Australian Government
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Flowering Ecology of Honey-Producing Flora in South-East Australia

RIRDC Pub. No. 08/098

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Australian Government
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Flowering Ecology of Honey-Producing Flora in South-East Australia

by Melanie J Birtchnell and Maria Gibson

July 2008

RIRDC Publication No. 08/098
RIRDC Project No. UD-3A

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ISBN 1 74151 686 2
ISSN 1440-6845
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Published in July 2008 by Union Offset, Canberra.

Foreword

Flowering ecology, which encompasses flowering patterns and the production of floral resources (i.e. nectar and pollen), is core to the survival of flora *and* fauna as well as many industries, including the Australian beekeeping industry. In particular, an understanding of long-term flowering patterns is critical to enable more effective resource management and to recognise conditions which trigger certain events, some of which can be devastating to honey production. Despite this, there is little research into long-term flowering ecology.

This report presents a detailed dissertation on flowering ecology of Australian melliferous (honey-producing) flora, as observed by highly experienced commercial apiarists. The research is the most detailed and long-term study of flowering ecology in melliferous species. Furthermore, it plays a vital role in recording anecdotal information, which often is not recorded formally by apiarists and, therefore, can be lost following their death.

The key findings of the report were; (i) frequency, intensity, timing and duration of flowering varied between melliferous species and, often, between sites used for honey production; (ii) flowering patterns and nectar production displayed short-term variation, largely influenced by environmental conditions; (iii) the relationship between flowering intensity and nectar production is not linear and, often, is unreliable; (iv) long-term decreases have affected flowering intensity and nectar production and may relate to climate change; (v) Bogong Moths (*Agrotis infusa*) and logging impact on nectar and/or honey production; (vi) reports of 'drunken' honeybees, high honeybee mortality, reduced honey yields and other impacts were related to nectar fermentation; and (vii) inter- and intra-specific variation in pollen quality occurs; (viii) intra-specific variation may be due to site specific differences; (ix) the bulk of pollen comes from only a few species; (x) the bulk of pollen comes from native species; (xi) bees have favourite pollen sources; (xii) 'toxic' pollen occurs which has immediate affects on bee and hive health; (xiii) beekeepers judge pollen quality holistically; (xiv) there are several important indicators for pollen quality; (xv) pollen quality can be poor in terms of nutrition but not detrimental with time if there is an abundant supply.

This project was funded from industry revenue which is matched by funds provided by the Australian Government.

This report, an addition to RIRDC's diverse range of over 1 800 research publications, forms part of our Honeybee R&D program, which aims to improve the productivity and profitability of the Australian beekeeping industry.

Most of our publications are available for viewing, downloading or purchasing online through our website <www.rirdc.gov.au>.

Peter O'Brien
Managing Director
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Acknowledgements

The authors are sincerely grateful to the apiarists who generously donated their time and expertise to complete interviews and surveys used as the basis of this research. Their knowledge of long-term flowering ecology of species used for honey production cannot be valued highly enough and we are honoured to have been privy to their insights. The ongoing support and enthusiasm for our research by apiarists also is gratefully acknowedged.

Thanks to Steve Asirvadem, Mahli Asirvadem, Rob Manning and apiarists Ray and Mark Hall, Colin Fleay, Bronwyn Shalders, Max Kane, Len Green, Ken Gell and Bob McDonald for assistance with fieldwork.

Dr David Guest and Dr Peter Beech provided methodological advice regarding nectar collection whilst Dr Rob Manning and Dr Michael Hornitzky provided advice on mycological matters. Dr Doug Somerville kindly provided direction and improvement to the pollen quality and nutrition surveys used for this research. Reporting was improved by assistance from Dr David Phelan, Dr Amanda Mercuri and Leanne Forster. Tim Sanders, Maria Amodio and Linda Moon provided invaluable technical assistance. Kerry Weeks deserves much thanks for her efforts in identifying the yeasts isolated from nectar.

Finally, the authors extend their thanks to the Honeybee Research and Development Committee and, more generally, the Rural Industries and Development Corporation (RIRDC) for their enthusiasm and financial support, both of which facilitated the continuation of this research. Funding also was provided generously by the Holsworth Wildlife Research Fund.

Abbreviations

% v/v percent volume per volume: describes the volume of the solute in mL per 100mL of the resulting solution (e.g. 20% v/v ethanol solution contains 20mL ethanol per 100 mL total volume).

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Executive Summary

What the report is about

This report examines the flowering ecology (flowering patterns and the production of floral resources, i.e. nectar and pollen) of important Australian melliferous (honey-producing) flora. Aspects of flowering ecology that can have a negative impact on invertebrates, including honeybees, were also investigated. The research was based on information sourced by highly experienced, commercial beekeepers and, so, provides a valuable written record of long-term observations relating to flowering ecology which otherwise may be lost following the death of beekeepers. Results of this study are of far-reaching importance, not only to the beekeeping industry, but to land managers, the general public and the future of Australian flora and fauna.

This research provides a valuable written record of long-term observations relating to flowering ecology. Results of this study are of far-reaching importance, not only to the beekeeping industry, but to land managers, the general public and the future of Australian flora and fauna.

Background

An understanding of flowering ecology is vital for many reasons, including implementing appropriate management practices which ensure the sustainability and growth of natural resources and industries like the beekeeping industry. Despite the importance of such studies, very little research has considered flowering ecology in Australian flora. Furthermore, research often was based on short-term data; long-term data are widely acknowledged as being necessary in such research in order to determine 'real' flowering patterns. Thus, studies of flowering ecology which use long-term data are vital.

Aims

The aims of this project were to: provide a written, accessible record of anecdotal information sourced from highly experienced apiarists; determine long-term flowering patterns of south-east Australian melliferous flora; investigate within Australian melliferous species the occurrence of nectar toxicity to honeybees; develop our understanding of pollen-related bee nutrition; and determine the effects of Bogong Moths and logging on nectar production in Australian melliferous flora.

Methods used

Data relating to flowering patterns, nectar production and the effects of Bogong Moths and logging on nectar production, as well as preliminary information relating to nectar toxicity to honeybees, were obtained by conducting face-to-face interviews with 66 Australian apiarists. Each apiarist had operated commercially for a minimum of 30 years and had managed a minimum of 350 hives during their beekeeping experience. The same apiarists were asked to complete surveys relating to their knowledge of pollen-related bee nutrition; 30 apiarists returned completed surveys whilst a further eight were returned due to an apiarists' ill health or death.

Subsequent investigation of nectar toxicity to bees involved collection of nectar from the floral cups of four melliferous species, mycological analysis to determine the presence/absence of yeasts and gas chromatography to determine the presence/absence of alcohol.

Results

The first section of the report presents information relating to flowering patterns and nectar production. Flowering frequency, period (timing and duration of flowering) and intensity are discussed, as are the quantity and frequency of nectar flows for each species. Factors which apiarists consider influence flowering patterns and nectar production are included. The most commonly cited factors were climatic factors, particularly rainfall. Spatial variation in flowering period within a species was observed, commonly northern areas of a species range flowered earlier than the southern areas. Bogong Moths and logging both were reported to affect nectar/honey yields. The relationship

between flowering and nectar production is not reliable and is not necessarily linear, therefore tools used by apiarists to successfully predict flowering and nectar production are presented. Flowering and nectar were affected by short-term perturbations, however, this study revealed that long-term decreases in flowering intensity and nectar yield were observed.

Section 2 of this report describes findings of investigations into nectar 'toxicity' to honeybees. Based on information provided by apiarists, we were able to show that 'toxicity' of nectar in the floral cup is caused by fermentation of yeasts. Furthermore, we explain how fermentation could cause those symptoms observed by apiarists of honeybees and hives. Species known to elicit such symptoms are provided.

The third section of the report describes aspects of pollen related nutrition. It was found that only half the beekeepers could recognise pollen detrimental to bee and hive health. Tools used by them to do this are presented. Inter- and intra-specific variation in pollen quality was noted. Intra-specific variation probably was due to site specific differences. The bulk of pollen comes from only a few species. Many of the important species providing pollen are native, which is quite different to what occurs overseas where most species are agricultural in nature (i.e. crops or weeds). This has implications for management. Bees were observed to have favourite pollen sources. 'Toxic' pollen was found to occur and had immediate affects on bee and hive health. It is explained that beekeepers judge pollen quality holistically so discrepancies can occur with chemical analyses. Several important indicators for pollen quality are documented and should aid beekeepers in management of their bees and hives. Finally, it is argued that pollen quality can be poor in terms of nutrition but not detrimental with time if there is an abundant supply.

Implications for relevant stakeholders

We present important information which has contributed greatly to the database of Australian melliferous resources, which is of value to the beekeeping industry, science and the community. This information can be used to identify sites supporting key honey-producing species and so aid in maintaining beekeeper access to important resources. Land management, such as development and implementation of Regional Forest Agreements (RFAs), also can be guided by our research resulting in improved conservation practices. Furthermore, the study provides an accessible record of alternative nectar sources in the event of a failed flowering episode. This will be of most value to new apiarists and the wider community.

Our investigation into nectar toxicity to honeybees has shown links between flowering, climatic conditions and impacts on honeybees/yield; whilst further research is paramount, beekeepers will be able to use the information provided here to better manage their use of floral resources. Certainly, if climate change theories are correct, the importance of understanding how climate (particularly rainfall) impacts on honeybees and honey production is critical.

This important research has contributed greatly to the database of Australian melliferous resources, and is of value to the beekeeping industry, science and the community.

Factors presented here which affect flowering and nectar production and pollen quality will enable predictive resource management by beekeepers and other land managers. This potential is increased by the publication of tools used by apiarists to predict floral resource availability. For example, zoologists can use this information to better understand faunal movement through the landscape and seed collectors will be able to improve their time collection efforts.

This research represents a strengthened relationship between scientists and the beekeeping industry, which ultimately provided the basis for this report. It is anticipated that faithful reporting of apiarists' observations and experience, such as that reported here, will strengthen this relationship further. Indeed, information provided by beekeepers provides vital baseline information which can be used by scientists for a raft of applications, the outcomes of which benefit the beekeeping industry.

Recommendations

Beekeepers can use the information here to increase productivity and reduce costs associated with honey production, namely transporting hives between sites. In addition, beekeepers will be able to predict the honey potential of flowering episodes *prior* to the onset of flowering. Also, they will be better equipped to judge the likelihood of being devastated by nectar toxicity and understand the factors which trigger such events. Our pollen quality surveys indicated that apiarists could benefit from learning which pollen flora were detrimental to hive health, which would further increase productivity.

We have highlighted many areas which require ongoing scientific research. Notably, these include: the potential impacts of climate change on flowering, nectar and honey production and pollen quality; how climate change will affect insect population dynamics; factors triggering nectar fermentation and pollen quality.

Introduction

Australia has a rich resource of melliferous plants. Understanding the floral ecology of these plants is vital for implementation of the correct or best management practices of their habitats. Understanding floral ecology and having best management practices is vital for the sustainability and growth of the honey industry. It aids understanding of potential honey production area, tonnage and, therefore, value; it aids prediction of resource availability, facilitates successful planning by apiarists for efficacious hive placements and capacity; and it provides important base-line information to guide habitat and biodiversity management. Many papers consider flowering patterns (e.g. Law et al. 2000) but most concern phenology of commercial crops (e.g. Clover, Soya Beans, Fava Beans, Wheat, Rape, Medics) while comparatively few consider native vegetation. Certainly commercial crops are important to the honey industry, but forest trees are the main honey resource. For example, 14 of 26 major honey sources in NSW were forest trees (Somerville and Nicholson 2004), and eucalypts provided about 70% of honey delivered to Capilano Pty Ltd by NSW-based producers (Somerville and Moncur 1997). Studies on nectar production are comparatively few although the last decade saw an increase in studies considering nectar production in Proteaceae (e.g. Nicolson and Van Wyk 1998; Lloye et al. 2002) and other Australian melliferous genera (e.g. Corbet 2003; Goldingay 2005; Mallick 2001).

For most studies on flower ecology, however, the prime importance seems to have been an associated nectarivorous vertebrate species, a view shared by Law and Chidel (2007). Many of these studies (e.g. Carthew et al. 1999; Franklin and Noske 2000; Oliver 2000; Saffer 2004; Sharpe and Goldingay 1998; Smith and Murray 2003) found that more research into flowering and nectar production patterns was vital for guiding future faunal studies. In addition, many studies investigated factors which might control flowering patterns (Moncur 1992; Wiltshire et al. 1998; Jordan et al. 2000), although most studies focussed only on a small number of factors (e.g. temperature, photoperiod or genetic influence). Somerville and Nicholson (2005) investigated primary melliferous flora associated with beekeeping within State forests of NSW but at the end of their study stated: 'The factors that trigger bud initiation, flowering periodicity and eventually nectar and pollen yields of individual species are still not clear. Given the extensive knowledge of melliferous flora possessed by beekeepers, there is an opportunity to record flowering patterns and possibly to identify factors influencing these patterns'.

The number of studies on pollen nutrition also has increased in recent years. Keller et al. (2005) reviewed pollen nutrition and colony development in honeybees with a focus on European studies. They found that the major proportion of pollen was collected from only a few floral sources with agricultural crops being those most commonly used. This is contrary to the results presented by Somerville and Nicholson (2004) for NSW. Keller et al. (2005) also noted that plant abundance was not the only factor affecting foraging of bees and stated that true preferences for certain pollen sources occurred in honeybees. Some studies claimed that bees are attracted to high quality pollens (Singh et al. 1999) but Kellerman et al. (2005) concluded that no experimental study showed this conclusively. Also, there is no consensus in the literature as to how pollen quality should be measured. It has been noted, however, that quality does vary. Chemical analyses show there are considerable differences in pollen collected from different species (e.g. Roulston et al. 2000; Somerville 2005). The principal reason cited for temporal variation was simply that different species had different pollen qualities and flowered at different times of the year. However Somerville (2005) showed that variation could occur within a species.

Few studies have considered nectar 'toxicity', yeasts in nectar or nectar fermentation other than incidentally (e.g. Keller et al. 2005; Spafford et al. 2004) or fermentation employed by insects to assist metabolic conversion and/or food preservation (Gilliam et al. 1985). Conversely, there is an expanding volume of anecdotal evidence provided by apiarists (Birtchnell and Gibson 2006; Birtchnell et al. 2005; R. Manning pers. Comm. 2005) and the wider community strongly indicating the morbid effect 'toxic' nectar and/or pollen exerts over *A. mellifera*.

Most studies dealing with any aspect of floral ecology have been short term studies. There is a critical paucity of long-term ecological studies, despite widespread and long-term acknowledgement of the necessity to determine 'real' flowering patterns rather than short-term aberrations (e.g. Franklin 1989; Pace and Cole 1989; Paini 2004; Specht and Brouwer 1975; Tilman 1989; White 1995). This deficiency is particularly evident in studies considering flowering patterns in temperate species; Law et al. (2000); Keatley et al. (2004) provided rare attention to long-term phenology of Australian species. Few studies have used anecdotal information as a basis for phenological research (see Keatley 2004), yet such information can provide a critical wealth upon which further research can be developed and is more expediently amassed than field assessments allow.

Long-term observations are critical for the determination of phenological cycles in long-lived species (Valiela et al. 1989) such as Eucalypts, yet few studies have monitored flowering patterns for more than five years (Ashton 1975; Porter 1978; Loneragan 1979; Dale and Hawkins 1983; Pook et al. 1997). Tilman (1989) found that 1.7: of 749 papers extracted from ecology over a ten year period involved research of more than five years duration. Furthermore, analysis of the few long-term studies indicated that even five years of observation was insufficient (Tilman 1989). Short-term studies may occur during years when flowering intensity is much reduced or nonexistent and so provide a false idea of normal patterns.

The case for long-term phenological research is further supported by proposals that rainfall data should span at least 30 years to show any patterns whilst patterns relating to temperature require between five and ten years (Bureau of Meteorology 1988). Likewise, Specht and Brouwer (1975) claimed that studies considering eucalypt shoot growth should span at least ten years to enable recognition of cyclical events and reduce 'perceived', rather than actual, variations. This could be extrapolated to research involving flowering cycles (Keatley 1999), although Newstrom et al. (1994) considered five years of data sufficient to describe variation in tropical flowering patterns. It is likely, however, that differences between tropical climates and the southern Australian climate contribute significantly to variations in plant phenological cycles: research into floral and fruit induction in arid Australia supported the notion that ten years was the minimum duration for research in this field (Freidel et al. 1993). It has also been argued that data should be collected over a period four times the length of the cycle under investigation, in order to reduce smaller scale variations and establish any long-term changes (Griffiths 1976; Specht and Brouwer 1975; Rathcke 1988; Freidel et al. 1993).

Long-term anecdotal records have been used extensively in many areas of scientific research (Creagh 1992; Finlayson and Brizga 1995; Lane 1997; Winklerprins 1999; Crowley and Garnett 2000; Endo et al. 2000; Johannes et al. 2000; Nursey-Bray 2000; Roberts and Sainty 2000; Kapoor 2001). In particular, the use of oral history as a methodology has increased significantly since the 1960s (Hamilton 1994) and has helped develop new perspectives of research directions (e.g. Lane 1997; Johannes et al. 2000; Roberts and Sainty 2000), however, it has rarely been used to examine flowering patterns. Porter (1978) was the first to use long-term observational data, i.e. anecdotal data, to determine eucalypt flowering, timing and frequency. The most thorough analysis, however, was by Keatley (1999) whose comparison between field data and anecdotal data found that the two were generally synonymous.

Apiarists are an important source of long-term observational data. Their understanding of flowering cycles and accuracy in assessing the relationship between flowering and nectar production is unparalleled, and is necessary considering the importance of this to their livelihood. Their observations, therefore, are likely to be significantly more accurate and continuous than any other anecdotal source. Furthermore, training is given from one generation to the next to remove differences in perception, thus data accrued over several generations can be considered as one 'long-term' study. Indeed, beekeepers' opinions were actively sought by forestry officers seeking clarification of 'unusual' events. In 1935, a forestry officer completing the Quarterly Budding and Flowering Report noted the formation of three stages of budding in *E. rubida* H. Deane and Miden. Having not observed the occurrence previously, the officer stated that conversations with beekeepers confirmed that this

occurred regularly across the state. It has been well known for some time that apiarists are invaluable for their intimate understanding of phenostages in eucalypts.

The importance of using traditional ecological knowledge such as that held by apiarists was discussed by Johannes et al. (2000): in a similar context, where long-term data sets were unavailable, older fishers were deemed the only source of information on historical changes in local fish resources and variations in marine environmental conditions. The implications of ignoring the critical information provided via oral history can, amongst other things, have serious practical consequences (Johannes et al. 2000).

To date, however, very little information from apiarists has been formally recorded and collated. This is despite efforts to do so: in 1920, the Victorian Apiarists Association (VAA) and the Department of Agriculture conducted a survey of beekeepers to collect information relating to flowering periods of eucalypts (Anon. 1920). Insufficient surveys were returned and the results were, therefore, inconclusive (Anon. 1921). Goodacre (1947) surveyed beekeepers on flowering behaviour and floral rewards of melliferous flora but also got insufficient returns. Goodman (2001) investigated the nectar and pollen resources at apiaries including the economic value of these resources. Information relating to flowering patterns was not obtained, nor was detailed information on the relationship between flowering and nectar production. Somerville (2004) examined various aspects of floral ecology but particularly nectar secretion measured by honey produced and the nutritional impact of pollen collected by bees.

Traditionally, bee keeping is a skill and profession which is passed down through generations, most typically from father to son, although occasionally to daughters. Many of today's apiarists are second or third generation beekeepers. Much of their success is owed to the invaluable information relating to flowering and nectar patterns of native melliferous plants observed by parents and grandparents. Recently, increased opportunities for younger generations to attain tertiary education and gain full-time employment in alternative fields has contributed to an apparent decline in the number of offspring following the family tradition of becoming apiarists.

This project is an extension of a previous project (Birtchnell and Gibson 2006) originally proposed by Dr Robert F Parsons from the Department of Botany at La Trobe University in response to concerns raised by a semi-retired apiarist, whose offspring had chosen alternative professions. In a situation becoming more common, there is a growing unease that information relating to flowering patterns of native melliferous species will be lost following the death of experienced, elderly apiarists. Sadly, a number have died during the term of this study. Apiarists' observations are potentially more accurate and continuous than any other anecdotal source, given the dependency their livelihood has on such knowledge. Observations accrued over generations can be considered as one long-term study on flowering patterns, therefore it is vital to record this information before it is lost forever, especially as published information on long-term flowering patterns of melliferous species is scarce, time consuming and costly to amass.

This study fills several gaps identified above:

1. It provides a written, accessible record of anecdotal information sourced from highly experienced apiarists.
2. It determines long-term flowering patterns of south-east Australian melliferous flora such as:
    - frequency, intensity, timing and duration;
    - long-term temporal differences in both flowering patterns and nectar production;
    - spatial differences in flowering patterns within species;
    - relationship between flowering and nectar yield; and
    - contributing factors to variations in flowering patterns and nectar yield.

3. It investigates occurrence of ‘toxic’ nectar in Victorian eucalypts, specifically:
    - reports of ‘toxic’ nectar on bee health;
    - which *Eucalyptus* species produce ‘toxic’ nectar;
    - relationships of ‘toxic’ nectar with occurrence of yeast in nectar; and
    - occurrence of different yeast strains in eucalypts.
4. It examines pollen-related bee nutrition such as:
    - Temporal and spatial variation in quality of pollen;
    - Factors affecting quality and quantity of pollen;
    - Pollen preferences;
    - Pollen effects on health; and
    - Pollen substitutes.
5. It also examines Bogong Moth visitation, logging and their effects on nectar production.

1. Flowering and nectar production patterns

1.1 Introduction

Flowering patterns and nectar production are one of the least studied aspects of natural environments. The reasons for this possibly stem from historical reliance on field-based studies. Such studies are costly and time-consuming to implement and therefore rarely continue for long enough to reveal true patterns emerging in Australia's highly variable flora. This is particularly true of longer-lived species (Valiela et al. 1989), such as those used for honey production in Australia. Nonetheless, there is an increasing recognition that long-term studies of flowering ecology and its relationship to climate can be valuable in monitoring environmental patterns, particularly climate change (Sparks et al. 2000).

Flowering and nectar production are critical for successful ecological functioning: during flowering, nectar serves as a floral reward for a wide array of potential pollinators (although less so in *Eucalyptus melliodora* [Yellow Box] – see Moncur and Boland 1989), thus facilitating the reproduction of the floral species. Flowering not only ensures long-term survival of the plant species but also that of countless species dependent on the carbohydrates (nectar) and/or protein (pollen) produced during flowering events (for example, the Honey Possum *Tarsipes rostratus* - see Bradshaw and Bradshaw 1999). Understanding the timing of such events is vital, as it enables land managers and industries, such as the Australian beekeeping industry, to better manage floral resources and related products. Skills in predicting flowering intensity and nectar production further advance natural resource management and potentially have a significant positive impact on economics in a range of industries.

Previous research relating to flowering patterns of Australian flora mostly has involved short-term studies and largely were focused on 'measurable' aspects of flowering, that is, flowering frequency (e.g. Blakely 1955; Davis 1968; Ashton 1975; Moncur and Boland 1989; Beardsell et al. 1993; Keatley 1999; Somerville 1999; Law et al. 2000; Goodman 2001) and flowering period (Goodacre 1947; Davis 1968; Goodman 1973; Clemson 1985; Moncur and Boland 1989; Brooker and Kleinig 1990; Keatley 1999; Somerville 1999). Flowering frequency relates to the interval between flowering events and often is unpredictable; all eucalypt species examined by previous research exhibited high variability. Some research argues that flowering frequency largely has been ignored (Bawa et al. 2003), and this is certainly more true of temperate, long-lived species than those in tropical climates or of annual species. Flowering period, or the timing or commencement and cessation of flowering in species probably is the most accessible, owing to the many field guides which provide expected flowering periods (e.g. Costermans 1983; Boland et al. 1984; Brooker and Slee 1996).

Factors which affected the timing and duration of flowering were considered but often independently of other factors, thus repressing interaction between factors. The knowledge of such interactions is critical for predicting floral resource availability. Factors known to affect flowering patterns included climatic conditions such as temperature (e.g. Ashton 1975; Helenurm and Barrett 1987; Allen and Platt 1990; Moncur 1992; Kudo 1993; Lechowicz 1995; Law et al. 2000; Osborne et al. 2000; Sparks et al. 2000; Keatley et al. 2002), rainfall (e.g. Johnson 1992; Fenner 1998; Keatley et al. 2002), solar radiation (e.g. Moncur 1992) and humidity, especially in tropical species (see Proença and Gibbs 1994). The effects of fire and logging on melliferous flora have received limited consideration (Law et al. 2000; Birtchnell and Gibson 2006).

Few studies considered nectar production or its relationship to flowering (but see Porter 1978; Clemson 1985; Horsking and Turner 1999; Goodman 2001). Climate, especially rainfall and resultant soil moisture, affected nectar production in eucalypts (Porter 1978; Law and Chidel 2007) and healthland Proteaceae (Wooller et al. 1998). Birtchnell (2002) found that the relationship between flowering and nectar production in Victorian melliferous eucalypts was highly unreliable and was affected by a range of factors including rainfall patterns, temperature and other environmental conditions as well as human-induced factors such as forest and land management practices. In 2002, apiarists indicated that additional factors affected nectar/honey production, none of which had been studied previously (Birtchnell 2002). The most disastrous of these in terms of honey production and the potential for impacts on native invertebrates and fauna were the impact of Bogong Moths (*Agrotis infusa*) and nectar/pollen toxicity on honeybees. Greater understanding of factors affecting nectar production in a wider range of Australian flora is critical for a range of applications such as resource availability assessment (e.g. Kavanagh 1987; Armstrong 1991) and requires the use of long-term data (see Law et al. 2000).

This study aimed to consider the flowering ecology (that is, flowering frequency, timing and duration, and intensity as well as nectar production) of Australian melliferous species using long-term data. Secondary aims were to determine factors which influenced flowering patterns and nectar production and tools which could be used to predict aspects of flowering and nectar production. Included in this was a detailed investigation of the impacts elicited by Bogong Moths and pollen/nectar toxicity to honeybees.

Importantly, the study provides long-term insights into flowering ecology, as it was based on observations made over several decades by highly experienced commercial apiarists. It represents the largest attempt at using oral history to explain flowering ecology anywhere in the world and provides information relating to melliferous flora from a greater area of Australia than any previous study. This research also plays a vital role in preserving invaluable knowledge which might otherwise be lost following the death of our elderly apiarists.

1.2 Methodology

1.2.1 The apiarists

Sixty-six apiarists were contacted and interviewed for this research. Apiarists resided in Victoria, New South Wales, the Australian Capital Territory (ACT), South Australia and Tasmania during their beekeeping years. However, the migratory nature of Australian beekeeping often necessitates shifting hives interstate (Figure 1.1). Many apiarists used New South Wales for honey production (28 out of a total of 66 respondents [28/66]), with half using both New South Wales and Victoria. No apiarists involved in this study were entirely dependent on the floral resources within the ACT. (Figure 1.1). Not surprisingly, the six Tasmanian apiarists interviewed used only resources from that state (Figure 1.1). Three apiarists utilised floral resources extending from Victoria through New South Wales and into the Western Riverine region of Queensland (Figure 1.1).

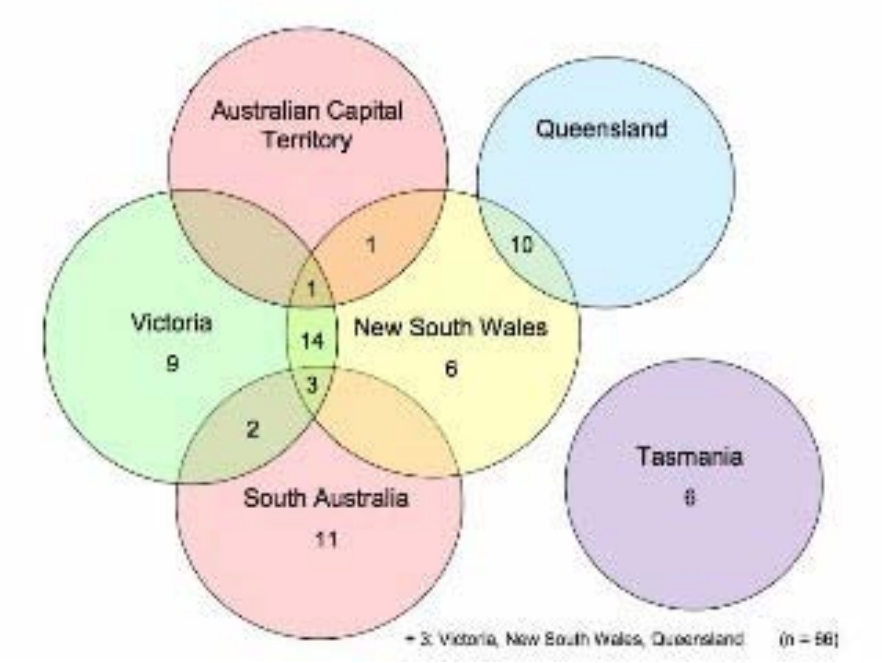

Figure 1.1 Australian states and territories used by apiarists involved in this research.

Each apiarist involved in this study had operated commercially for a minimum of 30 years and managed a minimum of 350 hives at any one time. This ensured apiarists interviewed had an intimate and long-term understanding of flowering and nectar production. Recruitment of apiarists who fulfilled the selection criteria was undertaken using two methods: first, the ‘gatekeeper’ approach (Berg 1999), whereby contact details for 11 apiarists were provided by the beekeeper who initially suggested the research concept; second, the ‘snowball’ technique (Gilbert 1993; Robson 1993), whereby each respondent was asked to provide details of other experienced apiarists. These techniques are commonly used in social research (e.g. Mesquita et al. 2001; Momartin et al. 2002; Poczwardowski and Conroy 2002) and employ existing interpersonal networks within closed communities and, in this case, a closed industry, to encourage participation in research (McLean and Campbell 2003). To ensure additional respondents were renowned for their expertise, each potential participant was recommended independently by at least two other participating apiarists. Participants were recruited and interviewed in accordance with Deakin University ethics requirements.

1.2.2 The interviews

Face-to-face interviews were selected as the most suitable method for obtaining data, particularly as a high response rate was necessary owing to the rarity of suitably qualified subjects. Perhaps more importantly, face-to-face interviews enabled a personal and intimate rapport and trust to be developed between the interviewer and the apiarists, compared to other techniques such as surveys or telephone interviews. Such methods may be suitable for follow-up data collection but were less likely to tap into knowledge traditionally restricted to family members and, less often, close beekeeping friends.

Interviews consisted of 40 open-ended questions relating to flowering ecology (Appendix 1). Specifically, questions related to the apiarists background in beekeeping, resources used for honey production (sites and floral species), flowering patterns (frequency, period and intensity), nectar production (volume and frequency), factors affecting flowering and nectar production, and miscellaneous questions which extended the knowledge of topics raised in previous research (Birtchnell 2002; Birtchnell and Gibson 2006) (Appendix 1).

1.3 Results

All apiarists involved in this study had operated commercially for a minimum of 30 years, with half the respondents having more than 50 years full-time commercial apicultural experience (33/66) (Figure 1.2). Many were first generation beekeepers (27/54), however more than half were second, third or fourth generation beekeepers (Figure 1.3). Several apiarists involved in the study were retired (12/66); although the majority were not retired. All beekeepers managed more than an average of 400 hives during their commercial operation, with many managing more than 1 000 hives (32/66) (range: 400-2 500 hives) (Figure 1.4).

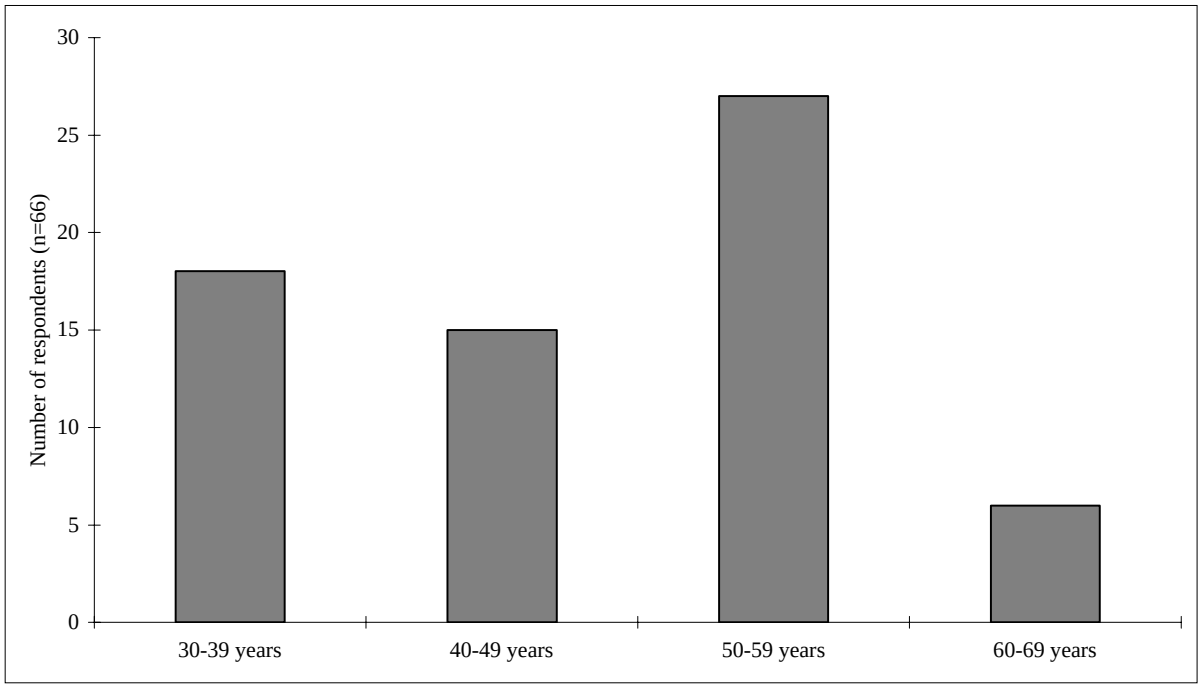

Figure 1.2 Duration of apicultural experience for each apiarist interviewed for this study.

In general, apiarists learnt the identification of melliferous species from other apiarists (33/42), including from family members (16/42). This is to be expected in an industry so reliant on trusting the observations of peers and highlights the importance of older beekeepers' knowledge in the long-term viability of apiculture and Australia's floral resources. Field guides played a supporting role in species identification (20/42), as did apiarists' local knowledge of an area (9/42) and interest and experience (7/42) in other industries such as forestry (4/42).

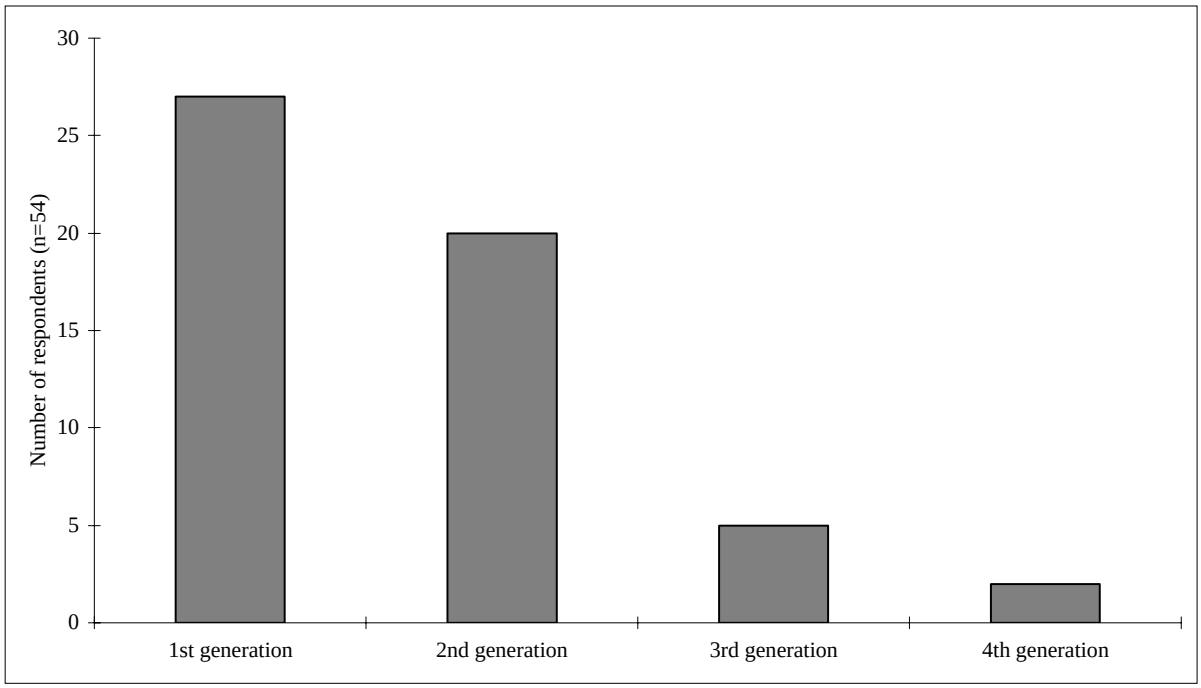

Figure 1.3 Number of first, second, third or fourth generational apiarists involved in this study.

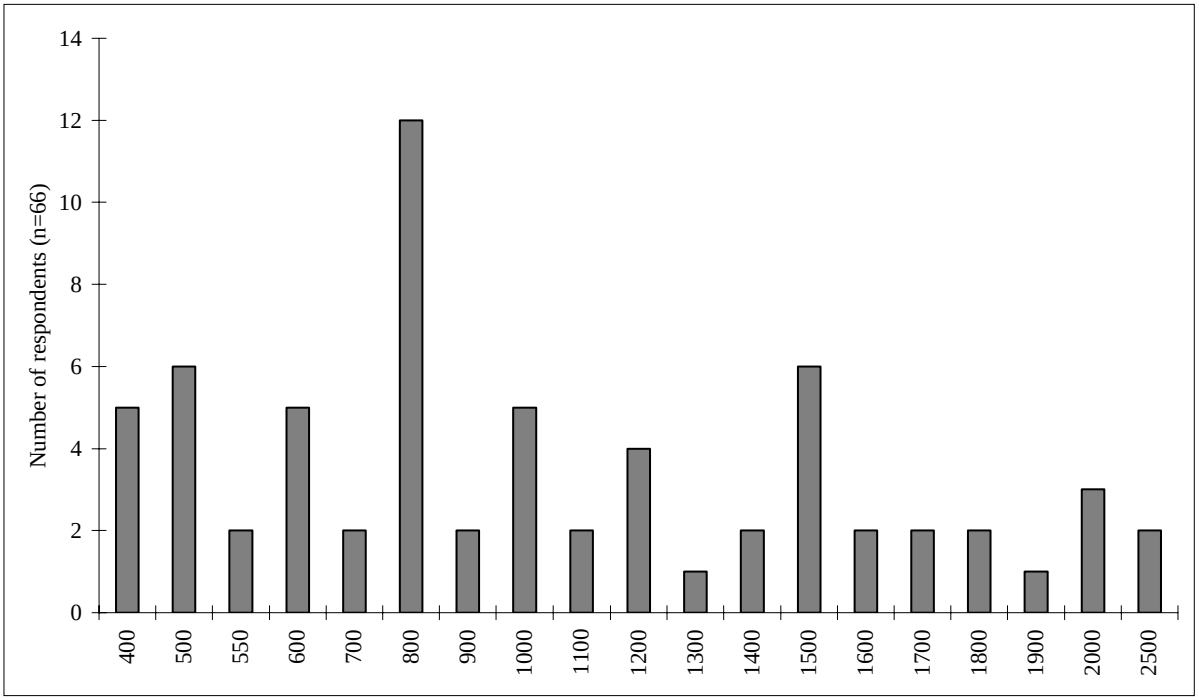

Figure 1.4 Minimum average number of hives managed by each apiarist involved in this study.

1.3.1 Resource utilisation

The flowering and nectar production patterns of 76 species were determined. Thirty-eight of these were used by three or more apiarists (Figure 1.5) whilst 38 species were used by one or two apiarists (Figure 1.6). This excludes information pertaining to use of *Eucalyptus* species by Victorian apiarists (see Birtchnell and Gibson 2006). Five plant families were represented by the melliferous flora considered in this study (Appendix 2), with the majority belonging to the Myrtaceae. This family includes the dominant genus *Eucalyptus*, which is associated with *Corymbia* and *Angophora*. Other Myrtaceous genera included in this research were *Leptospermum* (Tea-trees), *Melaleuca* (Paperbarks), *Lophostemon* and *Syncarpia* (Appendix 2). Most of the 77 species were *Eucalyptus* species (Figures 1.5 and 1.6; Appendix 2).

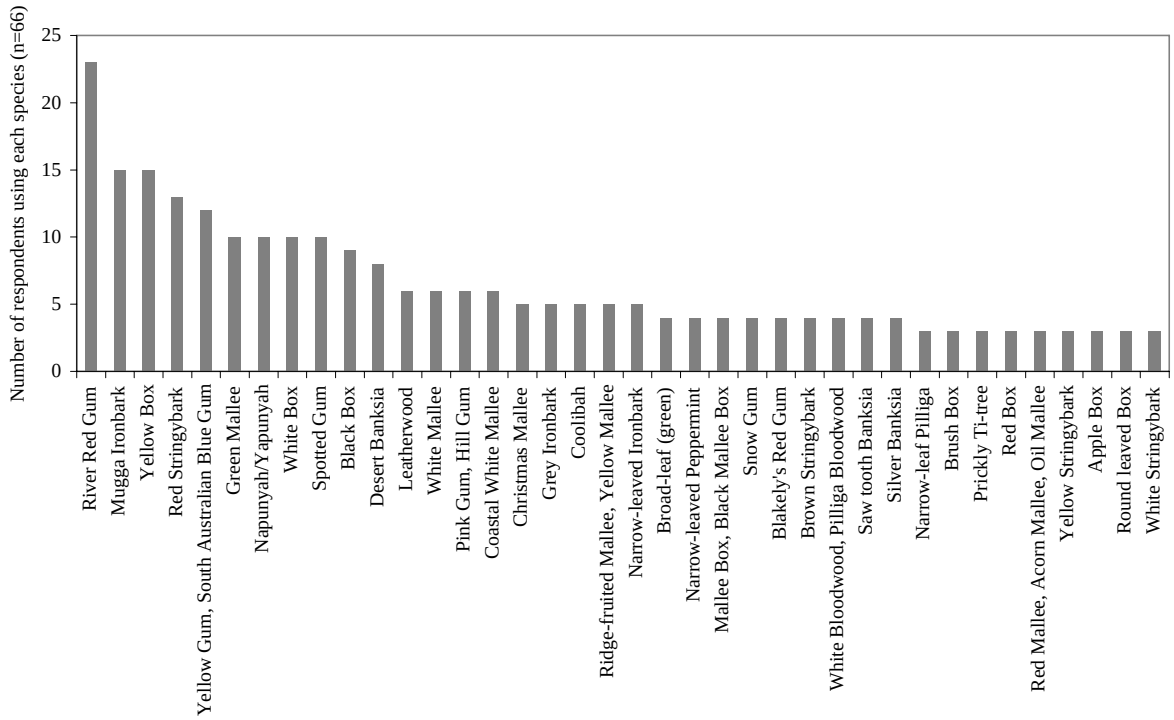

Figure 1.5 Melliferous species used by three or more respondents.

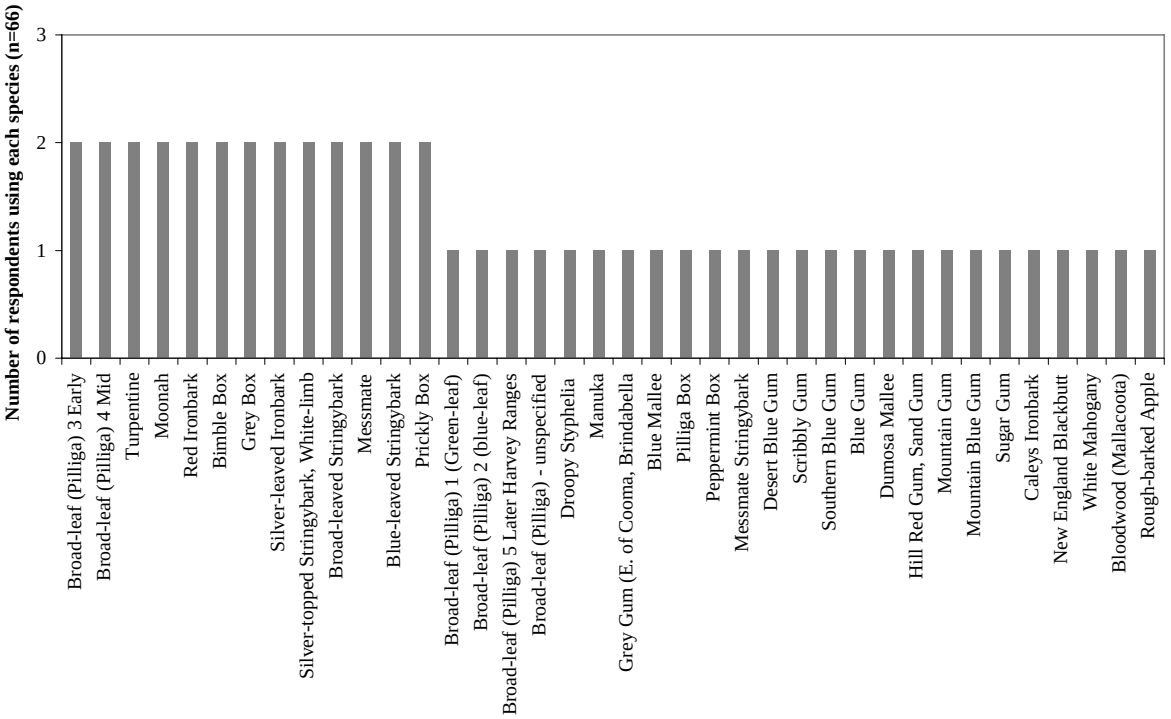

Figure 1.6 Melliferous species used by one or two respondents.

Primarily, species were selected for honey production (hence, melliferous) based on apiarists' access to resources (25/43), with availability of sites, location of, and distance to, resources featuring highly also (17/43, 11/43 and 9/43 respectively) (Figure 1.7). The reliability of species, that is, the strength of the relationship between flowering and nectar production, was of great importance for floral resource selection (23/43) (Figure 1.7). Some apiarists used advice from other apiarists (5/43), and/or relied on their own experience of species and sites (4/43) or on knowledge of rainfall patterns (2/43) (Figure 1.7). Eight respondents suggested that choice was influenced by honey production (Figure 1.7). In Tasmania, where migratory opportunities and the diversity of floral resources were limited, species selection centred around those species which were consistent nectar/honey sources and/or those which produced high-demand honey (e.g. Leatherwood) (Figure 1.7). Other factors (6/43) influencing species selection included security at the site of floral resources and the availability of flat land suitable for loading and unloading hives from the truck.

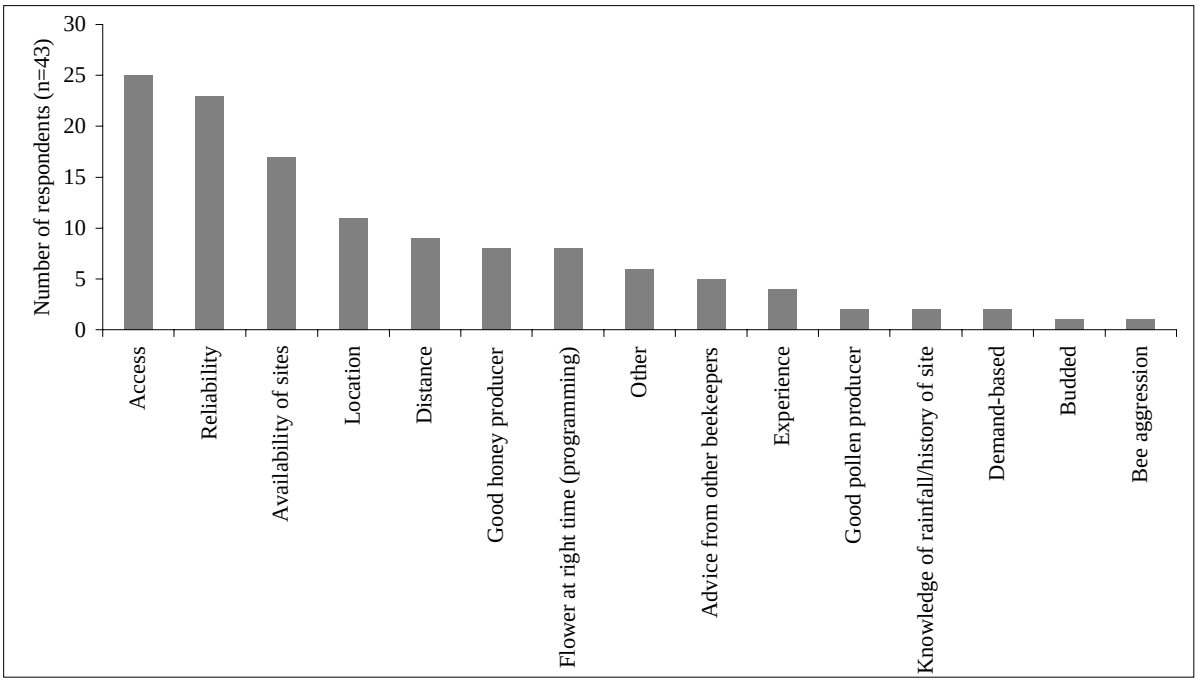

Figure 1.7 Factors influencing apiarists' selection of melliferous flora.

1.3.2 Flowering patterns

1.3.2.1 Flowering frequency

Numerous species flower annually, including Napunyah (also called Yapunyah), Leatherwood, Silver and Desert Banksias, Red Ironbark and Pilliga Box (Figure 1.8), although the latter averages a three year interval between flowering (Figure 1.8). Some species can flower at 10 year or greater intervals (e.g. Yellow Stringybark, Messmate, Brown Stringybark and White Box) (Figure 1.8). The mode of flowering for most species was two, three or four years.

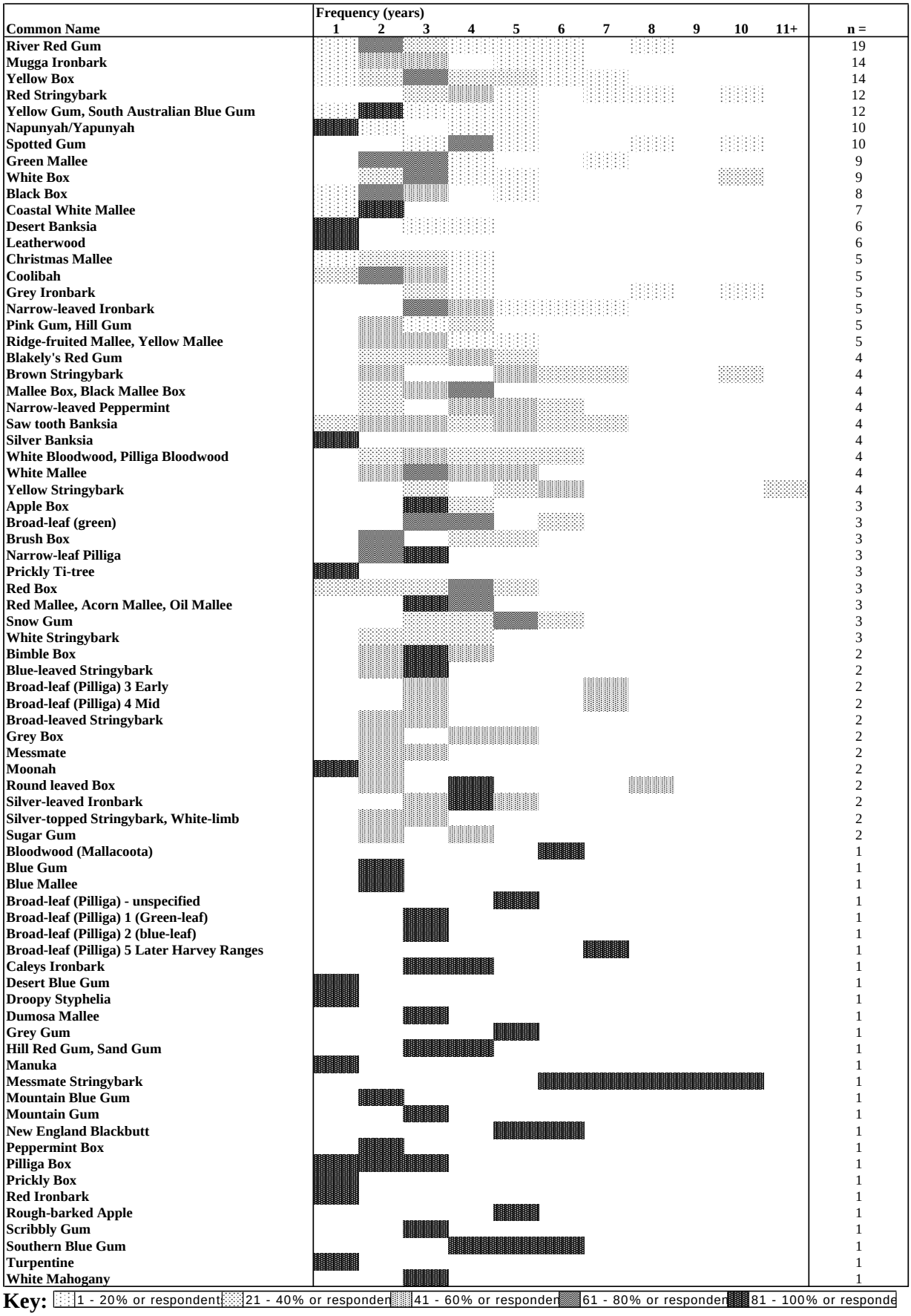

Figure 1.8 Flowering frequency of melliferous flora.

Most species considered in this study do not have a regular flowering frequency (30/45), that is, they do not always flower at those intervals identified in Figure 1.7. However, eight species were noted for their regular flowering frequency (Figure 1.9). Leatherwood and Yellow Gum (South Australian Blue Gum) were cited most often as having a regular flowering frequency (6/16). However, most species, were cited as having a regular flowering frequency only by one apiarist each (Figure 1.9). Yellow Gum was considered regular, probably owing to its extended flowering period; if flowering was interrupted during the early stages of flowering, flowering could continue as normal during the later stages (see Figure 1.12). Excepting Yellow Gum (South Australian Blue Gum), species noted as having regular flowering frequency were annual flowering species (Figure 1.8).

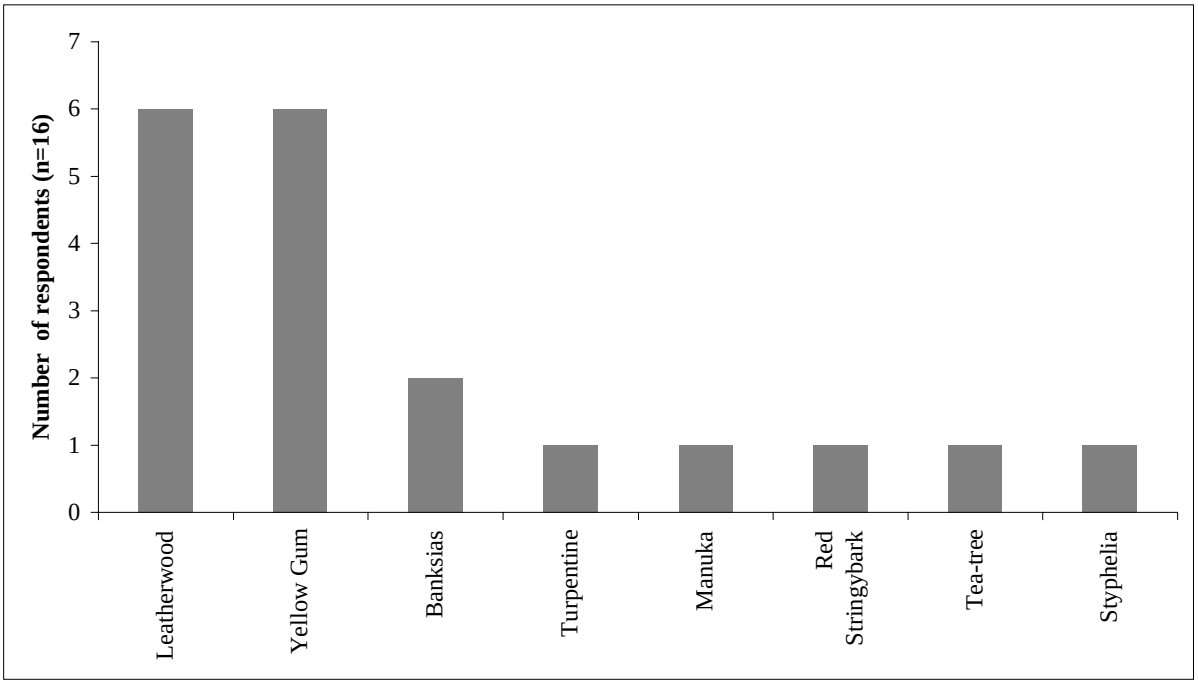

Figure 1.9 Melliferous species reported to have a regular flowering frequency.

Flowering frequency was affected by many factors (Figure 1.10) and responses indicated that a combination of factors was most influential. Rainfall, or lack thereof, was most influential over flowering frequency (36/45); seasonal rainfall, that is rain at the right time according to long-term seasonal patterns, also was considered vital (14/45) (Figure 1.10). It is likely that those apiarists who identified rainfall as a contributing factor considered seasonal rainfall also part of this factor. Whilst natural cycles were cited as controlling flowering frequency, human-induced factors such as altered flood regimes (6/45), insect level increases and attack (5/45) and agricultural practices such as clearing and fertilising (2/45) also were noted (Figure 1.10). Flowering frequency within a species usually did not vary across its range (25/49) although there were instances where flowering could be more or less frequent in one site than others (24/49). Variation in rainfall between sites was most likely to influence such differences (15/23), with spatial variation in flood patterns (6/23), soil type (1/23) and soil moisture (1/23) also potentially affecting flowering frequency between sites.

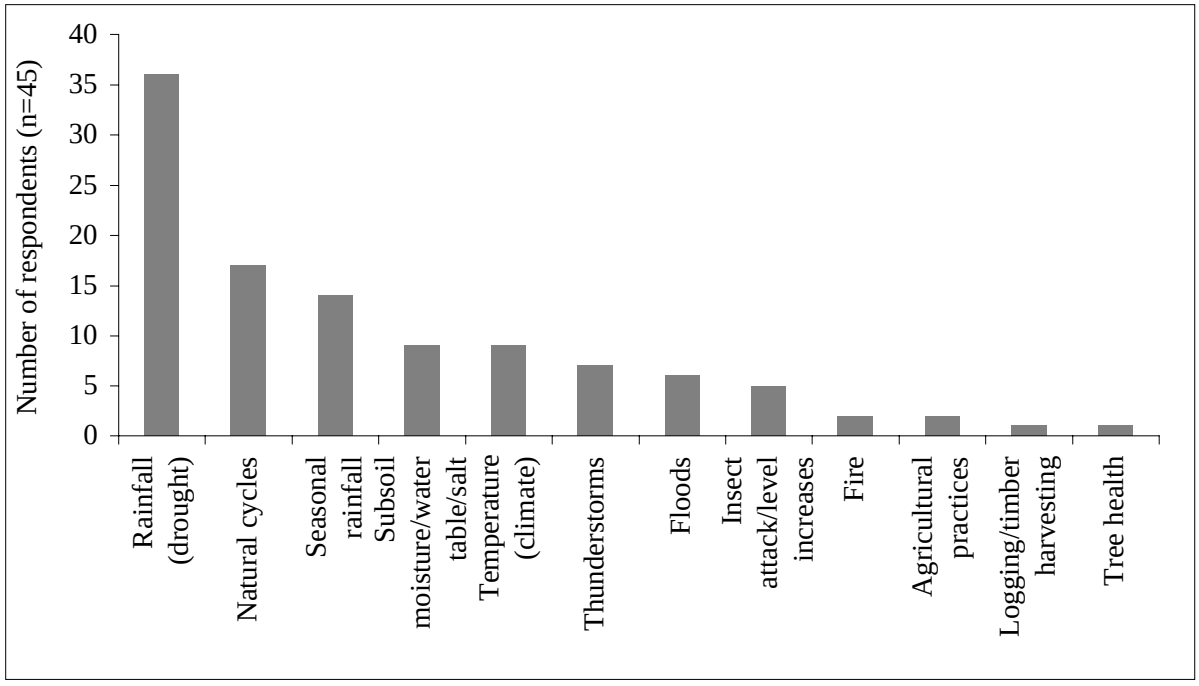

Figure 1.10 Factors affecting flowering frequency of melliferous flora.

The unpredictable nature of flowering in melliferous flora (Figure 1.8) necessitates being able to predict whether or not flowering will occur in order to plan for optimal honey production. Programming of hive migration often occurs 18 months in advance of a flowering event and therefore apiarists used tools to predict the onset of flowering (Figure 1.11). These tools, used in combination, were successful predictors on at least 80% of occasions (66/66).

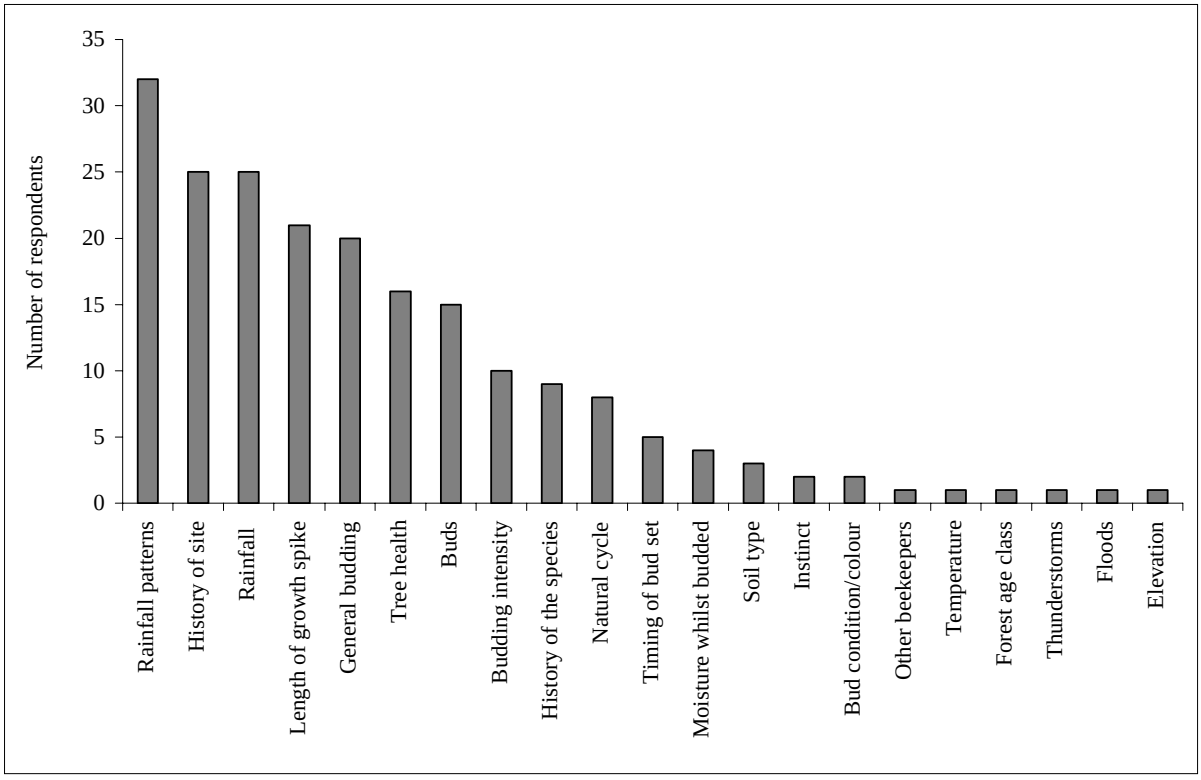

Figure 1.11 'Tools' used by apiarists to predict the likelihood of a flowering event occurring in melliferous flora.

The most important predictor was the timing of rainfall (i.e. seasonal rainfall) (32/44), with many respondents concurring that rainfall events were critical indicators of a potential flowering event (25/44) (Figure 1.11). Other climatic predictors included temperature (1/44), the location of thunderstorms (1/44) and flood events (1/44) (Figure 1.11). Some experienced apiarists claimed the 'big picture' approach was most effective, whereby knowledge of the history of the target species (e.g. when and where it last flowered) (9/44), the history of sites (e.g. the timing and volume of rainfall, when the target species last flowered at that site) (25/44) and an understanding of the natural cycles of each species (8/44) (Figure 1.11). Tree health, specifically the colour and 'look' of a species, prior to flowering was considered an effective predictor (16/44) which was as unquantifiable as the 'instinct' relied on by some apiarists (2/44) (Figure 1.11).

1.3.2.2 Flowering period

Flowering in melliferous flora occurred throughout the year (Figure 1.12). Most species used by more than ten beekeepers generally flowered during autumn and winter, whilst spring and summer flowering species tended to be used by six or fewer apiarists (Figure 1.12). Yellow Gum (South Australian Blue Gum) and Yellow Box displayed the longest flowering period (over 10 months), although the bulk of the flowering event extended for approximately six months (determined by the percentage of respondents observing flowering during any time). Mugga Ironbark, Napunyah, White Box and White Mallee flowered for approximately nine months whilst Grey Ironbark, Narrow-leaved Ironbark and Narrow-leaved Pilliga flowered for seven months (Figure 1.12). In general, species used by many beekeepers displayed a longer flowering period than those species used by fewer apiarists. For example, species used by one, two or three apiarists flowered for one to five months whilst species used by five or more apiarists often flowered for five to ten months. As the flowering period for each species was provided by apiarists using that species for honey production (i.e. more apiarists equals more observations of flowering period), it is likely that extended flowering periods recorded in species used by many apiarists resulted from observations made across a species' range. Therefore, flowering periods reported for those species reveal spatial variation in flowering period. Alternatively, the number of apiarists using each species could be influenced by the length of flowering period in any species. That is, those species with a longer flowering period may attract use by more beekeepers, as longer flowering periods mean fewer hive shifts per year.

Flowering was not restricted to seasons, nor to months (Figure 1.12). Indeed, at any time of year, there may be melliferous species flowering, however it is important to note that not all species flower every year (Figure 1.8) and so, flowering between species may not overlap. Furthermore, species which flower at the same time in the same year may not occur in the same area and, so, are not truly synchronous.

Spatial variation in flowering period within a species was observed (48/48), namely between the northern and southern extents of a species' range (36/48); this presumably was due to northern areas becoming warmer earlier than southern areas. Timing of flowering also could stagger from west to east (8/48) but this was more likely to be due to flood patterns and hence was observed most often in River Red Gum (*E. camaldulensis*). Altitudinal variation was experienced (24/48), with warmer, lower areas flowering earlier than cooler sites at higher elevations. Soil type and age class were thought to exert some influence over the flowering period (5/48 and 1/48 respectively). Generally, the flowering period could vary by four to six weeks and was related to temperature more than rainfall.

Despite short-term perturbations, long-term observations indicated that the flowering period has remained constant (42/48). In fact, the flowering period was so dependable that even if flowering frequency was spasmodic and irregular, flowering would commence at the expected time in years when flowering events did occur (41/41). Long-term alterations to the flowering period were attributed to general, slow climatic changes such as decreased annual rainfall, unseasonal rainfall patterns and extreme temperatures (hot and cold). Forest size did not affect the flowering period (66/66), but could affect the flowering frequency (4/66) as smaller forests were more susceptible to drying.

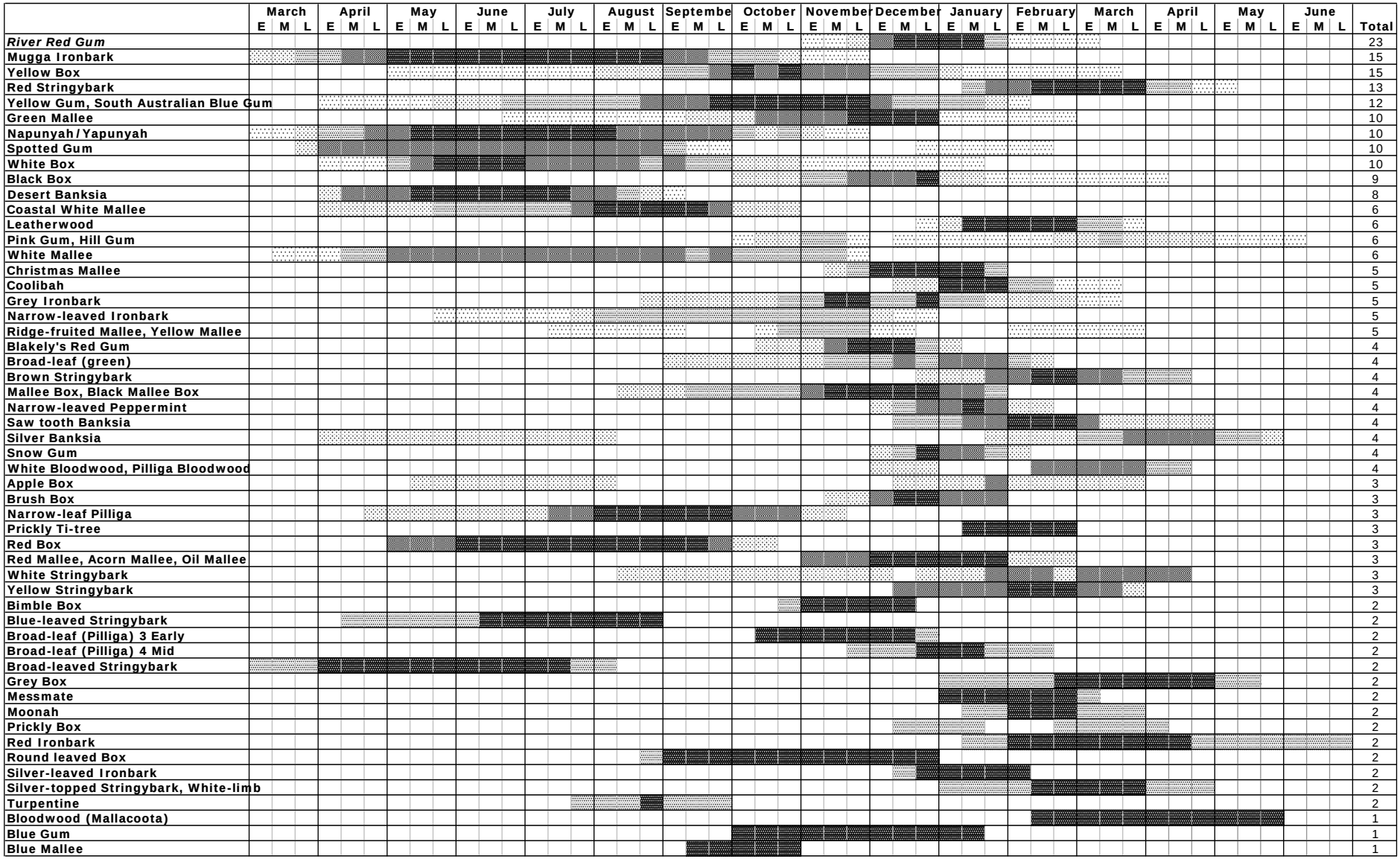

Figure 1.12 Continued on next page

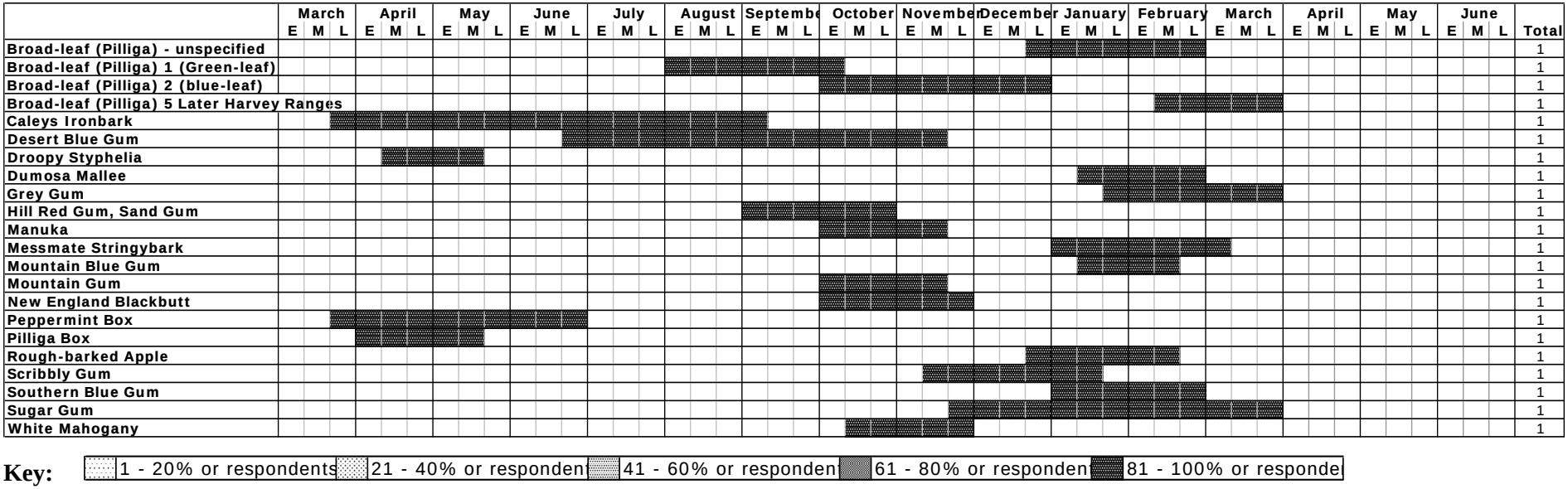

Figure 1.12 Commencement and cessation of flowering (flowering period) in melliferous flora.

1.3.2.3 Flowering intensity

Most apiarists determined flowering intensity by assessing the level of general budding (that is, the level of budding) throughout an area (66/66). General budding was considered 'good' when more than 70% of a target species within an area was in bud, whilst less than 40% of trees in bud constituted a 'poor' general budding. In addition to assessing general budding, the budding density of individual trees were observed to ensure that budding levels were uniform throughout the area (66/66). Often, apiarists had 'pet' trees which historically were reliable indicators of general budding levels.

Flowering intensity could be affected by many factors (Figure 1.13); as with flowering frequency, rainfall exerted the strongest influence over flowering intensity (38/45) as, ultimately, it is the factor which determines volume of bud set, with seasonal conditions (e.g. rain at the right time etc.) also considered important (18/45). In fact, most factors associated with flowering intensity (and, fundamentally, budding intensity) related to climatic conditions (Figure 1.13). Insect attack and tree health were related and were exceptions: apiarists noted that trees affected by insects (and, consequently, poor health) were less likely to bud and flower well, attributing this to resource depravation resulting from switching resources from reproduction to surviving insect attack. Likewise, fire reduced budding and flowering intensity whilst trees recover (1/45) (Figure 1.13). Despite short-term fluctuations (i.e. between flowering events) caused by these factors, most apiarists stated that long-term variation in flowering intensity was not observed (26/47). Nonetheless, it must be highlighted that long-term decreases in flowering intensity *were* observed by many apiarists (20/47). Only one apiarist was unsure whether flowering intensity had changed over the long-term.

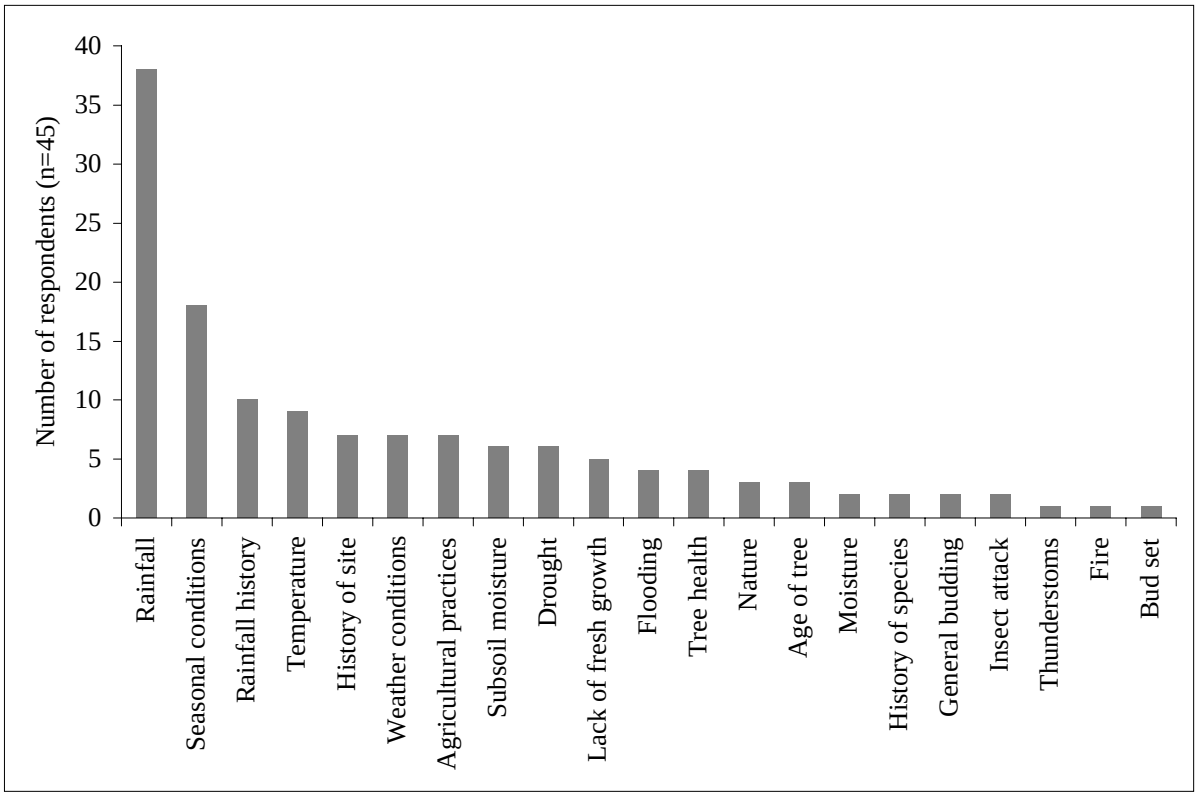

Figure 1.13 Factors affecting flowering intensity of melliferous flora.

1.3.3 Nectar production

Apiarists measure nectar production based on honey production (66/66) and thus, nectar flows are considered honey flows and volumes are determined after honey is extracted from hives. Traditionally, honey production was measured in 'tins' per hive, as honey was stored and sold in 60lb (~27kg) tins. Contemporary apiarists use 300kg drums to store and sell honey and so, technically, flows should be measured as fractions of a drum per hive. Despite this, we have opted to use the measure of tins per hive when discussing nectar production by melliferous flora; the reasons are twofold: firstly, the apiarists involved in this study were long-term operators who, for the most part, calculated using tins/hive and secondly, tins/hive is much more straightforward to calculate than determining the yield from one hive in new drum-based terminology (e.g. two tins/hive would equate to 0.18 drum/hive!).

Not surprisingly, those species used by the highest numbers of apiarists were the most prolific nectar producers, with many yielding 1.5 – 2 tins of honey per hive every two to four years (Table 1.1). In addition, these species could yield more than three tins/hive, although the frequency of these crops was less often (e.g. 10 or more years in River Red Gum, Mugga Ironbark, Red Stringybark and Yellow Box). Species used by fewer apiarists also could produce 1.5 - 2 tins/hive, however often such crops were less frequently obtained (e.g. New England Blackbutt which yielded 1-2 tins/hive every six years). Some species, such as Caleys Ironbark and Dumosa Mallee, yield as well as those species used by more apiarists – it can be assumed in such cases that other factors (e.g. access and availability of sites, see 1.3.1 Resource Utilisation) influenced use of these species for honey production. It must be noted that the figures provided are averages and, therefore, can vary between flowering episodes.

Nectar was not produced every time a species flowered (66/66), although some respondents added that it was uncommon not to obtain any honey (10/66). Even in poor years, sufficient nectar was produced to maintain hives but without excess (i.e. commercial) honey yield (9/44). Observations by most apiarists indicated there had been a long-term decrease in nectar produced by melliferous flora (43/66). Whilst 21 apiarists had not observed any long-term change in nectar production, all could relate stories from older, since deceased, apiarists of species which yielded significantly higher volumes of honey than is currently being observed. Of course, it is possible that yields related in such stories were anomalies and not typical.

Environmental factors were thought to be the major factors contributing to both short- and long-term variations in nectar yield (Figure 1.14). As was reported with flowering frequency and intensity, seasonal changes (18/30) and decreased rainfall (11/30) were most often cited as affecting nectar production (Figure 1.14). Possibly the most repeated phrase during interviews with apiarists was 'rain at the right time' – at times, this was the only factor considered to influence flowering and nectar production. Logging (8/30), agricultural practices (8) and flood regimes (2/30) were human-induced changes also thought to affect both flowering patterns and nectar yield, although the impact of overstocking sites with hives (2/30) only affected nectar production (Figure 1.14). Two apiarists observed a long-term increase in honey production due to improved apicultural practices and technology rather than an increase in nectar *per se* (Figure 1.14). Forest size did not seem to affect nectar production (12/15), although very small areas could suffer 'edge effects' and thus produce less nectar than larger forests (3/15). Lunar cycles were reported by some apiarists to influence nectar production (15/66). Of those apiarists who did not consider a relationship between lunar cycles and nectar production, only three had looked for such a relationship.

Table 1.1 Volume of honey produced by melliferous flora during a 'good' honey flow and expected frequency of such flows.

	Quantity (tins)									Frequency (years)											Total 1	Total 2
	0.5	0.75	1	1.5	2	2.5	3	3.5	4+	1	2	3	4	5	6	7	8	9	10	11+		
River Red Gum	3	1	7	7	16	6	2	0	0	0	3	0	2	7	2	1	2	1	3	1	20	18
Mugga Ironbark	0	0	5	5	10	3	3	0	0	0	4	7	5	2	2	0	0	0	2	1	15	15
Red Stringybark	1	0	0	4	8	2	2	0	0	0	0	3	7	2	1	1	1	0	2	0	13	12
Yellow Box	0	0	3	1	6	3	7	1	2	0	2	6	4	4	3	3	0	0	1	0	13	12
Yellow Gum, South Australian Blue Gum	1	0	3	5	6	2	0	0	1	1	9	1	1	0	0	0	0	0	0	1	12	12
Green Mallee	1	0	1	1	4	3	5	0	0	0	4	3	3	2	0	0	0	0	2	0	10	9
Napunyah/Yapunyah	0	0	1	1	4	2	5	2	2	6	4	2	0	0	1	0	0	0	1	0	9	9
Spotted Gum	0	0	1	4	7	2	3	0	0	0	0	0	7	3	1	1	1	1	2	1	9	9
Black Box	1	1	2	3	4	0	0	0	0	1	2	4	0	1	1	0	0	0	1	0	8	8
White Box	1	0	1	0	4	2	3	1	2	0	1	5	0	1	1	1	1	1	2	1	8	8
Coastal White Mallee	1	1	3	1	2	1	1	0	0	0	5	1	0	0	0	0	0	0	0	0	6	6
Desert Banksia	4	1	1	0	1	0	0	0	0	2	0	1	1	1	0	0	0	0	0	0	6	4
Leatherwood	0	0	0	1	1	1	1	2	5	3	0	0	0	0	0	0	0	0	2	0	6	5
Christmas Mallee	0	0	1	2	2	0	0	0	0	0	2	1	1	0	0	0	0	0	0	0	5	4
Coolibah	1	0	1	2	1	0	0	0	0	1	1	2	2	0	0	0	0	0	0	0	5	5
Grey Ironbark	0	0	0	2	2	0	1	0	0	0	0	1	1	0	1	0	1	0	1	0	5	5
Narrow-leaved Ironbark	0	0	0	4	1	0	1	0	0	0	0	3	4	1	0	0	0	0	0	0	5	4
Pink Gum, Hill Gum	1	1	4	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	1	1	5	5
Blakely's Red Gum	1	1	3	0	1	1	0	0	0	0	1	1	2	1	0	0	0	0	0	0	4	4
Mallee Box, Black Mallee Box	1	0	2	1	2	0	0	0	1	0	1	1	3	1	0	0	0	0	0	0	4	4
Narrow-leaved Peppermint	1	0	1	0	3	1	1	0	0	0	1	0	1	1	0	1	0	0	1	0	4	4
Ridge-fruited Mallee, Yellow Mallee	0	0	2	1	2	0	0	0	0	0	1	2	1	1	0	0	0	0	0	0	4	3
Saw tooth Banksia	0	1	1	0	2	0	0	0	0	1	1	1	0	1	1	0	0	0	0	0	4	4
Snow Gum	1	0	1	1	1	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	4	3
Yellow Stringybark	0	0	0	2	1	0	1	0	0	0	0	1	1	0	3	0	0	0	0	0	4	4
Broad-leaf (green)	0	0	0	1	2	2	1	0	0	0	0	2	2	0	1	0	0	0	0	0	3	3
Brown Stringybark	1	0	0	0	1	0	1	1	1	1	0	0	0	1	0	0	1	0	0	0	3	3
Brush Box	0	0	0	0	2	0	1	0	2	0	0	1	2	2	1	0	0	0	0	1	3	3
Narrow-leaf Pilliga	0	0	3	1	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	3	3
Prickly Ti-tree	0	0	2	3	0	0	0	0	0	3	2	2	0	0	0	0	0	0	0	0	3	3
Red Box	0	0	1	2	0	0	0	0	0	0	0	0	2	1	1	0	0	0	0	0	3	3
Red Mallee, Acorn Mallee, Oil Mallee	0	0	1	0	1	1	0	0	0	0	0	2	0	0	0	0	0	1	0	0	3	3
White Bloodwood, Pilliga Bloodwood	1	1	2	0	1	0	0	0	0	0	1	2	1	0	0	0	0	0	0	0	3	3
White Stringybark	0	0	1	2	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	3	3
Apple Box	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	2	2
Bimble Box	0	0	0	1	1	0	0	0	0	0	1	2	1	0	0	0	0	0	0	0	2	2
Blue-leaved Stringybark	0	0	2	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	2	2
Broad-leaf (Pilliga) 3 Early	0	0	1	1	1	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	2	2
Broad-leaf (Pilliga) 4 Mid	0	0	1	1	1	0	0	0	1	0	0	1	1	0	0	1	0	0	0	1	2	2

Table 1.1 Continued.

	Quantity (tins)									Frequency (years)												
	0.5	0.75	1	1.5	2	2.5	3	3.5	4+	1	2	3	4	5	6	7	8	9	10	11+	Total 1	Total 2
Broad-leaved Stringybark	0	0	2	0	1	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	2	2
Grey Box	1	1	1	0	1	1	1	0	0	1	0	0	1	0	0	0	0	0	0	0	2	2
Messmate	0	0	0	1	1	1	0	0	1	0	1	1	0	0	1	0	0	0	0	0	2	2
Moonah	0	0	2	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	2	2
Prickly Box	2	1	0	1	0	0	0	0	0	1	0	2	1	0	0	0	0	0	0	0	2	2
Red Ironbark	1	0	1	2	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	2	2
Round leaved Box	1	0	0	0	1	1	1	0	0	0	0	0	1	1	1	1	1	0	0	0	2	2
Silver-topped Stringybark, White-limb	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	2
Sugar Gum	1	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	2	2
White Mallee	1	0	1	1	1	1	1	0	0	0	1	1	0	0	0	0	0	0	1	0	2	2
Bloodwood (Mallacoota)	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1
Blue Gum	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1
Blue Mallee	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Broad-leaf (Pilliga) - unspecified	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1
Broad-leaf (Pilliga) 1 (Green-leaf)	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1
Broad-leaf (Pilliga) 2 (blue-leaf)	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1
Broad-leaf (Pilliga) 5 Later Harvey Ranges	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1
Caleys Ironbark	0	0	1	0	0	0	1	0	0	0	0	1	1	0	1	1	1	0	0	0	1	1
Desert Blue Gum	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1
Droopy Styphelia	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1
Dumosa Mallee	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1
Grey Gum	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1
Hill Red Gum, Sand Gum	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1
Manuka	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1
Messmate Stringybark	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
Mountain Blue Gum	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1
Mountain Gum	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1
New England Blackbutt	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1
Peppermint Box	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1
Pilliga Box	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1
Rough-barked Apple	1	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	1	1
Scribbly Gum	1	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1
Silver Banksia	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Silver-leaved Ironbark	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	1	1
Southern Blue Gum	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1
White Mahogany	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1
Turpentine	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1

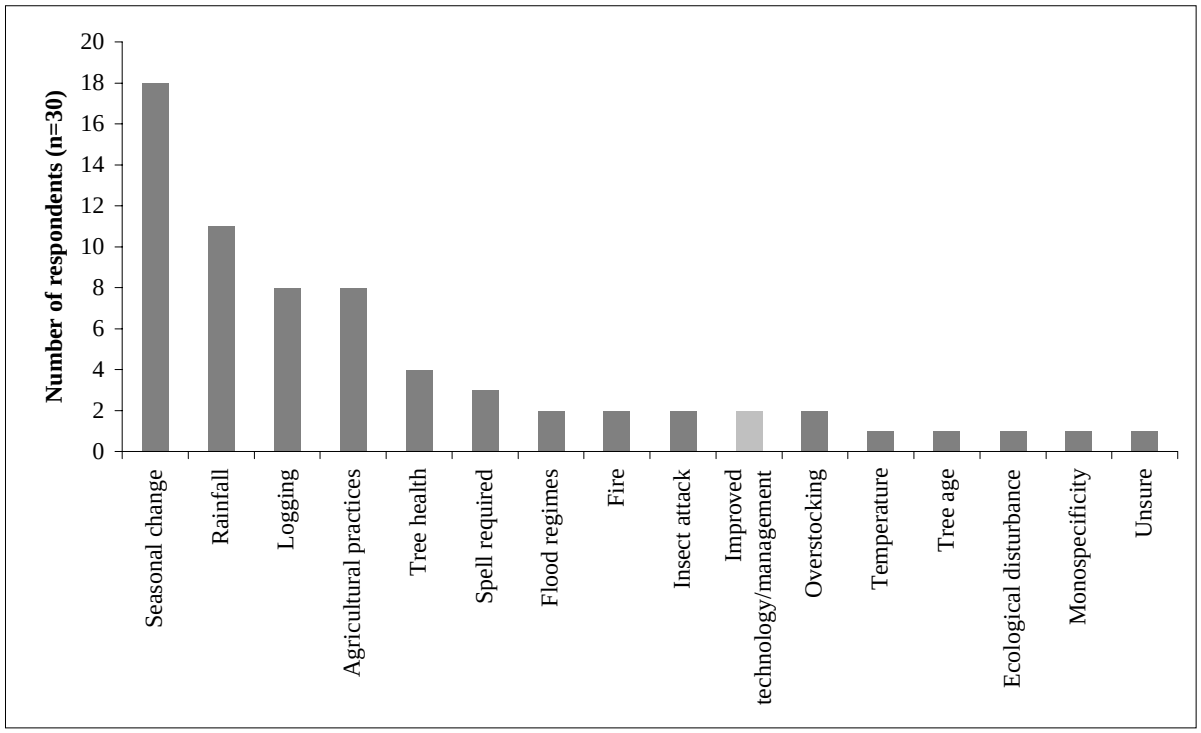

Figure 1.14 Influencing long-term variation in nectar production by melliferous flora.

Volumes of nectar produced *generally* were related to the flowering intensity of that species in that season, whereby bigger yields were obtained when general budding levels were high) (34/47). However this relationship was not dependable (57/66), as rain just prior to flowering (~ 4 – 6 weeks beforehand) could cause trees to 'grow over bud' and significantly reduce (or even cut completely) nectar and honey yields. Most apiarists who observed this recognised that moisture provided by rainfall had been diverted away from nectar production into growth. Species referred to as long-budders (i.e. those which produce bud but do not flower for another 12-24 months) were more likely to grow over bud and suffer reduced yields than 'short-budders', namely mallee species and Leatherwood. Thus, the worst affected species included River Red Gum, Red and Brown Stringybarks, Yellow Box and Yellow Gum (South Australian Blue Gum). High temperatures and northerly winds also disrupted the relationship between budding/flowering intensity and nectar yield, especially in River Red Gum and Yellow Gum, by causing trees to 'drop bud' prior to flowering thus reducing the capacity for nectar output.

Tools used to predict nectar yields (Figure 1.15) were similar to those used by apiarists to predict flowering (see Figure 1.11), for example, tree health (21/44), rainfall (18/44), normal seasonal conditions (17/44) and rainfall history/patterns (15/44) (Figure 1.15). Tools related to tree health included foliage colour (the 'look' of the tree) (11/44), a normal budding process (7/44) without growth over bud (7/44), bud appearance (2/44) and the colour and freshness of flowers (3/44 each) (Figure 1.15). More direct predictors included checking the floral cups for nectar (7/44) or observing nectar in hives (1/44) (Figure 1.15). Again, logging and agricultural practices such as the use of agricultural chemicals were considered predictors of nectar production by some apiarists (1/1 each) (Figure 1.15). Knowledge of the history of the site (18/44) and species (7/44) were considered vital to many apiarists, as species need time to recover between significant nectar yields (18/44). This collaborated the range of volumes and frequencies of nectar provided in Table 1.1), as low, then moderate, yields followed high yields in the build-up to the next high yielding flowering episode. For example, River Red Gum could produce 0.5 – 1 tin/hive every two years, intermitted by 'moderate' flows of 1 – 2.5 tins/hive every four to eight years, with large, 3 tin/hive crops obtained every 10 or more years (Table 1.1).

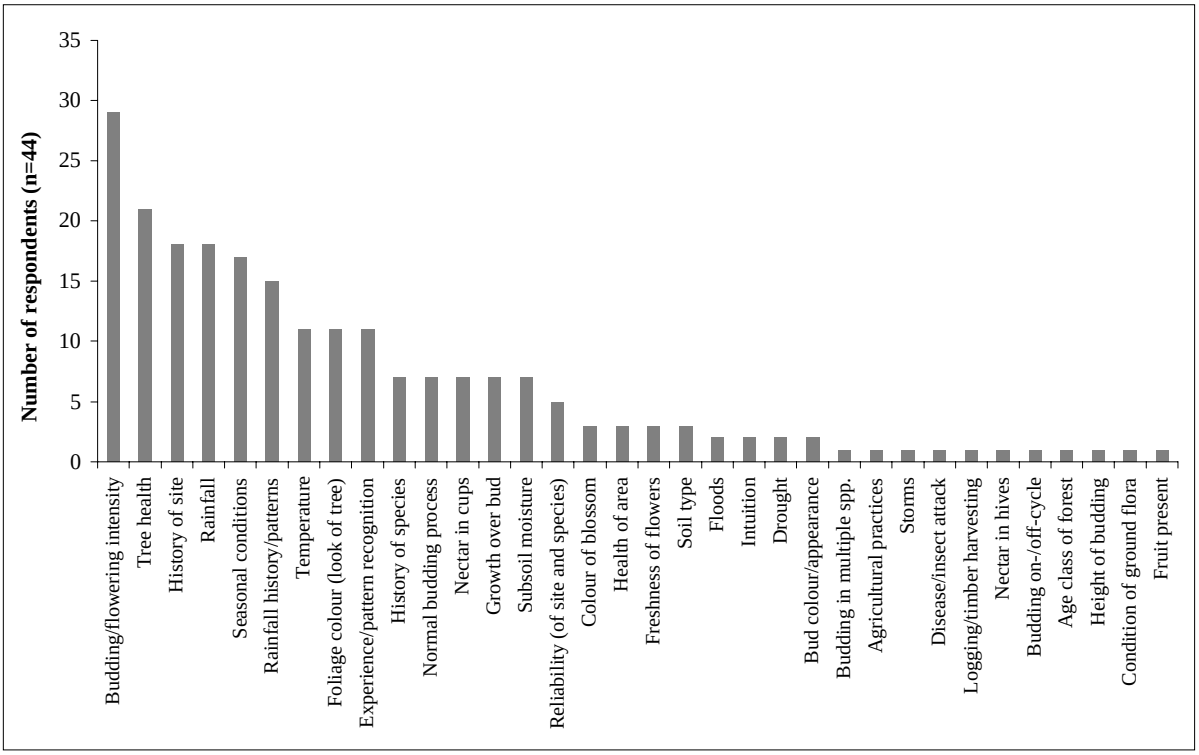

Figure 1.15 'Tools' used by apiarists to predict the likelihood of a flowering event occurring in melliferous flora.

In keeping with the importance of knowing the history of a site and/or species, beekeepers refer to areas and species as reliable or unreliable based on their nectar production history. Reliable areas and species are those that consistently produce commercially viable quantities of nectar (66/66). To some extent, it stands to reason that sites used by apiarists must be reliable although other factors determined species selection (see Figure 1.7). Most apiarists (54/58) reported that long-term reliability of areas and species has changed, with reliable areas becoming unreliable. Perhaps not surprisingly, the factors which affected reliability are much the same as those affecting both flowering and nectar production: rainfall (34/56), long-term seasonal changes (30/56), flood regimes (12/56), logging (15/56) and fire (10/56), and tree health reduction (3/56) (Figure 1.16). Increased insect levels also were detrimental to nectar production and reliability (8/56) (Figure 1.16). Insects reported include Bogong Moths (Noctuidae) (see 1.3.4.1), Yellow Box Beetle (Order: Coleoptera), Rutherglen Fly, Thrip (Order: Thysanoptera), Christmas Beetle (Scarabaeidae), Lerp (Psyllidae) and weevils (Order: Coleoptera) which affect River Red Gum.

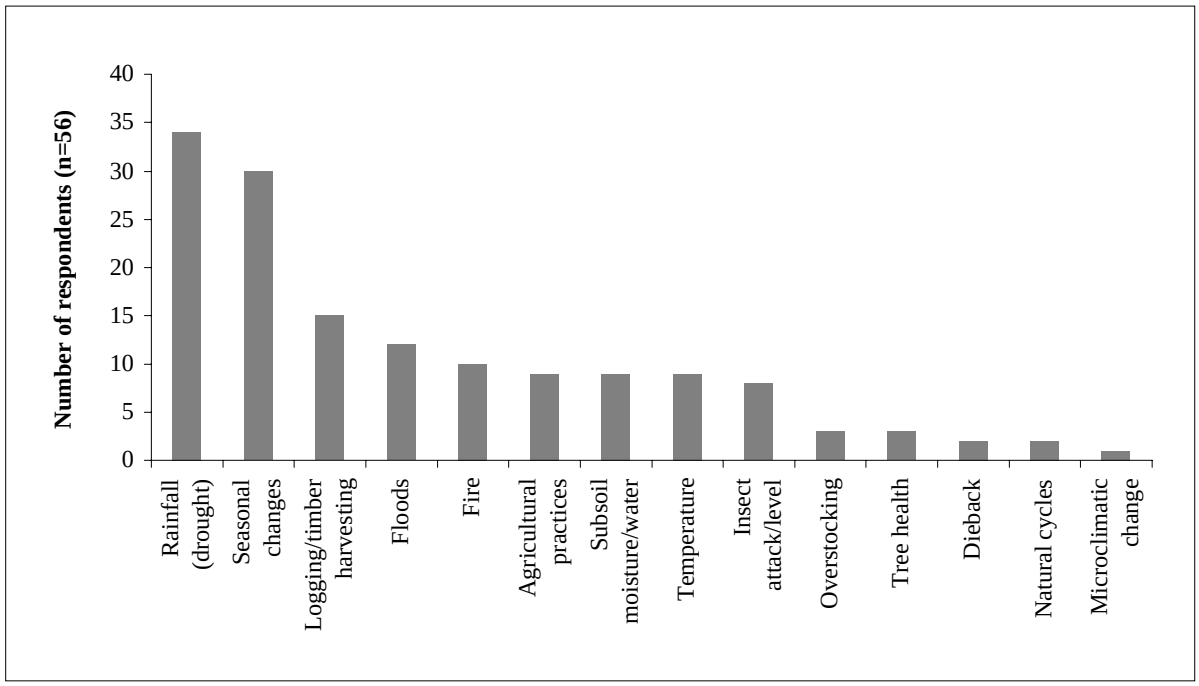

Figure 1.16 Factors altering the reliability of areas throughout south-east Australia.

1.3.4 Additional reports of effects on flowering and nectar production

Previous research by Birtchnell (2002) highlighted several issues raised by apiarists which needed further investigation. The following section presents information relating to these topics.

1.3.4.1 Bogong Moths and nectar yield

Bogong Moths (*Agrotis infusa*) have a dramatic impact on the apiculture industry, with most apiarists (45/66) noting an impact on hive health and honey yields during Bogong Moth plagues (45/45). The majority of those apiarists not affected by Bogong Moths operated beyond the moths' migration range. Bogong Moth plagues significantly reduced (30/45), and/or stopped altogether (19/45), honey flows; reports of reduced honeybee floral visitation (29/45), reduced honeybee activity and competition for nectar (10/45) may explain the impact on honey yields. If alternative nectar sources were available, honeybees may swap nectar sources, thus reducing the impact on honey yields. One apiarist reported that honeybees became aggressive during Bogong Moth plagues and another reported reduced bee population. It was suggested that Bogong Moths elicited these responses in honeybees by 'polluting' the blossom with a scent (24/45), fluff or powder (10/45), faecal matter (8/45) or an unidentified substance (6/45), any of which acted as a repellent. Twenty apiarists suggested nectar consumption by Bogong Moths was sufficient to deter honeybees. Only three apiarists were unsure of how Bogong Moths affected honeybees.

1.3.4.2 Logging and adjacent land use

Logging impacted the flowering and nectar production patterns of species used by most apiarists (27/50) who used sites which had been logged (n=50). Distinctions between clearfelling and selective logging were evident; clearfelling completely removed target melliferous flora which was later replaced with a reduced diversity of species (not necessarily valuable honey flora) in a single cohort, thus eliminating mixed age classes. This impacts on the honey industry, as mature trees were reported to yield more nectar/honey than younger trees. Furthermore, clearfelling results in tracts of land devoid of honey potential for years, whilst trees are growing and not yet reproductive. Edge effects were thought to have contributed to decreased honey yield in surrounding forest. In contrast, apiarists reported that selective harvesting comparatively had a lesser impact on honey yields, despite the

observation that mature (i.e. higher yielding) trees often were those harvested. Extant floral resources were available for honey production and diversity was not affected, thus ensuring sites' potential to support hives targeting more than one or two species. Some apiarists suggested that selective logging increased honey production by improving access to floral resources and allowing the remaining trees to increase crown size, in turn increasing budding and flowering intensity and potential for nectar production. Fewer apiarists were affected by clearfelling owing to the siting of their apiaries (i.e. on freehold land or in areas selectively harvested).

Fewer apiarists reported having been impacted by adjacent agricultural land use than by logging. Of those affected (25/66), all reported impacts on honey yields resulting from the use of agricultural sprays including fertiliser, herbicides and, more obviously, insecticides. Many affected apiarists considered agricultural chemicals had reduced tree health and, hence, productivity. Fertilisers were more detrimental than herbicides. Other agricultural practices which were attributed to decreased honey production included vegetation removal (including understorey vegetation which often provides valuable pollen sources) and soil compaction/nutrient increases related to livestock.

1.3.4.4 Pollen/Nectar toxicity to honeybees

Most apiarists had observed impacts on honeybees which they attributed to pollen (11/66) and/or nectar (47/66). Effects thought to be caused by pollen included bee mortality (11/11), nosema (actually, a set of conditions advertised as being caused by *Nosema apis* but which might occur in the absence of *Nosema* infection (Hornitzky 2008) (4/11), reduced bee/hive health (3/3), dysentery (i.e. severe diarrhoea) (3/11) and patchy brood nest (3/3). Interestingly, most of these impacts also are attributed to nectar (Table 1.2). Effects wholly relating to nectar include decreased honey yields, 'streaking' of honeybee faeces on hives, locomotory impacts such as 'drunken' behaviour and paralysis, and fermenting nectar/honey.

Table 1.2 Observed effects of seasonal pollen and/or nectar toxicity on honeybees.

Effect	Pollen (n=11)	Nectar (n=47)
Bee mortality	11	30
Nosema	4	19
Reduced bee/hive health	3	7
Dysentery	3	3
Patchy brood nest	3	-
Streaking in hives		4
'Drunken' behaviour		14
Paralysis		1
Collect fermented nectar		1
Thin honey (ferments)		4
Decreased honey yields		10

Toxicity was not present during every flowering event (57/57) and was 'triggered' by (mostly) environmental conditions immediately preceding, or during, flowering (Figure 1.17). High humidity (30/48) and cold weather (15/48) were most commonly cited as causing toxicity (Figure 1.17). Fermented nectar (14/48) and honey (5/48), and honey with a high moisture content (i.e. 'thin', unripened honey) (11/48), also were recognised as triggering the effects discussed above (Figure 1.17). Some apiarists explained the effects were a result of low carbohydrates in the nectar (3/48) or protein in pollen (4/48), a natural defence mechanism (3/48) or of agricultural sprays (1/1). One apiarist observed the impacts were worse when general budding was poor (Figure 1.17). Additionally, some species were more notorious than others for producing substances ultimately toxic to honeybees. Such species included Grey Box, White Box and Red Bloodwood [Mallacoota]. Importantly, species could produce high honey yields and have no negative effect on honeybees until the weather changed, after which point the species would become 'toxic' to bees.

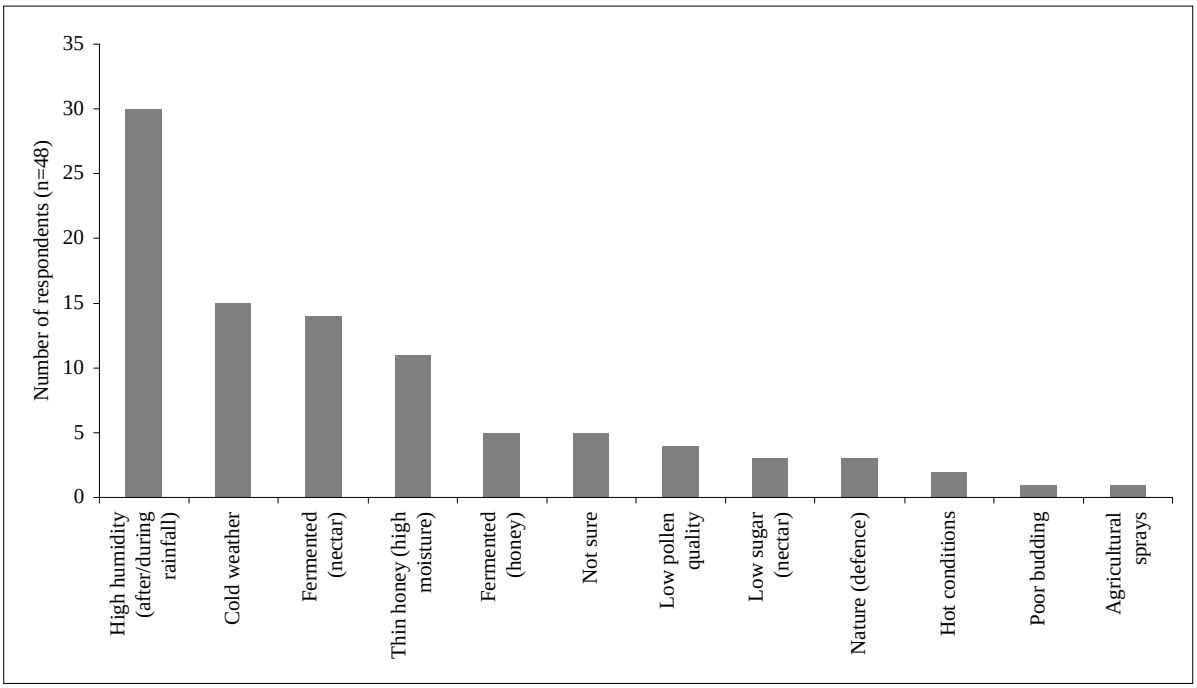

Figure 1.17 Factors 'triggering' pollen and/or nectar toxicity of melliferous flora to honeybees.

1.4 Discussion

This research was based on observations made over decades by very experienced individuals, each of whom was commercially dependent on having a strong understanding of flowering and nectar production patterns. Knowledge of flowering ecology, as well as the factors influencing flowering and nectar production, was critical for their livelihood and, ultimately, for the broader community. In fact, this research supported an earlier finding that apiarists have conducted the longest, most detailed study known on flowering patterns in any species (Birtchnell 2002). Apiarists' reliance on his or her own observations also means that each apiarist represents a single long-term study and thus, act as a replicate to be compared against studies undertaken by other apiarists. Therefore, this research is the most replicated and long-term study considering such a large group of species across such a wide area. Previous efforts to undertake similar research were valuable but were restricted only to one Australian state and/or genus (Somerville 1999; Birtchnell and Gibson 2006). Furthermore, this is the first study to consider flowering frequency, period **and** intensity **and** the relationship between flowering and nectar production in more than one genus in multiple Australian states and territories. This research also investigated several key issues identified by apiarists which have a significant, deleterious impact on the Australian beekeeping industry.

1.4.1 Flowering patterns

Whilst several species flowered annually, most species had more infrequent flowering episodes with the mode of responses for most species indicating two to four year intervals between flowering were most common. Similar patterns were observed in *Eucalyptus regnans* (Ashton 1975) and other melliferous species in Victoria (Birtchnell and Gibson 2006) and New South Wales (Somerville 1999). Indeed, a species-by-species comparison of the flowering frequencies reported here and in previous studies of melliferous flora (e.g. Somerville 1999; Birtchnell and Gibson 2006) indicated strong analogies. Subtle variations between flowering frequencies reported here and elsewhere may be due to differences in the level of detail presented (that is, the number of categories grouping the number of observations) and, more fundamentally, the spatial and temporal ranges from which observations were made. This is to be expected, and further highlights the value of long-term, broad scale data sets; such datasets reduce the 'noisy' element of data resulting from a number of factors (including those previously discussed) because results are averaged across a wider geographic and temporal area (Sparks et al. 2000).

Very few species considered in this study had a dependable flowering frequency, with short-term variations in flowering frequency commonly observed although less so in annual flowering species such as Leatherwood. This may explain why much of the literature relating to flowering frequency considers annual species – determining the factors which regulate flowering frequency would be more practical in species which flower at predictable (and short) intervals than those with extended and variable flowering frequencies. Nonetheless, factors controlling flowering frequency are complex (Ashton 1975). Whilst there is a growing mass of research which considers the role of genetics in flowering regulation (akin to 'natural cycles'), observable factors such as rainfall, temperature and moisture availability also have been considered (e.g. Porter 1978; Pook et al. 1997; Law et al. 2000) and were found in this study to influence flowering frequency. Flowering intensity was influenced by similar factors, a finding common to Birtchnell and Gibson (2006).

Spatial variation in flowering frequency was attributed to localised rainfall (and, hence, subsoil moisture) and floods, as well as soil type though to a lesser extent. In a political context, the impact of flood regimes is critical: further research, undertaken in conjunction with apiarists, is urgently needed to determine the optimum volume and timing of release of environmental flows, such as those planned along the Murray River (e.g. Thoms et al. 2000; Chong and Ladson 2003), for flowering ecology. Flows at the wrong time jeopardise survival of riparian and floodplain species (e.g. Jolly et al. 1996; Thoms et al. 2000) and the species and industries which are dependent on the survival of these species. This research should be implemented urgently.

Spatial variation in the timing of flowering also was observed and was possibly highlighted by extended flowering periods in those species used by more apiarists. Specifically, variation in flowering period was typcial between northern and southern areas of a species range. This has been observed in other studies, although in the northern hemisphere, southern areas flower before northern areas as temperature increases radiate laterally from the equator (Sparks et al. 2000). Flowering commencement in all plants considered in a British study which used long-term data was significantly related to temperature (Sparks et al. 2000) and Keatley et al. (2002) found temperature most powerfully explained the flowering periods of several Victorian melliferous eucalypts. Like Sparks et al. (2000), Keatley et al. (2002) used long-term data to reach this conclusion. These studies support observations made by apiarists involved in this research and hold interesting implications for the impact of climate change on flowering patterns. These implications are further compounded by beekeepers' observations that long-term changes in flowering and nectar production correspond to unseasonal rainfall patterns. Indeed, rain 'at the right time' was identified as a factor affecting all aspects of flowering and nectar production considered in this study. Rainfall patterns are predicted to be affected by global warming and some studies revealed rainfall patterns already have altered (e.g. Zhang et al. 2007). Altitudinal differences in the onset of flowering also may be affected by climate change as the higher areas, historically cooler than the lower areas, become homogenous.

1.4.2 Nectar production

Nectar production is related to honey production, as the volume of nectar secreted is indirectly reflected by the volume of the honey yield (see Law and Chidel 2007). This is not necessarily accurate, however, for a number of reasons. Firstly, other nectarivorous organisms may have depleted nectar resources prior to floral visitation by honeybees thus reducing honey yields, as less nectar is available for honeybees. Secondly, bee and colony health may reduce the quantity of nectar harvested and so, reduce the amount of honey produced. Also, more than one floral source flowering may be flowering at the time in that area. This could result in an increased honey yield, as there is more than one source of nectar from which to collect. Finally, there is a positive correlation between honeybee activity and temperature despite there being a negative correlation between temperature and nectar production (Bond and Brown 1979). Therefore, even though nectar production may be high during low temperatures, less nectar would be collected due to reduced honeybee activity, which is highest during warmer weather (Bond and Brown 1979). Care must be exercised when comparing honey yield to nectar production, however it can provide a valuable measure as long as these other influences are considered.

Most concerning is the apiarists' observed long-term decline in nectar production by Australian melliferous flora. Indeed, if nectar is produced at low temperatures, then increasing temperatures may decrease nectar production (and, thus, honey production) further. In addition, higher temperatures may increase the foraging potential of honeybees (which exhibit increased activity in warmer conditions), potentially to the disadvantage of other nectarivorous invertebrates and fauna. These species would already be finding it difficult to obtain nectar but also may have co-evolved with their food source and thus be more active at lower temperatures (i.e. less often). If this hypothesis is correct, then the instances of flowering events which do not yield commercial honey crops would increase and countless nectar-dependent species may perish. This situation is impacted further by the observation that nectar and rainfall/moisture at the 'right' time are linked and so, like flowering patterns, will be affected by climate change should predictions of altered seasons be correct. This would possibly increase the incidence of 'growth over budding', which was identified in this study as having a deleterious effect on nectar yields. Other tools used by apiarists to predict both flowering and nectar production could be studied in further detail, as they have the potential to be used by land managers and other industries.

1.4.3 Additional reports of effects on flowering and nectar production

This study represents the first detailed assessment of the interaction between Bogong Moths and Honeybees and was the result of incidental comments made during previous research by Birtchnell (2002). The impact of Bogong Moths on Honeybees and honey yields is interesting and requires further study – ideally with experimental methodologies. In addition, factors contributing to Bogong Moth plagues should be investigated, as these are the conditions contributing to decreased honey production. Also, research could consider the possibility of elemental arsenic being implicated: individual Bogong Moths were found to transport arsenic at low concentrations, however when Bogong Moths were *en masse*, as in a plague, arsenic levels were concentrated and bioaccumulation occurred (Green et al. 2001). The mostly likely source of arsenic carried by the Bogong Moths was agricultural land in which Bogong Moth larvae fed (Green et al. 2001). Research suggests that honeybees are sensitive to arsenic and so effects observed by apiarists may result from honeybees' detection of arsenic left in the floral cup by Bogong Moths. Additionally, this highlights the need for further research to be undertaken to determine the impacts of agricultural sprays on honeybees and honey production.

Impacts of logging on flowering ecology was another incidental topic raised during previous research with apiarists (Birtchnell and Gibson 2006); this study found that selective logging, whilst impacting honey yields, was less deleterious to flowering ecology and dependent fauna than clear-fell logging. Aside from the obvious impact this loss of resources has on nectarivorous fauna and ecological impacts such as edge effects, the impact of clear-fell logging on the beekeeping industry is significant.

The situation is exacerbated by the need for apiarists to retain apiary sites; sites which have been clear felled will not be commercially viable for years, even decades, yet annual lease fees must be paid in order for the leasing apiarist to maintain use of the site. Species used to regenerate the sites may not be as melliferous as those clear felled.

For the first time, detailed observations of pollen and/or nectar toxicity to honeybees were presented. The majority of apiarists considered nectar, rather than pollen, to be the cause of a devastating event. Symptoms associated include reduced honeybee and hive health, streaking of faecal matter in and on hives, dysentery, paralysis and 'drunken' behaviour. Infection by the microsporidian *Nosema apis* (nosema) was mentioned as being a symptom, however the use of this term probably relates to the set of symptoms just listed, as such symptoms commonly are attributed to *Nosema apis* despite our observations that the infection of affected honeybees by the parasite is rarely, if ever, confirmed. For example, Hornitzky (2008) found spotting on hives, a symptom identified by apiarists here, could not be used as an indicator of nosema as there was no association between spotting and nosema spore counts. In addition, apiarists involved in nosema studies often reported 'thin' honey, particularly during wet periods and/or towards the end of flowering in species identified here (e.g. Grey Box, Red Ironbark) (Hornitzky 2008). These conditions were reported by apiarists involved in this study but Hornitzky (2008) found no relationship between thin honey and environmental conditions and nosema spore counts. Thus, reports of *Nosema* generally relate to a set of symptoms (i.e. a 'condition') rather than an actual infection.

Certainly, we found that high bee mortality and other symptoms coincided with nectar and honey related issues, namely the high moisture content of honey in hives which precludes the ripening process. This may source from fermented nectar or may be fermenting in the hive, however observations of locomotory disorder and high mortality in workers suggests bees that collected nectar may not reach the hive. Thus, honey inside the hive may be fermenting due to a high moisture content. Indeed, the situation seems linked to flowering events which coincide with high humidity and cold weather and, therefore, most often affects bees collecting from species which flower during late autumn and early spring (e.g. Grey Box, White Box and Red Bloodwood [Mallacoota] in the latter stages of flowering) (Hornitzky 2008). The impact on apiarists is dramatic and extends beyond the problematic flowering episode as the hive takes up to a year to recover strength, hence annual honey production and income is severely affected. This situation requires additional research, although the potential for nectar to ferment and elicit symptoms like those reported by apiarists are considered in Section 2 of this report.

In summation, this study highlighted the long-term changes observed in flowering intensity, nectar production and the reliability of species and areas. Findings corresponded well to those reported in Birtchnell (2002) and other sources, but covered a broader geographic scale than previous studies. Factors influencing flowering ecology and tools used successfully by apiarists to predict flowering and nectar production also were investigated. Importantly, the research has highlighted critical areas for future research, namely the impact of flood regimes on flowering ecology, the effect of climate change on flowering and nectar production in honey flora and the anticipated impact this may have on the Australian beekeeping industry, and the impact of Bogong Moths and agricultural practices on honeybee health and behaviour.

2. Drunken honeybees – fact or fiction?

2.1 Introduction

Apiarists have long observed patterns in bee mortality, flowering and climatic conditions. In fact, apiarists report that, within a flowering episode, melliferous species can transform from valuable honey producers to savage killers (see Section 1.3.4.4). Beekeepers have also recognised that such a transformation primarily occurs in relation to increasing atmospheric humidity. For example, conditions experienced in the latter stages of autumn and throughout spring (when warm weather is interspersed with periods of rainfall and/or humidity) appear to trigger dramatic bee mortality (Section 1.3.4.4). Although high rainfall and atmospheric humidity are present during winter also, honeybees are less active (and, therefore, ingesting less nectar) during cold periods. Not surprisingly, then, melliferous species such as Grey Box and Red Bloodwood (Mallacoota), both of which flower through autumn (Figure 1.12), are notorious killers.

Grey Box provides apiarists with strong evidence of the relationship between honey production, bee mortality and atmospheric humidity: during the early stages of flowering, this species is one of Victoria's main honey producers, yielding up to 3 tins/hive (Table 1.1). The latter stages of flowering, however, coincide with late autumn/early winter and, therefore, increased atmospheric humidity. Beekeepers report that the first major autumn rainfall triggers massive bee mortality with several apiarists reporting losses of up to 90% of hive populations. Common symptoms exhibited by honeybees prior to death during this period include visible 'streaking' (smears of faecal matter) in and on hives, dysentery and 'drunkenness' (Section 1.3.4.4). Apiarists often use the term 'drunk' to best describe the behaviour of bees during this time, whereby bees fall from flowers to the ground, stagger and move in confused movements and, eventually, die. Generally, bees are not able to return to the hive and die *en masse*, often in front of the hive (Figure 2.1). One theory, based on observations of honeybees in Kenya, suggests that 'drunk' bees are detected by the colony and excluded from the hive (Hassan 1992). Importantly, a weak sugar solution which had fermented was inadvertently fed to honeybees in a caged feeding trial and had similar outcomes to those described here (R. Manning pers. comm. 2005).

Figure 2.1 Wandoo (*Eucalyptus wandoo* subsp. *wandoo*) in June 2006.

Dead honeybees carpet the ground in close proximity to the hive after humid conditions coincided with a Wandoo flowering event.

Over the years, the authors have heard many reports from the general community of bees acting 'drunk' and dying under trees, including *Robinia* species, Common Bottle-brush (*Callistemon longifolia*), Banksias, Lemon-scented Gum (*Corymbia citriodora*), Red Ironbark (*Eucalyptus tricarpa*) and various other eucalypt species (e.g. Birtchnell et al. 2005). Each episode reported by the public has coincided with similar climatic conditions as those identified by apiarists as triggering the problem. Observations are not restricted to honeybees. The authors have seen similar effects also affecting European Wasps (*Vespula germanica*) and native Flower Wasps (Tiphiidae) imbibing nectar from non-indigenous (planted) eucalypt species. Reports of drunken lorikeets are not uncommon; one Sydney reporter observed 'drunk' lorikeets feeding on *Schotia brachypetala.* This African species has the common name 'Drunken Parrot Tree' because it produces so much nectar that it ferments before it all can be consumed and has a narcotic effect on parrots (Wikipedia 2008). Dr Larry Vogelnest, a senior veterinarian at Taronga Zoo, has said 'basically, they [the lorikeets] behave like drunk people, staggering around … uncoordinated'.

It is possible that nectar could ferment, as it is a natural sugar solution and is therefore likely to be colonised by environmental micro-organisms, such as yeasts. In isolation, this would not result in fermentation, however, as the high sugar concentration would 'preserve' nectar. However, increased atmospheric humidity could encourage dilution of nectar reserved in the floral cup (atmospheric moisture - high, nectar moisture - low). In turn, reduced ratios of nectar sugars to water may reduce the sugars' ability to inhibit microbial growth (including yeasts) in the nectar. Thus, fermentation could occur, as ethanol is produced as waste by yeasts during sugar metabolism. Honeybees, when gathering this nectar, would thus be ingesting nectar laced with alcohol (ethanol) and may exhibit those symptoms observed by apiarists, the authors and members of the wider community.

This research, therefore, aimed to determine whether:

1. nectar, a naturally occurring sugar source, is colonised by yeasts
2. such micro-organisms ferment nectar retained within the floral cup
3. fermentation levels change throughout a species' flowering period and the relationship, if any, between alcohol concentration and climatic conditions, and
4. whether ingestion of fermented nectar by honeybees results in those symptoms reported by apiarists.

2.2 Methodology

2.2.1 Method development for nectar collection

Several methods for collecting nectar were trialled due to the difficulty in obtaining nectar. Early attempts to collect nectar from Yellow Box using the standard capillary tube method failed owing to the lack of nectar. Instead, floral cups were swabbed using urethral swabs moistened with sterile water. This allowed for culturing of microbiota but did not link microbiota specifically with nectar (although it is likely that yeasts in the floral cup *would* colonise nectar when present) nor did it enable investigation of ethanol in nectar. A subsequent method involved adding sterile water to the floral cup of Grey Box, *Eucalyptus microcarpa*, allowing the water to stand so as to 'wash' the floral cup of nectar traces, and then extracting this solution using a glass pipette and pipette filler. This method did not allow comparison of alcohol content, as the concentration of nectar diluted with water varied and, if present, alcohol would have been too diluted to be detected. These nectar collection trials provided valuable outcomes which guided the development of a very efficient and successful nectar collection method. Nonetheless, the aims of the research dictated the need to collect pure nectar which is notoriously difficult to obtain from the eucalypt species (e.g. Wilson 2002). Many visits to collect nectar thus were unsuccessful.

2.2.2 Nectar collection

Nectar was collected from four important melliferous species, Wandoo (*Eucalyptus wandoo*), Red Ironbark (*Eucalyptus sideroxylon*), Red Bloodwood (*Corymbia gummifera*) and Grey Box *(Eucalyptus microcarpa*). Other species were trialled unsuccessfully, for example Snow Gum (*Eucalyptus pauciflora*) around Lexton in western Victoria and Yellow Box (*Eucalyptus melliodora*), also in Victoria's western district. Sampling was conducted twice during a flowering episode, usually in the early stages and latter stages of flowering. In *Eucalyptus wandoo*, this resulted in two batches of nectar being obtained. In other species, nectar was obtained only during one sampling episode.

Nectar was extracted directly using a sterile technique from the floral cup of 60 flowers from three branches on each of ten trees (60 x 3 x 10 = 1 800 flowers sampled during each sampling effort for each species) (Figure 2.2). The high number of flowers from which nectar was collected is indicative of nectar scarcity; sampling fewer flowers would not have yielded sufficient nectar to address the aims of the research. Sterile glass pipettes were modified to more efficiently extract nectar – the pipette tip was heated over a Bunsen burner flame and pulled out to a fine, angled tube which was much finer than a capillary tube and bent for easier use. Modified glass pipettes were used in conjunction with a pipette filler, so that nectar could be 'sucked' from the floral cup and released into sterile eppendorf tubes.

During the first sampling period of Wandoo nectar, nectar from each branch was inserted into separate eppendorf tubes (∴3 tubes per tree) and analysed to determine variation within the tree. Whilst this provided highly detailed results, time constraints and insufficient nectar prevented continuation of this level of analysis. Subsequent samples then were combined on a tree level so that all nectar extracted from each tree (i.e. nectar from 60 flowers) was stored in one eppendorf tube (Figure 2.2). To minimise error, eppendorf tubes were immediately sealed with Parafilm M®, placed in resealable sandwich bags and placed in a cool Esky. Samples were transferred to a fridge (~ 4°C) as soon as practicable. Temperature and relative humidity were recorded at the time each tree was sampled.

Analysis of the nectar used a split sample approach, whereby part of the contents of each sample was used to determine the presence of yeasts and the remainder of the sample was used to determine the presence of alcohol (Figure 2.2). This enabled cross-analysis of the results of each treatment. In addition, split samples were considered more efficient than collecting two sets of nectar from each tree as the latter method would have required large and, probably often unattainable, volumes of nectar.

2.2.3 Determination of microbial presence in nectar samples

Using a standard sterile technique, a loopful of nectar from each eppendorf tube (and therefore each tree) was streaked across a plate containing Sabouraud's Dextrose Agar (Oxoid CM41). Plates were sealed with Parafilm M® and incubated in a culture cabinet at 18°C for 14 days (Figure 2.2). Colonies of yeasts were subcultured and purified. Samples of pure cultures were sent to Kerry Weeks (Mycology Laboratory, PaLMS, NSW) for identification where possible. The remaining nectar in each eppendorf tube was retained for determination of alcohol content.

2.2.4 Determination of alcohol content of nectar samples

Each nectar sample was analysed for the presence of alcohol using gas chromatography. Samples were manually injected (0.3 µL of each sample) into an Agilent Gas Chromatograph (Agilent Technologies 6890N Network GC system; column: Agilent 19091J-413 HP-5 5% phenyl methyl siloxane capillary, 30 m x 320 µm x 0.25 µm). Retention times of peaks were compared to various known alcohols and it was determined that ethanol was the alcohol present in nectar samples. Ethanol standards were manually injected and used to establish a calibration table which enabled determination of actual ethanol concentrations (% v/v) present in nectar samples.

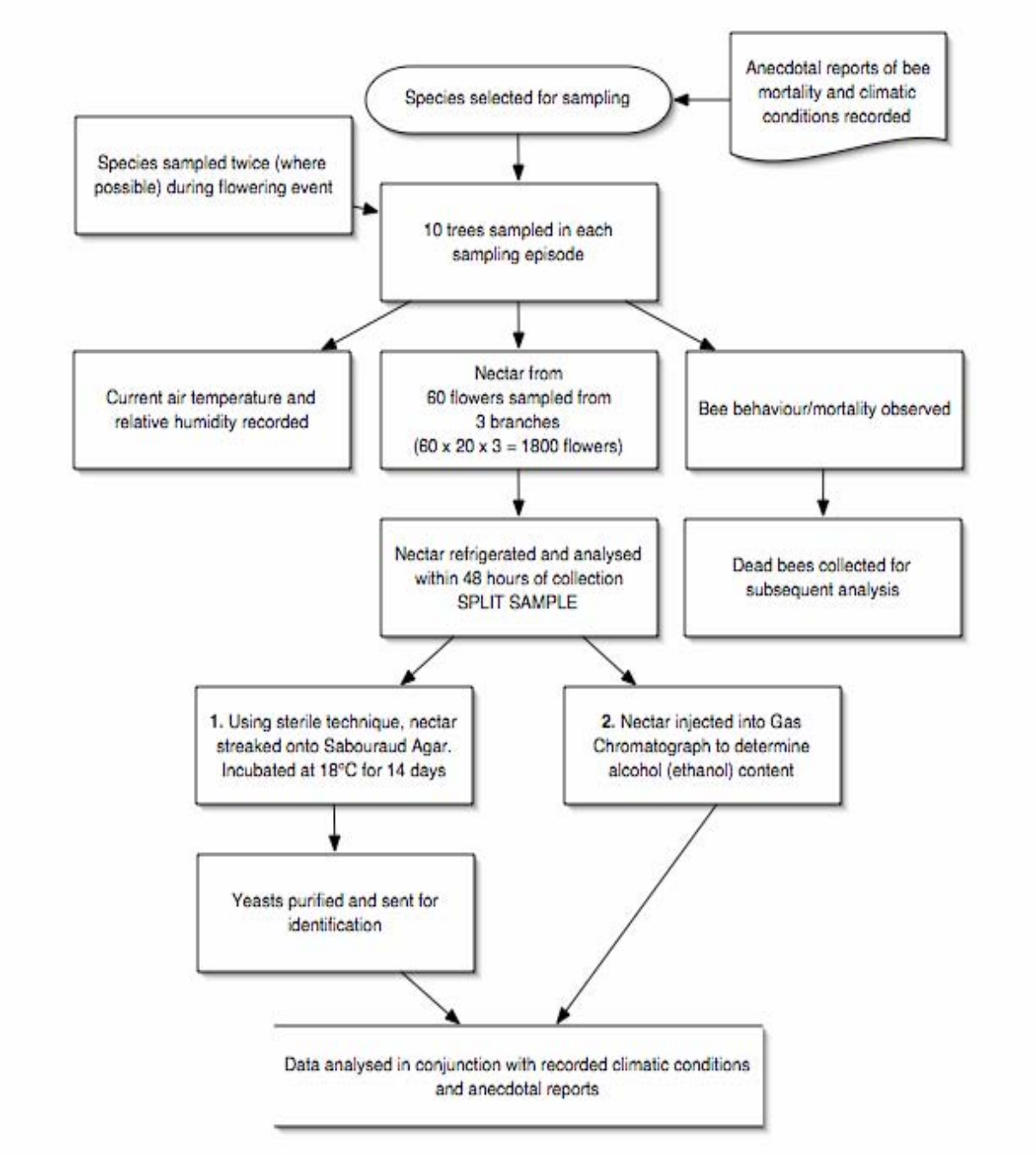

Figure 2.2 Method used to determine yeast presence and ethanol concentrations in nectar collected from melliferous flora.

* During the sampling periods, no episodes of mass bee mortality occurred and so, sampling of dead bees did not occur. However, an unsampled species flowered and killed bees *en masse* – these bees were collected and examined for Nosema (*Nosema apis*) spores but none were observed.

2.3 Results

Nectar was collected from ten trees of each species owing to the scarcity of nectar available for collection. Whilst nectar was found in approximately 70% of Wandoo trees, nectar was available only in two pockets of a Red Ironbark flowering event and in approximately 50% of trees. Red Bloodwood and Grey Box were particularly difficult, with less than 20% of trees yielding nectar. As a result, nectar was collected from ten trees in Wandoo and Red Ironbark and three trees in Grey Box and Red Bloodwood. Furthermore, attempts to collect nectar more than once during a flowering event were unsuccessful in species other than Wandoo, owing to dry, warm weather conditions. Wandoo was sampled twice: the first sampling episode immediately followed a period of honeybee toxicity and high humidity (Figure 2.1) whilst the second sampling event was undertaken two weeks later during dry, mild conditions.

2.3.1 Nectar mycology

Yeasts were present in nectar from all melliferous species considered in this study (Table 2.1). although not all trees within a species had all yeast species present (Table 2.2). Only four identifiable yeast species were cultured from nectar and these belonged to two genera: *Candida* and *Rhodotorula* (Table 2.1 and Table 2.2).

Table 2.1Yeasts observed in nectar from Australian melliferous flora.

	Yeast species				
	Candida sake	*Candida pulcherrima*	*Candida ?magnoliae*	*Rhodotorula glutinis*	Undet. sp.
Wandoo	✓	✓		✓	Black pigmented var. + other
Red Ironbark	✓	✓			✓
Grey Box			✓		
Red Bloodwood	✓				

Table 2.2 Comparison of yeasts isolated from trees within each native melliferous species.

	Yeast species					
	Tree number	*Candida sake*	*Candida pulcherrima*	*Candida ?magnoliae*	*Rhodotorula glutinis*	Undet. sp.
Wandoo – sampling episode 1	1	✓			✓	✓
	2		✓		✓	✓
	3	✓	✓		✓	
	4	✓			✓	✓
	5					
	6				✓	
	7	✓			✓	
	8		✓		✓	✓
	9					
	10	✓				
Wandoo – sampling episode 2	1		✓			
	2	✓	✓			
	3	✓			✓	
	4					None
	5					
	6					
	7				✓	
	8				✓	
	9	✓				
	10		✓		✓	
Red Ironbark	1		✓			Candida sp.
	2		✓			
	3		✓			
	4		✓			
	5	✓				✓
	6		✓			
	7		✓			
	8		✓			
	9		✓			
	10		✓			
Grey Box	1			✓		
	2					None*
	3					None*
Red Bloodwood	1	✓				
	2					
	3					

*No yeasts were detected, only bacteria.

2.3.2 Nectar fermentation

Nectar produced by Australian melliferous flora can ferment; alcohol (ethanol) was found in nectar collected from all species, although levels varied within and between species (Figure 2.3). Wandoo and Red Ironbark recorded higher ethanol volumes than Grey Box and Red Bloodwood (Figure 2.3), although no climatic variables were found to account for such differences. Average ethanol levels in nectar differed between sampling events in Wandoo; the first sampling event yielded an average of 0.02% v/v ethanol (range: 0.01 – 0.05% v/v) whilst the second samples yielded an average of 0.01% v/v ethanol (range: 0.00 – 0.03% v/v) (it is important to remember that the same trees were not necessarily sampled during both sampling efforts). Only trace amounts of ethanol were detected in Grey Box nectar (range: 0.001 – 0.002, i.e. 0.00 % v/v) and in nectar from one Red Bloodwood tree (0.0043% v/v) (Figure 2.3).

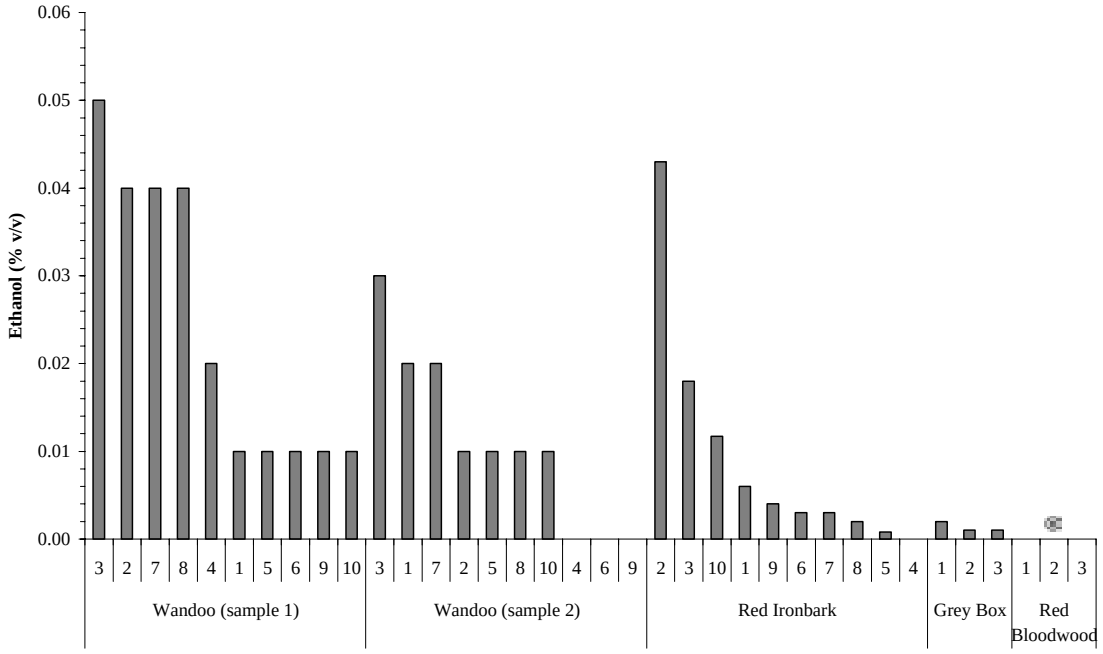

Figure 2.3 Ethanol (% v/v) found in nectar collected from native melliferous species. The numbers along the x axis represent the tree from which nectar was collected. In the case of *E. wandoo*, the same trees were not necessarily sampled during sampling effort 1 *and* 2. ⊙ trace quantities of ethanol were detected in this tree (0.00043% v/v ethanol).

2.4 Discussion

For the first time, ethanol has been detected and quantified in nectar produced by Australian melliferous flora. Much research has considered honey fermentation in hives and, particularly, in storage (e.g. Fabian 1932) but has not measured nectar fermentation. This is despite innumerous sources which discuss 'fermented' nectar (e.g. reports of lorikeets etc.).

We found that nectar was colonised by yeasts and that nectar obtained directly from the floral cup was fermented. Certainly, yeasts isolated from nectar are known fermenting agents (e.g. Zohre and Erten 2002; Rementeria et al. 2003; and are used by the Australian wine-making industry and, in the case of *Candida sake*, in the production of Sake (sake-moto). Of interest is the notion that *Candida* species initiate fermentation and often are dominant at the beginning of fermentation but die off as ethanol concentrations increase, being replaced by the strongly fermentative *Saccharomyces cerevisiae* (Heard and Fleet 1986; Ciani 1997). This suggests that nectar used here may recently have begun fermenting when collected and that yeast species composition and the volume of ethanol present in nectar may vary, possibly in relation to temperature and humidity as observed by the apiarists. Therefore, ethanol quantities presented may be modest in comparison to potential ethanol levels. Further research should

be undertaken in order to monitor changes in yeast populations and in ethanol levels, potentially under artificial climatic treatments. Also, fermentative bacteria could be considered for their role in fermenting nectar.

Evidence exists that ethanol levels can vary during a flowering episode and that humidity could play a role in fermentation. Wandoo nectar collected during the first sampling event yielded higher ethanol levels than nectar collected subsequently (Figure 2.3). In addition, ethanol was detected in nectar from more trees sampled during the first sampling event than in nectar collected from the second event. This suggests that ethanol levels may have been higher during the first sampling event owing to climatic conditions immediately preceding nectar collection. These conditions coincided with mass honeybee mortality, which ratifies apiarists' observations and those reported by the general public. Studies to further strengthen this evidence are necessary and of high importance to the beekeeping industry.

The question remains: can honeybees exhibit symptoms described by apiarists? In nature, there are many sources of ethanol, for example, fermenting plant matter. Thus, some insects such as the fruit fly, *Drosophila melanogaster*, are exposed regularly to ethanol yet are resistant to the alcohol's toxic effects (Guarnieri and Heberlein 2002). Fruit flies metabolise ethanol efficiently, using ethanol as an energy source and for lipid biosynthesis (Guarnieri and Heberlein 2002). Nonetheless, at high concentrations, ethanol is toxic to fruit flies (McKechnie and Greer 1984). The primary ethanol-metabolising pathway in fruit flies (and in mammals) involves two enzymes: Alcohol Dehydrogenase (ADH), which oxidises ethanol to acetaldehyde, and Acetaldehyde Dehydrogenase (ALDH), which converts the acetaldehyde to acetate (Guarnieri and Heberlein 2002). ADH plays a vital role in ethanol detoxification and flies which lack functional ADH are much more sensitive to ethanol (Guarnieri and Heberlein 2002). *Drosophila* larvae and adults metabolise ethanol differently, with ADH being more useful than ALDH in ethanol metabolism by larvae (Geer et al. 1985). Of interest to us, is that honeybees also display ADH activity (Martins et al. 1976) and thus, can metabolise alcohol. Like *Drosophila*, alcohol metabolism during larval stages differs to adults – ADH was not detected in young larvae and was absent in emerging bees, but was at maximum levels in pre-pupal and white-eyed pupal phases (Martins et al. 1976). This suggests that larvae have evolved with ethanol and that fermenting nectar or honey in the hive, when fed to larvae, is of little consequence and is metabolised efficiently. Adult honeybees, however, are less able to metabolise alcohol and yet will readily consume ethanol solutions (Abramson et al. 2000).

Honeybees and fruit flies metabolise alcohol in a similar way to vertebrates and display similar behavioural responses (Guarnieri and Heberlein 2002). At low doses of ethanol, the insects and vertebrates exhibit stimulation (e.g. disinhibition and euphoria) whilst high doses result in sedation (incoordination, confusion, coma and death) (Guarnieri and Heberlein 2002). As internal ethanol levels rise, an initial increase in locomotion is followed by incoordination, loss of bodily control and eventually sedation and immobility/paralysis (Guarnieri and Heberlein 2002). These symptoms all have been reported by apiarists describing honeybee behaviour following ingestion of what we show is probably fermented nectar. Further, fruit fly experiments showed that ethanol dramatically affected walking patterns, where intoxicated flies rarely walked in straight lines and often changed direction (Singh and Heberlein 2000) (i.e. staggered and appeared 'drunk', as per apiarists observations of honeybees). In addition, after extended exposure to ethanol, flies became sedated and often fell on their sides or backs. Similarly, bees showed difficulty walking and flying after consuming ethanol-laced solutions and locomotion tests revealed that the response of bees given alcohol was 75% lower than bees given sucrose (Abramson et al. 2000). Both honeybees and fruit flies, therefore, have been used to model ethanol consumption in vertebrates (including humans) (e.g. Abramson et al. 2000; Guarnieri and Heberlein 2002). The extent to which native invertebrates are affected is unknown and deserves further consideration.

In conclusion, we have found that nectar from several Australian melliferous species is colonised by yeasts, which ferment nectar to varying extents, and this is likely to be influenced by high humidity. Honeybees will readily consume fermented nectar and will experience behavioural responses ultimately leading to those symptoms observed by apiarists, the authors and the general public. Further research should be implemented to develop further this understanding.

3. Pollen quality and honeybee nutrition

3.1 Introduction

Pollen sources have been declining for many years as countries become more industrialised. Australia is no exception. Our forests with their multiple pollen sources have made way for towns and associated infrastructure and for agricultural systems consisting of single or very few pollen sources. Climate change and increased salinisation of soils has added further stresses to cause decline in pollen availability, as has logging. This is of serious concern, more so as pollen quality, thus bee and hive health also may be affected.

To maintain healthy bees and hives, we need to know which species provide good quality pollen and how variable pollen quality and availability is with time, particularly in the long term so that appropriate management can be implemented with greatest efficacy. It was detailed in the Introduction that long term data sets are important for determining plant phenological and ecological cycles (Franklin 1989); Pace and Cole 1989; Specht and Brouwer 1975, White 1995), particularly where events display high variability and/or complex phenomena (Franklin 1989; Tilman 1989). Thus long-term observations are needed to determine the factors affecting quality and quantity of pollen. It is well known that pollen quality varies from species to species but reports on pollen quality suggest variation also may occur within a species.

Pollen quality usually is determined by nutritional levels (Keller et al. 2005). A number of studies have investigated pollen nutrition including protein (Roulston et al. 2000; Somerville and Nicol 2006), amino acid (Roulston and Cane 2000; Somerville and Nicol 2006), lipid (Day et al. 1990; Manning and Harvey 2002; Singh et al. 1999; Somerville 2005; Todd and Bretherick 1942; Youssef et al. 1978) and mineral analyses (Herbert and Miller-Ihli 1987). These are important works and provide knowledge of the nutritional breakdown of pollens but there is some argument as to what nutritional components should be used to determine pollen quality (Keller et al. 2005). Ultimately, it is bee and hive health that should be the final determinants of pollen quality as this is the aim of having good quality pollen. If pollen is not of good quality, bee and hive health deteriorates, something for which beekeepers are ever watchful. Also, beekeepers know how much variation occurs over extended periods of time and pay careful attention to any factors that may cause such variation. They have been making such observations for generations! Their livelihood depends on it. The aim of this section of the study was to determine variation in pollen quality of melliferous plants, aspects of pollen nutrition and underlying causes to any variation by tapping into the long-term knowledge of apiarists.

Keller et al. (2005) presented a review on pollen nutrition and colony development in honeybees. All studies they reviewed reported that the bulk of pollen collected came from only a small number of plant species and that agricultural crops played an important role as pollen sources. Moezel et al. (1987) suggested that although the composition of bee-collected pollen could reflect the abundance of particular plant species, it also could reflect true preferences of bees. Visscher and Seeley (1982) reported that bees showed preferences and foraged on only a few species on any single day, even if another more abundant species was present in the foraging area. Because of this, they suggested bees had dislikes for certain pollens as well as preferences. Bee preference could vary from year to year (Moezel et al. 1987). Pollen quality as determined by nutritional value varies with plant species. It is unknown whether bees prefer pollens with higher nutritional value although it has been suggested both anecdotally and in the literature (Cook et al. 2003; Waddington et al. 1998). If the foraging likes and dislikes of bees are known, chemical analyses of such pollen can determine their nutritional content. This knowledge is important for management of apiaries and the bee industry as it would then be known which species to focus attention on so as to protect important pollen resources. This study also investigates whether or not apiarists have noticed a preference for particular pollen sources by their bees.

When pollen quality is poor, beekeepers must use a supplement or risk the health of their bees and hives. If protein is insufficient, brood rearing decreases markedly (Kleinschmidt and Kondos 1976), and bees do not live as long (Sakagami and Fukuda 1968). Another aspect of this project was the investigation of pollen substitutes by beekeepers, in the first instance to determine whether any honey flows required pollen supplements more so than other honey flows, and secondly to determine what ratio of protein, fatty acids and other components of pollen supplements is considered necessary to maintain hive health.

3.2 Methods

A total of 66 apiarists were sent surveys on pollen quality and bee nutrition. Thirty returned completed forms. Notification was received regarding another eight beekeepers who, unfortunately, had either died or become too ill to participate in the survey. Taking this into account, the response rate was 52%. This is considered very good as normally a 25 to 35% response is considered adequate (Somerville 2004). It also must be remembered that these beekeepers previously had been interviewed for 3-5 hours regarding flowering and nectar production patterns, so the survey on pollen quality and bee nutrition was a second impingement on their time. Again, only apiarists who had operated commercially for a minimum of 30 years and managed a minimum of 400 hives at any one time were included in the survey. This ensured apiarists had an intimate and long-term understanding of pollen quality and its variation, and of bee nutrition. Participants resided in Victoria, New South Wales, Tasmania and South Australia.

The questionnaire consisted of 20 closed and open-ended questions (Appendix 3) which can be divided into categories.

1. Identification of pollen detrimental to hive health.
2. Variation in pollen quality and underlying causes: this set of questions aimed to determine the main pollen flora used and their pollen quality, whether short- or long-term variation in quality occurred within species and whether this varied seasonally or geographically.
3. Pollen preferences: these questions were to determine whether bees showed particular likes or dislikes for any pollen sources and whether these changed with time. Factors that influenced bee choice for a pollen source also were investigated.
4. Pollen effects on health: these questions determined whether particular pollens were more or less beneficial to bee and hive health than others and what specific effects were observed. Questions also aimed to determine whether a single pollen source was sufficient to maintain hive health or build hive populations or whether multiple pollen sources were necessary.
5. Pollen substitutes: the aim of this set of questions was to determine whether apiarists used pollen substitutes to maintain or improve hive health or build hive populations. Investigations were conducted into whether or not apiarists made their own pollen substitutes and what ratio of protein, fatty acids and other nutritional components were used.

3.3 Results

3.3.1 Identification of pollen detrimental to hive health

About half of the apiarists believed they could identify which pollen was detrimental to hive health if multiple pollen sources were available at the apiary and hive health was declining (Figure 3.1), but there was no consistent manner used by the apiarists. All, however, used multiple criteria to determine harmful pollen: colour (5/15), feel (1/15), oily appearance (1/15), small amounts collected (3/15), appearance of brood (4/15), quality of brood (4/15), smell of the hive (1/15), smell of bee gut (1/15), bee death (2/15), occurrence of nosema in the following spring (1/15).

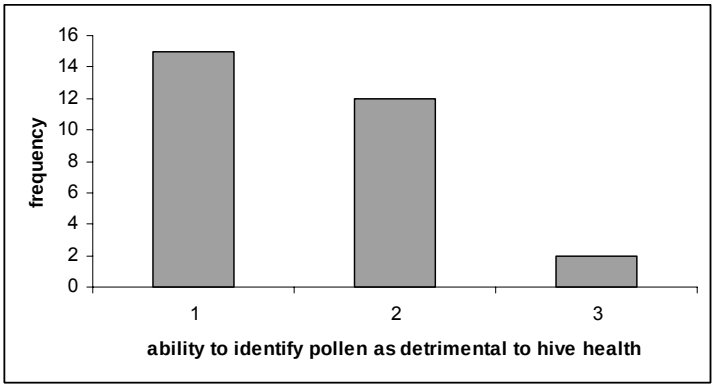

Figure 3.1 The ability of apiarists to identify pollen as detrimental to hive health. 1. number of respondents in the affirmative; 2. number of respondents in the negative 3. number of non respondents.

3.3.2 Variation in pollen quality and quantity and underlying causes

Pollen quality was recorded for 97 species (Table 3.1) using a scale of 1-5, where one reflected very low and 5 reflected very high quality. These species constituted the main pollen sources used by apiarists. Forty-six species were cited only once, 15 twice, ten thrice and all others more than five times out of a possible 30. Only seven species were cited by more than 10 respondents: River Red Gum, Cape Weed, Canola, Messmate, Patersons Curse, Grey Box, and Stringy Bark. River Red Gum and Cape Weed were by far the most commonly used species. Fifty species were considered to have an average pollen quality of four or greater, 22 species two or less (Table 3.1; Figure 3.2). Just over half the species (50) appeared to have a consistent pollen quality (Table 3.1; Figure 3.2) when one considered responses from all respondents, but 46 of these were cited by only one apiarist. The other four species were cited by two or three respondents. Forty-seven species had a variable pollen quality (column 2, Table 3.1; Figure 3.2) when considering all respondents. Twelve varied in quality from 1-5 and included six of the above seven species. Clover had a reliable and high pollen quality of 4-5 (9/30), as did Turnip, Onion Weed, Almonds and Spotted Gum cited by 6/30, 5/30, 5/30, and 4/30 respondents respectively. Thus it appears that introduced species are more reliable than native species.

When pollen quality was considered on the basis of the experience of each individual apiarist, only 12 species had variable quality (column 4, Table 3.1), i.e. in the experience of each apiarist, pollen quality was constant for most species. But different apiarists gave different ratings for a single species, thus in the above paragraph, 47 species were cited as having variable pollen quality. It would seem that pollen quality varied from site to site because of this.

Table 3.1 Pollen quality of species considered a good nectar source on a scale of 1-5 where 1 reflects a very low pollen quality and 5 a very high pollen quality.

Species	average pollen quality rating	range of rating	number respondents citing species (n = 30)	number of respondents who consider pollen quality variable
St Barnaby Thistle *Centaurea solstitialis*	5	5	2	0
Gorse *Ulex europaeus*	5	5	2	0
Pear *Pyrus communis*	5	5	1	0
Yellow Bloodwood *Corymbia eximia*	5	5	1	0
Blakely's Red Gum *Eucalyptus blakelyi*	5	5	1	0
Crowfoot *Erodium cicutarium*	5	5	1	0
Yellow Mallee *E. incrassata*	5	5	1	0
Orange Trees *Citrus* spp	5	5	1	0
Clover *Trifolium* spp	4.9	4 to 5	9	0
Almonds *Prunus dutas*	4.8	4 to 5	5	0
Spotted Gum *Corymbia maculate*	4.8	4 to 5	4	0
Messmate *Eucalyptus obliqua*	4.7	1 to 5	14	0
Turnip *Brassica rapa*	4.6	4 to 5	6	0
Hill gum *Eucalyptus fasciculosa*	4.5	4 to 5	2	0
Faba beans *Vicia faba*	4.5	4 to 5	2	0
Lignum *Muehlenbeckia florulenta*	4.5	4 to 5	2	0
Strawberry Clover *Trifolium fragiferum*	4.5	4 to 5	1	1
River Red Gum *E. camaldulensis*	4.4	1 to 5	20	0
Onion Weed *Asphodelus fistulosus*	4.4	4 to5	5	0
Manna Gum *Eucalyptus viminalis*	4.3	1 to 5	8	0
Peppermint *Eucalyptus radiata*	4.3	3 to 5	3	0
Stringy Bark *Eucalyptus* spp	4.2	3 to 5	11	0
Patersons Curse/Salvation Jane *Echium plantagineum*	4.1	2 to 5	14	1
Blue Gum/Yellow Gum (SA) *Eucalyptus leucoxylon*	4	4	3	0
Tea Tree *Leptospermum lanceolata*	4	3 to 5	3	0
Skeleton Weed *Chondrilla juncea* .	4	4 to 5	3	0
Onion Grass *Romulea rosea*	4	4 to 4	2	0
Red Mallee *E. oleosa*	4	4	2	0
White Box Spring *Eucalyptus albens*	4	4	1	0
Green Mallee *Eucalyptus viridis*	4	4	1	0
Apple *Malus domestica*	4	1 to 4	1	0
Wildflowers Tas	4	4	1	0
Coastal Wattle (SA) *Acacia longifolia*	4	4	1	0
Mallees *Eucalyptus* spp	4	4	1	0
Soap Mallee *E. diversifolia*	4	4	1	0
Yellow box *Eucalyptus melliodora*	4	4	1	0
White Clover *Trifolium repens*	4	3 to 5	1	1
Sydney Blue Gum *Eucalyptus saligna*	4	4	1	0
Ellangowan *Myoporum deserti*	4	4	1	0
Boobialla *Myoporum insulare*	4	4	1	0
White Mallee *E. Dumosa*	4	4	1	0
Coolibah *Eucalyptus intertexta*	4	4	1	0
Daisies	4	4	1	0
Sweet Rough Barked Apple *Angophora floribunda*	4	4	2	0
Ribbon Gum *E. nobilis*	4	4	1	0
Swamp Gum *E. ovata*	4	4	1	0
Paddy Melon *Cucumis myriocarpus*	4	4	1	0

Species	average pollen quality rating	range of rating	number respondents citing species (n = 30)	number of respondents who consider pollen quality variable
Shaggy pea *Dillwynia*	4	4	1	0
Tallow Wood *Eucalyptus microcroys*	4	4	1	0
Long Leaf Box *Eucalyptus. goniocalyx*	3.8	2 to 5	7	1
Brown Stringy Bark *Eucalyptus baxteri*	3.8	1 to 5	4	1
Cape Weed *Arctotheca calendula*	3.7	3 to 5	19	2
Apple Box *E. bridgesiana*	3.7	3 to 5	3	0
Blackberry *Rubus fruticosus*	3.7	3 to 4	3	0
Lucerne *Medicago sativa*	3.7	3 to 4	1	0
Giant Angular Mallee *Eucalyptus angulosa*	3.6	1 to 5	7	0
Christmas Mallee *Eucalyptus socialis*	3.6	3 to 5	5	0
Ironbark (other)	3.5	3 to 4	1	1
Turnip Mallee *Brassica rapa* subsp. *sylvestris*	3.3	1 to 5	6	0
Canola *Brassica napus*	3.2	1 to 5	15	0
Red Stringy Bark *Eucalyptus macroryncha*	3.2	1 to 5	9	1
Thistle	3.2	1 to 5	6	2
Dandelion *Taraxacum officinale*	3.2	1 to 5	5	0
Banksias	3.2	2 to 4	5	0
Blue Mallee *Eucalyptus polybractea*	3	1 to5	2	0
Evening Primrose Oenothera biennis	3	2 to 4	2	0
White Stringybark *Eucalyptus globoidea*	3	3	2	0
Blue Gum Tas *Eucalyptus globulus*	3	3	1	0
Inland Bloodwood *Eucalyptus polycarpa*	3	3	1	0
E. foecunda	3	3	1	0
Epacridaceae (Heath)	3	3	1	0
Acorn Mallee *Eucalyptus oleosa*	3	3	1	0
Heliotrope *Heliotropium amplexicaule*	3	3	1	0
Leatherwood *Eucryphia lucida*	2.7	1 to 4	3	0
Sugar Gum *Eucalyptus cladocalyx*	2.6	2 to 3	6	1
Willow *Salix* spp	2.5	1 to 4	2	0
Yellow Mallee *Eucalyptus incrassata*	2.4	2 to 3	5	0
Blackbox *Eucalyptus* largiflorens	2.3	1 to 3	3	0
Grey Box *Eucalyptus microcarpa*	2.1	1 to 5	12	3
Red Mallee *Eucalyptus calycogona* or *E. gracilis* or *E. oleosa* or *E. socialis*	2	1 to3	2	0
White Box Winter *Eucalyptus albens*	2	2 to 2	1	0
Flat Weed *Hypochoeris radicata*	1.9	1 to 4	7	0
White Box Unspecified *Eucalyptus albens*	1.8	1 to 4	3	0
White Mallee *Eucalyptus gracilis*	1.5	1 to 2	2	0
Acacias	1.3	1 to 2	4	0
Pine	1	1	3	0
(Yellowgum/Bluegum (SA) *Eucalyptus leucoxylon*	1	1	2	0
Napunyah/Yapunyah *Eucalyptus ochrophloia*	1	1	2	0
Golden Wattle *Acacia pycnantha*	1	1	1	0
Cherry *Prunus* spp	1	1	1	0
Rye Grass *Lolium* sp	1	1	1	0
Corn *Zea mays*	1	1	1	0
Hop Bush *Dodonea* sp	1	1	1	0
White Gum *Eucalyptus dunnii*	1	1	1	0
Blackwood *Acacia melanoxylon*	1	1	1	0
Prickly Box *Bursaria spinosa*	1	1	1	0

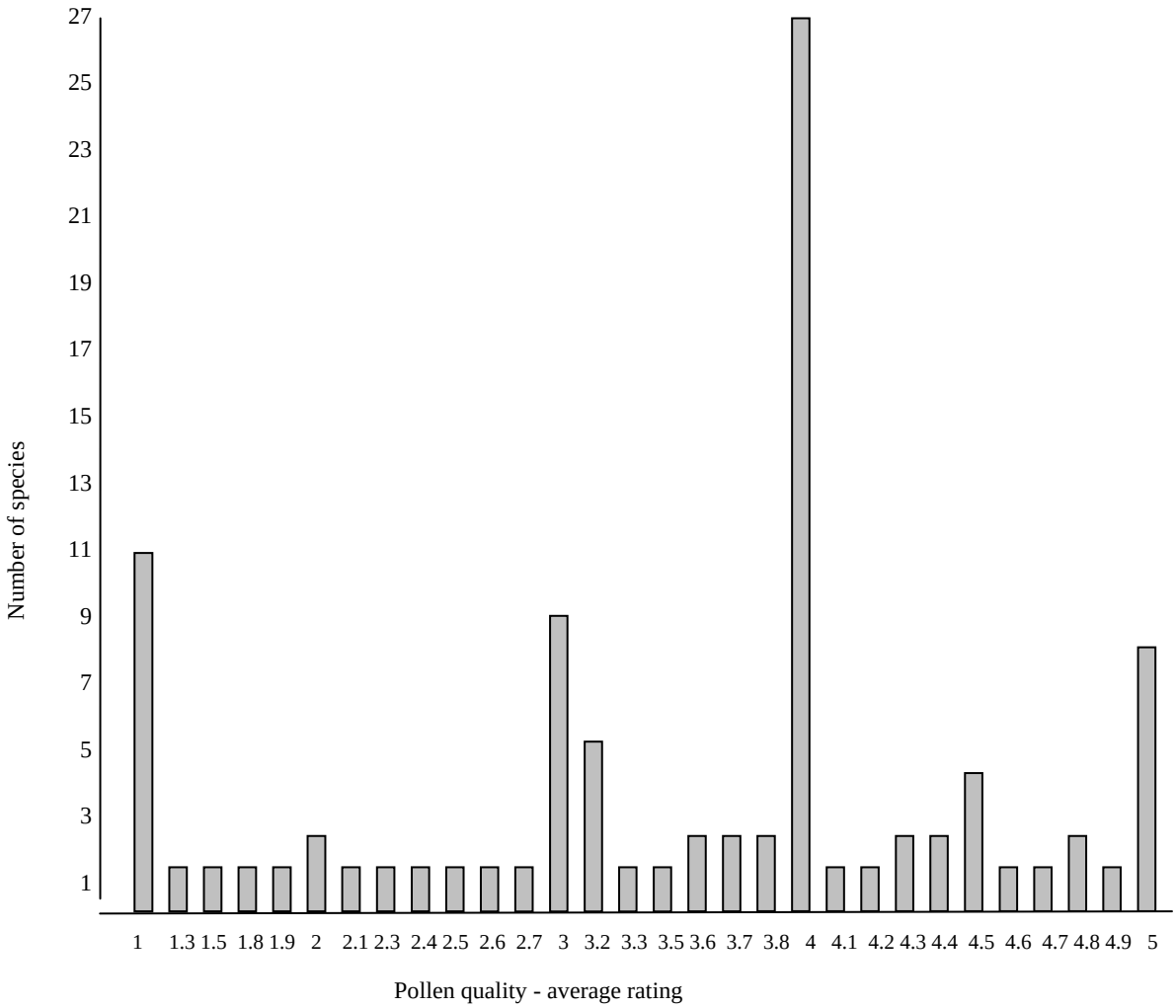

Figure 3.2 Frequency of mean pollen quality on a scale of 1-5. 1 reflects a very low pollen quality and 5 a very high pollen quality.

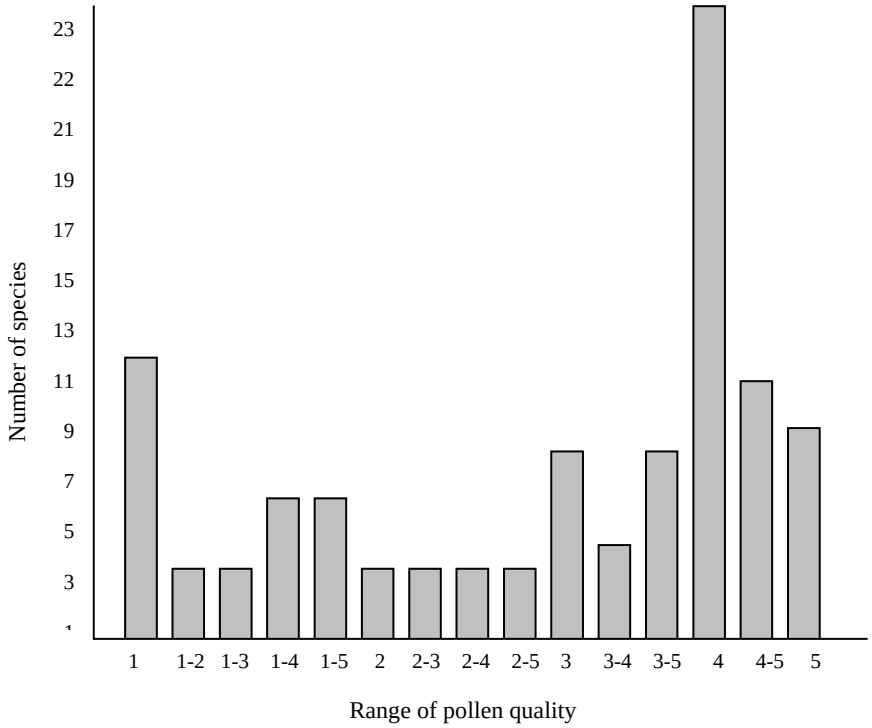

Figure 3.3 Ranges of pollen quality as determined by beekeepers on a scale of 1-5. 1 reflects a very low pollen quality and 5 a very high pollen quality.

When apiarists specifically were asked whether pollen quality could vary within a species in the short-term the majority said it could vary during a single flowering event, on a seasonal basis (in longer flowering species) and from site to site (Table 3.2). Few provided comments for this question but those who did considered temperature and rainfall to be most significant in determining pollen quality. Hot temperatures were considered detrimental but rainfall beneficial. Budding intensity and soil type also were believed to affect pollen quality. Species cited as having variable quality were Grey Box in particular, which was not surprising as it was one of the 12 species identified as variable in Table 3 (column 4), Patersons Curse, also identified above, and Canola and Lucerne, neither of which was identified in Table 3, column 4, as one of the species with variable pollen quality. In a question identifying what factors were used to rate pollen quality, Red Stringy Bark was cited as variable depending on soil type (see below).

Table 3.2 Infraspecific variation of pollen quality

variation (n = 30 in each instance)	no. apiarists stating pollen quality varied	no. apiarists stating pollen quality did not vary	no. apiarists that did not know whether pollen quality varied	no. apiarists who did not answer question
during a flowering event	21	6	2	1
on a seasonal basis	23	4	0	3
from site to site	15	8	1	6

When asked whether long term variation occurred in pollen quality within a species, 13/30 apiarists said yes, 15/30 no, one did not know and one did not answer. Again not surprisingly, Grey Box was cited by 5/13 apiarists that said yes and River Red Gum by 4/13. Also cited were, Sugar Gum, Tea Tree, Flat Weed, Red Stringybark on granite and 'some Stringybarks'. One respondent claimed all ground flora showed long term variation and two that all species varied depending on climate.

Ten apiarists noted long term variation at particular sites, nineteen did not. Sites specifically mentioned were the Mallee and Maryborough areas. Other comments relating to whether any sites had shown long term variation were:

- all sites if conditions are dry,
- weeds growing after use of a herbicide always produce poor pollen,
- agricultural, pasture sites,
- depends on species,
- Red Stringy Bark on granite,
- Grey Box everywhere,
- Grey Box in terms of whether it is an on or off year,
- mostly on Yellow Box or Ironbark sites.

Fourteen factors that influenced an apiarist's rating of pollen quality were identified (Table 3.3). Most (21/30) respondents used more than one factor. Pollen colour, size and volume were most important (Table 3.3) with taste and texture being of lesser importance. Bee health and longevity, colony health, brood health and layout by the queen also were mentioned as important in determining pollen quality but were cited by less than five apiarists. Similarly, soil type, rainfall/moisture and seasonal variation were cited by less than five respondents. Number of citations does not make one factor more or less important. One factor may have a greater influence in one site than another, or particular factors may be easier to discern than others. Also, one apiarist may have a more refined ability to detect changes in certain criteria but not others.

Table 3.3 Factors influencing rating of pollen quality

Factor	no. respondents (n = 30)
pollen volume	19
pollen size	12
pollen colour	9
pollen taste	5
brood health	4
soil type	4
rain/moisture	4
protein/nutritional value of pollen	3
bee health	3
pollen texture	2
colony health	2
seasonal conditions	2
bee longevity	1
layout by queen	1

Grey Box specifically was cited as an example whereby colour could be used to determine pollen quality. When pollen was dark or dull it was of poor quality, but when it was creamy the quality was good. Grey Box also affected the brood rearing response of a hive in a deleterious manner when pollen quality was poor i.e. a rating of 2 as opposed to 4.

Red Stringybark was cited as producing poor quality pollen when on granitic soils but good quality pollen when on volcanic soils, however this was related to soil moisture levels. Ten and eight beekeepers said they believed soil type affected quality and quantity of pollen respectively when asked in a direct question. Those in the affirmative cited the following (each comment was cited only once or twice):

- moisture levels affect quality:
- Red Gum on limestone produce good quality and amounts of pollen but on granite poor quality and quantities are produced;
- Rich soils produce better quality pollen; and
- in deep sand, Flat weed and Lucerne produce copious pollen of high quality which maintains vigorous brood health.

Tree age did not affect either quality or quantity of pollen according to twenty and 15 respondents respectively. Only two respondents thought the quality of pollen was affected but eight responded that quantity was affected. In terms of quantity, it was argued that older trees were larger, therefore could produce more flowers hence more pollen.

3.3.3 Pollen preferences

Nearly all apiarists (28/30) believed bees had a ‘favourite’ pollen source. One respondent did not know whether bees had a preference and another did not answer the question. Thirty one species were cited as favourites to bees (Table 3.4) and, considering the span of country involved, this is not surprising. Red Gums were most favoured (13/30), then Cape weed (6/30), Canola (5/30), Patersons Curse (5/30), Messmate (5/30) and Clover (4/30) times. All other species were cited less than four times each.

Four apiarists commented that bees preferred pollen of higher protein content such as Red Gum, Clover, Patersons Curse, Cape weed, Gums generally, Pear and Dandelions, as these bred large, healthy hives. Indeed, pollen from these species previously were identified as high quality with the exception of pollen from willows which had an average pollen quality rating of 2.5, although a range of 1-4. Support for the idea that bees might have pollen preferences was shown by a number of observations, e.g. where 95% of trapped pollen in hives was of Pear yet Canola was only 200 m away, or Red Gum had both abundant nectar and pollen, but bees visited Dandelion instead.

Most apiarists(20/30) noticed that variation in the preferred pollen source could occur within a single day. This principally was attributed to weather conditions (Table 3.5) such as temperature, rainfall, wind and the occurrence of storms.

Twenty-six apiarists noted that honeybees began collecting pollen from a source as soon as flowering started and 16 believed honeybees continued to do so until flowering in that species ceased.

Table 3.4 List of pollen sources 'favoured' by bees

Species	no. citations
Red Gum including River Red Gum	13
Cape Weed,	6
Canola	5
Patersons Curse/patersons curse	5
Messmate	5
Clover	4
Almond	3
Pear	3
Stringybark group including red stringybark	2
Manna Gum	2
Willows	2
English Dandelion	2
Peppermint (black)	2
Banksia	1
Spotted Gum	1
Most ground flora	1
Faba Bean,	1
Ti-tree	1
Apples	1
Coastal Wattle	1
Strawberry Clover	1
Mountain Eucalypts	1
Turnip	1
Wild Turnip	1
All introduced ground flora,	1
Rape	1
Gorse	1
Orange trees	1
Yellow Box	1
Rough Barked Apple	1
Flatweed	1

Table 3.5 Factors determining daily preference for a pollen source

Factor	**no. of respondents**
weather conditions	9
flowering patterns, and	3
time of day	2
moisture levels	2
hive requirement	2
blossom freshness,	1
nutrient content of the pollen	1
bee preferences	1
history of bee movement	1

3.3.4 Pollen effects on health

Seven apiarists felt pollen colour affected hive health (Table 3.6) yet earlier it was reported that only five were able to detect detrimental pollen by colour. Twenty apiarists said colour had very little or no affect on hive health (Table 3.6). Pollen colour varied during a flowering episode within a site (17/30) and between sites (18/30) (Table 3.6). There was little difference in the number of apiarists that felt climatic factors affected pollen colour (12/30) before or during flowering and those that did not (13) (Table 3.6). Temperature, humidity, rainfall and soil moisture were determining factors in the variation of pollen colour. Rainfall was considered necessary to produce suitable pollen. Dry conditions resulted in desiccation of pollen, making it undesirable to bees. Only small loads of pollen were collected from Red Stringy Bark in dry conditions but large loads after rain. Other species showing changes in pollen colour during a honey flow included Long Leaf Box and Patersons Curse.

Table 3.6 Responses to questions relating to pollen colour and effects of tree age and soil type

	number of respondents			
Question	**no answer**	**yes**	**no**	**didn't know**
Does colour affect hive health?	1	7	20	2
Does variation in colour occur during a flowering episode?	2	8	17	3
Does variation in colour occur between sites?	4	5	18	3
Do climatic factors affect colour variation?	2	12	13	3

Thirty-one pollen sources were considered more beneficial than others (Table 3.7) but 34 were considered less beneficial (Table 3.8). Nine species were included in both lists: Cape Weed, Stringybark, Canola, Red Stringybark, Dandelion, Manna Gum, Acacia, Grey Box and Lucerne. River Red Gum was cited most often (13/30) as being more beneficial, then Capeweed (8/30) and Patersons Curse (7/30) (Table 3.7). Clover, Stringy Bark and Canola each were cited 6/30 times, 17 species were cited only once (Table 3.7). Grey Box was cited most often (4/30) as less beneficial (Table 3.8), then Canola (3/30). Seven species were cited twice and 25 species only once (Table 3.8). Of the nine species included in both the 'more beneficial' and 'less beneficial' lists, the majority were cited most often as 'more beneficial'. Only Grey Box and Acacia were cited more often as 'less beneficial'. Capeweed was cited eight times as more beneficial and only once as less beneficial, Stringy Bark and Canola both were cited six times as more beneficial but three times and once respectively as less beneficial.

Species considered more beneficial were thought to specifically increase bee longevity, bee health, brood health and hive health (Table 3.7). Conversely, species considered less beneficial were believed to decrease these factors (Table 3.8). Healthy bees were stronger, had greater stamina and were fatter. A healthy brood had greater vigour and filled a larger expanse of the frame. Twenty-six species improved brood health , 18 increased bee health, but only a few increased bee longevity (4) and hive health (3) (Table 3.7). In terms of detrimental impacts, a decrease in bee health and bee longevity was cited most often, nine and seven times respectively (Table 3.8). Decreases in brood health and hive health had five and four citations respectively (Table 3.8).

Twenty-two respondents believed pollen could be detrimental to bee/hive health over a single flowering episode, four said this did not occur, two did not know and one respondent did not answer the question. Deleterious pollen appeared common. Twenty-eight species were specifically cited (Table 3.9), Grey Box 4/30 and Flatweed 2/30, all others 1/30 times. Nectar of Grey Box also played a role (section 2). One respondent stated that any species could produce poor pollen depending on season and/or climatic conditions. Stringy Bark was cited as producing poor pollen under cold and wet conditions.

Table 3.7 Impact of 'more beneficial' pollen

species	more beneficial pollen	increased bee longevity	increased health	increased brood health	increased hive health
River Red Gum	13	✓	✓	✓	✓
Cape Weed	8		✓	✓	
Patersons curse	7	✓	✓	✓	
Clover	6	✓	✓		✓
Stringybark	6		✓	✓	
Canola	6			✓	
Wild turnip radish	4	✓	✓	✓	
Messmate	4		✓	✓	
Almond	3		✓	✓	
Red Stringy Bark	3		✓	✓	
Spotted Gum	2		✓	✓	
Dandelion	2		✓		
Brown Stringy Bark	2				
Gorse	2				
Manna Gum	1			✓	
Pear	1			✓	
Acacia	1			✓	
Coastal Wattle	1			✓	
Grey Box	1				
Apple Box	1		✓		
Lucerne	1				
Lipia	1		✓	✓	
Willow	1				
Blackberry	1				
Epacridaceae	1				
Black peppermint	1				
Blue Mallee	1			✓	
Onion Weed	1			✓	
Lignum	1			✓	
Daisies	1			✓	
Skeleton Weed	1		✓		

Table 3.8 Impact of 'less beneficial' pollen

species	less beneficial pollen	decreased bee longevity	decreased bee health	decreased brood health	decreased hive health
Grey Box	4	✓	✓		
Canola	3	✓	✓		
White Mallee	2		✓	✓	
Yellow Mallee	2	✓			
Flatweed	2		✓		
Acacia	2				
Banksia	2				
White Box	2			✓	✓
Ironbark	2		✓	✓	✓
Stringybark	1				
Black Mallee	1				
Manna Gum	1				
Cape Weed	1				
Dandelion	1				
Prickly Moses	1				
Evening Primrose	1				
Yellow Gum/Blue Gum E. leucoxylon	1				
Red Stringy Bark	1	✓			
Egg and bacon	1				
Long Leaf Box	1				
Red Bloodwood	1				
Lucerne	1		✓		
Sunflower	1			✓	✓
Black Box	1			✓	✓
Leatherwood	1				
Heliotrope	1				
Acorn Mallee	1				
Christmas Mallee	1				
Red Mallee	1				
Sugar Gum	1	✓			
Green Mallee	1	✓			
Yellow Box E. melliodora	1		✓		
Acacia melanoxylon Blackwood	1				
Bursaria spinosa Prickly Bush	1				

Table 3.9 Species producing detrimental pollen during a single flowering episode.

Species	time taken for pollen to produce detrimental results	flowering stage at which pollen is detrimental
Canola	takes time	throughout
Darling Pea (Swainsona) most	takes time	throughout
Flatweed	takes time, brood affected immediately	throughout
Faba Bean	takes time	3-4 weeks into flowering
Grey Box	takes time, brood affected immediately	any time or throughout
Peppermint Box	takes time	throughout
Sugar Gum	takes time	throughout
Blackwood	takes time	throughout
Sunflower	takes time	
Stringybark	takes time	
Blue Mallee	matter of weeks	
Dandelion	matter of weeks	
Kunnajong	matter of weeks	throughout
Lucerne	matter of weeks	throughout
Maize	matter of weeks	throughout
River Oak	matter of weeks	throughout
Blue Gum (SA)	immediately	early stages
Stinkweed	immediately	throughout
Bloodwood		any time or throughout
Night Shade		early stages
Green Mallee		any time or throughout
Lombardias		late stage
Mugga Ironbark		any time or throughout
Skeleton weed		
Sweet Pea		early stages

Specific responses were provided for a number of species, i.e. Lombardias could be particularly potent as bees were killed while collecting pollen; bees bred on Canola but, if this was the first pollen after winter, they bred ‘gutless’; bees using Faba Bean broke down with European Foul Brood.

The time taken for pollen to produce detrimental results varied amongst species (Table 3.9). Only two respondents reported immediate affects; six that effects occurred within a matter of weeks and 10 that effects took some time to develop. In the latter case, it was believed that poor pollen nutrition explained the length of time before any noticeable effects occurred. In the case of Flatweed and Grey box, there was disagreement as to when effects occurred with one person claiming effects took time without a mention of what the effect actually was, and another person stating that the brood was affected immediately.

The flowering stage at which pollen was noted to be detrimental also varied amongst species (Table 3.9). Detrimental pollen generally could occur at any time throughout the flowering period. For four species: Grey Box, Mugga Ironbark, Green Mallee and Bloodwood, detrimental pollen was produced at particular stages during flowering or throughout the entire flowering period. Three respondents cited this for the Grey Box. Blue Gum, Sweet Pea and Night Shade produced deleterious pollen only in the early stages of flowering, Faba Bean three to four weeks into flowering and Lombardias only in the late stage of flowering.

There was not much difference in opinion by apiarists as to whether one or multiple sources of pollen were *sufficient* to maintain hive health and to build hive populations, however, all but three stated that multiple sources were better. This was attributed to multiple sources resulting in stronger bees and hives, bees with stamina, longer living bees and improved brood rearing. It was believed that multiple pollen sources provided a more balanced diet and more protein. Three of the respondents, however, stated that some single sources of pollen matched the benefits of multiple sources, e.g. Red Gum, Mountain Eucalypts, White and Strawberry Clover, Patersons Curse and Stringy Bark.

Twenty-seven respondents believed that worker bees collected pollen from multiple sources. The proportion bees collected from each source varied and depended on:

- what was available,
- the quantity available,
- the composition of the pollen,
- the distance needed to travel,
- the taste and requirement of the individual hive
- the time of day,
- season,
- weather i.e. temperature, rainfall, wind,
- length of flowering, and
- insect prevalence.

If pollen was of good quality, it was believed the bee would prefer to stay with that species, collecting only a small percentage of pollen from another source.

3.3.5 Pollen availability

Most apiarists (24/30) found pollen was available throughout the flowering period. Three found that pollen was available either throughout the flowering period or only during part of the flowering period. Of these, one found that pollen was available throughout the flowering period only if the forest was well budded. If new growth was present, this did not always occur. Two of the three respondents found that it depended on the species and the weather, e.g. in the case of White Mallee, pollen only became available if it was cold.

Twenty apiarists found there was variation in the quantity of pollen available during flowering. Nine said there was no variation. Two apiarists commented that it depended on the species, occurring in some plants but not others. Another stated that less pollen was available at either end of the season.

The period of nectar collection usually was shorter than the period of pollen collection (15/30). Five considered the two collecting periods to be similar, four that nectar collection occurred for a longer period and three that variation occurred. Two respondents did not answer the questions.

Sometimes (2/30), pollen collection commenced when flowering began while nectar yields began afterwards. Alternatively, pollen and nectar collection could slowly diminish together but sometimes both would cut out overnight (1/30), or pollen would remain to be collected when no nectar was available or vice versa. One respondent noted that once pollinatation had occurred, nectar secretion stopped. Three respondents commented that nectar availability was controlled by temperature and rainfall.

3.3.6 Pollen supplements

The use of pollen supplements to *maintain* hive health was not done readily by Australian apiarists. Ten had never used supplements; two stated they were using supplements more frequently in recent times and only one apiarist used supplements for most of the year. All others used supplements only rarely, some in particular seasons such as early spring when pollen was scarce and in winter, others used supplements depending on the species which bees foraged, such as Ironbark, Grey Box, Lucerne and Yellow Box, and others used supplements only during drought.

The use of supplements to *build* hive health or size, however, was a different story. Fifteen apiarists stated they did so, 12 did not. Again, comments showed supplement use was done so reluctantly.

Twenty-two apiarists believe some honey flows required pollen supplements more than other honey flows, four did not. Twelve species were cited. Twelve apiarists cited Ironbarks or a particular Ironbark, nine cited Yellow Box, five Yellow Gum and three White Mallee. Red Box, Lucerne and Blue Gum each were cited twice while Pink Gum, Napunyah, Green Mallee and Grey Box each were cited once. Another apiarist stated that supplements were needed when bees foraged on southern Boxes.

Only nine apiarists made their own pollen supplements, twelve bought their supplements. When asked about the components of the pollen substitute used, the following comments were received:

- mainly protein,
- soy flour, own honey, vitamin supplement,
- soy flour, white sugar, malt, cottonseed oil and water,
- Rod Palmer's substitute,
- Soya bean flour, 49% protein, 6% oil,
- 80% soy flour, 10% torula yeast, 10% natural pollen, dash of amino acid, and
- high levels of bee collected pollen of proven value.

3.4 Discussion

3.4.1 Identification of pollen detrimental to hive health

Pollen is a vital resource for bees. Nectar may be the major energy source of a hive (Pernal & Currie 2001) but honeybees need pollen as a source of protein, amino acids, fats, minerals, vitamins and sterols to maintain bee and hive health, but especially brood growth (Herbert 1992). In spite of this, bees keep only a small reserve of pollen within a hive at any one time (Pernal & Currie 2001) making bees and, subsequently, their hives susceptible to environmental variations of pollen supply and quality. It is important that beekeepers can determine variation in the quality of pollen being brought back to the hive, but they particularly must be able to determine whether a pollen source is detrimental. Only about one half (15) of beekeepers believed they could identify pollen detrimental to hive health if multiple pollen sources were available at an apiary and hive health was in decline (Figure 3.1). However, 21 of the 30 respondents stated in a later question in the survey that they used more than one factor to determine pollen quality. It is possible that pollen may be poor in quality but not necessarily detrimental, particularly if sufficient pollen is available such that more can be collected to make up for a deficiency in some nutrient. On the other hand, some of the factors used in determining pollen quality (as opposed to detrimental pollen) were bee health and longevity, colony health, brood health and layout by the queen (Table 3.3).

The ability to determine pollen detrimental to a colony is important, as is the ability to determine pollen quality generally. Beekeepers able to discern detrimental pollen commonly used a number of features to determine whether such pollen occurred, rather than relying on just one feature. This probably is important as there was no single feature that was commonly used. Pollen colour was most frequently cited but only by five apiarists. It is probable that the plant species involved may contribute to this inability of apiarists to use colour as a dependable characteristic of pollen quality. After all, how variable is pollen colour within a species? Some species may show more variation than others. Thus the ability for beekeepers to detect problematic pollen by colour may depend on whether the pollen resources they use show greater or lesser colour variation. Certainly in the question relating to pollen quality generally (again as opposed to recognising detrimental pollen) colour was again mentioned as important in rating pollen quality – this time by nine apiarists – but it was not ranked as important as pollen volume.

If beekeepers could identify detrimental pollen *easily* it would be a boon to their business and the honey industry. Unfortunately, there does not seem to be a simple solution. Pollen colour could provide a simple solution, however much research is needed to determine its potential as an indicator. Particularly needed is a study on the variation in pollen colour of the many plant resources and the relationship, if any, to pollen quality. This study has contributed at least some information to fill the knowledge gap on determination of detrimental pollen but much more is needed!

3.4.2 Variation in pollen quality and quantity and underlying causes

This study identified that the bulk of the pollen generally came from only a few plant species. This was not surprising and was known to occur (McClellan 1976; Shawer 1987; Synge 1947). The five species used most frequently were River Red Gum, Cape Weed, Canola, Messmate and Patersons Curse. In a review of about 25 studies by Keller et al. (2005), Canola also ranked as one of the five top pollen sources around the globe. This is not surprising considering the importance of this crop worldwide. The make-up of the top five in this study was quite different from the studies used by Keller et al. (2005) which only included agricultural species, albeit two weeds. This study included two native tree species in the top five, two weeds and one crop species. Fifteen of the 97 pollen resources identified in this study also occurred in the group of 30 important pollen sources identified by Keller et al. (2005) and reflects the cosmopolitan nature of these plants. They include corn, clover, dandelion, the Brassicaceae, Asteraceae, Almond and Faba Bean to name but a few. Sixty-three of the 97 species identified as pollen sources in this study were native with the vast majority being Eucalypts. In other countries, the vast majority of important pollen resources are agricultural in nature, either as crops or weeds. This means that any management or biological issues relating to the Australian bee industry will be quite different in nature to those from overseas, although overlap will occur. The Australian bee industry must be aware of and involved in forest management, both current and predicted, to a much greater degree than occurs overseas. The Australian bee industry also must pay great attention to possible effects of climate change in the natural environment. This is a much more difficult scenario than determining effects of climate change on agricultural systems, which constitute environments that can be more easily manipulated.

The frequency a pollen resource is used does not necessarily reflect its pollen quality, for example, Cape weed, Canola and River Red Gum were frequently cited yet protein analyses showed the first to be of poor quality and the latter two of average quality (Somerville & Nicol 2006). A number of frequently used pollen sources, however, showed high protein contents, e.g. Patersons Curse and clover (Somerville & Nicol 2006).

Beekeepers judge pollen quality on a holistic basis. They see whether or not detrimental effects occur either immediately or with time. Because of this their views of pollen quality may not match those determined by chemical analyses, e.g. River Red Gum and Manna Gum are viewed as having excellent quality by beekeepers (i.e. an average rating greater than 4) but only average quality by protein analyses (Somerville & Nicol 2006). Also, they might take into account quantity of pollen available when determining quality. This is discussed further under ‘Bee preferences’.

It is well known that pollen quality varies amongst plant species (Keller et al. 2005) and, certainly, this study supports that view, but it is less well known how variable the pollen quality is within a species. This study has identified that there is a good deal of variation in pollen quality within a species, with just under half the species cited being given different quality ratings by the beekeepers, resulting in the range of ratings in column two of Table 3.1. In column three of this table, the number of respondents who consider any one species to have a variable pollen quality is extremely small. One could argue that the variation seen amongst beekeepers could be because each has a different benchmark but the beekeepers are a close-knit group having much discussion with each other, so this is unlikely. It is probable, therefore, that the variation is spatial and, so, determined by environmental factors specific to location. When asked directly whether site variation occurred, half the number of respondents said it did. Also, Somerville (2005) has shown that variation could occur within a species.

A number of factors were identified as responsible for differences in pollen quality within a species. Tree age was not one of them according to two thirds of the respondents; only two respondents stated that tree age was important. However, this could be dependent on species. In terms of nectar, tree age was cited as important for yields on the basis of the fact older trees were larger so would have more flowers. Temperature and rainfall were considered most significant but budding intensity and soil type also were important. Pollen quality decreased when temperatures were too hot and/or rainfall too little. This is well known, at least anecdotally if not within the literature. If budding intensity was poor, pollen quality was poor. This is not surprising as a positive relationship also occurred with nectar production, although correlations between nectar production and pollen quality are not always positive (Keller et al. 2005). Budding intensity potentially is a good indicator of pollen quality as it easily is determined by beekeepers but quantitative data is necessary to determine whether this is a perceived or actual phenomenon. Similarly, it would be useful to compare pollen quality with chemical analyses of the various soil types to quantify whether soil type provides a reliable surrogate for pollen quality.

Interactions between variables are complex. Often a deficiency in one variable can be counteracted by a sufficiency in another, e.g. if soil is high in nutrients it can counteract the effects of low rainfall, at least to a certain extent. Similarly, if temperatures are high but soil water content is high, the detrimental effects of temperature on pollen can be mitigated. This can result in different responses to questions by apiarists as they are reporting data pertinent to their area, thus it can explain some of the variation in responses. The surveys are an important source of information but they do not replace the necessity for verification with quantitative analyses. The surveys, however, should be used to direct further studies.

Other factors affecting pollen quality was timing within a flowering episode and season. Season could be a reflection of the different species in flower, a fact which is widely acknowledged in the literature (Keller et al. 2001), but it also could be a reflection of weather conditions. Hot, dry conditions were cited above as reducing pollen quality, so species flowering in summer might produce lesser quality pollen because of weather conditions and not because of their genetics. Variation within a single flowering episode also may be species dependent as about 70% of respondents stated this was common.

Forty-three percent of beekeepers believed there was long-term, infra-specific variation in pollen quality but 50% of beekeepers did not. This, again, could be due to site specific variables including the nature of the pollen resources available, especially as the majority of those that felt such variation occurred, noticed variation between sites and within particular species such as Red Stringy Bark on granite. Such soils are of poor nutritional quality which could explain poor quality pollen in terms of its nutritional content (pollen also could be classed as poor because it occurs in small quantities or is undesirable to the bees). This would be exacerbated by reduced annual rainfall levels predicted to occur more commonly with climate change. Some plant species were considered to have poor quality pollen at either or both the beginning of flowering and the end of flowering, whereas other species could produce poor quality pollen at any time of flowering. Causes for this were unknown and are difficult to explain. Poor quality pollen at the end of flowering seems logical as soil resources could be

depleted because of plant growth and competition, but at the start of flowering one would expect resources to be adequate if not better than at later stages of flowering. This could be due to changed rainfall patterns. More commonly of late, beekeepers are saying that rainfall is not falling at the appropriate times, which may affect pollen availability and quality. The fact that change in rainfall patterns may be due to climate change is supported in the literature (e.g. Zhang et al. 2007).

3.4.3 Pollen Preference

A number of studies demonstrated that honeybee colonies regulated pollen foraging in response to changing protein demands (e.g. Dreller et al. 1999; Fewell and Bertran 1999). Colony foraging was increased in proportion to decreased pollen storage (Lindauer 1952; van Laere and Martens 1971). Experimental manipulation of stored pollen resulted in compensatory responses in terms of the numbers of foragers sent from the hive and subsequent rate of pollen collection (Camazine 1993; Dogterom and Winston 1999; Dreller et al. 1999; and Fewell and Bertram 1999). Pernal and Currie (2001) go further and document that changes in foraging at the colony level occurred in response to deficits in either quantity or quality of pollen. This resulted from an increase in the proportion of foraging bees. The hive produced more foragers so an increased number of young, inexperienced foragers were sent out in response to quality and quantity deficits of pollen. These tend to collect larger loads of pollen and sample more widely as a result of a better energetic capacity (Pernal and Currie (2001). Older bees make compensatory responses for wing wear and degeneration of the flight mechanism (Cartar 1992; Pernal and Currie 2001).

Almost all beekeepers in this study believed bees had a favourite pollen source. The information above does not support this but suggests that increased income of pollen, thus protein, occurs, in response to a deficiency in the hive because an increased number of foragers with a higher energetic capacity are sent out. This study listed thirty-two species as favourite pollen sources by bees (Table 3.4), which seems a lot but, because of the breadth of area covered by this survey, it is not surprising. Within any single apiary the number of species listed as favourites were small, i.e. 1-4. It makes ecologic sense that bees would prefer pollen with a higher nutritional content as this would improve their health and longevity, enabling higher reproductive capacity, but there is considerable argument in the literature (Keller et al. 2001). There has been no clear demonstration that bees prefer pollens of higher nutritional content, as experiments performed did not take into account olfactory cues. Pernal and Currie (2001) clearly demonstrated that foragers responded to changes in odour concentration. They did not respond to changes in protein content of soya bean flour offered (Pernal and Currie 2002). Analysis of the species cited in this study showed that 21 of the 31 species were considered to be of an excellent quality i.e. a rating of 4 or higher, one was of poor quality i.e. a rating of less than 2 and nine had an average quality i.e. a rating of less than 4 but greater than 2. Somerville and Nicol (2006) listed 17 of these species against crude protein contents (Table 3.10). There were 11/17 (65%) matches between beekeepers' estimates of pollen quality and those listed by Somerville and Nicol, with two near misses (12%). This can be seen as somewhat more than chance but is not an excellent match. However, a beekeepers' determination of pollen quality is not based simply on protein content. It is a holistic determination, so by definition takes into account all things pertaining to pollen quality including availability and protein, mineral and fat content, but, most importantly, it takes into account bee and hive health. There is no consensus in the literature as to how pollen quality should be measured. If lipid content is used, different levels of quality are provided for a species than when protein content is used (Somerville 2005).

Although there is no direct evidence that bees have preferences, whether it be for pollen of higher nutritional content or not, indirect evidence has been presented in this study and occurs in the literature (Keller et al. 2005; Levin and Bohart 1955). This study showed bees collected pollen of Pear when Canola was only 200 m away i.e. 95% of trapped pollen in hives was of Pear, and Red Gum was ignored when it had both abundant nectar and pollen, instead, bees visited Dandelion. Why is this?

Keller et al. (2005) demonstrated that different colonies at the same location would collect pollen from different sources. Preferences, however, were not fixed. (Moezel et al. (1987). These results depended

on the assumption of equal availability but microhabitat changes may be influential e.g. shading of hives might be slightly different hence bees would delay foraging (Keller et al. 2005). Certainly, abundance is not the only factor affecting foraging of bees (Keller et al. 2005). This survey did not investigate habitat variables in preferred pollen sources. It is difficult to determine foraging preferences as any experiment will have subtle differences which may or may not affect a bee preference so, for now, whether or not bees show a true preference for certain pollens remains a mystery. Another explanation for pollen 'preferences' may deal with social behaviour, but this needs further investigation. One final comment - it has been argued that as bees take pollen back to the hive and do not consume it directly they probably cannot determine the quality of pollen and, for this reason, can collect toxic pollen (Keller et al. 2005). Bees have shown olfactory responses (Pernell and Currie 2001). Other animals, including humans, not only determine toxicity by olfactory means but also desirability (quality) of a food source. Why not bees? As occurs with other animals, some toxins are detected easily while others are not.

Table 3.10 Pollen quality of sources 'favoured' by bees. E = excellent, A = average and P = poor.

Species	this study value	grade	Somerville & Nicol (2006)
Red Gum including River Red Gum	4.4	E	A
Cape Weed	3.7	A	P
Canola	3.2	A	A
Patersons Curse/Salvation Jane	4.1	E	E
Clover	4.9	E	E
Almond	4.8	E	E
Pear	5	E	E
Stringybark group including Red Stringybark	4.2	E	A (RSb)
Manna Gum	4.3	E	A
Willows	2.5	A	P
Banksia	3.2	A	E
Spotted Gum	4.8	E	E
Faba Bean,	4.5	E	A
Coastal Wattle	4	E	A
Turnip	4.6	E	E
Gorse	5	E	E
Orange trees	5	E	P
Flatweed	1.9	P	P

3.4.4 Pollen effects on health

Nectar is the major energy source of a hive but without pollen the hive does not function. Pollen provides the protein, fat, mineral and vitamin needs to meet dietary requirements. Without these, bees have reduced longevity (Knox et al. 1971) and brood rearing decreases Kleinschmidt and Kondos 1976, 1977), resulting in declined hive productivity. Beekeepers believe certain pollens are more beneficial than others. The principal effect noted by beekeepers was increased brood health. Species cited as more beneficial by six or more beekeepers were River Red Gum, Cape Weed, Patersons Curse, clover, Stringybark, and Canola. They classed each of these to be of an excellent pollen quality with the exception of Cape Weed, which was classed as average, whereas Somerville and Nicol (2006) classed only Patersons Curse and Clover as having excellent quality pollen; River Red Gum, Stringybark and Canola had average pollen qualities and Cape Weed was of a poor pollen quality.

Earlier, it was stated that beekeepers judged pollen quality holistically so pollen quantity would be taken into consideration. Each species is widely available. Possibly it is the quantity of pollen that is producing the beneficial effects as increased quantity ensures fulfilment of dietary needs. This does not negate the possibility of true preferences by bees for a particular pollen source, but the real story probably is very complex and could involve an interaction of pollen availability, odour, perhaps nutritional content, macro and micro environmental factors, energetics and perhaps even social behaviour.

Less beneficial pollen sources were cited far less frequently. This is understandable considering that half the beekeepers could not determine detrimental pollen if multiple sources were used, although they could determine quality in terms of which were more or less beneficial or had higher or lower quality. Grey Box, Flat Weed, Blue Gum (SA) and Stinkweed caused immediate deleterious effects and should be examined further to determine why. Others showed detrimental effects after a matter of weeks or longer. These may well relate to nutritional levels as a deficiency in one nutrient would cause a decline in bee and hive health. If bees become weakened they are more prone to disease such as nosema or European Foul Brood. Some Beekeepers found these diseases followed use of particular pollen sources. Some pollen sources may contain a high protein content but lack sufficient accessible nectar, e.g. Faba bean, so the effects could be nectar related too.

Pollen showing immediate deleterious affects has been referred to as ‘toxic’ pollen by beekeepers. The occurrence of toxic pollen has been noted in the literature (Herbert 1979; Keller et al. 2005; Nation and Robinson 1968; Somerville and Nicol 2002) and has been attributed to high mineral concentrations, specifically sodium, calcium (Herbert 1979; Nation and Robinson 1968) and zinc (Anderson 1997). Mineral content often is higher in darker coloured honey than lighter coloured honey (Somerville and Nicol 2002) so beekeepers using colour to determine pollen quality are on the right track, but it would seem that this varies from one species to another.

3.4.5 Pollen supplements

When pollens are deficient in nutrients or unavailable, beekeepers can supplement the nutritional needs of bees. Beekeepers surveyed rarely used supplements to *maintain* hive health but half did so to *improve* health or hive size. It might be wiser for beekeepers to use supplements to prevent a drop in health in the first instance as there would be a time lag before a hive recovered its vigour and growth rate. The greater the decline in colony health, the longer the lag time for recovery.

Not much information was forthcoming in terms of nutritional content of supplements.

3.4.6 Concluding statements

This study found that only half the beekeepers surveyed could identify pollen detrimental to bee and hive health. Factors enabling identification were documented and should aid beekeepers to develop their skills. Multiple factors should be used to provide greater confidence. Pollen quality could be poor in terms of nutrition but not necessarily detrimental over time if a sufficient supply exists.

Possible indicators of pollen quality were noted and should help beekeepers in the management of their hives. Pollen colour and volume were considered most important for ranking pollen quality. Budding intensity potentially is a good indicator of pollen quality but quantitative data is needed to determine whether a true relationship occurs.

Beekeepers judge pollen quality holistically, explaining why rankings may not match those determined by chemical analyses. Comparisons with chemical analyses were good although not excellent. Beekeepers take into account quantity/availability of pollen, nutritional content, and bee and hive health. Chemical analyses do not. There is no agreement in the literature as to how pollen quality should be determined in terms of chemical analyses.

Inter- and intra-specific variation in pollen quality occurred. Intra-specific variation may well be due to site specific differences. The bulk of pollen came from only a few species including forest trees, which constituted 65% of pollen sources cited. Overseas, the bulk of pollen comes from agricultural species. This has serious implications for management and any biological issues, such as disease and changing flowering patterns because of climate change. The beekeeping industry must be aware of and involved in forest management, both current and predicted.

Bees have favourite pollen sources. Preferences could involve interaction of pollen availability, odour, nutritional content, macro and micro environmental factors, energetics and, possibly, social behaviour. Some pollen sources caused immediate deleterious affects while others only did so with time. The former are considered ‘toxic’ pollen. The nature of the toxicity and the reasons as to why bees cannot detect it requires investigation. It may just be that bees cannot detect it in certain plants. In this case they would forage on them and subsequently show ill health.

Beekeepers use supplements reluctantly for maintaining bee and hive health but more frequently to improve hive health or size. Because of the lag phase in returning hives to a previously healthy state, supplements are recommended for use at appropriate times to prevent health decline in the first instance.

Surveys are a convenient and cheap way of amassing data but do not replace the need for quantitative analyses. Surveys provide information that can best determine future research directions with greater efficacy.

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Appendix 1

Interview Questions

1. For what length of time were you a commercial beekeeper?
2. What generation beekeeper are you?
3. How long have you been retired?
4. While you were operating your business, how many hives did you manage?
5. Which Australian states did you use? What districts in each state? Which forests?
6. Did you refer to areas as being reliable or unreliable? If so, please define these terms.
7. Did you notice a shift in the reliability of areas during your experiences in beekeeping (i.e. did reliable areas become unreliable, etc.)?
8. What factors do you consider would have contributed to reliable areas becoming unreliable and vice versa, if relevant?
9. How did you learn the identification of each species?
10. Which species did you use for honey production?
11. Why did you use those species (reliable nectar plants? availability?)

Flowering patterns

12. Did any species have a regular flowering frequency?
13. What was the interval between flowering (i.e. shortest/longest observed and average interval) for each species?
14. Was the flowering frequency for each of these species the same in all of the sites you used?
15. What factors do you think influenced flowering frequency?
16. Did you use tools to predict when a species would flower in a particular area? What patterns did you recognise as potentially triggering flowering?
17. Were these tools successful at least 80% of the time?
18. How did you measure flowering intensity?
19. Did you notice a change (increase/decrease) in flowering intensity over the years?
20. To what do you attribute variations in flowering intensity?
21. For each species used, when did flowering begin and end?
22. Did the beginning of flowering, or flowering period, change over time?
23. Did flowering period vary in different areas?
24. If flowering frequency was spasmodic, was flowering period still reliable and constant (i.e. did flowering begin at the same time regardless of the interval since last flowering event)?
25. Did forest size affect flowering patterns? If so, how? Which forests, if any, were effects particularly observed?

Nectar production

26. What did you consider to be a good nectar flow?
27. For each species, how frequently did you observe a good nectar flow?
28. Did you find nectar flows were related to flowering intensity?
29. Did you find nectar flows were related to the size of the forest you were using (i.e. did smaller fragments yield different volumes to large fragments)?
30. Was nectar produced every time a tree/forest flowered?
31. What tools did you use to predict nectar flows in any particular area (i.e. percentage in flower etc.)?
32. Did you notice an increase or decrease in nectar production by trees/forests over time?
33. What factors do you consider influenced any change in nectar production?

Miscellaneous

34. Have you observed any effects on honeybee health or honey yields resulting from visitation by other insects (e.g. Bogong Moth)? If so, what effects were observed, how long since last affected, under what circumstances (e.g. level of visitation, plague proportions). What factors do you consider resulted in these effects?
35. Have you experienced a phenomenon where trees produce toxic pollen and/or nectar? What are the effects on bee health/flowering/nectar production/honey yield? Does it affect particular areas or particular species, or both? Is it present every flowering event? What factors cause production of toxic pollen and/or nectar? Are there any factors preceding production? Was there a relationship between toxic pollen and visitation by other insects (e.g. Bogong Moths)?
36. Have you noticed an effect from logging on flowering intensity/frequency?
37. Did you find adjacent land use affected flowering/nectar yield? E.g. agricultural land, logging.
38. What effect, if any, did growth over bud have on nectar production?
39. What is the ‘optimal’ time for rain to avoid growth over bud?
40. Have you noticed any influence from lunar cycles on flowering/nectar production? If so, what is the relationship?

Appendix 2

List of species considered in this study

Common Name	Scientific Name	Family
Leatherwood	*Eucryphia lucida* (Labill.) Baill.	Cunoniaceae
Droopy Styphelia	*Styphelia* Sm. sp.	Epacridaceae
Apple Box	*Eucalyptus bridgesiana* R.T.Baker	Myrtaceae
Bimble Box	*Eucalyptus populnea* F.Muell.	Myrtaceae
Black Box	*Eucalyptus largiflorens* F.Muell.	Myrtaceae
Blakely's Red Gum	*Eucalyptus blakelyi* Maiden	Myrtaceae
Bloodwood (Mallacoota)	*Corymbia gummifera* (Gaertn.) K.D.Hill & L.A.S.Johnson	Myrtaceae
Blue Gum	*Eucalyptus globulus* Labill.	Myrtaceae
Blue Mallee	*Eucalyptus polybractea* R.T.Baker	Myrtaceae
Blue-leaved Stringybark	*Eucalyptus agglomerata* Maiden	Myrtaceae
Broad-leaf (green)	Undet.	Myrtaceae
Broad-leaf (Pilliga) 5 Later Harvey Ranges	Undet.	Myrtaceae
Broad-leaf (Pilliga) - unspecified	Undet.	Myrtaceae
Broad-leaf (Pilliga) 1 (Green-leaf)	Undet.	Myrtaceae
Broad-leaf (Pilliga) 2 (blue-leaf)	Undet.	Myrtaceae
Broad-leaf (Pilliga) 3 Early	Undet.	Myrtaceae
Broad-leaf (Pilliga) 4 Mid	Undet.	Myrtaceae
Broad-leaved Stringybark	*Eucalyptus caliginosa* Blakely & McKie	Myrtaceae
Brown Stringybark	*Eucalyptus baxteri* (Benth.) Maiden & Blakely ex J.M.Black	Myrtaceae
Brush Box	*Lophostemon confertus* (R.Br.) Peter G.Wilson & J.T.Waterh.	Myrtaceae
Caleys Ironbark	*Eucalyptus caleyi* Maiden	Myrtaceae
Christmas Mallee	*Eucalyptus socialis* Miq.	Myrtaceae
Coastal White Mallee	*Eucalyptus diversifolia* Bonpl.	Myrtaceae
Coolibah	*Eucalyptus intertexta* R.T.Baker	Myrtaceae
Desert Blue Gum	*Eucalyptus leucoxylon* subsp. *stephaniae* Rule	Myrtaceae
Dumosa Mallee	*Eucalyptus dumosa* A.Cunn. ex J.Oxley	Myrtaceae
Green Mallee	*Eucalyptus viridis* R.T.Baker	Myrtaceae
Grey Box	*Eucalyptus microcarpa* Maiden	Myrtaceae
Grey Gum (E. of Cooma, Brindabella Ranges)	*Eucalyptus punctata* DC.	Myrtaceae
Grey Ironbark	*Eucalyptus paniculata* Sm.	Myrtaceae
Hill Red Gum, Sand Gum	*Eucalyptus dealbata* A.Cunn. ex Schauer	Myrtaceae
Mallee Box, Black Mallee Box	*Eucalyptus porosa* F.Muell. ex Miq.	Myrtaceae
Manuka	*Leptospermum scoparium* J.R.Forst. & G.Forst.	Myrtaceae
Messmate	*Eucalyptus andrewsii* Maiden subsp. *andrewsii*	Myrtaceae
Messmate Stringybark	*Eucalyptus obliqua* L'Herit.	Myrtaceae

Moonah	*Melaleuca lanceolata* Otto	Myrtaceae
Mountain Blue Gum	*Eucalyptus cypellocarpa* L.A.S.Johnson	Myrtaceae
Mountain Gum	*Eucalyptus dalrympleana* Maiden	Myrtaceae
Mugga Ironbark	*Eucalyptus sideroxylon* A.Cunn. ex Woolls	Myrtaceae
Napunyah/Yapunyah	*Eucalyptus ochrophloia* F.Muell.	Myrtaceae
Common Name	**Scientific Name**	**Family**
Narrow-leaf Pilliga	Undet.	Myrtaceae
Narrow-leaved Ironbark	*Eucalyptus crebra* F.Muell.	Myrtaceae
Narrow-leaved Peppermint	*Eucalyptus radiata* Sieber ex DC.	Myrtaceae
New England Blackbutt	*Eucalyptus andrewsii* subsp. *campanulata* (R.T.Baker & H.G.Sm.) L.A.S.Johnson & Blaxell	Myrtaceae
Peppermint Box	*Eucalyptus odorata* Behr	Myrtaceae
Pilliga Box	*Eucalyptus pilligaensis* Maiden	Myrtaceae
Pink Gum, Hill Gum	*Eucalyptus fasciculosa* F.Muell.	Myrtaceae
Prickly Ti-tree	*Leptospermum juniperinum* Sm.	Myrtaceae
Red Box	*Eucalyptus polyanthemos* Schauer	Myrtaceae
Red Ironbark	*Eucalyptus tricarpa* (L.A.S.Johnson) L.A.S.Johnson & K.D.Hill	Myrtaceae
Red Mallee, Acorn Mallee, Oil Mallee	*Eucalyptus oleosa* F.Muell. ex Miq.	Myrtaceae
Red Stringybark	*Eucalyptus macrorhyncha* F.Muell. ex Benth	Myrtaceae
Ridge-fruited Mallee, Yellow Mallee	*Eucalyptus incrassata* Labill.	Myrtaceae
River Red Gum	*Eucalyptus camaldulensis* Dehnh.	Myrtaceae
Rough-barked Apple	*Angophora floribunda* (Sm.) Sweet	Myrtaceae
Round leaved Box	*Eucalyptus baueriana* Schauer	Myrtaceae
Scribbly Gum	*Eucalyptus haemastoma* Sm.	Myrtaceae
Silver-leaved Ironbark	*Eucalyptus melanophloia* F.Muell.	Myrtaceae
Silver-topped Stringybark, White-limb	*Eucalyptus laevopinea* R.T.Baker	Myrtaceae
Snow Gum	*Eucalyptus pauciflora* Sieber ex Spreng.	Myrtaceae
Southern Blue Gum	*Eucalyptus globulus* Labill. ssp. *pseudoglobulus*	Myrtaceae
Spotted Gum	*Corymbia maculata* (Hook.) K.D.Hill & L.A.S.Johnson	Myrtaceae
Sugar Gum	*Eucalyptus cladocalyx* F.Muell.	Myrtaceae
Turpentine	*Syncarpia glomulifera* (Sm.) Nied.	Myrtaceae
White Bloodwood, Pilliga Bloodwood	*Corymbia trachyphloia* subsp. *amphistomatica* K.D.Hill & L.A.S.Johnson	Myrtaceae
White Box	*Eucalyptus albens* Benth.	Myrtaceae
White Mahogany	*Eucalyptus acmenoides* Schauer	Myrtaceae
White Mallee	*Eucalyptus gracilis* F.Muell.	Myrtaceae
White Stringybark	*Eucalyptus globoidea* Blakely	Myrtaceae
Yellow Box	*Eucalyptus melliodora* A.Cunn. ex Schauer	Myrtaceae
Yellow Gum, South Australian Blue Gum	*Eucalyptus leucoxylon* F.Muell.	Myrtaceae
Yellow Stringybark	*Eucalyptus muelleriana* A.W.Howitt	Myrtaceae
Prickly Box	*Bursaria spinosa* Cav. subsp. *spinosa*	Pittosporaceae
Desert Banksia	*Banksia ornata* F.Muell. ex Meisn.	Proteaceae
Saw tooth Banksia	*Banksia serrata* L.f.	Proteaceae
Silver Banksia	*Banksia marginata* Cav.	Proteaceae

Appendix 3

Interview Questions - Pollen quality and bee nutrition survey

The following questions relate to your knowledge of your main honey and pollen flora.
PLEASE NOTE, THE PAGES ARE DOUBLE-SIDED – THERE ARE 20 QUESTIONS

1. Scenario: multiple pollen sources are available at the apiary; hive health is declining.

   a. Can you identify which pollen is detrimental to hive health? ☐ Yes ☐ No

   b. If yes, how? …….

2a. In the following table, please list your main pollen flora and rate each one (from 1 – 5) according to pollen quality. 1 = very low pollen quality; 5 = very high pollen quality.

Pollen flora	Rating	Pollen flora	Rating

b. What factors influence your rating of pollen quality?

☐ Colour ☐ Size ☐ Volume collected by bees ☐ Taste ☐ Soil type

☐ Other ……..

3. Can pollen quality within a species vary?

   a. DURING a flowering event? ☐ Yes ☐ No e.g……..

   b. according to SEASONAL factors (in the case of longer-flowering species)

   ☐ Yes ☐ No e.g……..

   c. from SITE to SITE? ☐ Yes ☐ No e.g……..

4. Have you observed LONG-TERM variation in pollen quality within a SPECIES?

   ☐ Yes ☐ No

   If yes, please provide examples of which SPECIES……
   ……

5. Have you observed LONG-TERM variation in pollen quality at any particular SITE?

☐ Yes ☐ No

If yes, please provide examples of which SITES.……
……

6. Are any particular pollen sources a 'favourite' to bees? ☐ Yes ☐ No

If yes, please provide examples ……
……

7. Are there pollens more or less beneficial than others? ☐ Yes ☐ No

If yes, please complete the following table:

Species	**More beneficial**	**Less beneficial**	**Impact of exposure**

8. Can the pollen of any plant species affect bee/hive health DURING a flowering episode?

☐ Yes ☐ No

If yes, which species produce detrimental pollen?……
……
If yes, is the pollen immediately detrimental or does it take time to become so?…….
……
If yes, at what stage of flowering does the pollen become detrimental to bee health?…….
……

9a. When is pollen produced?

☐ Throughout duration of flowering

☐ Only during part of flowering. Please specify…….

b. Have you noticed variation in the quantity of pollen produced during the flowering episode ?

☐ Yes ☐ No

10. Is the period of nectar collection longer or shorter than the period of pollen collection?

……

11a. To maintain hive health, is one pollen source sufficient or are multiple sources required?

……

……

……

b. Does this also relate to building hive populations?

☐ Yes ☐ No

c. What is the effect of one vs. multiple pollen sources on hive health?…….

……

……

…….

12a. At any one time, do all worker bees collect from one source or from different sources?

☐ One source ☐ Multiple sources

b. If from multiple sources, roughly what proportion would bees collect from each source?

……

……

……

c. Does this proportion from each source change (within a day, week, flowering episode)?

……

……

……

d. If so, what factors do you think influence this variation in proportion?

……

……

……

13a. Have you observed variation in the preferred pollen source WITHIN A DAY?

☐ Yes ☐ No

b. What factors do you think influence this? ……..

……

……

……

14a. Do honeybees begin collecting pollen from a source as soon as flowering in that species begins?

☐ Yes ☐ No

b. Do honeybees continue to collect pollen from a source until flowering in that species ceases?

☐ Yes ☐ No

15a. Does the colour of pollen produced by a species affect hive health?

☐ Yes ☐ No

b. How much variation in pollen colour occurs WITHIN A SPECIES? ……..

……
……
……

c. Does pollen colour vary between flowering episodes?

☐ Yes No ☐

Does pollen colour vary between sites?

☐ Yes ☐ No

d. Do climatic factors before or during flowering affect pollen colour?

☐ Yes ☐ No

Examples……....
……...……

16a. Does tree age affect pollen quality?

☐ Yes ☐ No

b. Does tree age affect pollen quantity?

☐ Yes ☐ No

If yes to either of the above, how does tree age affect pollen?……....
……..…
……..……
…….

17a. Does soil type affect pollen quality?

☐ Yes ☐ No

b. Does soil type affect pollen quantity?

☐ Yes ☐ No

If yes to either of the above, how does soil type affect pollen?……...…

……..…
……..……
…….

18. Please list any other factors you consider influence pollen quality ……...

……..
…….
……..…
……..

19a. How often do you rely on pollen substitutes to maintain hive health? ……

……
……
……

b. Do you ever supplement pollen flows to build hive health/size? ……

……
……
……

c. Do some honey flows require pollen supplements more than other honey flows?

☐ Yes ☐ No

If YES, please give examples.……...
……
……
……

20a. Do you make your own pollen substitutes?

☐ Yes ☐ No

b. Do you purchase pollen substitutes?

☐ Yes ☐ No

c. What ratio of protein, fatty acids and other components of a pollen substitute do you find is necessary to maintain hive health? …….
……..……
……..……
……..……

Do you have any additional comments relating to pollen quality and/or bee nutrition?
……..……
……..……
……..……

Sincerest thanks for the time, effort and expertise you have invested in completing this survey.
Your input is greatly appreciated!

Flowering Ecology of Honey-Producing Flora in South-East Australia

RIRDC Pub. No. 08/098

This report examines the flowering ecology of important Australian melliferous flora. Aspects of flowering ecology that can have a negative impact on invertebrates, including honeybees, were also investigated.

The research was based on information sourced by highly experienced, commercial beekeepers and, so, provides a valuable written record of long-term observations relating to flowering ecology which otherwise may be lost following the death of beekeepers. Results of this study are of far-reaching importance, not only to the beekeeping industry, but to land managers, the general public and the future of Australian flora and fauna.

An understanding of flowering ecology is vital for many reasons, including implementing appropriate management practices which ensure the sustainability and growth of natural resources and industries like the beekeeping industry. Despite the importance of such studies, very little research has considered flowering ecology in Australian flora. Furthermore, research often was based on short-term data; long-term data are widely acknowledged as being necessary in such research in order to determine 'real' flowering patterns. Thus, studies of flowering ecology which use long-term data are vital.

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