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Effects of Logging on Nectar-Producing Eucalypts

Spotted Gum and Grey Ironbark

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Foreword

This project aimed to quantify for the first time the effect of logging on canopy nectar production in tall forest trees. The two eucalypt species chosen for research, Spotted Gum *Corymbia maculata* and Grey Ironbark *Eucalyptus paniculata*, are both of prime importance to nectarivorous wildlife, the timber industry and beekeepers. Of the 26 floral sources identified by beekeepers as the major honey sources, 14 are exclusively forest species, indicating the importance of State forests as the major honey resource for the apiary industry in NSW. However, beekeepers have expressed concern about the effects of logging on nectar production, especially the perception that young trees do not produce as much nectar as mature trees. While State Forests already have a number of management practices in place to retain nectar-producing trees during logging operations, there is no information on how much nectar is produced by retained trees or young trees re-growing after logging. It is the aim of this research to promote sustainability in forest management and to raise the awareness of forestry organisations that the nectar resource requires careful management in State forests. It also aims to raise the awareness of beekeepers about current forest management by quantifying nectar availability under different logging histories.

To successfully measure nectar in the canopy of tall forest trees, a combination of cranes and cherry-pickers were used. These mobile towers allowed nectar to be measured on a number of sites within a range of forests with different logging histories, thus allowing an investigation of how nectar production varies under different conditions. In addition, the project was undertaken over a number of years that spanned bushfires, drought and periods of heavy rain that washed out field work. These various environmental conditions proved useful in helping to isolate the effects of different weather patterns on nectar production. The report also discusses how variations in nectar production from year to year compared with honey yields collected by local beekeepers. It was found that honey yields were similar over a range of logging histories and that, in exceptional years, 1000 ha of spotted gum forest flowering from April-August could yield five tonnes of honey. Furthermore, improved communication between these industries would benefit both parties.

Most importantly, the report provides a scientific basis for assessing the effectiveness of current forest management prescriptions and justifies the existing additional prescriptions that retain mature trees of locally important flowering species.

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This report, an addition to RIRDC's diverse range of over 1600 research publications, forms part of our Honey Bee Research Program, which in part aims to provide a better understanding of the impact of bees on natural resource management and to maintain access to melliferous resources on public lands.

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Abbreviations

ANOVA	analysis of variance
dbh	diameter at breast height
BKDI	Byram-Keetch Drought Index
GEE	generalized estimating equation
h	hour
ha	hectare
J	joule
kJ	kilojoules
m	meter
SE	standard error
SF	State Forest
SNK	Student-Newman-Kuels test

Contents

Executive Summary

What the report is about

Nectar is a significant resource for native fauna and European honeybees *Apis mellifera* in the Australian environment, but its production has not been quantified in tall forest canopies over multiple sites. The focus of this research is on nectar production by spotted gum *Corymbia maculata* and grey ironbark *Eucalyptus paniculata*, both tree species of prime importance to the timber industry, beekeepers and nectarivorous wildlife.

Who is the report targeted at?

This report will be relevant to the forest and apiary industry as well as organisations charged with the responsibility of conserving and managing Australia's nectarivorous fauna.

Background

State forests provide the major honey resource for the apiary industry in NSW. Recent surveys of beekeepers using state forests have highlighted the beekeepers' concern about the effects of logging on nectar production, especially the perception that young trees do not produce as much nectar as mature trees. Forest NSW research has partly investigated this concern with a ten year study on flowering patterns of forest trees and the effects of climate and logging (Law *et a*l. 2000). However, this research did not measure nectar production.

Aims/Objectives

The project aimed to investigate the impact of logging on nectar production in the canopy of spotted gum and grey ironbark. In addition we quantified the magnitude of canopy nectar production and how this varied over the different years we sampled in relation to prevailing and preceding climate. Given the variability in flowering and nectar production between years we also benchmarked our nectar measurements with the amount of honey produced by local beekeepers as determined by questionnaires distributed to them.

Methods used

The study was undertaken on the south coast of New South Wales, where nectar was measured on large and small trees between 2003 and 2006. Cherry-pickers and cranes were used to access the canopy in replicate sites in different logging histories – recently logged, regrowth and mature/old regrowth forest. Nectar was measured in flowers bagged over-night (to prevent access by pollinators) and in unbagged flowers. Nectar production was then scaled up from the flower level to the forest stand by incorporating transect counts of the number of flowers per tree and trees per hectare. Spotted gum nectar was primarily measured in 2005, although some measurements of unbagged flowers were also undertaken in 2003. Nectar was measured in *Eucalyptus paniculata* over three consecutive years (2004-2006) in each of the logging histories. We benchmarked our nectar measurements against honey yields by distributing questionnaires to local beekeepers.

Results/Key findings

For spotted gum in 2005, we found that neither logging history nor tree size significantly affected over-night nectar production in bagged flowers; a significant interaction indicated that nectar production per flower was low in small trees in recently logged sites and high in small trees in regrowth sites. When nectar production was scaled up to the forest stand, mature forest produced almost ten times as much sugar per hectare as recently logged forest, with regrowth being intermediate. Less nectar after logging is explained by the fact that regrowing canopy is mainly formed by small and medium sized trees. We found that these trees flower less often than large trees. At the compartment scale, the difference between mature forest and recently logged forest was reduced to a factor of two times when the extent of areas left unlogged under current practices was considered. Areas reserved from logging in NSW include riparian buffers, high conservation old growth forest, over-ridge connection corridors, threatened species habitat as well as habitat trees and recruits within logging zones.

One distinctive characteristic of *Corymbia maculata* nectar in 2005 was its high sugar content (40-60 %), much higher than the concentrations measured in 2003 (mean = 18 %). Nectar was not a limiting resource in 2005 as extensive flowering was recorded across the south coast and it was found that nectar was only slightly depleted in unbagged flowers measured in the morning and the afternoon. Logging history had no effect on the degree of nectar depletion. We estimated that, on average, mature spotted gum forest produced a vast resource over-night. This is by far the greatest nectar energy density yet published: 35,000 kJ ha^{-1}.

Flowers measured in 2003 provided a strong contrast with occasional flowering stands with much less sugar per flower early in the morning and virtually unmeasurable quantities after 0930 hours. At such times, nectar is limiting with morning nectar presumably consumed most quickly in areas recently logged. Models of nectar production collated over both years, using climate and site variables, indicated nectar volumes and sugar concentration respond differently to environmental conditions. Predicting the nectar resource, which is made up of both components, was most consistently related to recent conditions that were unfavourable to foliage production. In general, more nectar was produced after a week of colder than average mornings, regardless of rainfall or after warmer mornings (if rainfall in the previous month was below average and there were only a few flowers on the tree).

Our results for *Eucalyptus paniculata* showed similarities to *Corymbia maculata* with regard to the impact of logging, but the species differed markedly in other aspects of nectar production. Nectar was produced during the day and night, unlike spotted gum which has been observed previously to produce nectar over-night. We found great similarity in nectar production between autumn flowering in 2004 and late-winter flowering in 2005, but these differed considerably from early summer flowering in 2006. Low average floral sugar levels in the early morning bagged flowers in 2004 and 2005 (1 mg sugar per flower) corresponded to the low levels for spotted gum in 2003 (1 mg sugar), while the sugar-rich nectar in grey ironbark in 2006 (5.3 mg sugar) was similar to spotted gum for 2005 (4.8 mg sugar). This means that nectar in *Eucalyptus paniculata* flowers was a limited resource in 2004, to a lesser extent in 2005 and not in 2006. Nectar standing crops were determined by an interaction between environmental conditions that influenced nectar production and the feeding activity of flower visitors at the time, which itself is affected by prevailing temperatures and nectar attributes, such as sugar concentration.

Logging history and tree size, when taken individually, had no significant effect on nectar production per flower in *Eucalyptus paniculata*, although they did differ when compared between logging histories. However, these differences were relatively minor in comparison to the negative effect of drought. Little nectar was produced under any logging history in droughts, while during good conditions nectar production varied depending on logging history. When scaled up to the forest stand, logging history had a marked effect on nectar production with old regrowth forest producing seven times as much sugar per ha as recently logged forest, with regrowth forest 15-20 years old being intermediate. However, at the compartment scale, the difference between old regrowth forest and recently logged forest was reduced to a factor of two times when the extent of areas left unlogged under current practices was considered.

Environmental correlates of nectar production per flower in *Eucalyptus paniculata* were primarily related to drought. Sugar-rich flowers were only found when our drought index indicated better than average conditions for up to 12 months prior to flowering. The negative effect of drought is surprising as *Eucalyptus paniculata* is more drought-tolerant than co-occurring species and it clearly differed from the factors that influenced nectar production in *Corymbia maculata*. We can summarise the differences between the two species as follows: the winter-flowering spotted gum appears to maximise nectar production when conditions are unsuitable for growth, such as when it is dry or cold, while the slower-growing grey ironbark, which can flower in a variety of seasons, yielded its richest nectar in summer that was warm and moist.

Benchmarking our nectar measurements with records of honey production from local beekeepers revealed that *Corymbia maculata* flowering in 2005 had honey yields (54 – 83 kg/hive from April-October) above the typical maximum values reported for the species. This confirms the prolific and extensive nature of the flowering in that year. In contrast, during the poor flowering year of 2003 few hives were deployed in the forest and no honey production was reported at this time. For *Eucalyptus paniculata*, the yearly differences in the quantity of sugar produced per flower were related to considerable variations in honey production. In particular, summer 2006 saw prolific honey production close to the maximum previously reported for this species, reflecting the copious, sugar-rich nectar that we measured. Differences in honey production in 2004 and 2005 were apparently related to nectar standing crops rather than actual nectar production.

Honey productivity was comparable across the three treatments of logging history. Also, comparisons of the estimated requirements of hives with the amount of sugar produced by the forest indicate that the spotted gum forest in 2005 was producing excess nectar for commercial honeybees. This demonstrates that, when flowering is prolific, good honey yields can be obtained from recently logged and regrowth sites. Yet in years when flowering is less prolific (e.g. 2003), nectar may be limiting and retained areas of unlogged and regrowth forest are very important in ameliorating the effects of logging in such years.

We estimate that a hive of commercial honey bees produced about 1 kg honey/ha/month during 2005 and that a 1000 ha spotted gum forest flowering from April-August could yield 5 tonnes of honey. Given a wholesale price of spotted gum honey in 2007 of $2.20 per kg, this values the spotted gum honey resource per 1000 ha of spotted gum forest in 2005 as $11,000. It should be noted that was a prolific flowering year for spotted gum and there was little blossom in the immediately preceding years.

Implications for relevant stakeholders

This project has shown that current logging practices in NSW halve the nectar resource, but that in years of good flowering there is a surplus of nectar and honey production. However, there is justification for the existing additional prescriptions that retain mature trees of locally important flowering species, because in years of poor flowering nectar is rapidly consumed in the mornings and is thus a limiting resource at those times.

Recommendations

The main recommendation of this report is to further disseminate the results of the project to promote sustainability in forest management, to raise the awareness of forestry organisations that the nectar resource requires careful management and to raise the beekeeper's awareness about current forest management. Improving communication between apiarists and foresters would be valuable to establish formal guidelines on the management of apiary sites and the nectar resource in forests. Further research on how climate change will affect flowering levels and subsequent nectar production could be critical to the apiary industry and the conservation of nectarivorous fauna.

1. Introduction

A prominent feature of the Australian environment is the prevalence of nectar-rich plants visited by diverse species of vertebrates such as honeyeaters, lorikeets, bats, gliders and possums as well as the European Honeybee *Apis mellifera* (Ford *et al*. 1979; Woinarski *et al*. 2000; Hall and Richards 2000). For example, Ford *et al*. (1979) suggest that about 1000 species of plants in Australia have birds as their pollinators. As a consequence there have been many studies on the foraging ecology of nectarivorous animals, patterns of nectar production and pollination ecology and flowering phenology, especially in Banksia dominated communities that typically grow as heath (Pyke 1983; Paton and Turner 1985; Copland and Whelan 1989; Cunningham 1991; Law 1994). The focus on Banksia-dominated communities is partly because these are nectar-rich environments, but also because their flowers grow at a height that is easily accessible for biologists to measure nectar. In comparison, the Australian forest landscape is dominated by tall eucalypt trees, but the attributes of nectar production in the canopy of these forests is poorly known.

The importance of blossoming eucalypt (species of *Eucalyptus, Corymbia* and *Angophora*) forests to a range of fauna has been established mainly from direct observations of foraging behaviour or associations between nectarivores and blossom abundance (Kavanagh 1987; Goldingay 1990; Eby 1991; McGoldrick and Mac Nally 1998; Wilson and Bennett 1999; Law *et al*. 2000; Sharpe 2004). Although these studies are of great value, very few studies have directly measured nectar in eucalypt trees within forests. This is a major limitation given that the relationship between flowering and nectar production in eucalypts is considered unreliable (Wykes 1947; Porter 1978). Those studies that have measured nectar in eucalypts tend to be limited to sampling only a few trees and in shorter mallee, and low woodlands and forests (Bond and Brown 1979; Paton 1985; Pyke 1985; Horskins and Turner 1999; Timewell and Mac Nally 2004; Goldingay 2005).

Accessing the canopy in tall forests is clearly a major logistical problem. Some studies have sampled from fixed canopy cranes, but these major structures tend to be located in rainforest not eucalypt forest. Even if multiple trees are sampled, the crane is restricted to a single site (e.g. Boulter *et al*. 2005). Given this paucity of knowledge, little is known about aspects of nectar production in canopies of tall forests, such as the quantity and quality of nectar produced. Moreover, there is little data available to assess the influence of disturbances such as logging on nectar production, together with the effect of other attributes such as site quality, tree size/age and climatic variables. Indeed, we are a long way from being able to predict which will be a good “nectar year” and how this might vary spatially.

Beekeeping and State Forests

In addition to providing an important nectar and pollen resource for native wildlife, State forests provide the major honey resource for the apiary industry in NSW (Somerville and Nicholson 2004). Of the 26 floral sources identified by beekeepers as the major honey sources, 14 are exclusively forest species. In terms of honey deliveries to Capilano Pty Ltd, eucalypts supply on average 70 % of the honey crop obtained by NSW-based producers (Somerville and Moncur 1997). The State Forests resource also has a relatively large social impact as 3,749 occupation permits were issued for beekeepers in 1995/96. In 1994, an exceptional flowering year for spotted gum *Corymbia maculata*, 1,281,393 kg of honey was delivered to Caplilano Pty Ltd (Somerville and Moncur 1997).

Despite the importance of State forests to honey production in NSW, recent surveys of beekeepers using state forests have highlighted the beekeepers’ concern about the effects of logging on nectar production, especially the perception that young trees do not produce as much nectar as mature trees (Somerville and Nicholson 2004). Forest NSW research has partly investigated this concern with a 10 year study on flowering patterns of forest trees and the effects of climate and logging (Law *et a*l. 2000). However, this research did not measure nectar production. Information on how flowering and nectar production is influenced by logging is also required by Forests NSW for effective management of nectarivorous threatened species (e.g., the recently listed Grey-headed Flying Fox).

Study Aims

Our study aimed to quantify the impact of logging on nectar production in spotted gum *Corymbia maculata* and grey ironbark *Eucalyptus paniculata* to specifically test predictions that flowers on larger trees produce more nectar than those on smaller trees (Brereton *et al*. 2004). Both tree species are of major importance to nectarivorous wildlife, the timber industry and beekeepers. To achieve our aim, emphasis was placed on sampling many trees of different sizes, across replicate sites that span different disturbance histories. To deal with the logistical problem of accessing the canopy of tall forest trees we used a combination of either cherry-pickers or mobile cranes.

A secondary aim was to quantify the nectar resource produced in the canopy of a stand of trees and to investigate the influence of climatic and site factors on nectar production. Given the variability in flowering and nectar production between years, we also wanted to benchmark our nectar measurements with the amount of honey produced by local beekeepers. To achieve this we consulted local beekeepers using a questionnaire survey to assess the amount of honey production during the period when most of our measurements were taken and related this to the quantity of nectar flow.

2. General Methods

Study Area

The study was located on the south coast of New South Wales (NSW) (Figure 2.1). Forests sampled were typically on flat to undulating terrain on the lowlands. Mean annual rainfall for the study area is 1000 mm, with severe droughts occurring periodically (Forestry Commission 1982). Monthly rainfall tends to be uniform, but with slightly drier conditions in July and August. The mean minimum of the coolest month (June) is 8^{o}C. Spotted gum is a dominant species in a number of forest types in the area (e.g. types 70 and 74 – Forestry Commission of NSW 1989), although several species of co-dominant eucalypts occur, especially grey ironbark. Forest structure ranges from wet sclerophyll forest to open dry sclerophyll forest. For spotted gum, three regions were selected on the basis that they were representative of large blocks of *C. maculata* forest. They were denoted as Nowra (Nowra and Currambene State Forest and nearby forest on private land), Ulladulla (Kioloa, Termeil and South Brooman State Forest) and Batemans Bay (Murramurang National Park and Benanderah State Forest). Grey ironbark sites were selected from the same region, but were chosen more opportunistically based on the presence of flowering trees and logging histories (see Chapter 4).

The forests have a long history of timber extraction. Selective logging for ship-building timbers in spotted gum forests near Nowra probably began as early as 1820 and for a range of other products by the 1880s (Forestry Commission 1982, 1983). Ironbarks were one of the species favoured prior to 1890 for poles and railway sleepers, resulting in a depletion of this resource (Forestry Commission 1983). “Group selection”, where canopy gaps of no more than 50 m are created over about 20 % of the logged area, is the main silvicultural system used locally. It was first implemented in the 1950s (Forestry Commission 1983). Such a long history of management for timber extraction has left the forests as an irregular mosaic dominated by stands of regenerating trees (15-25 m high), also including individuals or groups of residual old mature trees but, rarely, stands of mature trees (30-40 m high).

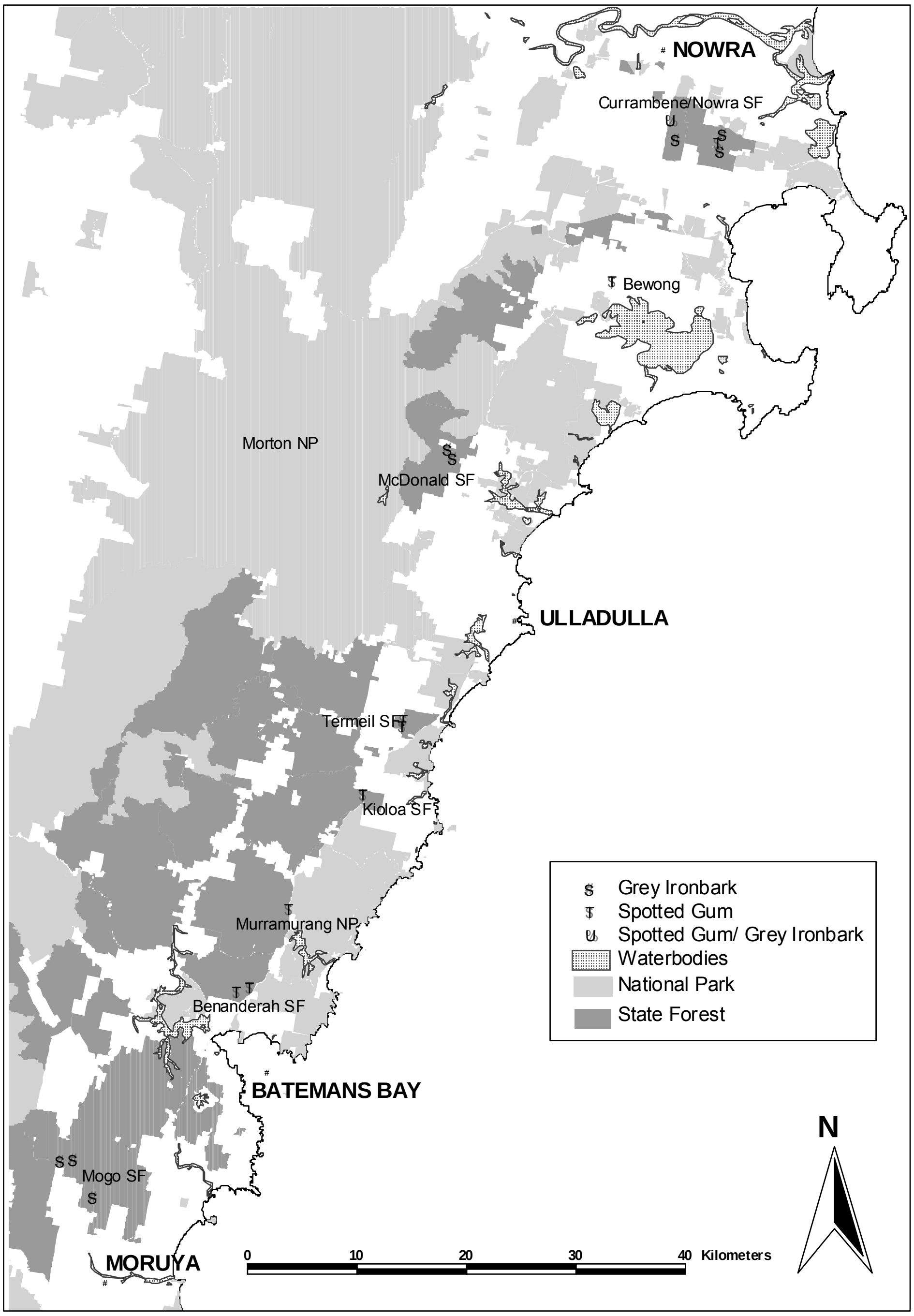

Figure 2.1: Map of south coast region showing spotted gum *Corymbia maculata* and grey ironbark *Eucalyptus paniculata* study sites.

Climate during the study

The south coast experienced an El Nino event from 2002-03, experiencing a severe rainfall deficiency in the 12 month period prior to commencement of flowering in April 2003 (Figure 2.2; Bureau of Meteorology). However, there was good rainfall in the following two months and the area was no longer rainfall deficient by the time of nectar measurements. In comparison, there was no rainfall deficiency in the lead up to our 2005 nectar measurements (Figure 2.2; Bureau of Meteorology).
For instance, the Byram-Keetch drought index and other weather variables were accessed from the closest weather station to each study region via the Bureau of Meteorology. The drought index gives a cumulative daily estimate of soil dryness in the top one metre layer by incorporating the effects of evaporation, transpiration and rainfall. Values range from 0-200 (0-24- mild, 25-63 - average, 64-100 – serious to severe drought, 100-200 – extreme drought) (Bureau of Meteorology).

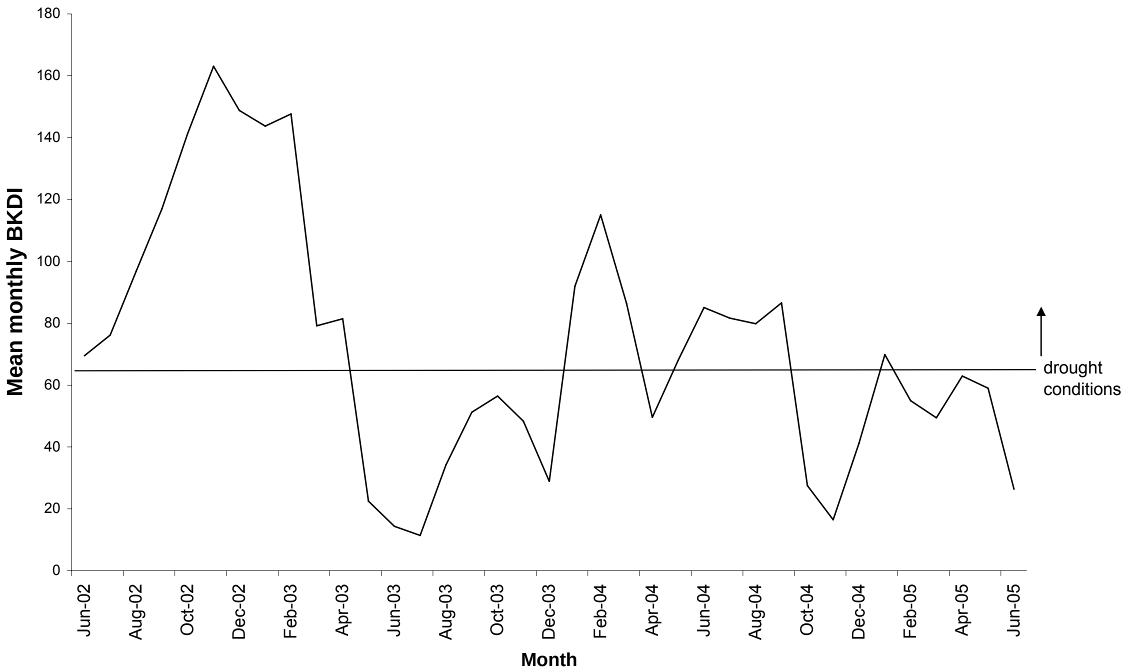

Figure 2.2: Drought conditions on the south coast of NSW expressed as the Byram-Keetch Drought Index averaged each month between 2002 and 2005. The drought index gives a cumulative daily estimate of soil dryness in the top one metre layer by incorporating the effects of evaporation, transpiration and rainfall. Values range from 0-200 (0-24- mild, 25-63 - average, 64-100 – serious to severe drought, 100-200 – extreme drought).

Source: Data supplied by the Bureau of Meteorology

Sampling nectar

Flowers in the canopies of trees were accessed by cherry-pickers (< 23 m high) or cranes (23-33 m high). The use of such equipment to access tall canopies restricted sampling to forest bordering road-sides, although we were able to sample from dirt roads penetrating forest where logging practices did not differ from the forest interior. Patches of forest with a different logging history were located primarily on the basis of the presence of sufficient trees in flower and logistical constraints of accessing trees with a cherry picker or crane. The logistics involved in setting up cherry-pickers and cranes and subsequent measurement of flowers limited our sampling to one site (i.e. four large and four small trees in one logging history) per 24 hour period.

Floral nectar was measured on rain-free days with no more than slight winds. To measure nectar production we bagged flowers with mosquito netting (mesh size = 2 x 1 mm) in the late afternoon (hereafter pm) and allowed nectar to accumulate over-night. Spotted gum is known to produce little nectar during the day (A. Oldfield and M. Moncur pers.. comm.), however, nectar has not been measured in grey ironbark before. Two bags were used per tree to enclose 20-50 flowers each, thus excluding invertebrates, birds, bats and gliders. Logistically it was not possible to remove nectar from flowers prior to bagging, thus nectar in bagged flowers in the morning reflects nightly production or apparent secretion rate (sensu Corbet 2003) under conditions whereby pollinators are excluded and any natural reabsorption could occur (Corbet 2003). When forager visits are frequent, a measure of nectar production (gross secretion rate) from repeated sampling of nectar is likely to be higher. Flowers were removed in the morning (15-17 h after bagging - hereafter am) by cutting the branch with secateurs and measuring nectar back on the ground.

In addition to measuring nectar production in bagged flowers, we measured standing crops (nectar in unbagged flowers) to quantify the amount of nectar available to pollinators at the time of measurement. We cut unbagged flowers for nectar measurements on two separate bunches per tree during both the pm and am sessions. While twenty bagged flowers were measured per tree to quantify nectar production, five unbagged flowers per tree were measured in each am and pm session for standing crops.

Nectar volume per flower was measured using calibrated micropipettes (5, 10, 20 and 25 μL, Blaubrand, IntraMARK). Sugar concentration (%wt/wt) for each flower was then measured from a drop of nectar using a hand refractometer. To calculate total sugar per flower (mg), nectar concentrations (% wt/wt) were first converted to mg sugar per 100 ml of solution (% wt/vol.) (Bolten *et al.* 1979) and then multiplied by the volume measured in the flower. Measurements were made on flowers of various developmental stages as nectar was observed to be present as soon as stamens unfurled and when they began to brown, as long as the stigma was still receptive. Flowers containing larva of eucalypt nectar flies (*Drosophila*) were not measured.

Nectar production per area

To scale up the quantity of nectar per flower to the level of the tree and forest stand we estimated the number of flowers on different trees in each size-class and the density of those size-classes at each site. We established a 200 m x 10 m (5 m either side of road) transect in each site to estimate the density of flowering *C. maculata* by counting every stem in the transect, allocating them to one of three size-classes (small < 25 cm diameter at breast height (dbh); medium 25-40 cm dbh; large > 40 cm dbh) and noting whether the tree was flowering. Unopened buds and young fruit of finished flowers were not counted, nor were other tree species that were occasionally flowering in the transects. The median number (to lessen the effect of some very high flower counts) of flowers per tree was calculated from a random sample of flowering stems in the transect. Flower numbers were estimated using binoculars from the ground, after having scanned the canopy from the cherry-picker/crane. First, we counted flowers in a section of canopy and then multiplied this by the number of canopy sections in the tree (Kavanagh 1987). Thus, the amount of nectar produced per site (0.2 ha) was estimated by multiplying the number of flowering trees in each size-class by the median number of flowers carried by trees in those size-classes and the mean amount of nectar (mg sugar) per flower in each tree size-class in that site. We estimated mean sugar per medium-sized tree as the average of measurements on large and small trees in that site.

3. Spotted Gum *Corymbia maculata*

Introduction

Spotted gum is a tall, dominant tree in a number of forest types on the south coast of NSW, extending to the Hunter Valley in the north (e.g. types 70 and 74 – Forestry Commission of NSW 1989). Several species of codominant eucalypts occur in these forests, especially grey ironbark *Eucalyptus paniculata*.

Spotted gum in the study area typically flowers between April and October, with floral buds taking at least 14 months to develop before reaching anthesis (Pook *et al*. 1997). The species does not usually flower annually; rather it is highly variable in flowering frequency. A long term study by Pook *et al*. (1997) in southern NSW found that flower buds on canopy trees were produced every 2-3 years, but less frequently on subordinate trees. Significant flowering occurred only three times in 15 years. Local beekeepers consider that heavy flows of nectar occur about once in 8-10 years (Cocks and Dennis 1978). Drought is known to abort floral buds (Pook *et al*. 1997).

This chapter aims to quantify the impact of logging on nectar production in spotted gum *Corymbia maculata* at the scale of both the individual flower and the tree stand. A secondary aim is to quantify the extent of the nectar resource produced in the canopy of a stand of trees and to investigate the influence of climatic and site factors on nectar production.

Methods

Experimental design

To determine the effect of logging on nectar production, a partly nested (split-plot) design with three factors was implemented in June and July 2005, when flowering was prolific and in the middle of the winter flowering season of *C. maculata*. The three factors were region (see above) (random factor), logging history (fixed) and tree-size (fixed). Within each region three logging histories were sampled:

1. Recently logged/thinned forest (< 5 years old, trees 5-25 m high).
2. Regrowth forest (15-30 years old, trees 10-25 m high).
3. Mature forest (> 50 years old, 30-35 m high).

Most mature sites contained trees with multiple hollows, indicating many individuals were considerably older than 50 years. Within each logging history, two size-classes of trees were sampled:

a) Small trees < 25 cm dbh and 4-14 m high.
b) Large trees > 40 cm dbh and 15-33 m high.

The large trees in recently logged and regrowth sites were trees that were retained during logging for various reasons, such as habitat for wildlife, recruits or as a source of seed. We sampled four trees for each tree size-class within a 500 m transect of forest. On each tree nectar was measured in 20 bagged flowers. As an example of sampling effort using this design, in the mature forest treatment we measured nectar in 3 regions x 2 tree-sizes x 4 trees x 20 flowers = 480 flowers. Over the three logging histories we measured nectar production in 1440 flowers. The number of flowers and the method of assessing nectar production differed in 2003 when flowering was poor.

Variation in nectar production between years

In addition to measurements in 2005, we also measured nectar from unbagged flowers of *C. maculata* in June and July 2003. The south coast experienced an El Nino event from 2002-03, experiencing a severe rainfall deficiency in the 12 month period prior to commencement of flowering in April 2003

(Figure 2.1; Bureau of Meteorology). However, there was good rainfall in the following two months and the area was no longer rainfall deficient by the time of nectar measurements. In comparison, there was no rainfall deficiency in the lead up to our 2005 nectar measurements (Figure 2.1; Bureau of Meteorology). Flowering was poor in 2003 in that stands of flowering trees were scarce and flowering trees were usually sparsely scattered among many non-flowering trees. Nectar was measured at five sites with differing logging histories in the Nowra region, two of which we considered to be flowering profusely, although only at a localised scale. In comparison, in 2005 each of our nine sites forming our main experimental design was flowering profusely, and in general this was the case throughout the entire south coast in that year. In 2003, nectar was only measured in unbagged flowers between 0630 h and 1215 h (20 flowers per tree). Thus comparisons of nectar between 2003 and 2005 were restricted to measurements from unbagged flowers measured in the morning.

Correlates of nectar production

To derive a predictive model of nectar production, a number of tree, site and weather co-variates were recorded concurrently with nectar measurements (Table 3.1). These were chosen on the basis that they have potential to influence nectar production per flower. For instance, the Byram-Keetch drought index and other weather variables were accessed from the closest weather station to each study region via the Bureau of Meteorology. The drought index gives a cumulative daily estimate of soil dryness in the top one metre layer by incorporating the effects of evaporation, transpiration and rainfall. Values range from 0-200 (0-24- mild, 25-63 - average, 64-100 – serious to severe drought, 100-200 – extreme drought) (Bureau of Meteorology).

Statistical analysis

The effect of logging history and tree-size on nectar production per flower was tested with a partly nested (split-plot) analysis of variance (Quinn and Keough 2002). Region (random) and logging history (fixed) were between plot factors and tree-size was the within plot factor. Logging history was tested against the logging history x region error term, tree size was tested against the logging history x tree size error term and the logging history-tree size interaction was tested against the logging history x region x tree size error term. *F* tests for each term in the analysis were tested against the appropriate denominator using the custom tests option in Statistica 7 (Statsoft). To test whether nectar depletion differed across sites with different logging histories, we used the interaction term of a two factor ANOVA (analysis of variance) with the following factors: region (random), logging history (fixed) and bagging (bagged, am unbagged, pm unbagged - fixed). For all analyses nectar (mg sugar) was log10 (x+1) transformed to homogenize variances. Student-Newman-Kuels (SNK) tests were used for post-hoc comparisons. To reduce the chance of type II errors given our limited replication (three sites per region), we accepted significant differences as $P<0.1$.

To test whether nectar produced per flower was correlated within trees, sites or regions we calculated the intraclass correlation coefficient (Zar 1984) using the Variance Components module of Statistica 7.

Predictive models of nectar quantity in unbagged flowers (am) for both years with measurements (2003 and 2005) were built using the Regression Tree approach in S-PLUS (Version 7, Insightful Corp). The “prune.tree” function (Kavanagh, Law et al. 2000) was used to obtain a parsimonious model. This technique displays data as a dendogram, illustrating the major binary splits in the data structure. The method makes no assumptions about the distribution of the data, the relationships among predictors or the form of the relationship between the predictors and the response variable. It is particularly useful for revealing hierarchical interactions between predictors, especially if threshold effects are operating (Andersen *et al*. 2000).

Table 3.1: Tree, site and weather co-variates used to build predictive models of nectar production in Spotted Gum

Tree
Number of flowers per tree
Tree dbh (cm)
Tree height (m)
Distance from canopy (tree height – flower height) (m)
Crown radius (m)
Canopy aspect (degrees)
Site
Topography (1, hill-top – 9, depression)
Weather
Rain in previous 24 h (mm)
Rain in previous week (mm)
Rain in previous month (mm)
Maximum temperature of previous day (^{o}C)
Minimum temperature of measurement day (^{o}C)
Mean maximum temperature of previous week (^{o}C)
Mean minimum temperature of previous week (^{o}C)
Mean temperature of previous week (^{o}C)
Relative humidity at 9:00 am of measurement day (%)
Mean Byram-Keetch Drought Index of previous week
Mean Byram-Keetch Drought Index of previous month
Mean Byram-Keetch Drought Index of previous 12 months

Spotted Gum *Corymbia maculata* flowers, cherry-picker, crane and mesh exclusion bags on the canopy of a small and large tree.

Spotted Gum logging histories sampled in southern NSW. a – recently logged, b – regrowth and c – mature forest.

a

b

c

Results

Nectar per flower

The amount of nectar produced over-night was highly variable across the study. Nectar volumes per flower ranged from 0-83.9 μL, sugar concentrations (on measurable quantities of nectar) ranged from 10-84 % and mg of sugar ranged from 0-45.3 mg sugar per flower. Such variability was also typical between flowers within a tree. Intraclass correlations between flowers within a tree were low for mg sugar (r_I=0.30) and total nectar volume (r_I=0.26). A major contributor to the poor correlation between flowers within trees was the fact that there were usually some flowers with no nectar, even in trees where the nectar reward was usually high (Figure 3.1). Variation (e.g. for mg sugar) was even greater between trees within a site (r_I=0.17) and sites within a region (r_I=0.02) than between flowers within a tree. Figure 3.2 shows the variation in mg sugar across 20 flowers within trees and across the 8 trees sampled at the mature forest site, Murramurang National Park. For sugar concentration only flowers with nectar were considered and the intraclass correlation was markedly higher (r_I=0.66). Nonetheless, within tree variability existed, for example in one tree sugar concentrations measured in 20 flowers ranged from 15-59 % (Figure 3.2). Intraclass correlations for sugar concentration were moderately high within sites (r_I=0.52), but less so within regions (r_I=0.35); clearly predictability within class dropped with increasing spatial scale. There was also no consistent change in sugar production or concentration from early June to late July when our measurements were undertaken.

Comparisons of bagged versus unbagged flowers (standing crops)

The mean volume of nectar per flower was lower in pm standing crops (7.5 μL) than am standing crops (10.8 μL) and both were lower than in bagged flowers (12.2 μL) ($F_{2,195}$=4.54, P<0.05). In contrast, mean sugar concentration was greatest in pm standing crops (55 % wt/vol) and lower in am standing crops (41 % wt/vol) and bagged flowers (36 % wt/vol). Nectar volume was not correlated with sugar concentration in bagged flowers (r = 0.02) or am standing crops (r = -0.15), but there was a negative correlation for pm standing crops (r = - 0.3; P<0.05). When converted to total sugar, on average more mg sugar accumulated over-night in bagged flowers than was present in either am (oneway ANOVA SNK test, P=0.07) or pm (SNK test, P=0.007) standing crops (Figure 3.3c). However, there was probably little depletion of nectar over-night as unbagged flowers were measured up to 4 h after dawn and through this time, total sugar declined from 5.1 mg sugar per flower in the 1^{st} hour after dawn, which was virtually identical to the amount that accumulated in bagged flowers over-night (4.9 mg sugar), to 2.9 mg sugar by 1130 h. There was no significant difference between am and pm standing crops (SNK test, P>0.1) and both am and pm standing crops were correlated with nightly nectar production (r=0.49; r=0.41, P's <0.05, respectively).

Effects of logging history and tree-size

A split-plot ANOVA of 2005 data revealed that logging history had no significant effect on sugar production per flower ($F_{2,4}$=2.5, P=0.2). However, there were few degrees of freedom for this analysis and there was a trend for flowers in regrowth to produce more mg sugar per flower than recently logged forest or mature forest (Figure 3.4). Tree size had no significant effect on sugar production per flower ($F_{1,2}$=0.5, P=0.6). The lack of influence of tree dbh on sugar production is further illustrated by the fact that the two variables showed no correlation (*r*=-0.05, *P*=0.7, dbh range:13-131 cm). There was a significant interaction between logging history and tree size ($F_{2,4}$=13.1, P<0.02 - Figure 3.4), whereby flowers of small trees in regrowth produced more sugar than all other trees except large trees also in regrowth (SNK tests, P<0.05). Small trees in recently logged forest produced the least amount of sugar (SNK tests, P<0.05). Although not specifically tested for because of its use as a random blocking term, region had little influence on sugar produced per flower (means for Nowra = 5 mg, Ulladulla = 4.8 mg, Batemans Bay = 6 mg). Logging history and tree-size also had no significant effect on am or pm standing crops of mg sugar (split-plot ANOVAs, P's>0.1).

When sugar is broken down into its components, logging history influenced ($F_{2,4}$=5.3, P=0.08) sugar concentration (wt/vol), with recently logged forest having more dilute nectar at an average of 27 % sugar, compared to 38 % and 43 % for mature and regrowth forest, respectively. There was no effect due to tree size ($F_{1,2}$=0.12, P=0.7). Total volume of nectar produced was not different between logging histories ($F_{2,4}$=1.6, P=0.3) or tree sizes ($F_{1,2}$=1.3, P=0.4). There was a significant interaction between logging history and tree size ($F_{2,4}$=4.4, P=0.09), whereby large trees in mature forest produced 20 % less nectar volume than other treatments (SNK tests, P<0.05).

Logging history had no detectable effect on the amount of nectar depleted in unbagged flowers, as determined by a non-significant interaction term of logging history and bagging ($F_{4,8}$=0.6, P=0.7). In other words, while bagged flowers contained more sugar than unbagged flowers (see above - Comparisons of nightly nectar production with standing crops), logging history did not influence this pattern (Figure 3.5).

Effects of logging history on nectar levels scaled up to the forest stand

When floral nectar is scaled up to the forest stand level based on estimates of the number of flowers present, a one way ANOVA found that logging history had a significant effect on total sugar produced ($F_{2,6}$=3.88, P=0.09). Recently logged forest produced just over one tenth of the sugar per 0.2 ha (50 g sugar per night) of mature forest (450 g), while regrowth forest was intermediate (200 g) and not significantly different from either mature or recently logged forest (Figure 3.6 - SNK test). Data were highly variable for both mature and regrowth forest, while recently logged sites produced uniformly low amounts of sugar.

To further understand the factors responsible for the significant effect of logging history on sugar produced in a stand of trees, we analysed the proportion of trees in flower. After arcsin transformation, logging history had no effect on the proportion of trees in flower ($F_{2,4}$=3.8, P=0.12), but tree-size had a large effect ($F_{2,8}$=14.7, P<0.01). About 60 % of large trees were in flower, compared to 42 % of medium trees and 20 % of small trees. Flower numbers also varied enormously with tree size. On average, large trees carried 3600 flowers compared to 816 flowers on medium trees and 283 flowers on small trees. A maximum of 74000 flowers was estimated on a large tree compared to a maximum of only 4,000 flowers on a medium tree. Thus the mature forest site that produced exceptional quantities of sugar (Murramurang NP) had many large trees covered in flowers (median of 8000 per tree), but another mature site (Princes Highway, Nowra) produced relatively little sugar, because there was a median of only 1800 flowers per large tree at this site. Similarly among regrowth, one site (Termeil State Forest (SF) - a median of 5650 flowers per large tree) produced as much nectar as the mature forest average (Figure 3.6), but another that was towards the end of flowering (Benanderah SF – a median of 350 flowers per tree) fell within the range of recently logged sites even though the quantity of nectar produced per flower at this site (10.5 mg sugar) was the highest of all of sites.

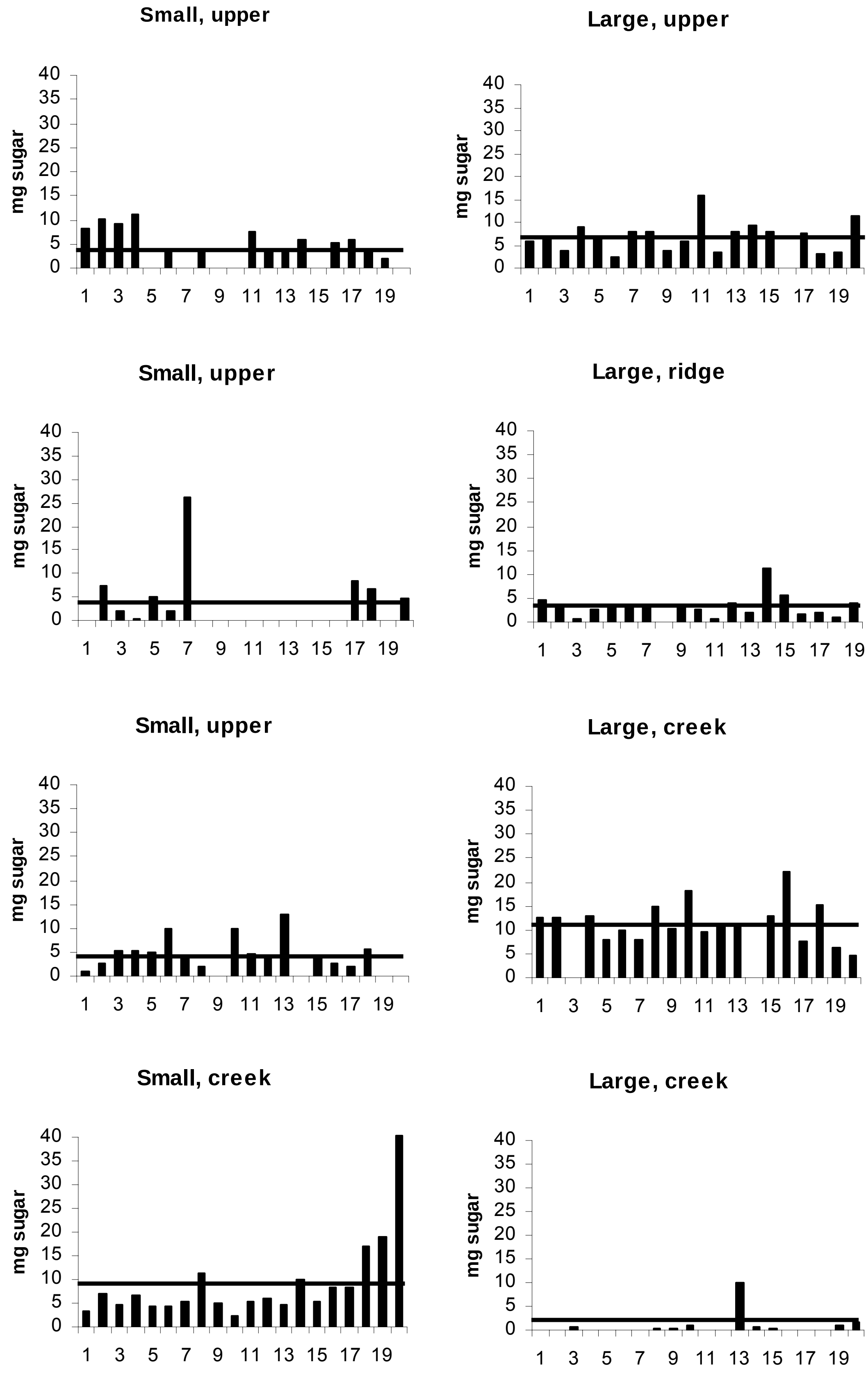

Figure 3.1: Within tree variation in mg sugar across 20 measured flowers and between tree variation across eight trees sampled at one mature forest site, Murramurang National Park. Tree size and topographic position is also indicated for each tree. The horizontal line illustrates the mean mg sugar per flower for each tree.

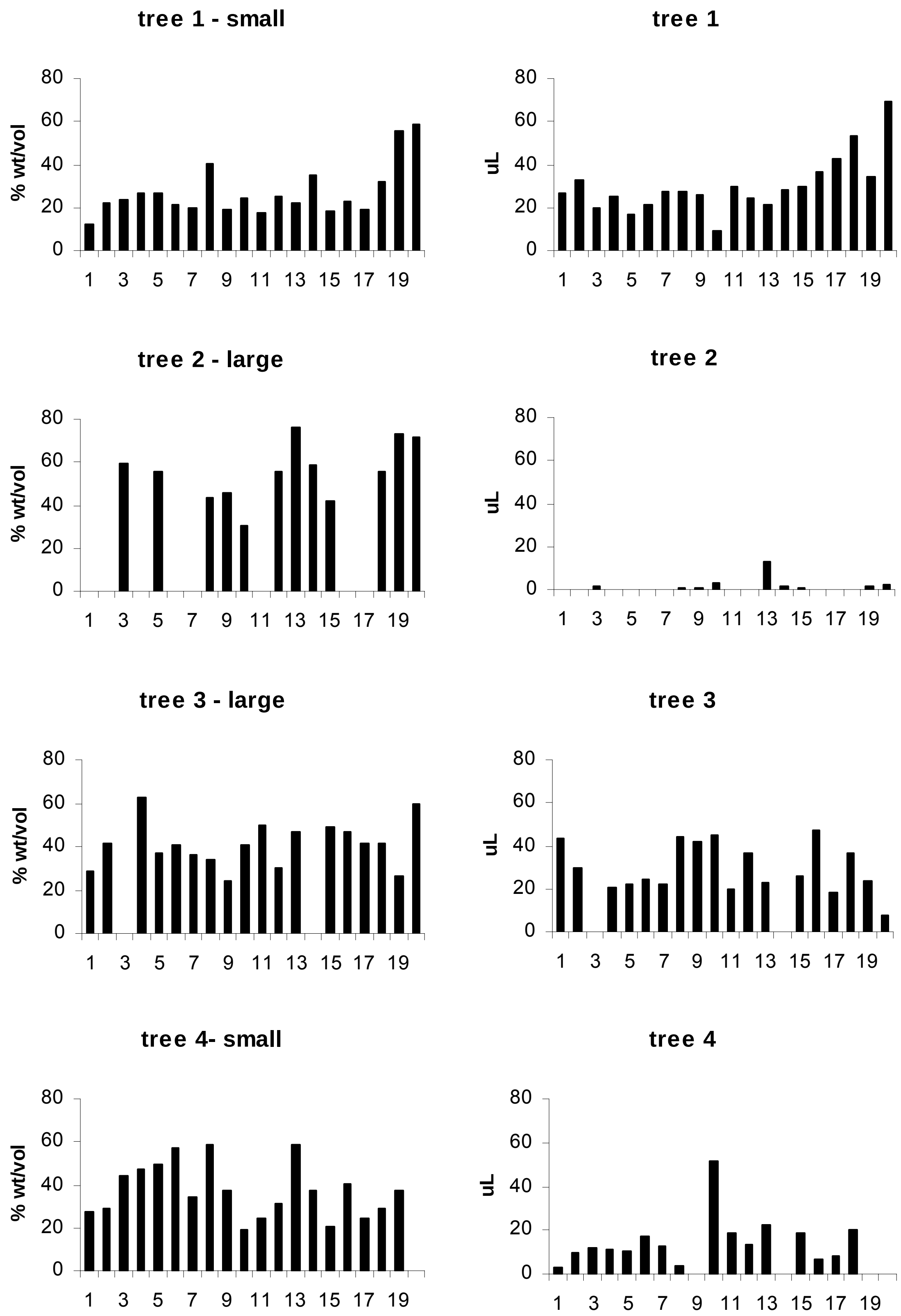

Figure 3.2: Examples of within and between tree variation in floral sugar concentration (% wt/vol) and volume (μL) across 20 measured flowers. Two large and two small trees from one mature forest site, Murramurang National Park are shown.

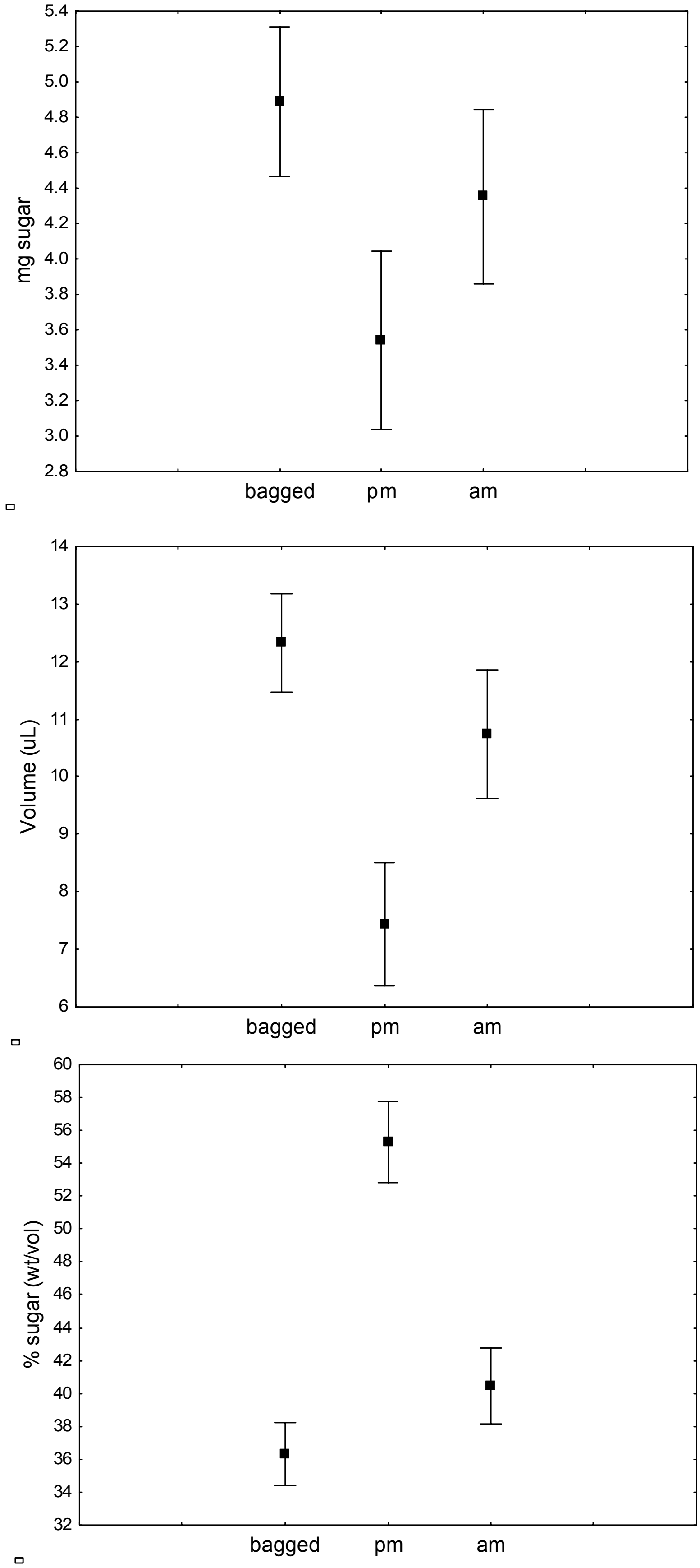

Figure 3.3: Floral nectar in flowers bagged over-night in 2005 and measured the following morning and in unbagged flowers measured in the afternoon (pm) and in the morning (am). a) the amount of sugar (mg), b) total volume of nectar (μL) and c) % sugar (wt/vol) per flower. Values are mean ± standard error (SE), n=4320 bagged flowers, 360 am unbagged flowers and 360 pm unbagged flowers.

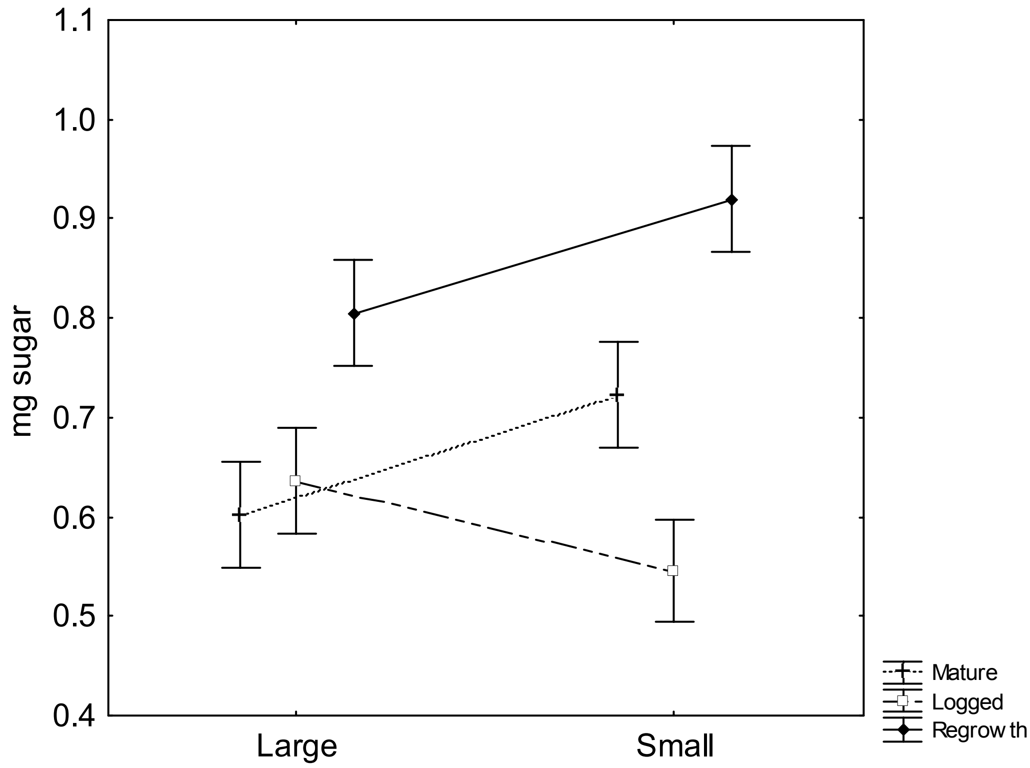

Figure 3.4: The significant interaction (P=0.02) between logging history (n=3) and tree size (n=2) on sugar levels per flower in bagged spotted gum flowers measured in the morning. Data are log (x+1) transformed. Values are mean + SE.

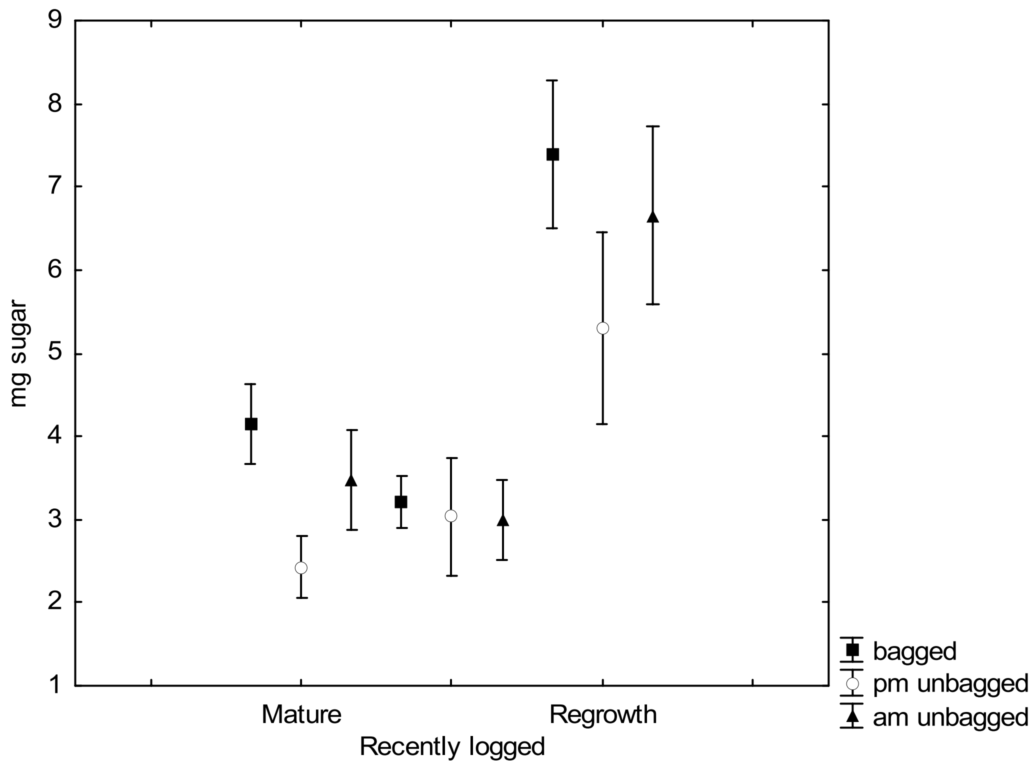

Figure 3.5: The effect of logging history on the amount of nectar depleted in unbagged flowers compared to bagged flowers. Unbagged flowers were measured in the early morning (am) and later afternoon (pm), bagged flowers were enclosed over-night and measured in the morning. Values are mean + SE.

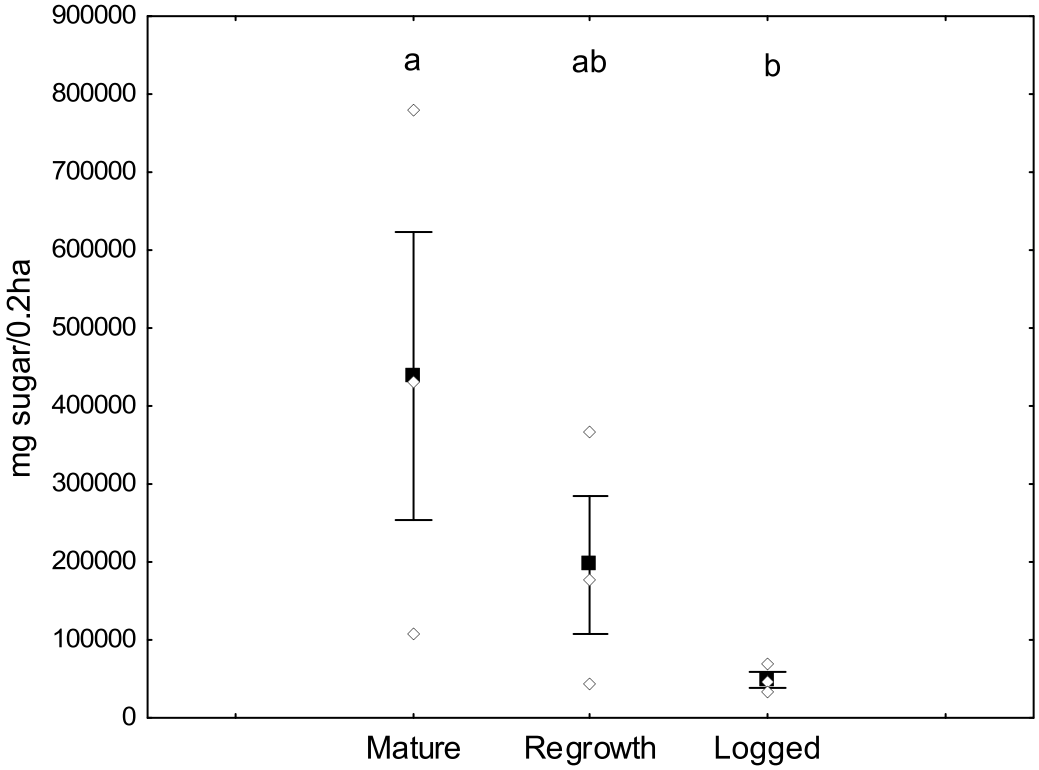

Figure 3.6: Sugar produced over-night in bagged flowers per 0.2 ha of spotted gum forest under three logging histories. Untransformed means ± SEs are shown. Diamonds show the amount of sugar produced in each of the three sites sampled for each logging history. Different lower case letters denote significant differences.

Between year variation in nectar availability per flower

In 2003, we measured nectar in flowers from 39 trees. Standing crops per flower declined rapidly after 0930 h to virtually zero nectar (Figure 3.7). Prior to 0930 h, lorikeets and honeyeaters foraged in large flocks on the spotted gum flowers, while honeybees became active at about 0930 h. Because nectar was depleted during mornings in 2003 and the fact that we did not bag flowers in that year, only trees measured before 0930 h were used for between-year comparisons (n=20 in 2003).

The sugar content per flower was more than four times higher in 2005 compared to 2003 (U=254, P<0.001) (Figure 3.8). Differences in nectar volume were at best a minor contributor to this difference as it was similar between the two years (U=603, P=0.24). More important was sugar concentration, which in 2005 was more than twice that in 2003 (U=240, P<0.001). Similar to 2005, tree diameter had no effect on early morning floral sugar quantities in 2003 (dbh < 20 cm – mean = 0.8 mg sugar, n=6; dbh > 40 cm – mean = 0.6 mg sugar, n=8).

Predictive models of nectar abundance

Regression trees were used to explore associations between floral nectar and site/climatic variables (Table 3.1) for the two years sampled. Plots of the data revealed that some variables (Byram-Keetch Drought Index (BKDI) of previous week and month) displayed little variation over the study period (Figure 2.1) and were deleted by the tree regression. The Tree Regression of the floral am standing crops found that nectar volume was high following a week of warm days (Figure 3.9). The greatest depth in the tree follows this first split, indicating that temperature explains the most variance in the model. Nectar volume was high when, compared to long-term averages, days were warm, while cool-mild days and warm mornings were associated with low nectar volume.

Variables explaining variation in sugar concentration were different. The Tree Regression on this variable indicated that the highest sugar concentrations were found on mornings with low humidity and after a run of warm mornings in the previous week (Figure 3.10). Nectar was at its most dilute when humidity was high and when it rained the previous day, presumably because rain water entered flowers. To a lesser extent, trees growing below mid-slope topographies were also predicted to have diluted nectar. Moderate concentrations of sugar were found over a range of conditions.

When these two interacting components of nectar are integrated into mg sugar the tree regression indicated that sugar-rich flowers could be found either side of the 1st split in the tree, probably reflecting the variable conditions that can lead to high sugar content, depending on whether sugar concentration or nectar volume is favoured. When mornings of the previous week were cold, sugar content was high (Figure 3.11). But sugar-rich flowers were also found when mornings in the previous week had not been cold, the previous month dry and when there were relatively few flowers on trees. Sugar content was very low when mornings in the previous week had not been cold and rainfall approached or bettered the average for the previous month (long-term mean for Nowra in May = 70 mm).

These models were consistent with models using only the data from bagged flowers in 2005. Most importantly, the weather variables temperature and humidity had the most explanatory power with most site and tree variables omitted. High sugar concentration was related to warm daily temperatures and low humidity. High nectar volume was related to warm days, cold mornings and low flower numbers per tree. When combined, high total sugar content followed a week of cold mornings or warmer mornings with low humidity and was recorded in trees growing below mid-slopes.

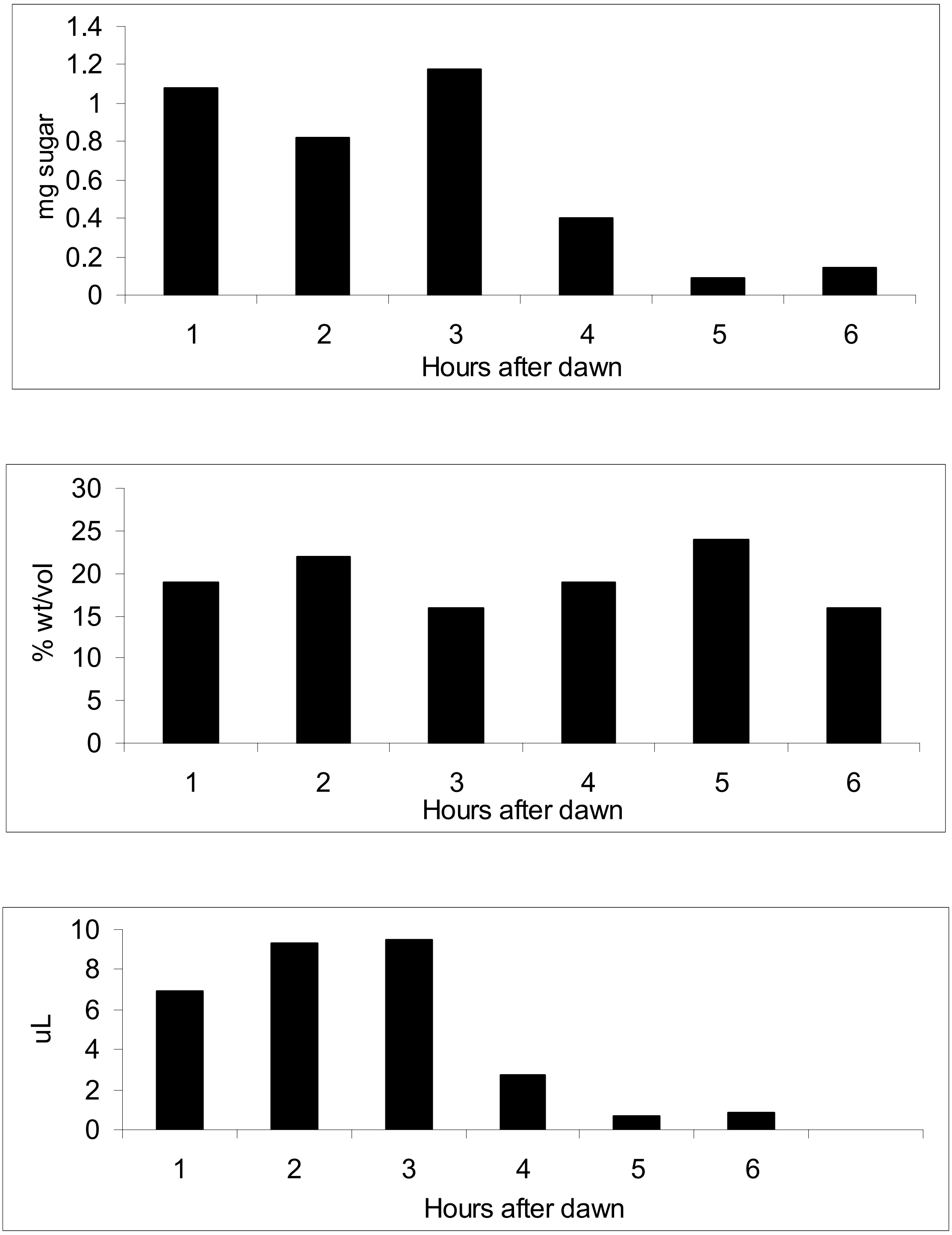

Figure 3.7: Changes in floral standing crop during the morning as measured on different flowers on 39 *Corymbia maculata* trees in 2003. a – total sugar, b – sugar concentration, c- nectar volume. Only minor quantities of nectar were measurable after 0930 h.

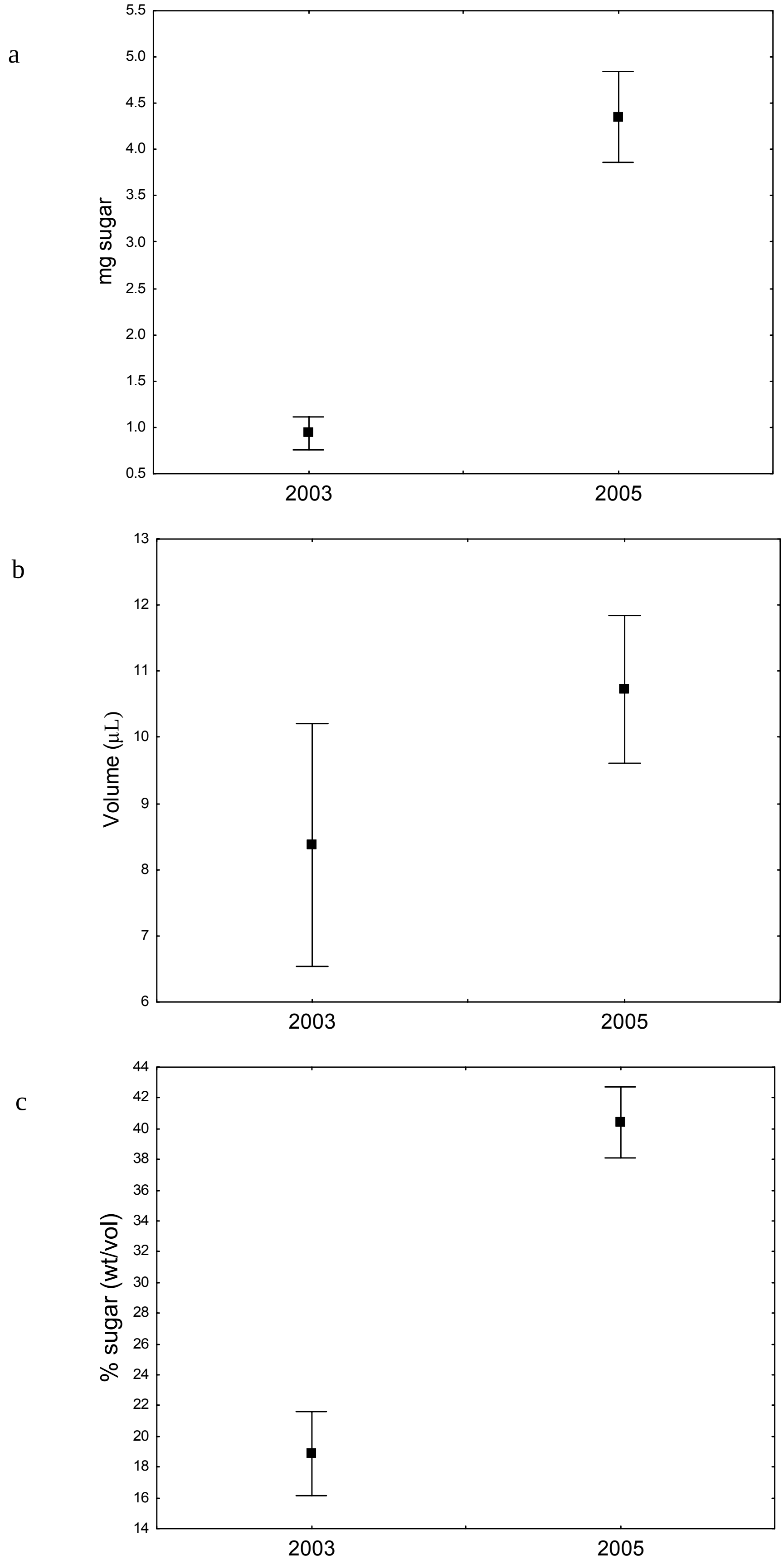

Figure 3.8: Nectar standing crops per unbagged flower measured before 0930 h in 2003 (n=20 trees) and 2005 (n=72 trees). a) the amount of sugar (mg), b) total volume of nectar (µL) and c) % sugar (wt/vol) per flower. Values are means ± SE.

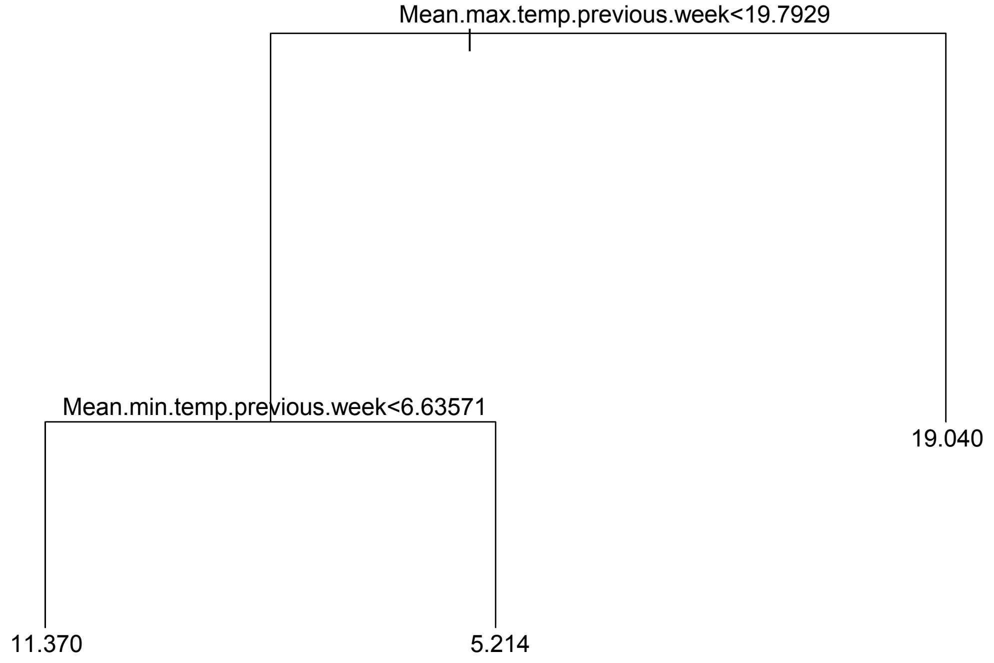

Figure 3.9: Pruned regression tree of nectar volume (μL) in am standing crops and predictor variables pooled for 2003 and 2005. The length of the node represents the relative importance of each split and terminal nodes show predicted values of nectar volume.

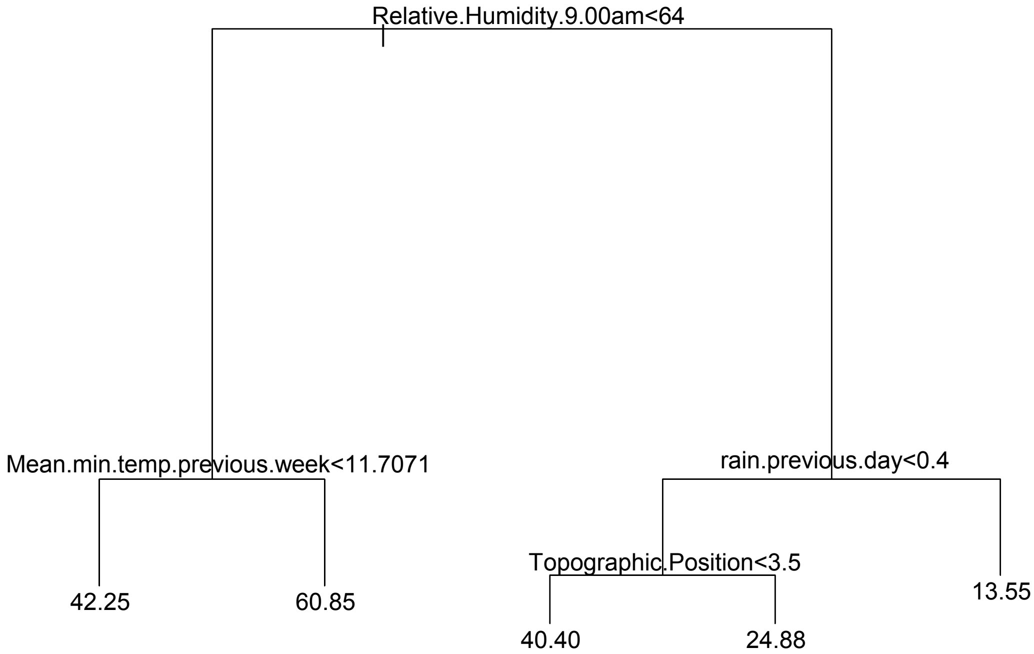

Figure 3.10: Pruned regression tree of sugar concentration (wt/vol) in am standing crops and predictor variables pooled for 2003 and 2005. The length of the node represents the relative importance of each split and terminal nodes show predicted values of sugar concentration.

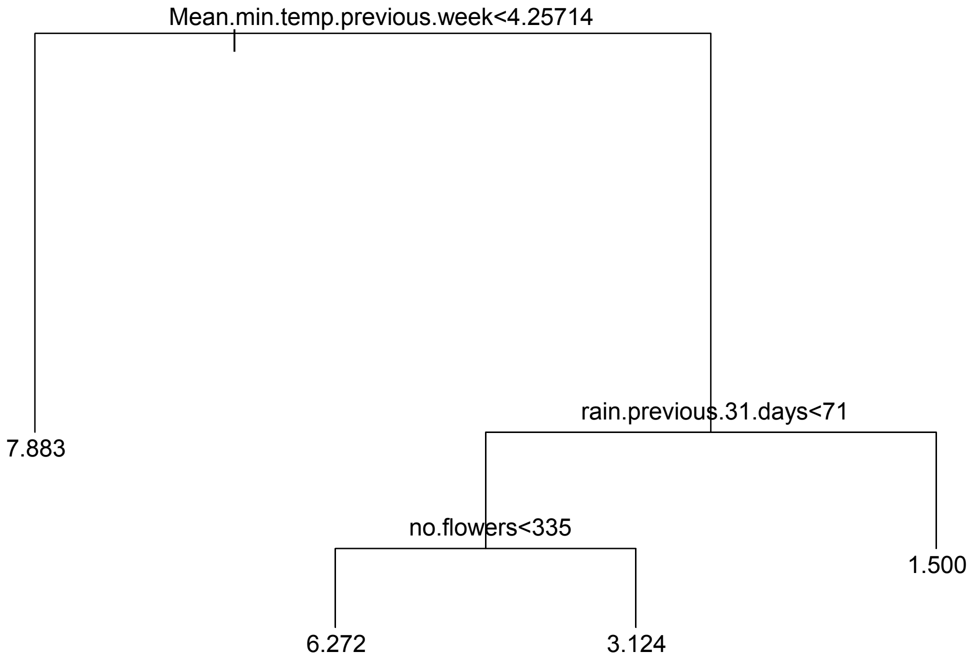

Figure 3.11: Pruned regression tree of total sugar (mg sugar) in am standing crops and predictor variables pooled for 2003 and 2005. The length of the node represents the relative importance of each split and terminal nodes show predicted values of total sugar.

Discussion

This is the first study to quantify the effect of logging on canopy nectar production of a tall forest tree. Nectar is a relatively simple substance measured as volumes and percentage sugar, but these components interacted differently to environmental conditions and the year of sampling, resulting in spatially and temporally variable nectar production. Disturbance in the form of logging was found to have little influence on nectar produced per flower. Scaling this up to the forest scale and assessing logging effects at that level requires the careful assessment of a number of factors.

Variability of the nectar resource

The nectar resource of *C. maculata* flowers was highly variable even within a tree, although sugar concentration was more predictable at both the tree and site level. Pyke (1988) also found that, in heath, nectar production per flower and sugar concentration is variable spatially and temporally within and between flowering seasons. Red Bloodwood *Corymbia gummifera* is similarly variable between trees, although data are not available on variation within trees (Goldingay 2005). Variability within an individual is consistent with the view that this is related to individual size (Zimmerman and Pyke 1988) and that, for trees, variability in nectar would encourage movements of pollinators between trees rather than simply from one flower to the next within a tree. In the rainforest canopy, *Syzygium sayeri* is also known to produce highly variable amounts of nectar, even in similar aged flowers (Boulter *et al.* 2005).

Sugar quantities per flower

The amount of sugar we recorded from flowers bagged over-night incorporates both that produced through the night and the amount present in the flowers prior to bagging in the previous afternoon. Based on average values, 7.5 μL were present in flowers in the afternoon while 12.2 μL were present in bagged flowers the following the morning. Although this suggests that 4.7 μL is secreted in flowers over-night such estimates need to consider that nectar production might have been greater if flowers had been drained prior to bagging, which was not logistically possible in our study, or if volumes had been continuously measured or harvested by pollinators through the night (Corbet 2003). In 2003 when flowers were empty during the day, a volume of 8.4 μL accumulated overnight.

Average early morning floral sugar levels of *C. maculata* in 2005 (4.8 mg sugar per flower) were considerably higher than that produced by *C. gummifera* (~ 1 mg sugar – Goldingay 2005; Pyke 1985) and Tasmanian leatherwood *Eucryphia lucida* (0.5 mg sugar - Mallick 2001) and are similar to a range of other eucalypts such as red ironbark *E. tricarpa* and white box *E. albens* (5 mg sugar - Oliver 2000; Timewell and Mac Nally 2004). Maximum values (43.5 mg sugar) for *C. maculata* are substantially greater than these, but similar to *E. globulus* (37-56 mg sugar -Hingston 2002). One distinctive characteristic of *C. maculata* nectar in 2005 was its high sugar content. Means ranged from 40 % in the morning up to 60 % in the afternoon. The increase in sugar concentration in *C. maculata* during the afternoons is most likely due to evaporation (Nicolson 1994; 1995), suggesting that sugar reabsorption is minimal. Flowers of the red-flowered gum *E. ficifolia* contain most nectar at dawn (mean volume = 50 μL) with concentration varying from 20 % in the morning to 35 % late in the afternoon (Nicolson 1994). Sugar concentrations in 2005 were much higher than those measured in 2003 (mean = 18 %) and higher than the typical concentration of honeyeater (22 %), bat (19 %) and bee flowers (36 %) (Pyke and Waser 1981). Most species of smaller nectar-feeding birds prefer dilute nectar (Tam and Gass 1986; Mitchell and Paton 1990; Fleming *et al*. 2004) and this might partly explain the few observations of nectar-feeding in 2005 compared to 2003, although body size limitations are likely to be less relevant to larger nectarivores like lorikeets, flying foxes and marsupial gliders (Mitchell and Paton 1990; Law 1993). Casual observation suggested that honeyeaters fed on nectar more after rain or in the mornings when nectar was more dilute (B. Law pers.. obs.). The resource was important for the rare migratory species, the swift parrot *Lathamus discolor*, with at least 80 birds being observed in flowering *C. maculata* in 2005 (D. Saunders, Australian National University, pers.. comm., 2007).

Predictive models of nectar abundance

Predicting years of good nectar flow is complex because spotted gum carries its floral buds for two years and so different climatic conditions will be responsible for the amount of budding and the amount of nectar finally produced per flower. We found nectar production per flower to vary in relation to a complex interaction of many factors operating on either nectar volume or sugar concentration to influence overall sugar content of a flower. Pook (1986) also found that the foliage canopy of spotted gum forest displays complex dynamics in response to prevailing climate, even extreme droughts, which are not predictable on the basis of simple models, such as rainfall deficiencies. Indeed, we found distinct differences in nectar between years of measurement, that broadly corresponded to different climatic conditions leading up to winter flowering in each year (BKDI in previous 12 months), however, by the time of measurement drought indices were similar. Also, most conditions on the day of measurement or the previous day had little effect on nectar production. Rather temperature patterns of the previous week were likely to be of more influence. Rain on the previous day and humidity on the morning of measurement were exceptions to this pattern as moisture was found to dilute sugar concentration. In general, more nectar was likely to be produced after a week of cold mornings, but nectar-rich flowers were also found after warmer mornings when rainfall had been below average and on trees with fewer flowers. The importance of cold mornings and below average rainfall to nectar production in *C. maculata* could be related to the fact that foliage production in *C. maculata* is opportunistic and occurs whenever environmental conditions are favourable (Pook 1984a). The exceptions being drought and winter cold snaps (Pook 1984a). At such times resources may be diverted to nectar rather than foliage, which parallels that for *E. sideroxylon*, in that wet winters reduce honey production in spring because starch reserves are depleted by growth (Wykes 1947; Porter 1978). As most of our winter measurement periods experienced average rainfall conditions, we predict that flowering in a cold, somewhat dry winter, following satisfactory lead-up conditions to promote budding and flowering, would result in even higher nectar production than we recorded. Conditions of extreme dry, however, can lead to abortion of buds and less nectar production (Pook *et al*. 1997).

Quantifying the nectar resource in spotted gum forest

In comparison to flower counts on other eucalypts (Kavanagh 1987), our flower counts were relatively low. While it is possible that we under-estimated flower numbers on large trees due to their extensive canopies, it should be noted that we only counted opened flowers and individual *C. maculata* trees progressively open their flowers over a number of months and the flowering season extends for 5-6 months (authors pers.. obs.), unlike the pulse flowering seen in many other eucalypts. Even considering somewhat lower flower counts, when we scaled up to the forest stand, spotted gum forest clearly provided a vast nectar resource. We calculate (assuming 15.5 J per mg sugar), on average, that mature forest produces over-night 35,000 kJ ha^{-1} compared to 15,500 kJ ha^{-1} for regrowth and 3,900 kJ ha^{-1} for recently logged forest. The maximum we recorded for a single stand was 60,500 kJ ha^{-1} in Murramurang National Park. It is important to remember that there is a strong temporal dimension to these data. Apart from the influence of the seasonal flowering phenology of *C. maculata*, it is well known that the species flowers unreliably between years (Pook *et al*. 1997). Indeed, we found that the nectar resource differed markedly in 2003. In that year when there were few flowering trees and sugar content was much lower, we calculate a mean standing crop from five flowering sites of only 350 kJ ha^{-1}, with those sites selected on the basis that there were more flowering trees than the surrounding forest. The most productive site in 2003 was calculated to yield 1,300 kJ ha^{-1}. For comparison there are few other published data on nectar density at large spatial scales. Open eucalypt woodland near Sydney at its peak produces about 800 kJ ha^{-1}(Pyke 1985) compared to peaks of 7000 kJ ha^{-1} in dry sclerophyll forest in Victoria (Paton 1985). Productive areas of heath near Sydney and in northern NSW produce 3,000-10,000 kJ ha^{-1} (Pyke 1983; McFarland 1986; Armstrong 1991; Law 1994). In rainforest of Costa Rica, seven bat-pollinated plants together provide about 3,000 kJ ha^{-1} (Tschapka 2004). Thus, in a good year, an average hectare of mature spotted gum forest can produce 3-10 times the amount of energy as that recorded by other studies. As far as we are aware, the nectar produced by the canopy of spotted gum forest is by far the greatest yet published.

Is nectar a limiting resource in spotted gum forest?

In the extensive flowering year of 2005 pollinators did not substantially deplete nectar standing crops, indicating that nectar was not limiting. As an example, the mature forest site in Murramurrang National Park was visited at night by large numbers of grey-headed flying foxes *Pteropus poliocephalus* (authors pers.. obs.). The site is nine km south of a seasonally occupied camp of this bat, which at the time of our study was considered to contain more than 300,000 animals (P. Craven, Department of Environment and Conservation, pers.. comm., 5/9/2005). Yet flowers bagged overnight at this site contained on average 5.1 mg sugar compared to 4.7 mg sugar in am standing crops, indicating little nectar depletion. During the day when birds and insects were foraging, standing crops averaged over all sites fell from 5.1 mg sugar at dawn to 3.6 mg sugar in the late afternoon, a difference that was not statistically significant. This suggests that diurnal flower visitors were not measurably depleting nectar availability in 2005.

Poor flowering in 2003 provided a strong contrast because nectar in spotted gum flowers was depleted rapidly, with little nectar left after 0930 h. Honeybees were first noted foraging at this time, while prior to this, large flocks of nectar-feeding birds foraged at our sites. This suggests that the small stands of flowering trees in 2003 offered a highly patchy resource that the combined efforts of birds and honeybees were able to deplete. By contrast in 2005, flowers were abundant and widespread throughout the 300,000 ha of spotted gum forest on the south coast (Tozer *et al*. 2006) and large flocks of nectar-feeding birds were not observed, suggesting that their numbers were dispersed. Many commercial hives of honeybees were deployed throughout the forest at this time, but they and nectar-feeding birds had minimal effect on floral nectar levels. Armstrong (1991) found a similar pattern in heath near Sydney in that honeyeaters depleted nectar in flowers of various species when nectar was relatively scarce. Nectar was not depleted through winter when the widespread *Banksia ericifolia* was in full flower, producing much more nectar than honeyeaters could consume (Armstrong 1991).

The effect of logging on nectar in spotted gum forest

Logging history and tree size, when taken individually, had no measurable effect on sugar levels per flower. However, a significant interaction found that small trees in regrowth produced more sugar per flower than all other trees except large trees also in regrowth. One interpretation of this result is that small trees in regrowth are growth suppressed (Forestry Commission of NSW 1985) and may be able to allocate more resources to nectar production per flower. In accordance with this hypothesis, small trees in recently logged forest produced the least sugar (most dilute nectar), possibly because more soil moisture and light was available after logging due to reduced competition and thus trees were diverting starch resources to growth (Forestry Commission of NSW 1985). Importantly, large trees retained during logging produce an equivalent amount of nectar per flower as trees in mature forest.

At the forest stand scale, logging history had a marked effect on nectar production with mature forest producing almost 10 times as much sugar per ha as recently logged forest, with regrowth forest 15-30 years old being intermediate. It might have been expected that regrowth forest would have been more comparable to mature forest because it supports a virtually continuous canopy. However, regrowth canopy is formed by small and medium sized trees and these trees flower less often than large trees in *C. maculata* (see also Pook *et al*. 1997; Law *et al*. 2000). It has also been documented in young plantations of *Eucalyptus nitens* that close spacing of stems reduces flower numbers per ha (Williams *et al*. 2006). Although nectar differences between logging histories are large, a thorough assessment of the effect of logging should take place on at least the compartment scale, which is the management unit to which logging is applied (200-400 ha). Within each logged compartment many areas are now reserved from logging, such as riparian buffers, high conservation old growth forest, over-ridge connection corridors, threatened species habitat as well as habitat trees and recruits within logging zones. Retention of trees in gullies and lower slopes is likely to be important for nectar production because trees below mid-slope were predicted to have flowers with high total sugar content, usually with more dilute nectar. These informal reserves have been estimated to represent about 57 % of the state forest landscape (New South Wales Department of Urban Affairs and Planning 1999).

Calculations for 2001-2004 in Forests NSW Southern Region, found that, on average, 39 % of the gross compartment area that was available for logging was informally reserved, although 67 % was left unlogged in that year (K. Boer Forests NSW pers.. comm.). Under a worst case scenario, if 61 % of compartments were to be logged, a compartment scale mature forest in 2005 would produce 2.2 times the amount of nectar as a compartment of recently logged forest and about 1.5 times the amount as a compartment of 15-30 year old regrowth with existing prescriptions. This estimated impact of logging is identical to that estimated for flowering levels of eucalypts on the north coast of NSW (Law *et al*. 2000).

The final crucial consideration for the assessment of logging impacts is whether nectar is a limiting resource after logging. Although unbagged flowers in 2005 contained less nectar than bagged flowers, on average, in the afternoon and morning more than 70 % and 90 % of the resource was left unconsumed, respectively (Figure 3). The extent of the available nectar is particularly notable given the large concentration of grey-headed flying foxes in the area at the time and the extensive use by commercial beekeepers (Section/Chapter 5). Moreover, even though recent logging reduced nectar availability in a stand of trees, we found that nectar depletion during either the day or night was no greater in logged areas. It is possible that this result could be due mobile foragers like flying foxes focusing on resource-rich stands (mature forest) that may be close to recently logged forest, thus leading to lower foraging effort in the latter. However, mature stands are now scarce in the study region with regrowth of various ages making up the bulk of the remaining forest. Given that nectar was not fully consumed in any of our tree stands, we can conclude that in years of massive flowering, over extensive areas, nectar is not a limiting resource. However, the result was very different in a poor flowering year. In 2003, nectar-feeders were concentrated on small stands of flowering trees leading to depletion of nectar to unmeasurable levels in the morning. Nectar was depleted across all of our sites, presumably due to the combination of nectar-feeding birds and honeybees. Depletion of nectar in poor flowering years justifies management prescriptions that retain mature trees of locally important flowering species (currently six per ha) in the areas zoned for logging. The fact that total sugar content tends to be higher in lower slope areas (e.g. riparian zones) is also important in ameliorating logging impacts.

4. Grey Ironbark *Eucalyptus paniculata*

Grey ironbark *Eucalyptus paniculata* is a tall tree that typically grows on heavy or loamy soils in coastal areas of NSW. On the south coast it occurs as a co-dominant, especially with spotted gum, in a range of forest types (e.g. type 66, 74 – Forestry Commission of NSW 1989). It is considered to be one of the most important honey producing trees on the south coast, yielding large quantities of first grade, light honey (Cocks and Dennis 1978; Somerville and Nicholson 2004), while its timber is also considered to be of high quality, being valued for railway sleepers and poles. Beekeepers consider that *E. paniculata* needs to be at least 20 years old before it begins to yield significant honey crops (Somerville 1998).

It has a highly variable flowering pattern. In Sydney it flowers from May-August (Fairly and Moore 1989). On the south coast Cocks and Dennis (1978) reports it to flower from September to the end of January and is considered to produce well for honey about every seven years. Somerville and Barnes (1994) report that it flowers between November-January in the Batemans Bay area, with typically two to five years between flowers. For Nowra, it is reported to flower between July-December (Somerville and Colley 1990).

This chapter aims to quantify the impact of logging on nectar production in Grey ironbark at the scale of both the individual flower and the tree stand. A secondary aim is to quantify the extent of the nectar resource produced in the canopy of a stand of trees and to investigate the influence of climatic and site factors on nectar production.

Methods

Experimental design

Broad areas of flowering grey ironbark were selected for measuring nectar. Due to patchy flowering throughout the south coast region, measurements were repeated over three consecutive years, from 2004-06. The period of flowering differed in each year with flowering occurring in February-March in 2004 (Currambene SF), July-September in 2005 (McDonald SF and Currambene SF) and December-January (Mogo SF) in 2006. Flowering was most extensive across the south coast region in 2005 and the crop of seed capsules carried into the following year seemed to influence the patchiness of flowering in 2006 to areas that hadn’t flowered in 2005.

In each year 3-4 sites were chosen to represent a range of logging histories (Table 4.1). These were:

1. Recently logged/thinned forest (3-10 years old, trees 5-25 m high).
2. Regrowth forest (15-20 years old, trees 10-25 m high).
3. Old regrowth forest (25-50 years old, 30-35 m high).

One old regrowth site at Nowra was sampled in 2004 and 2005, after having been non-commercially thinned and burnt in 2003.Within each logging history two size-classes of trees were sampled:

a) Small trees < 25 cm dbh and 4-14 m high.
b) Large trees> 40 cm dbh and 15-33 m high.

The large trees in recently logged and regrowth sites were trees that were retained during logging for various reasons, such as habitat for wildlife, recruits or as a source of seed. We sampled four trees for each tree size-class within a 500 m stretch of forest. On each tree nectar was measured in 20 flowers. As an example of sampling effort using this design, in the recently logged treatment we measured nectar in 3 years x 2 tree-sizes x 4 trees x 20 flowers = 480 flowers. Over the three logging histories we measured nectar production in 1600 flowers (noting that four sites not three were measured in 2004).

Our study focused on flowers bagged at dusk with nectar production measured the following morning. However, flowers at one additional site near Nowra were measured in March 2004 to investigate differences in diurnal and nocturnal production of nectar. Two clumps of flowers were bagged on each of three trees either at dawn or dusk with nectar in 20 flowers per tree measured 12 hours later.

Table 4.1: Site details for grey ironbark *Eucalyptus paniculata* nectar measurements.

Year	Season	Region	Site Logging History
2004	Summer-autumn	Nowra	Recently logged (thinned)
			Regrowth
			Regrowth
			Old regrowth, thinned
2005	Winter-spring	Batemans Bay/Nowra	Recently logged
			Old regrowth
			Old regrowth, thinned
2006	Summer	Moruya	Recently logged
			Regrowth
			Old regrowth

Statistical Analysis

We assessed the relationship of logging history and tree size to nectar production and its components (volume and sugar concentration) per flower using generalized estimating equations (GEE's) (Liang and Zeger 1986; Quinn and Keough 2002). GEE's are an extension of generalized linear models that account for serial correlation in longitudinal data or in our case spatial correlation of large and small trees measured within sites. As we measured nectar production over three consecutive years, each in a different season, we searched for correlations of nectar production with local climate variables obtained from the Bureau of Meteorology. The BKDI averaged over the previous month was found to be negatively correlated with nectar production, so it was included as a factor whereby a score > 61 denoted drought and $\leq$ 61denoted mild to average conditions. For sugar concentration, rain in the previous 24 hours can dilute nectar so it was included as a continuous variable. Models were built manually by testing individual factors and sets of factors and significance was set at the P=0.05 level. Distributions were specified after checking histograms of the response variables. All analyses were conducted using the R-package v2.4.1 (R Core Development Team, 2006) in conjunction with the geepack library (Yan 2002).

We tested for the effect of logging history on nectar production per stand of trees using a one-way analysis of variance, after log transformation to normalise data. The mean BKDI of the previous month was included as a co-variate to account for year to year differences in climate. Given the low replication for logging history (n=3) we accepted significance at P=0.1.

Figure 4.1: Grey ironbark *E. paniculata* flowers with a cherry-picker and crane accessing the canopy for nectar measurements. Mesh exclusion bags can be seen on the canopy of a small tree and a profusely flowering tree.

Figure 4.2: Grey ironbark logging histories sampled in southern NSW. a – recently logged, b – regrowth and c – old regrowth forest

a

b

Results

Day versus night nectar production

Measurements from six trees revealed that grey ironbark flowers produced nectar during both the day and night (Figure 4.3). Flowers bagged during the day produced twice the volume of nectar per flower (2.4 µL) and at a higher concentration (54 %) than flowers bagged at night (34 %). This resulted in the production of about twice the amount of sugar (1.3 mg sugar) during the day compared to at night (0.6 mg sugar). However, none of these differences were statistically significant (P's>0.1), partly because of small sample sizes and that nectar was variable between the three trees measured in each period (Figure 4.3). Standing crops of nectar at the time of these measurements, in am and pm time periods, were all zero.

Nectar per flower

The amount of nectar produced over-night showed a moderate amount of variation across the study. Nectar volume per flower ranged from 0-46 µL, sugar concentrations ranged from 2-85 % and sugar ranged from 0-35.3 mg sugar. Flowers within a tree showed a moderate degree of correlation for mg sugar (r_I =0.46) and total nectar volume (r_I =0.49). A major factor limiting the correlation was the fact that there were usually some flowers with no nectar, even in trees where the nectar reward tended to be high. Variation (e.g. for mg sugar) was slightly greater within years (r_I =0.41) and between trees within a site (r_I =0.35). For sugar concentration only flowers with nectar were considered and the intraclass correlation was markedly higher (r_I=0.82). Within tree variability was only high when we sampled in light rain with water entering some flowers and reducing sugar concentration, but not in others. Intraclass correlations for sugar concentration were also high between trees within sites (r_I=0.71), but not between sites within years, probably because two sites experienced rain on the night prior to measurement leading to more dilute nectars (r_I=0.23).

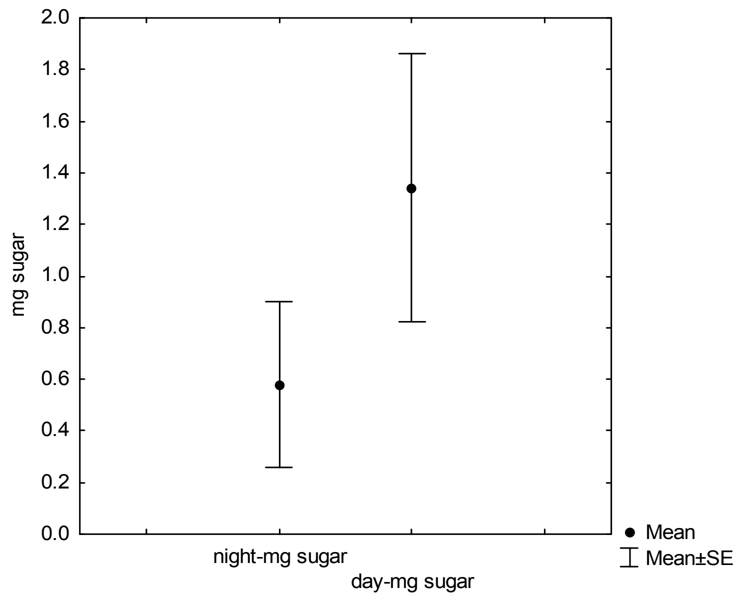

Figure 4.3: Nectar produced per flower in Grey ironbark, when flowers were bagged throughout the day or night. n=3 trees for each time period.

Yearly comparisons of nightly nectar production and standing crops

Over-night nectar production in bagged flowers and standing crops in unbagged flowers was similar between 2004 and 2005, but 2006 was characterised by greater nectar yields (Figure 4.4). In bagged flowers the mean volume of nectar per flower ranged from 3 μL in 2004 and 2005 to 9 μL in 2006. Mean sugar concentration ranged from 35-40 % in 2004 and 2005 to 60 % in 2006. Mean sugar content per flower followed a similar pattern, ranging from 1 mg per flower in 2004 and 2005 to 5.3 mg in 2006. Standing crops also varied considerably, with very low amounts of sugar present in 2004 and 2005 (Figure 4.4). In 2004 there was less than 0.1 mg sugar in flowers in am and pm periods and in 2005 there was 0.9 mg sugar in am standing crops and significantly less in pm standing crops (0.2 mg, SNK tests for 2 Factor ANOVA). The year 2006 was notably different with more sugar in bagged flowers than pm standing crops (2.9 mg sugar), but not am standing crops (4.1 mg sugar per flower) (SNK tests). Across all years, nectar volume was not correlated with sugar concentration in bagged flowers (r =0.07), am standing crops (r =-0.01) or pm standing crops (r = 0.20), although in 2006 low volumes in pm standing crops corresponded to higher sugar concentration.

Effects of Logging History and Tree-size

GEE's revealed that nectar production per flower was most strongly and negatively related to drought, but not logging history (Table 4.2). While tree dbh was not correlated with nectar production across all sites (r=0.1, P=0.3; dbh range: 5-102 cm), tree size interacted with logging history to influence nectar production. Small trees in old regrowth produced more nectar per flower than large trees, but the effect of tree size was reversed in regrowth and was not significant different in recently logged sites (Figure 4.5).

When sugar is broken down into its components, nectar volume was negatively related to drought and not logging history (Table 4.2). Flowers on small trees produced less nectar than large trees in both recently logged and regrowth sites, but more nectar than in flowers on large trees in old regrowth. For sugar concentration (wt/vol), there was a negative relationship with rainfall on the previous day plus recently logged sites produced more dilute nectar than old regrowth. In old regrowth, small trees produced more dilute nectar than large trees, but tree size did not influence sugar concentration in the other logging histories.

Effects of logging history on nectar levels scaled up to the forest stand

When floral nectar is scaled up to the forest stand level, based on estimates of the number of flowers present, a one way ANOVA found that logging history had a significant effect on total sugar produced ($F_{2,6}$=3.49, P=0.09). Old regrowth forest (232 g sugar per night per 0.2 ha) produced just over 7 times the sugar of recently logged forest (32 g), while regrowth forest was intermediate (91 g) and not significantly different from either old regrowth or recently logged forest (Figure 4.6 - SNK tests). Data were highly variable for both old regrowth and regrowth forest, while recently logged sites produced uniformly low amounts of sugar. The co-variate, mean BKDI of the previous month, was also negatively related to stand nectar production ($F_{1,6}$=19.16, P<0.01). Little nectar was produced under any logging history in droughts, while during good conditions nectar production varied depending on logging history.

To further understand the factors responsible for the significant effect of logging history on sugar produced in a stand of trees, we analysed the proportion of trees in flower. After arcsin transformation, logging history had no effect on the proportion of trees in flower ($F_{2,9}$=0.08, P=0.93), but tree-size had a significant effect ($F_{2,9}$=4.86, P<0.05). About 81 % of large trees were in flower, compared to 60 % of medium trees and 24 % of small trees. Flower numbers also varied enormously with tree size. On average, large trees carried 12555 flowers compared to 1024 flowers on medium trees and 686 flowers on small trees. A maximum of 250000 flowers was estimated on a large tree compared to a maximum of only 15000 flowers on a medium tree.

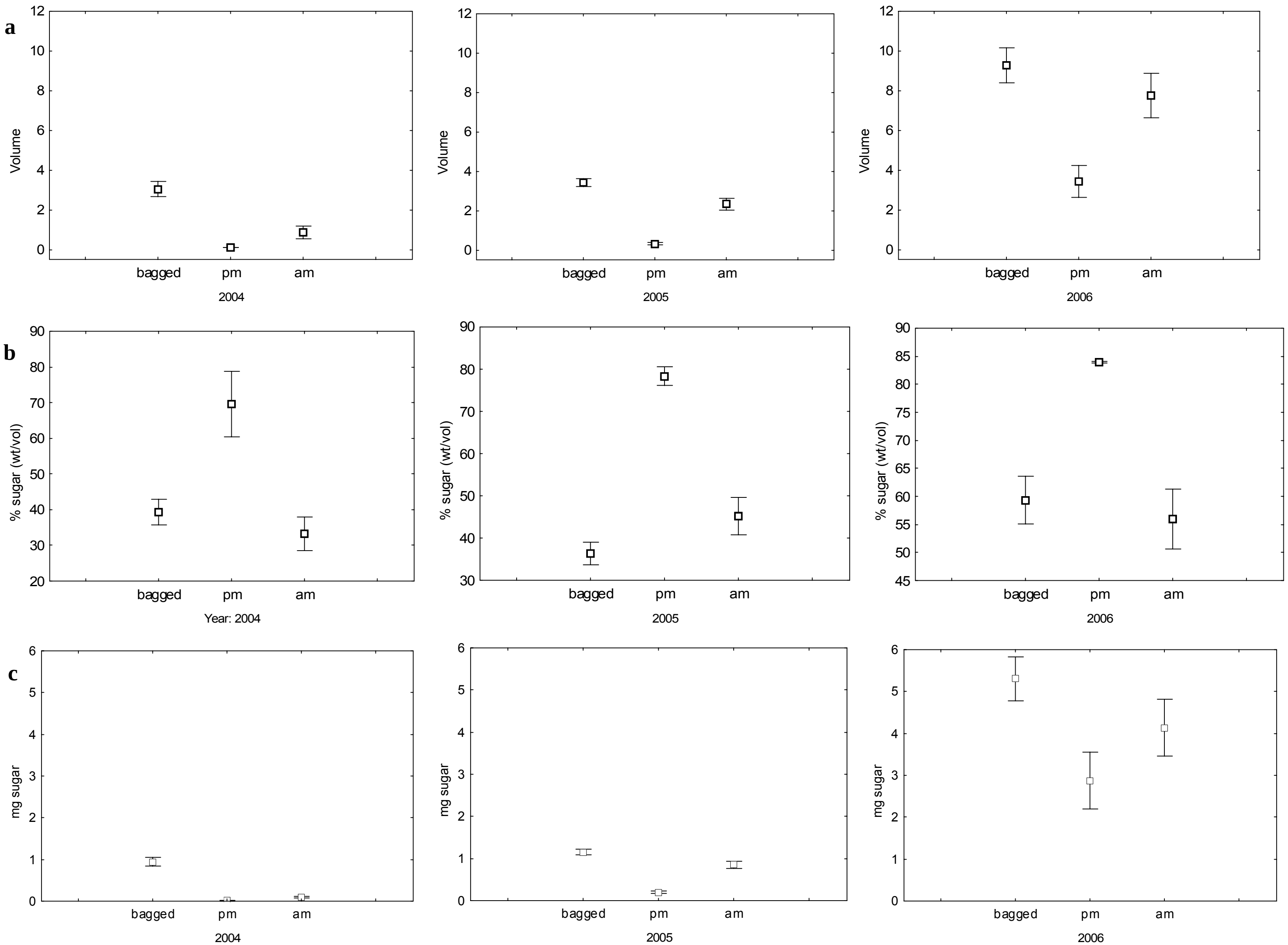

Figure 4.4: Floral nectar in 2004, 2005 and 2006. Flowers were bagged over-night and measured the following morning or left unbagged and measured in the afternoon (pm) or in the morning (am). a) total volume of nectar per flower (µL), b) % sugar (wt/vol) and c) the amount of sugar (mg). Values are mean ± SE, n=1600 bagged flowers, 400 am unbagged flowers and 400 pm unbagged flowers.

Table 4.2: Results of Generalised Estimating Equations with three response variables (mg sugar, nectar volume, sugar concentration) and the factors logging history (recently logged, regrowth, old regrowth), tree size (small, large) and drought (BKDI > 61) or rainfall in the previous 24 hours.

	Estimate	Standard error	Significance
mg sugar			
- Drought	-1.17	0.39	<0.01
- OR vs RG	0.35	0.36	0.33
- OR vs RL	0.15	0.49	0.76
- Small vs Large (OR)	0.26	0.06	<0.001
- Small vs Large (RG)	-0.78	0.19	<0.001
- Small vs Large (RL)	-0.70	0.37	0.06
Volume			
- Drought	-0.61	0.27	0.03
- OR vs RG	0.24	0.32	0.47
- OR vs RL	0.81	0.56	0.15
- Small vs Large (OR)	0.33	0.06	<0.001
- Small vs Large (RG)	-0.79	0.16	<0.001
- Small vs Large (RL)	-0.77	0.26	<0.01
Sugar Concentration			
- Rain	-0.01	0.01	0.01
- OR vs RG	0.11	0.20	0.58
- OR vs RL	-0.17	0.06	0.001
- Small vs Large (OR)	-0.10	0.03	<0.001
- Small vs Large (RG)	0.04	0.05	0.45
- Small vs Large (RL)	0.06	0.05	0.27

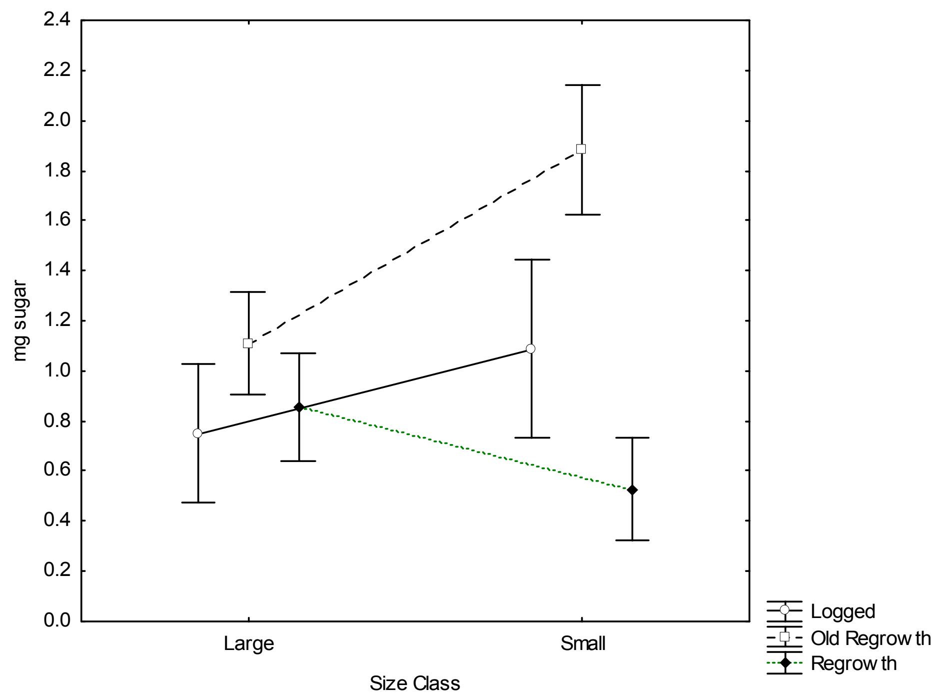

Figure 4.5: The interaction between logging history (n=3) and tree size (n=2) on sugar levels per flower in bagged grey ironbark flowers measured in the morning. Data Values are mean + SE, computed for the mean of the co-variate BKDI in the previous month.

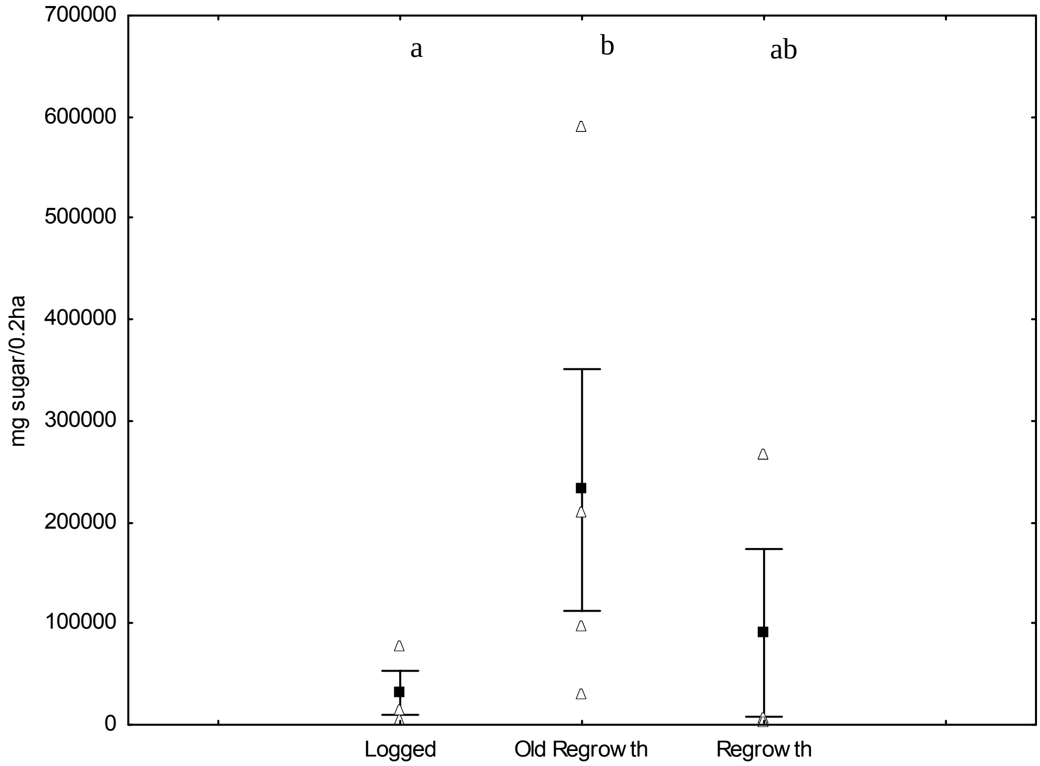

Figure 4.6: Sugar produced over-night in bagged flowers per 0.2 ha of grey ironbark forest under three logging histories. Untransformed means + SEs are shown. Open triangles show the amount of sugar produced in each of the 3-4 sites sampled per logging history. Different lower case letters denote significant differences.

Predictive models of nectar abundance

Regression trees were used to explore associations between floral nectar and site/climatic variables (Table 4.3) across all the three years sampled. Most of the variables, especially tree and site factors, were omitted from the regression trees because they accounted for little variation in the response variables. The Tree Regression of bagged flowers indicated that nectar volume was high when the mean BKDI of the previous month had been mostly better than average (25-63), indicating soil moisture was high (Figure 4.7). The greatest depth in the tree follows this first split, indicating that the drought index explains the most variance in the model. Nectar volume was highest when minimum temperatures of the previous week approximated the summer average. Nectar volumes were lowest when the BKDI indicated average conditions or drier and when morning humidity was drier than average.

Variables explaining variation in sugar concentration were different. The Tree Regression on this variable indicated that the highest sugar concentrations were found on mornings with low humidity, with extremely high concentrations occurring after a week of warm mornings (Figure 4.8). When humidity was average or higher, nectar was at its most dilute under a range of BKDI, except extreme dry, when moderate concentrations were produced. Thus moderate concentrations of sugar were found over a range of conditions.

When these two interacting components of nectar are integrated into mg sugar the tree regression indicated that sugar-rich flowers could be found when the mean BKDI had been better than average, both in the previous month and over previous year. Average BKDI scores or worse were related to sugar poor flowers (Figure 4.9).

Table 4.3: Tree, site and weather co-variates used to build predictive models of nectar production in Grey ironbark

Tree
Number of flowers per tree
Tree dbh (cm)
Tree height (m)
Distance from canopy (tree height – flower height) (m)
Crown radius (m)
Canopy aspect (degrees)
Site
Topography (1, hill-top – 9, depression)
Weather
Rain in previous 24 h (mm)
Rain in previous week (mm)
Rain in previous month (mm)
Maximum temperature of previous day (^{o}C)
Minimum temperature of measurement day (^{o}C)
Mean maximum temperature of previous week (^{o}C)
Mean minimum temperature of previous week (^{o}C)
Mean temperature of previous week (^{o}C)
Relative humidity at 9:00 am of measurement day (%)
Mean Byram-Keetch Drought Index of previous week
Mean Byram-Keetch Drought Index of previous month
Mean Byram-Keetch Drought Index of previous 12 months

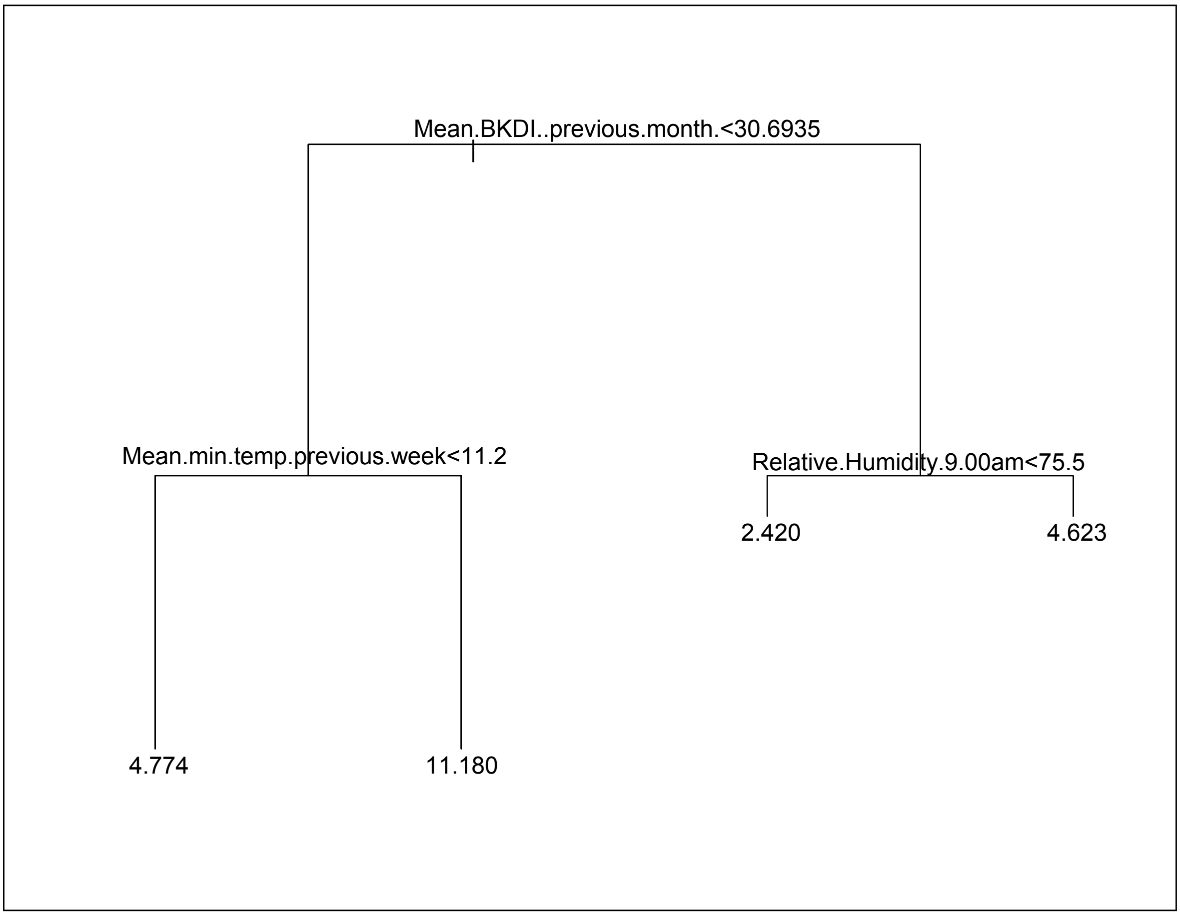

Figure 4.7: Pruned regression tree of nectar volume (μL) in bagged flowers of grey ironbark and predictor variables pooled for 2004, 2005 and 2006. The length of the node represents the relative importance of each split and terminal nodes show predicted values of nectar volume.

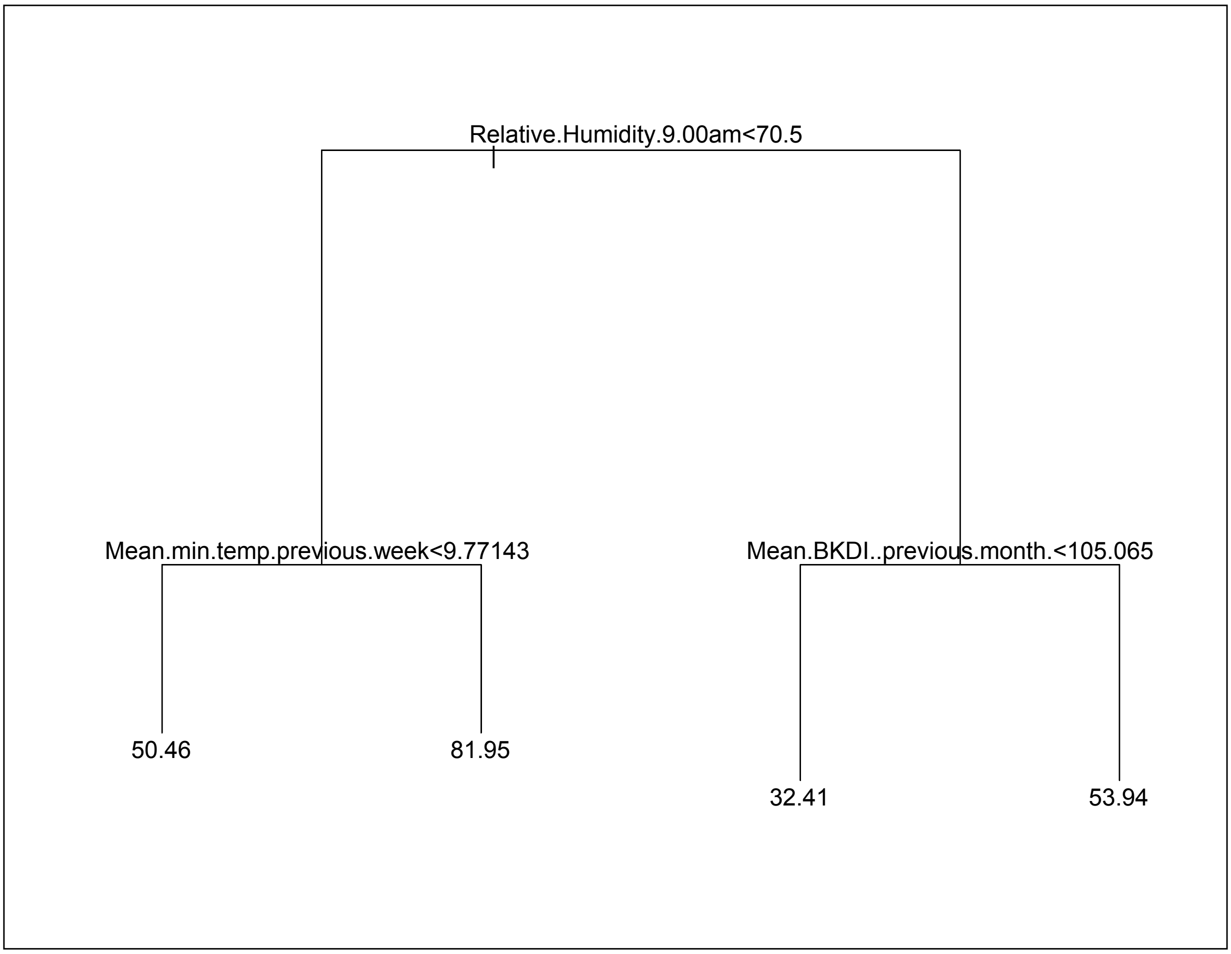

Figure 4.8: Pruned regression tree of sugar concentration (wt/vol) in bagged flowers of grey ironbark and predictor variables pooled for 2004, 2005 and 2006. The length of the node represents the relative importance of each split and terminal nodes show predicted values of sugar concentration.

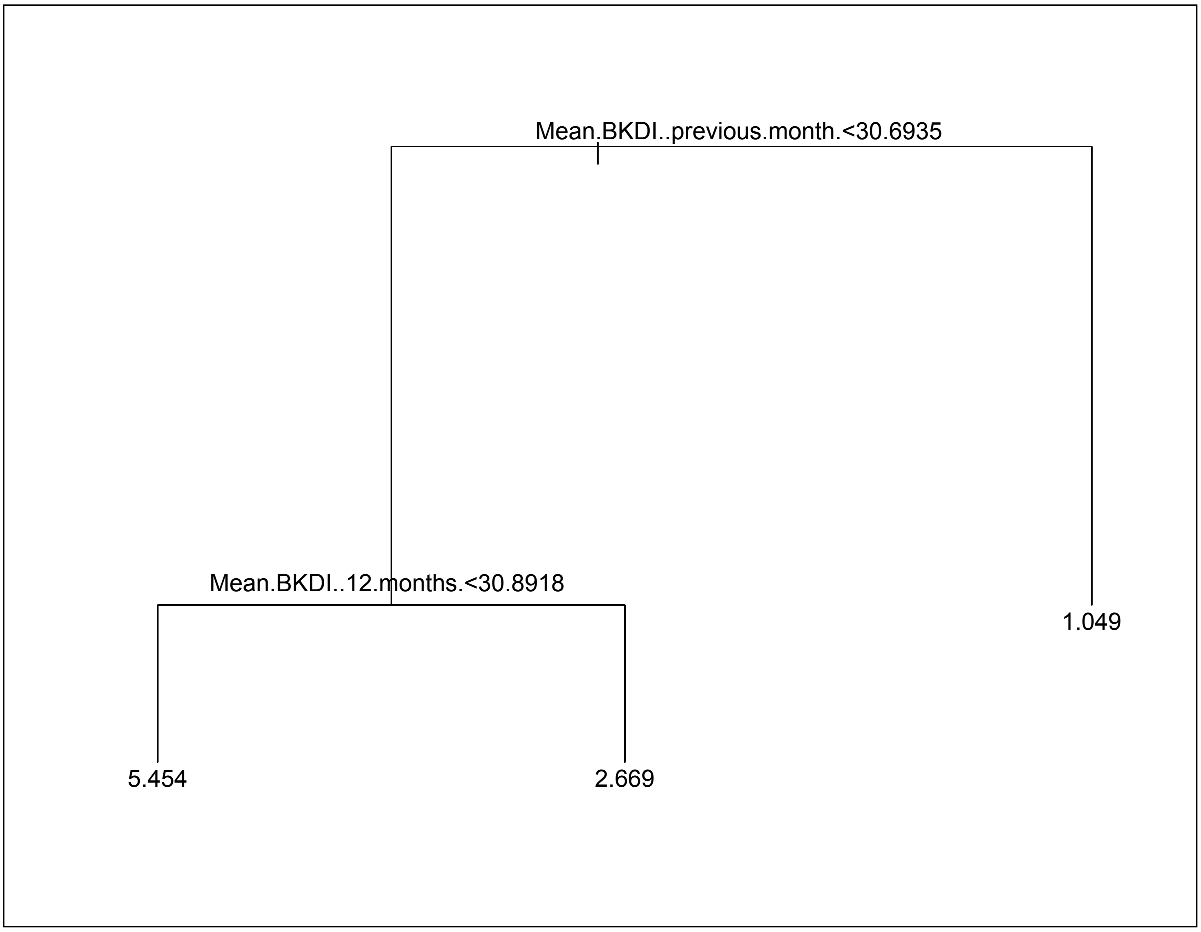

Figure 4.9: Pruned regression tree of total sugar (mg sugar) in bagged flowers of grey ironbark and predictor variables pooled for 2004, 2005 and 2006. The length of the node represents the relativeimportance of each split and terminal nodes show predicted values of total sugar.

Discussion

Grey ironbark nectar production differed in a number of ways from that of spotted gum. Nectar was produced during both the day and night, unlike spotted gum which has been observed previously to mainly produce nectar over-night. The main attributes of nectar that we measured were less variable in ironbark flowers than in spotted gum. This was notable for nectar per flower within trees, sites and years. We also found great similarity in nectar production between autumn flowering in 2004 and late-winter flowering in 2005, but these differed considerably from early summer flowering in 2006. Low average floral sugar levels in the early morning for grey ironbark in 2004 and 2005 (1 mg sugar per flower) corresponded to the low levels for spotted gum in 2003 (1 mg sugar), while the sugar-rich nectar in grey ironbark in 2006 (5.5 mg sugar) was similar to spotted gum for 2005 (4.8 mg sugar).

Predictive models of nectar abundance

Predicting years of good nectar flow will be influenced by factors related to bud formation (5-9 months prior to flowering in grey ironbark) and then the amount of nectar finally produced per flower. We found nectar production per flower was very sensitive to drought conditions. Sugar-rich flowers were only found when the BKDI indicated better than average conditions for a period up to 12 months prior to flowering. The effect of drought had the most influence on nectar volumes, although moisture was also the key factor driving sugar concentration, especially morning humidity, over-night rainfall or extreme drought. Tree and site attributes were not selected as predictors of nectar production. As an example, one ridge site in Currambene SF was sampled in two consecutive years and sugar concentration in flowers decreased from a mean of 56 % in March 2004, when the mean BKDI over the previous month had been very high (105) to 29 % in August 2005 when the BKDI over the previous month was low (29). In contrast, moderate rainfall deficiency was related to copious sugar-rich nectar in spotted gum and it is notable that spotted gum yielded rich nectar in 2005, compared to grey ironbark in that year, which yielded small quantities of dilute nectar, although over extensive areas. The over-riding inhibiting effect of drought to nectar production in grey ironbark is interesting as the species is known to be more drought-tolerant than co-occurring species, producing a greater root-shoot ratio where soil moisture is likely to be limiting (Kamis 1977; Pook 1984b). Perhaps being drought-tolerant allows grey ironbark to continue growing under dry conditions and it is only able to produce copious nectar under very moist conditions. We can summarise the differences between the two species as follows: the winter-flowering spotted gum appears to maximise nectar production when conditions are unsuitable for growth, such as when it is dry or cold, while the slower-growing grey ironbark, which can flower in a variety of seasons, appears to yield its richest nectar in summers that are warm and moist.

A variety of patterns have been reported in other eucalypts presumably reflecting the different conditions under which these species grow/have evolved. Diurnal nectar production in *E. melliodora* is independent of temperature above a threshold of 18^{o}C (Nunez 1977). Nicolson (1994) noted high rates of production in *E. ficifolia* were related to conditions of high humidity, sometimes leading to nectar dripping from flowers. Temperature has a positive effect on nectar production in *Grevillea robusta* where even flowers on shaded branches contain less nectar (Nicolson 1995).

Quantifying the nectar resource in grey ironbark forest

In comparison to flower counts on spotted gums, counts on grey ironbark were much higher. This is most likely because grey ironbark flower as a concentrated pulse while individual spotted gum progressively open their flowers over a number of months and the flowering season extends for 5-6 months (authors pers.. obs.). Despite the high flower counts on grey ironbark, scaling up to the forest stand indicates that it produces a smaller nectar resource than spotted gum forest. We calculate (assuming 15.5 J per mg sugar), on average, that old regrowth forest produces over-night 18,000 kJ ha^{-1} compared to 7,000 kJ ha^{-1} for regrowth and 2,500 kJ ha^{-1} for recently logged forest. Differences in nectar density between 2006 and the preceding years is emphasised by the maximum recorded for a single stand: 45,700 kJ ha^{-1} in Mogo State Forest in 2006 compared to a minimum for old regrowth of

2,300 kJ ha^{-1} in Currambene State Forest in 2004. It is important to note that there was virtually no nectar left in flowers at the latter site by the late afternoon. The average nectar density produced by old regrowth grey ironbark is 51 % of that produced in mature spotted gum (Chapter 3), but still considerably greater than other values published in the literature. Open eucalypt woodland near Sydney at its peak produces about 800 kJ ha^{-1}(Pyke 1985) compared to peaks of 7000 kJ ha^{-1} in dry sclerophyll forest in Victoria (Paton 1985). Productive areas of heath near Sydney and in northern NSW produce 3,000-10,000 kJ ha^{-1} (Pyke 1983; McFarland 1986; Armstrong 1991; Law 1994). In rainforest of Costa Rica, 7 bat-pollinated plants together provide about 3,000 kJ ha^{-1} (Tschapka 2004).

Is nectar limiting in grey ironbark forest?

Nectar in grey ironbark flowers was a limited resource in 2004, to a lesser extent in 2005, but not in 2006. In March 2004 grey ironbark flowering was localised in the Nowra area, but there was little elsewhere. Bagged flowers contained on average 3 µL of nectar, but nectar was absent from open flowers in both the morning and afternoon. At the time flowers were being visited by feral honeybees and a range of native invertebrates, such as large nectar flies, but not vertebrates. The absence of nectar in the morning, even at dawn, suggests that invertebrates continued to deplete nectar over-night during the warm weather of late summer (12-21^{o}C). Nectar was absent from open flowers in the afternoon even though a similar volume of nectar was produced in bagged flowers during the day. In late winter 2005 morning standing crops were similar to bagged flowers, probably because the nights at this time of year were cold (8-9^{o}C) thus limiting nocturnal invertebrate activity and the fact that grey ironbark flowering was reasonably extensive in 2005. Morning nectar levels were sufficient to support foraging by small numbers of honeyeaters, lorikeets and commercial honeybees, with the latter beginning to forage at 0930 h. No vertebrates were observed feeding on flowers while spot-lighting early in the night, possibly because flowers were empty by late afternoon and would require a number of hours to replenish. In early summer 2006, nectar was depleted by the afternoon, but not exhausted, compared to over-night bagged flowers and unbagged flowers in the morning. Surprisingly, no vertebrates were observed foraging on flowers at this time, possibly because of the extraordinarily high sugar concentrations (> 60 %). A number of studies have demonstrated that the optimal sugar concentration for nectar-feeding animals is 30-50 %, but that more dilute nectar is likely to be preferred in the field when smaller volumes of nectar are available per visit (Tam and Gass 1986; Mitchell and Paton 1990; Law 1993). Smaller species of birds with smaller tongues tend to prefer more dilute nectar (Mitchell and Paton 1990), so an avoidance of sugar-rich nectar may not hold for larger animals, like lorikeets, marsupial gliders or flying foxes, although none were observed during nectar measurements or while spot-lighting one night (authors pers.. obs). Commercial honeybees were yielding large quantities of honey at this time (Chapter 5) and honeybees are known to prefer more concentrated nectar, usually 40-60 % sugar (Bolten and Feinsinger 1978; Pyke and Waser 1981). Clearly then, standing crops are determined by an interaction between environmental conditions that influence nectar production and the feeding activity of flower visitors at the time (Bond and Brown 1979), which itself is affected by prevailing temperatures and nectar attributes, such as sugar concentration.

Effect of logging on nectar production in grey ironbark forest

After the strong effect of drought on nectar production per flower was accounted for in analyses, logging history and tree size, when taken individually, had no significant effect. However, a significant interaction found that small trees in old regrowth produced more sugar per flower than large trees, but the effect of tree size was reversed in regrowth. One interpretation of this result is that small trees in old regrowth are growth suppressed and may be able to allocate more resources to nectar production per flower. The reverse effect found in younger regrowth may be because large trees retained after logging are usually mature and will grow less compared to small trees in this stage of forest regeneration, thus large trees allocate fewer resources into growth than nectar. This differs from spotted gum (Chapter 3) because small stems of spotted gum in regrowth are known to lock-up (Forestry Commission of NSW 1985), whereas grey ironbark are more shade and drought tolerant and have a greater net assimilation rate of energy, allowing restricted crowns to continue to grow slowly

(Kamis 1977). The lack of difference between small and large trees in recently logged sites may be because both size classes are responding to the reduced competition for resources, for example large trees extending their crowns. Consistent with the hypothesis of less competition for soil moisture, large and small trees at recently logged sites produced large quantities of the most dilute nectar. Importantly, large trees retained during logging produce an equivalent amount of nectar per flower as trees in mature forest.

At the forest stand scale, logging history had a marked effect on nectar production with old regrowth forest producing seven times as much sugar per ha as recently logged forest, with regrowth forest 15-20 years old being intermediate. This result is very similar to that found for spotted gum, although the differences are not as large. Less nectar after logging is explained by the fact that regrowth canopy is mainly formed by small and medium sized trees and we found that these trees flower less often than large trees. Although nectar differences between logging histories are large, a thorough assessment of the effect of logging should take place on at least the compartment scale, which is the management unit to which logging is applied (200-400 ha). Within each logged compartment many areas are now reserved from logging, such as riparian buffers, high conservation old growth forest, over-ridge connection corridors, threatened species habitat as well as habitat trees and recruits within logging zones. These informal reserves have been estimated to represent about 57 % of the state forest landscape (New South Wales Department of Urban Affairs and Planning 1999). Calculations for 2001-2004 in Forests NSW Southern Region, found that, on average, 39 % of the gross compartment area that was available for logging was informally reserved, although 67 % was left unlogged in that year (K. Boer Forests NSW pers.. comm.). Under a worst case scenario, if 61 % of compartments were to be logged, a compartment scale old regrowth forest in 2005 would produce 2.1 times the amount of nectar as a compartment of recently logged forest and about 1.6 times the amount as a compartment of 15-20 year old regrowth with existing prescriptions. This estimated impact of logging is virtually identical to that estimated for spotted gum in Chapter 3 and flowering levels of eucalypts on the north coast of NSW (Law *et al.* 2000). Such impacts will be most important when nectar is limiting such as in 2004 and 2005, and would be less important when nectar is in surplus, like in 2006.

5. Benchmarking Nectar Measurements with Commercial Honey Production as Determined by Surveys of Beekeepers

Flowering levels and nectar production vary considerably between years, especially within eucalypts. As a result it was considered useful to benchmark our nectar measurements on Spotted Gum with data from commercial honey production in the same areas. To achieve this we consulted local beekeepers using a questionnaire survey to assess the amount of honey production in 2005 and relate this to the quantity of nectar flow, when most of our measurements were undertaken. Part of our aim was to compare the quantity of honey produced under the different logging histories sampled in Chapters 3 and 4, although it must be noted that there are a number of limitations in attempting to do this, especially the activities of beekeepers themselves. Many variables, including strength/health of the hive and the various ways beekeepers utilise the resources differently are likely to influence honey yields. As part of this questionnaire survey we also asked beekeepers to comment on forestry management practices and climatic events in relation to honey yields.

Methods

We obtained contact information for beekeepers that held apiary sites in the forests of our study area from the Forest NSW GIS database. During the poor flowering year of 2003, direct phone conversations were made to two beekeepers about the state of their bees and honey production. More detail and a formal response was sought in the prolific flowering year of 2005. A letter and questionnaire (see Appendix 1) was sent to beekeepers to access information on honey production and flowering intensity. Each beekeeper was asked to rate both spotted gum and grey ironbark flowering intensity from April to October 2005 and to provide details on hive number and location with an estimate of honey yield (kg/hive) for each month in this period. Most beekeepers hold permits to multiple apiary sites, so this required 121 questionnaires to be posted to 38 beekeepers.

It is generally considered that honey bees will predominantly forage within a two km radius of their hive in their search for honey and pollen (Paton 1996). Special emphasis was therefore placed on obtaining information from permit holders in a two km radius around each of our study sites.

Results

Spotted Gum

During 2003 spotted gum flowering was patchy and nectar flows were reported by beekeepers to be very low. During this time bee hives located in Currambene SF among stands of flowering spotted gum where we concurrently measured nectar (Chapter 3) did not produce honey, but rather required supplementary feeding to sustain the hives (Ron Impey pers.. comm.). The majority of the spotted gum forest on the south coast did not flower in 2003 and thus most commercial bee hives were located elsewhere at that time.

In 2005, 54 % (21) of beekeepers responded to our survey and returned 25 completed questionnaires. Some apiary sites were not used during the period of our study. There were various reasons for questionnaires being either incomplete or not returned that included beekeeper ill health, hives not being used for fear of infection of hive beetle from surrounding apiaries and some being used as backup sites only. Also one mature forest site, on the Princes Highway at Bewong, and forests surrounding it, is not located within State Forest. Contact information for beekeepers that may utilise this land was not available so no honey production information was obtained for this site.

Both spotted gum and grey ironbark were generally considered to have flowered well across the sites during 2005, although some beekeepers felt that the lasting effects of the drought and high moisture at certain times may have contributed to a less than expected yield (see Table 5.1).

Table 5.1: A sample of quotes by beekeepers from completed questionnaires.

• "2005 was the best yield from spotted gum in the last 15 years"
• "Grey ironbark had a very heavy nectar flow, the best it has produced for 20 years"
• "Spotted gum was the main nectar source from mid may to end of August and Grey ironbark from September through to the end of November"
• "Spotted gum failed to yield as much as expected probably because it was so dry"
• "bees had trouble ripening it (honey)"
• "The forest around this site was thinned out in the last 12 months , I believe this to be a major contributing factor in the increased production"
• "Thinning will be beneficial to spotted gum when it next flowers"
• "Cannot get honey from small trees, dead trees or stumps"

Spotted gum flowering was rated the highest in May through to July with about 60% of respondents rating the months as "good flowering" intensity. In comparison grey ironbark was highest in July, August and October (see Table 5.2).

Average honey yield/hive was high across the region. High yields are consistent with the good flowering intensity (as rated by beekeepers) by one or both species in all months except July. In July only 9 out of the 19 apiaries that completed questionnaires harvested honey. At this regional level the mean number of hives/apiary between April and October ranged from 115 – 136 and mean honey yield/hive ranged from 5 – 14.6 kg (see Table 5.2). Hive number was lowest in September and October.

On a local scale we looked at the mean number of hives/month within a 2km radius (1257 ha) around our nectar measurement sites. Average hive numbers ranged from 120 – 539/month. This Figure is largely determined by the number of completed responses we received. The sites with a greater proportion of responses have the highest number of hives. Mean honey yield/hive ranged from 5.4 – 18kg/month (see Table 5.3). The lowest value (5.4 kg) is not likely to be an accurate representation of the site due to the lack of questionnaires returned (n = 1). Low honey yield in July is due in part to only 9 out of 19 apiaries collecting honey in this month (Figure s 5.1 and 5.2). Mean honey/ha ranged from 0.52 –4.1 kg/ha per month. At sites where low productivity was recorded this is likely to be a function of the lack of returned questionnaires rather than a true indication of the site. However, where a higher proportion of questionnaires were returned these values would more accurately reflect the productivity of that forest.

Table 5.2: Mean hive number and honey production per state forest apiary site from all completed questionnaire replies across the entire study region (n = 25). Percentage of flowering intensity rated as good for each month according to all replies.

Month	Mean hives/apiary	Mean honey/hive (kg)	Mean honey/ha/month (kg)	% beekeeper to rate flowering intensity as 1 (Good)	
				Spotted Gum	Grey ironbark
April	136	12.9	1.4	47.4	25.0
May	136	14.6	1.6	63.6	40.0
June	136	11.2	1.2	60.9	33.3
July	135	5.0	0.5	58.3	57.1
August	131	13.1	1.4	23.8	60.0
September	117	9.5	0.9	33.3	35.7
October	115	11.3	1.0	0.0	66.7

Table 5.3: Mean number of hives and honey/month for apiary sites with questionnaire replies within a 2km radius of our nectar measurement sites. Estimates of the requirements of hives/month assuming managed hives require 1 kg per day under favourable conditions (Paton 1996).
* means calculated from all completed questionnaires. Logged (n = 10), Regrowth (n = 5) and Mature (n = 3).

	Mean hives/ Month	Mean Honey/hive/ Month (kg)	Estimate requirements of hives/month (kg sugar)	% of total area with replies
Recently Logged				
East Stump	168	18.0		59
Termeil Logged	306	10.5		38
Shannons Road	539	9.6		53
Mean	355*	11.8*	11000	
Regrowth				
Western Boundary Road	120	18.0		30
Termeil Regrowth	306	10.5		41
Picnic Rd	539	9.6		53
Mean	340*	11.5*	10540	
Mature				
Pacific Highway (Bewong)	N/A	N/A		0
18 Mile Peg	120	5.4		25
Kioloa Rest Area	239	10.0		42
Mean	180*	7.7*	5580	

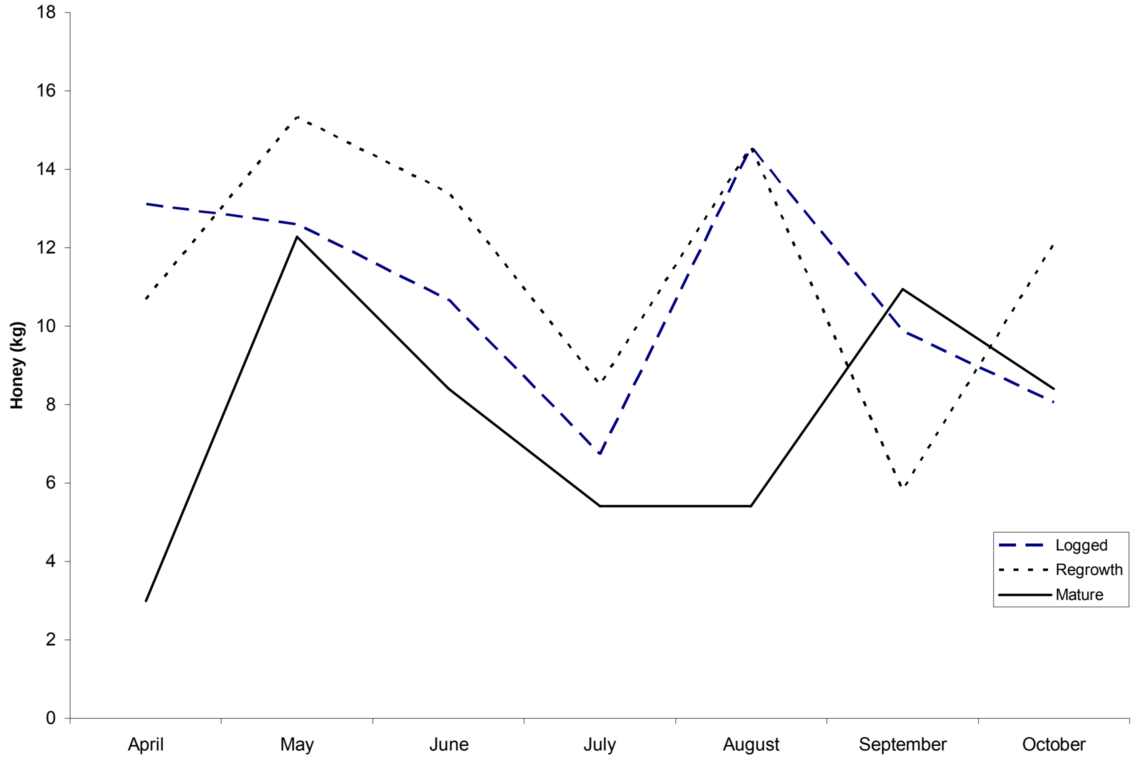

Figure 5.1: Mean honey produced per hive/month for each logging treatment. Low honey yield in July due to only 9 out of 19 apiaries collecting honey in this month.

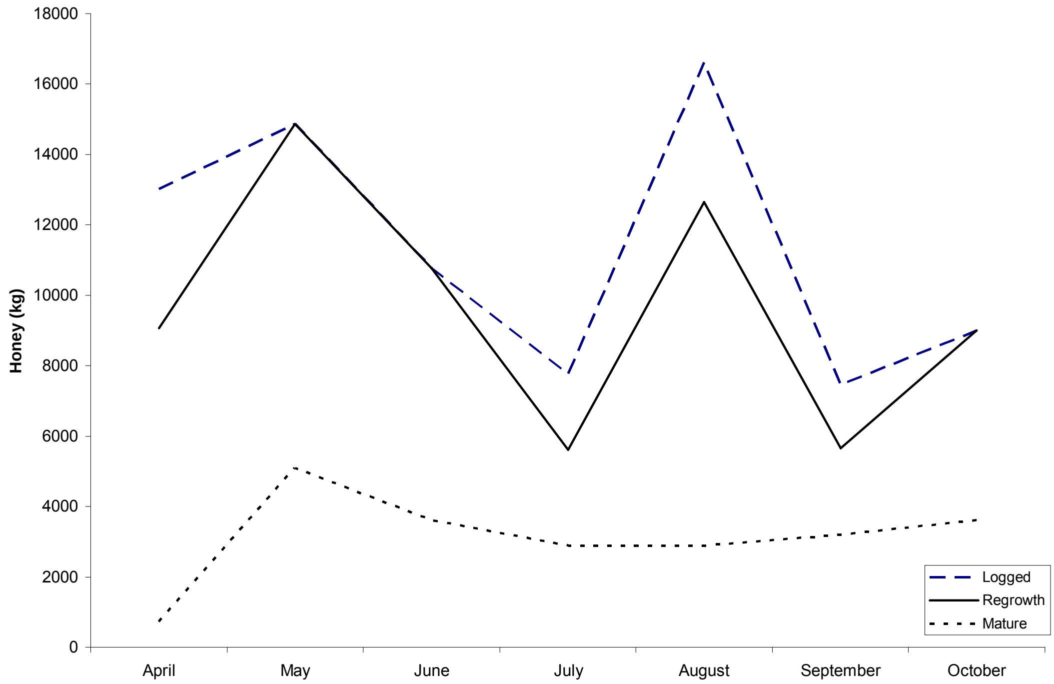

Figure 5.2: Total honey/month produced for each logging treatment. Low honey yield in July due to only 9 out of 19 apiaries collecting honey in this month.

Of the state forest apiary area within the 2km radius around each site completed replies averaged 59% (0-100%). A greater number of replies were received from beekeepers around recently logged and regrowth sites than there was for mature sites (see Table 5.3). Two of the mature sites only had a small number (n = 1 – 2) of beekeepers reply and one had no land in State Forest. The average number of hives at recently logged and regrowth sites were almost double that recorded at mature sites and predictably greater total honey production was recorded at these sites. A more appropriate comparison in this situation is to compare average honey production for individual hives. Average honey production per hive was similar across the three treatments with the recently logged and regrowth sites producing slightly more (11.5 – 12 kg/month) than the mature sites (8kg), although we had a small sample size for mature sites.

We estimated the requirements of commercial hive bees following Paton (1986), whose upper estimate of the requirements for each managed hive is 1 kg sugar per day. Based on this Figure , honeybees would have been harvesting 6-11 tonnes sugar/month around state forest apiary sites (Table 5.3). This can be compared to the productivity of the forest; assuming bees typically forage within a 2km radius of the hive (Paton 1986) and using Figure s of sugar production by spotted gum from Chapter 3. We estimate that in the prolific flowering year of 2005, mature spotted gum forest produced 88 tonnes sugar/month/2km foraging radius (1257 ha), regrowth forest produced 39 tonnes sugar/month/apiary and recently logged forest produced 10 tonnes sugar/month/apiary. These Figure s of sugar availability are generally well in excess of the requirements of commercial honeybees at those sites. They are close to the amount of sugar available in recently logged forest, although this is under the unrealistic assumption that the entire 1257 ha area had been logged (see below). Interestingly, during 2003 when hives were either not deployed in spotted gum forest or required supplemental feeding, the best flowering stands of forest were producing 3.3 tonnes sugar/month/apiary. This is less than the requirements estimated for the typical number of hives per apiary, without considering the nectar harvested by native fauna.

Grey Ironbark

While some of the data presented above for 2005 includes honey produced by grey ironbark, especially for August-October, we also collated further beekeeper observations for other years that we measured nectar in this species. The only year beekeepers were unable to tap into the resource was the autumn of 2004 when nectar standing crops were empty during both the day and night. Beekeepers at the time commented that the trees were not producing nectar, although our nectar measurements indicated nectar was produced, but that flower visitors were removing the nectar as fast as it was produced. During winter 2005, one beekeeper commented “Grey ironbark had a very heavy nectar flow, the best it has produced for 20 years” (R. Impey pers.. comm.), yielding 18 kg per hive in August when grey ironbark was flowering and spotted gum was finishing. A different beekeeper with hives nearby did not remove honey, but instead allowed his bees to gain condition through the late winter season. In comparison, in 2006 when nectar was sugar-rich and copious, commercial honeybees obtained 3 times this amount of honey (90 kg/hive from December-January – T. Pettini pers.. comm.). The latter is at the upper level of the estimates given for *E. paniculata* (27-104 kg - Cocks and Dennis 1978; Somerville and Nicholson 2004).

Beekeeper Thoughts

Beekeepers reported that a number of other species produced good nectar flows during the period of our study. In particular red bloodwood (April-May) and white stringy bark (July-October) contributed to honey production around Benanderah SF.

Grey ironbark had good nectar flows but it provided some problems for beekeepers. The small quantities of pollen that it produces meant that at some locations bees had to be removed even though the ironbarks still had plenty of nectar. This may account for lower hive numbers in September and October.

Heavy rain over winter was reported to have reduced yield at some sites. At other sites with good spotted gum and grey ironbark flowering, honey production was not good, with suggestions that this was a consequence of the effects of the drought (see Table 5.1). High moisture content in the honey meant it was considered to have a negative effect on yield.

Silviculture activities in the form of thinning operations were considered by some to have a positive effect on nectar flows, but logging was considered by a number to be a problem and a contributing factor in declining honey production. Over harvesting of certain species, mainly ironbark was a concern.

Discussion

The average annual yield of honey has been estimated for bee hives around Nowra as 50 – 100 kg and the contribution from spotted gum and grey ironbark to this yield can be extremely high, up to 25 – 50 kg (Somerville and Colley 1990). Beekeepers in our seven month study period in 2005 reported honey yields well above this range. Between April and October yield/hive in each of our three different treatments ranged from about 54 – 83 kg (Table 5.4). Thus our nectar measurements for 2005 (Chapter 3) can be benchmarked against honey production for that year that was above the typical maximum values reported. In contrast, during the poor flowering year of 2003 few hives were deployed in the forest near the few isolated stands of flowering trees and no honey production was reported at this time. Hives in the forest were said to require supplemental feeding. Most apiary sites were left unused in this year, whether they were adjacent to mature forest or in young regrowth.

For grey ironbark, the yearly differences in the quantity of sugar produced per flower (Chapter 4) were related to considerable variations in honey production. In particular, summer 2006 saw prolific honey production close to the maximum previously reported for this species, reflecting the copious, sugar-rich nectar that we measured. Interestingly, prolific flowering of grey ironbark in this year was very patchy, mostly confined to sections of forest near Moruya. Differences in honey production in 2004 and 2005 were apparently related to nectar standing crops rather than actual nectar production. The latter was modest and almost identical between the years, but standing crops were much higher in late winter 2005 when insect activity was presumably lower, especially over-night, compared to autumn 2004 when unbagged flowers were mostly empty, even at dawn.

To gauge the extent of nectar and honey production in 2005 from the replies of beekeepers we calculated quantities and dollar values per hectare of forest. With commercial honey bees producing about one kg honey/ha/month during 2005 (Table 5.2), a 1000 ha forest flowering from April-August could yield five tonnes of honey. The wholesale price of spotted gum honey in 2007 was $2.20 per kg (R. Impey pers.. comm.), which values the spotted gum honey resource per 1000 ha of forest as $11,000. It should be noted that 2005 was a prolific flowering year for spotted gum and there was little blossom in the immediately preceding years.

Despite these massive rates of harvesting by bees, we found that nectar supplies during 2005 were not a limiting resource (Chapter 3). Comparisons of the estimated requirements of hives with the amount of sugar produced by the forest confirm this pattern and indicate that the spotted gum forest in 2005 was producing excess nectar for commercial honeybees. Not surprisingly then, honey productivity was comparable across the three different treatments (Table 5.4). This demonstrates that, when flowering is prolific, good honey yields can be obtained from recently logged and regrowth sites. Because the nectar resource was not limiting across all sites it is not possible to attribute any variation in production to the different treatments. This is contrary to the views expressed by some beekeepers that recently logged forest does not produce much nectar. Yet in years when flowering is less prolific (e.g. 2003), nectar may be limiting and at these times recently logged forest will be less productive (Chapter 3). Retained areas of unlogged and regrowth forest are likely to be very important in ameliorating the effects of logging in years when flowering is less prolific. For example, the effect of current management prescriptions is to retain on average 39 % of a forest compartment, although the actual per cent not logged is much more, averaging 67 % near Batemans Bay (K. Boer Forests NSW pers.. comm.).

The unbalanced response from beekeepers in the various treatments complicates the interpretations of results and limits the direct comparisons between logging histories to that presented above. This is further compounded by other species flowering at some sites. The variation in yields reported at different sites is most likely to have been influenced by the activities of beekeepers rather than forestry activities. Many variables, including strength/health of the hive and the various ways beekeepers utilise the resources differently are likely to influence honey yielded. For instance strength is heavily influenced by the where and what the bees were feeding on previous to the current location, age of the queen (Paul Manns pers.. comm.), while some beekeepers may not extract much honey during the cold winter period to ensure the hive remains strong during this period (Stephen McGrath pers.. comm.).

Table 5.4: Average total yield/hive (April – October) within a two km radius of our nectar measurement sites for each logging treatment according to questionnaire replies.

Treatment	Honey/hive (kg)
Logged	82.9
Regrowth	80.4
Mature	53.9

6. Management Practices for nectar producing trees in Australian State Forests

Within each state a variety of silvicultural systems are used, which means logging practices will vary from area to area. For example single-tree selection and group selection are applied at compartment scales of 200-400 ha in northern NSW and they result in a mosaic of gaps and retention areas. More intensive forms of logging such as clear-fall are most commonly employed in southern Australia and these create much larger gaps and leave behind fewer retained trees. For example, the seed tree silvicultural system is used in East Gippsland, Victoria on coupes up to 40 ha, with all trees being removed, except habitat and seed trees, and other exclusion areas such as along riparian zones (Dooley 2004). A hot burn is usually applied after logging to stimulate regeneration. Another common silvicultural practice is thinning, which is applied to younger regenerating forests with the aim of removing suppressed trees and allowing retained trees to develop larger crowns.

To minimise the impacts of timber harvesting on nectarivorous wildlife and beekeeping, different management practices have been formulated by different state forestry departments. However, until this study, there was no information on how much nectar is produced by retained trees or young re-growing trees after logging, even though these trees produce flowers. This information is highly relevant to the careful management of natural resources in State Forests, especially so that beekeepers can continue to access this resource. Given that many native fauna (some species listed as Threatened) are nectarivorous; this research will also have significant positive benefits for biodiversity. Examples of practices used in two states are presented below.

Forests NSW have no specific management practice that targets beekeeping, although there a number of management practices in place to retain nectar-producing trees for wildlife during logging operations. The Forests NSW prescription for tree retention specifically targeting the flowering resource includes the following:

> "At least four eucalypt feed trees must be retained in every two hectares of net logging area where they occur. Where a retained eucalypt feed tree also meets the requirements of a hollow-bearing or recruitment tree, the eucalypt feed tree can be counted as a hollow-bearing or recruitment tree. Damage to flowering or fruiting banksias and *Xanthorrhoea* spp. should be avoided during forestry operations."

As an example of standard tree retention rates for wildlife in Southern Region, a minimum of ten hollow-bearing trees plus recruits must be retained per two hectares of net logging area. Species-specific prescriptions also apply to nectarivorous fauna, such as yellow-bellied glider, squirrel glider and swift parrot, if they are recorded in the forest.

The more general retention of "landscape features" is likely to have more importance to maintaining the nectar resource. Within each logged compartment, many areas are now reserved from logging, including riparian buffers, high conservation old growth forest, over-ridge connection corridors and non-nectarivorous threatened species habitat within logging zones. These informal reserves have been estimated to represent about 57 % of the state forest landscape (New South Wales Department of Urban Affairs and Planning 1999). Calculations for 2001-2004 in Forests NSW Southern Region, found that, on average, 39 % of the gross compartment area that was available for logging was informally reserved, although 67 % was left unlogged in that year (K. Boer Forests NSW pers.. comm.).

The Department of Sustainability and Environment in Victoria use an Apiary Plan (Department of Sustainability and Environment 2004) that targets the seed silvicultural system used in East Gippsland (Dooley 2004).

This plan involves the use of zoning around apiary sites, with five zones employed based on the importance of each apiary site:

- Apiary Zone 1 is the forest within 1 km radius of designated high-importance apiary sites. This AZ1 is managed so that at any point in time, at least two thirds of the forest will be more than 40 years old
- Apiary Zone 2 (medium importance sites) is generally in areas of higher timber value and where the density of apiary sites is quite low
- Apiary Zones 3, 4, & 5 have generally low importance for honey production.

The current practice of Forests NSW that leaves 67 % of a compartment unlogged in a given year is in effect similar to that designated for Apiary Zone 1 in Victoria.

7. Recommendations

Apart from issues discussed in Chapters 3 and 4, the main recommendation of this report is to further disseminate the results of the project, mainly by preparing a number of papers that target a range of audiences. It is the aim of this research to promote sustainability in forest management and to raise the awareness of forestry organisations that the nectar resource requires careful management. It also aims to raise the awareness of beekeepers about current forest management by quantifying nectar availability under different logging histories. Accordingly, the three primary chapters of this report will be prepared as manuscripts for submission to scientific journals. Summaries will also be submitted to the publications of various organisations, like the Bush Telegraph (Forests NSW), Australasian Beekeeper and Agriculture Today in The Land. An article on the research has already appeared in the Sydney Morning Herald on 28/12/2006.

To improve communication between apiarists and foresters it would be valuable to establish formal guidelines on the management of apiary sites and the nectar resource in forests. This could include a mechanism to forewarn apiarists when logging is planned near to their apiary site. Part of the purpose of these guidelines could be to establish a scheme of monitoring at certain apiary sites, where honey yields are monitored over time to document changes in productivity with changes in the mosaic of logging histories in the forest.

One further development from data collected in this project is the production of nectar maps across key areas of State forest, with the aim being to delineate areas of high productivity where there might be an increasing management focus on apiculture. Such maps could be feasibly produced using CRAFTI vegetation mapping that was put together for the Comprehensive Regional Assessments in the 1990's. CRAFTI maps include a data-layer of Structure and Disturbance that defines various tree age-class and stand density parameters for forests. These could be combined with our estimates of average nectar densities produced under different logging histories to show how nectar availability varies spatially across the landscape.

8. References

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Appendix 1: Beekeepers questionnaire

NSW DEPARTMENT OF
PRIMARY INDUSTRIES

HONEY PRODUCTION &
SPOTTED GUM / GREY IRONBARK
FLOWERING SURVEY

(Please use separate form for each apiary location)

Beekeeper Name			
Permit Number		Site Number (see Attached map/s	
State Forest			
Apiary Location (road name with nearest intersection)			

Month	Spotted Gum Flowering Intensity (1-3)*	Grey ironbark Flowering Intensity (1-3)*	Number of Hives	Estimate Honey production boxes** or kg/Hive for each month
April				
May				
June				
July				
August				
September				
October				

*
- 1= Good flowering, sufficient to support brood rearing or an increase in area and honey production.
- 2=Moderate flowering, sufficient to maintain hive population but does not support honey production
- 3= Patchy flowering, brood area declining, bees may have required supplementary feeding and did not produce honey.

**
- Number of ¼, ½, ¾, or full boxes each month.

Was there any other species in flower? If so what month and what contribution did they have in honey production?

Please add any other comments you wish.

Mark Chidel PO Box 100 Beecroft NSW 2119