptus oil: imports into Germany, 1983-90

tonnes

	1983	1984	1985	1986	1987	1988	1989	1990
Total	285	363	338	374	440	463	421	541
of which from:								
China, People's Rep. of	140	158	158	206	316	221	293	409
Portugal	73	102	107	33	30	56	26	12
Spain	18	34	40	67	49	33	28	52
South Africa	13	–	–	17	–	96	23	–
Other countries	41	69	33	51	45	57	51	68

Sources: *Aussenhandel nach Waren und Landern; Eurostat* (1990).

Table 7I Eucalyptus oil: imports into Spain, 1984-90

tonnes

	1984	1985	1986	1987	1988	1989	1990
Total	104	81	213	248	238	342	529
of which from:							
China, People's Rep. of	–	1	50	141	108	211	373
UK	...	1	1	9	4	1	1
France	...	–	3	5	3	–	10
Portugal	–	–	10	32	24	30	18
Brazil	61	40	58	29	44	12	14
Uruguay	...	3	5	–	2	3	–
South Africa	41	30	71	16	47	48	59
India	–	–	–	–	–	36	54
Other countries	2	6	15	16	6	1	–

Sources: *Estadistica del Comercio Exterior de España; Eurostat* (1990).

Table 7J Eucalyptus oil: imports into the European Community, 1983-90

tonnes

	1983	1984	1985	1986	1987	1988	1989	1990
Total	1309	1516	1194	1568	2025	1939	1987	2646
of which from:								
China, People's Rep. of	732	807	460	771	1275	891	1139	1790
Portugal	186	229	204	156	172	164	171	117
Spain	104	132	182	172	146	131	144	175
Brazil	79	179	116	...	...	...	...	...
South Africa	88	68	80	...	...	...	146	164
Other countries	120	101	152	469	432	753	387	400

Sources: *NIMEXE; Eurostat* (1989, 1990).

Table 7K Eucalyptus oil: imports into the United States, 1983-90

tonnes

	1983	1984	1985	1986	1987	1988	1989	1990
Total	304	384	226	293	378	312	326	378
of which from:								
China, People's Rep. of	186	225	59	217	198	210	205	268
UK	15	16	5	7	17	14	15	14
Portugal	37	68	74	27	28	7	22	7
Spain	19	16	48	7	20	9	13	7
Brazil	26	43	–	7	31	14	11	26
South Africa	–	5	10	5	5	–	13	–
Hong Kong	–	2	3	4	65	22	10	21
Australia	11	3	13	1	–	23	21	1
Other countries	10	6	14	18	14	13	16	34

Source: *Foreign Agricultural Circular*, US Department of Agriculture.

Table 7L Eucalyptus oil: imports into Australia, 1982/83-1989/90[a]

tonnes

	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89	1989/90
Total	160	117	204	124	176	104+	128+	135+
of which from:								
China, People's Rep. of	41	3	–	6	42	?	?	?
Swaziland/South Africa	119	114	202	112	134	104	128	135
Other countries	–	–	2	6	–	?	?	?

Source: Australian Bureau of Statistics.

Note: [a] For 1987/88, 1988/89 and 1989/90, classification is defined as 'essential oils (excl. citrus fruits, geranium, jasmin, lavender or lavandin, mints and vetiver)'; figures for Swaziland/South Africa are known to refer to eucalyptus oil; figures for the People's Republic of China and other countries remain in doubt and are indicated by '?'

Printed by Hobbs the Printers of Southampton

The Bulletin series presents the results of research and practical scientific work carried out by the Natural Resources Institute. It covers a wide spectrum of topics relevant to development issues ranging from land use assessment, through agricultural production and protection, to storage and processing.

Each Bulletin presents a detailed synthesis of the results and conclusions within one specialized area, and will be of particular relevance to colleagues within that field and others working on sustainable resource management in developing countries.

A combination of desirable features – adaptability, high growth rate and multipurpose use – has made *Eucalyptus* one of the most widely planted genera in the world. **Eucalyptus Oils: A Review of Production and Markets** provides information on the technical and economic aspects of the production of steam-volatile oils from eucalyptus leaf, including the harvesting of the leaf and its distillation. It also reviews recent trends in the world market for eucalyptus oils.

The book is intended for prospective new producers of eucalyptus oils as well as organizations and individuals appraising projects involving their production. It is particularly intended for those in developing countries.