The Perception of Forest Architecture:

An Experimental Evaluation of Tree Hollow Survey Methodologies.

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ABSTRACT

This study examined the accuracy and precision of tree hollow detection utilizing standard ground survey methodology. A survey set of 49 hollows were located and described using a climbing technique, in a mixed eucalypt stand of the Wombat forest, in Victoria, south – eastern Australia. The survey results of eight ground surveyors were compared with benchmark data gathered in the climbing survey.

In the event that tree hollow characteristics are to be surveyed from the ground, it is likely that the quality of information will be compromised. In this study, ground surveyors failed to locate one out of every three of all existing tree hollows, and located an additional false hollow for every two actual hollows detected. False negative error of 37%, and false positive error of 32% were recorded for the survey, suggesting that two types of systematic bias prevent an accurate assessment of tree hollows.

These results indicate that the likelihood of detection success is significantly related to measurable parameters at the level of the hollow. The height of a hollow, the planar orientation of a hollow and, the associated vegetative obstruction of the hollow, were all found to be negatively correlated with detection success. In addition, the education and experience of individual researchers is a source of variation in detection success. Correction factors to control for survey bias are discussed.

This study noted that particular structural forms of tree hollow might systematically escape detection in ground surveys. In particular, tree pans are generally obscured from view for a ground surveyor.

Forest managers are encouraged to develop hybrid survey techniques that utilize climbing methodologies, to provide baseline information on hollow distribution, abundance and, ecology

DECLARATION

I herby declare that the work presented in this thesis is original and has not been presented in another degree or at another institution for examination.

Signed:

Darren J Holloway

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1. INTRODUCTION

Tree hollows have a specific relevance in the Australian landscape (Tyndale-Biscoe & Calaby, 1975). The forest environments of Australia are home to a significant range of hollow dependent fauna, and a considerable number of fauna that use hollows on an opportunistic basis (Gibbons & Lindenmayer, 2002).

Tree hollow research has developed out of fauna studies where the species in question is found to be hollow using. Hollow characteristics have been described out of these fauna studies (Ambrose, 1983), and the common systems for hollow descriptions and classification reflect the basis of a utility to fauna (Gibbons *et al*, 2002). Not all hollow using fauna have been adequately described (Lumsden *et al*, 1994), and hollow types that are not known to be utilized (such as micro-hollows) are regularly excluded from analysis.

Tree hollows provide an increased level of safety from predators due to their general inaccessibility, hence they are regularly chosen as roost, den, or nesting sites by a wide range of species (Gibbons & Lindenmayer, 2002). In addition, tree hollows provide protection from severe environmental stresses such as heat, cold and, rain; and are potential source collection points for food and prey (Dickman, 1991).
The formation of tree hollows involves the interrelated activities of several key factors (Jacobs, 1955). Tree species are known to exhibit a wide range of tolerances to decay, and this is related to decay resistance and wood properties of each species. Hollows may be created mechanically (Gill, 1974), through the action of fire or wind; or hollows may result through a biotic excavation of the wood fibre (Creffield, 1996). A combination of factors will ultimately create the conditions for tree hollow development to occur.

The study of tree hollows can be undertaken utilising a range of techniques. The bulk of research on the subject has developed from assessments made by observers operating at ground level (Bennet *et al*, 1993). Recent methods have pioneered the technique of research ‘salvage’, examining the hollows in trees felled for timber extraction (Mackowski, 1984; Gibbons *et al*, 2000).
There is a range of problems with ground survey of tree hollows, chiefly, that the researcher can rarely access a typical hollow and there is a requirement to make a range of assumptions and measurements regarding hollow size and occupancy. Hollows examined following the tree being felled, are prone to damage, and there are a number of ethical problems in relation to association with extractive industry (Anderson, 2003).

The results of tree hollow studies indicate that there are potential sources of error in the data collection process that may lead to a systematic bias across the experimental design. The most commonly described source of bias is where the tree hollow researchers fail to locate tree hollows that exist within the survey bounds. This is known as false negative survey bias (Wintle et al,

2003) and is commonly described (Harper, 2002, Carlson & Schmiegelow, 2002) as the principal component of survey error.
This study sought to examine the reasons that a ground observer might fail to locate a particular tree hollow, and to consider the survey implications of these results. A survey method was developed to utilize a tree climbing system to inspect a range of tree hollows in detail. Specific characteristics of the hollows (such as hollow height) were measured and compared to the survey results achieved by a disparate group of ground observers using a similar reporting methodology. It was assumed that a climbing survey would provide the most accurate estimation of the total number of tree hollows on a particular site, and that apart from observer error, the survey figure achieved would be close to the true figure. Based off the assumption that the climbing count was equal to the actual count, a benchmark was in place to compare responses from a range of observers.

Attention to the design of the data entry system, allowed a method to compare the actual locations of hollows described by the observer group with the specific locations recorded in the climbing survey. It was then possible to determine precisely which hollows were missed, apart from those accurately detected. In addition, it was possible to delineate a further source of error, false positive error; where observers locate and record details of hollows that do not actually exist.

1.1 Aims and Objectives

1. The principal objective was to assess the divergence in survey results achieved through a climbing survey and a ground-based survey of tree hollows.

2. A main objective was to determine whether the qualifications and experience of observers had an effect on detection success.

3. A main objective was to measure the variation in key hollow parameters and to relate this variation to changes in the success of hollow location for the ground survey method.

4. A main objective was to examine the types of error occurring in a ground survey method, and to assess the likelihood of systematic bias in these sources of error.

5. A supporting objective was to evaluate the ecological implications of error and bias in the survey method, delineating hollow types and dependent species that may be affected by management interpretation of biased results.

STUDY HYPOTHESES

The null models developed for testing included;

1. There is no difference between the results of tree hollow surveys undertaken using the ground survey method and the climbing survey method.

2. The experience of individuals within the observer group does not affect the likelihood that a hollow will be detected.

3. The height and orientation of a tree hollow is not related to the likelihood of detection success

4. The vegetative obstruction of the adjacent forest environment does not affect the likelihood of hollow detection

5. Tree hollows with the largest entrance sizes are more likely to be detected than hollows with small entrance sizes

2. LITERATURE REVIEW

The main objective of the literature review was to examine the existing research framework in relation to tree hollows. The focus of the review was to assess the range of studies undertaken, and to outline the key techniques used to provide data. It was evident that there were several key components to any understanding of tree hollows, and that any discussion of specific survey methodologies was predicated upon an understanding of these components (Fig 2.1).

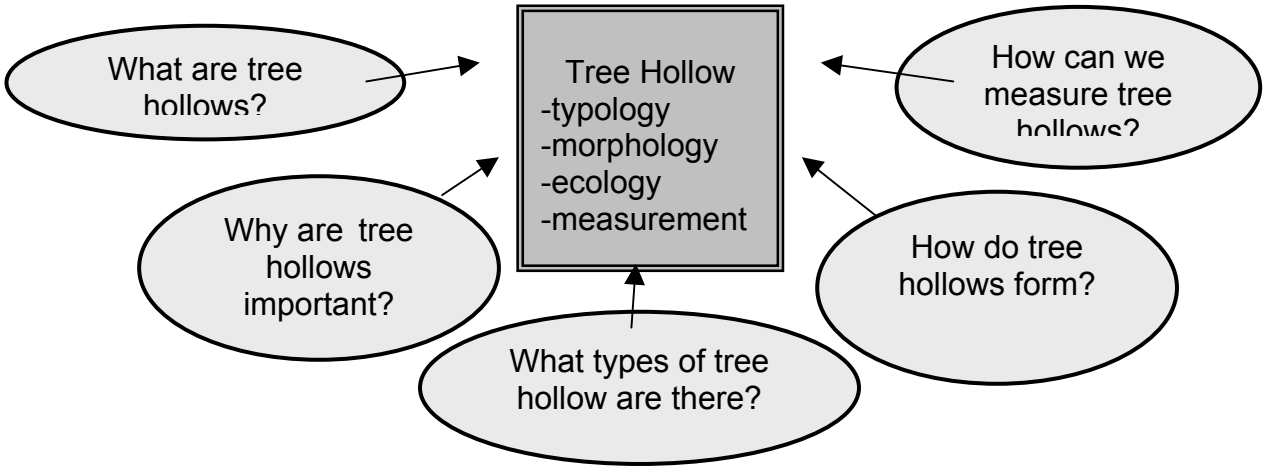


Figure 2.1, Literature Review Structure

Following is a structured review of the scientific literature pertaining to tree hollows, and their importance in Australian forest ecosystems.

2.1 Tree Hollow Survey Techniques

Tree hollows are commonly identified by a ground survey. This is the most basic and efficient method for creating an indication of hollow abundance and distribution within a survey area (Traill, 1991).
Visual perception is the key method in the determination of hollow occurrence. This is a significant factor in forest environments where there may be lower levels of light and higher levels of vegetative screening, effectively reducing the ocular capacity of the observer (Bibby *et al*, 1993). The interrelated effect of landscape variables upon visual clarity (Thompson, 2000) can reduce the likelihood of hollow detection.

Accurate estimations are dependent on a range of factors, not all of which are controllable within the limitations of a ground survey. In general, the greater the distance between the observer and the hollow, the greater the opportunity for error in assessment of hollow parameters (Harper, 2002). This is a significant issue in surveying Mountain Ash (*Eucalyptus regnans*) and other types of tall trees.

In an effort to enhance these visual limitations, it is common practice to employ the use of binoculars, cameras, rangefinders, and other ocular enhancement equipment to inspect the hollow in increased detail (Lindenmayer *et al*, 1993, Taylor & Haseler, 1993). It is therefore the case that hollows in tall trees, or more specifically, the hollows in the highest portion of a tree canopy, are more likely to be overlooked (Gibbons & Lindenmayer, 2002).

In addition, the angle of presentation of the hollow entrance is an important factor in detection success (Calder *et al*, 1983). Hollows, which are oriented in an essentially upward direction, are less likely to be located by a ground-based observer. The location of the hollow is also a factor in identification. Hollows with small entrance dimensions may not be observable from the ground. Detection success is associated with a specific understanding by the researcher of the range of species that may utilize such hollows, such as forest bats (Lumsden *et al*, 1994). These understandings inform the observer during a survey.

Finally, it is often the case that a view into a specific tree canopy is blocked by the presence of mid-story trees (Kanowski *et al*, 2001a). This is commonly the case within the wetter forest types within Australia. The cumulative effect of these sources of bias is to reduce the likelihood of detection success.
Traditional indigenous peoples manually accessed the upper sections of forest trees to obtain resources such as small animals, fruits, and eggs, without the aid of modern equipment (Flannery, 1994; Norton, 1988). Colonial botanists and birds egg collectors began to access tree canopies with the aid of rope or cable ladders developed for cave exploration. Contemporary canopy access systems are more diverse in scope, reflecting the requirement for specialized systems of access to suit project design criteria and budget. A significant body of research has been obtained through the use of these canopy access methods (Aubrey & Raley, 2002, Harper, 2002). In addition, there are overarching legislative frameworks to provide safety in the workplace, and OH & S risk management strategies are an essential component of height related access.

In the absence of a source of access to the upper sections of a tree, observers have devised methodologies for ground based surveying of tree hollows and arboreal fauna (Lindenmayer *et al*, 2000). These ground-based techniques have a range of sources of bias, which are emphasized later in this section.

2.1.1 Hollow tree definitions

The nomination of a specific tree as a hollow bearing tree is problematic. There is not an agreed definition with respect to the essential parameters of such trees. The failure to reach a definitional consensus in part reflects that many individual hollow researchers have tailored definitions to capture or exclude data that relates to specific arboreal species that are under study. Thus Gibbons *et al* (2000a) measured hollows from a height of 3m above

ground while Lindenmayer *et al* (1990) defined hollow bearing trees as greater than 6m high. The measurable characteristics of trees are formally defined (Specht, 1970), and these definitions do not allow for the full range of hollow bearing tree forms (such as hollow bearing stems under 6m in height). These definitions informed Lindenmayer *et al* (1990) in formalising minimum tree height at 6m.

Similarly, researchers have set different minimum tree diameters for inclusion in their research. Tree diameters under 50cm are regularly excluded from hollow surveys, (Lindenmayer *et al*, 1990; Q.D.N.R., 1998) despite evidence for hollow use by vertebrates in trees of smaller diameter Inions et al (1989).

Hennon *et al* (2002) found that existing hollow bearing tree- classification systems were inadequate for describing all forms of species deliquescence and that deviations from upright tree form were a precursor for hollow formation. Deliquescence describes the process of tree decay as a visual-spatial concept where an ageing tree develops a spreading canopy form, or a complex spatial arrangement of dead and decaying wood tissue (Gibbons *et al*, 2000). The dying tree will further deliquesce into forest litter. These types of deliquescing tree form have been categorised as a basis for stratifying hollow tree information (*Fig 2.2*). Hollow bearing trees are classified as live or dead as a primary level of definition. There is no evidence that fauna prefer living or dead trees, but there are implications for forest management in maintaining the age and structure composition of habitat areas (Loyn, 1985, Lindenmayer *et al*, 1997). For hollow researchers, dead trees present issues of safe access to an unstable structure.

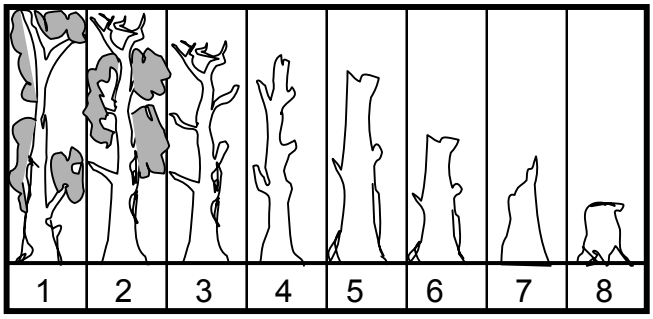


Fig 2.2, Hollow bearing tree forms
(After Fig 2 of Lindenmayer *et al*, 1991**)**

2.1.2 Measuring hollow bearing trees

A significant feature of ground-based techniques for detecting hollows is reliance on the correspondence between tree characteristics (e.g., age, form) and hollow formations (Lindenmayer *et al*, 2000). Characteristics of tree form are measured or estimated and then assessed as to their relationship with other hollow characteristics and occupancy data.
At a landscape scale, stand features such as height and maturity can be examined using GIS to infer hollow distributions (Ball *et al*, 1999, Lindenmayer *et al*, 2001a).

It is important to distinguish between measurement of the hollow entrance and branch characteristics, and the hollow cavity and internal parameters. Estimation and measurement of hollow entrance characteristics from ground survey are open to sources of bias (Harper, 2002), and may vary in their relationship with actual hollow cavity dimensions (Whitford, 2001). Hence, measurement of physical tree parameters such as diameter and tree size, are used as surrogate measures of hollow distribution.

In the situation that measurement must be undertaken from the ground, Gibbons (1997) suggested recording; 1) the minimum entrance width, 2) the diameter of the branch on which the hollow occurred, 3) whether the branch was living, part living, or dead.

2.1.3 Locating hollows

Most authors do not describe the process of how hollows are detected in their research. As noted, many hollows are excluded from surveys in the design phase (Taylor & Haseler, 1993).

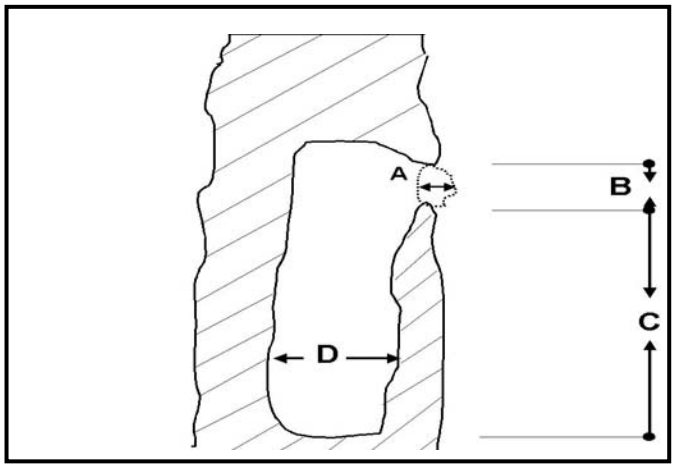
There is an established body of research relating to avian census studies (Bibby *et al*, 1993). Transect and point count methods have been developed for the detection of birds (Recher *et al*, 1983; Bibby *et al*, 1993) and for other vertebrates (Morgan, 1986). Cunningham *et al* (1994) assessed the effectiveness of three ground survey methodologies in locating birds. Differences between census methodologies were not significant in comparison to the effects of observer differences, although *Field et al* (2002) noted that same day counts tended to underestimate species richness. *Field et al* (2002) emphasized the difficulty in surveying mobile species; issues that are not applicable to the survey design for hollow location. Comparative studies of this type have not been completed to assess effective survey methods for tree hollows. These authors have highlighted the issues of observer experience as an important factor in bird detection, and it is possible that the same principle applies to tree hollow detection.

Cunningham *et al* (1999) recommended that the mean count of at least two observers be used as an estimate of abundance. This is in effect, a suggestion for a double sampling program (Bart & Earnst, 2002). This method has been adapted for tree hollow detection (Harper, 2002). This author describes an efficiency ratio, which delineates the correct proportions of ground survey component, and climbing survey component that are required to maximize survey efficiency. There is some concern that the efficiency ratios as designated will not necessarily be transferable to other forest types, where there is a different structural assemblage of vegetation.

2.1.4 Measuring cavity parameters

The recording of internal hollow cavities has been undertaken using a variety of equipment such as probes on telescopic poles (Soderquist & Lee, 1994),

physical measurement with rulers (Calder *et al*, 1983), and optical and laser equipment (Arbotom, 2003).
There are a range of variables that are measurable when considering the hollow cavity. The key dimensions are shown in *Fig 2.3* (Whitford, 2001). The main variables recorded are the diameter of a spherical hollow entrance or, the minimum and maximum dimensions of an irregular hollow entrance.



A – Minimum entry dimension

B – Maximum entry dimension

C – Hollow depth

D – Average width at the widest point

Figure 2.3, Measurable Dimensions of Tree Hollows
(Saunders *et al*, 1982; Whitford, 2001).

2.1.5 Landscape perspective and modelling

Modeling programs have been developed to predict the occurrence and distribution of tree hollows (Ball *et al*, 1999). Extending the spatial representation of data, in effect manipulating environmental parameters to ascertain probabilities of occurrence and distribution, enables predictive mapping to occur. Critical to the effectiveness of the model is the assumptions and data, which support the method (Ferrier, 1991), (Loyn *et al*, 2001). Derived information can be utilized as a basis for creating population models (Possingham, 1991). This allows the researcher to make specific assertions regarding target species, in areas which have not been directly ground surveyed. This information is compiled by government agencies within the Statewide Forest Resource Inventory in a GIS format (D.N.R.E., 1997). The SFRI collates layers of information that relate to species distribution and abundance, as well as layers relating to the cultural and economic uses of the area in question. Data sets are manipulated and analyzed to evaluate distribution data at multiple scales (Ball et al, 1999; Lindenmayer et al, 2001a).

Canopy structure may be ascertained via aerial survey, specifically the extent of dead wood in the canopy. This information can be overlaid onto spatial arrangements of supporting forest structures (such as feed trees). The quality of aerial information requires testing. Aerial survey of sap trees of the Yellow-bellied glider (Petaurus australis) in north Queensland was not a reliable means of locating these trees (Bradford & Harrington, 1999).

2.1.6 Survey techniques

There are several techniques used to locate hollows from the ground. Some techniques use systems of tracking animals to locate hollows, while other methods allow the researcher to directly access the hollow.
Stagwatching techniques are employed to locate arboreal fauna after prospective hollows have been identified, or particularly after a likely hollow bearing tree has been visually identified (Lindenmayer *et al*, 1990, Lindenmayer & Cunningham, 1997). Thus stag watching can be a complement to other hollow location techniques. Specific methods are in place to minimize sources of observer bias, (Seebeck *et al*, 1983), (Smith *et al*, 1989). Spotlighting describes the use of portable lighting to illuminate a silhouetted animal in the tree canopy where researchers rely on specific eye shine colours and improved overall view, to identify species, (Henry, 1984; Kanowski *et al*, 2001a). Spotlighting is regularly employed in conjunction with stagwatching (Lindenmayer *et al*, 2001b, Moloney *et al*, 2002). Some vertebrates, e.g. Ringtail Possum (*Pseudocheirus. peregrinus*) are not obligate hollow users, and are unlikely to be found using this method (Lindenmayer *et al*, 1991). Therefore hollows used by these species are unlikely to be located using this method. The height of trees and density of understorey are important in stagwatching success (Davey, 1984) and, detectability is sensitive to weather conditions.

Call payback involves playing back the recorded vocalizations of target fauna or their predators (Milledge *et al*, 1991*)*. This technique has been used to identify presence or absence of arboreal fauna (Soderquist *et al*, 2002). Call playback is also an important technique for surveying forest owls (Debus, 1994), which have a primary relationship with hollow dependent fauna. In this respect, the technique can be an aid to search success in terms of hollow location, particularly in conjunction with active search techniques such as spotlighting.

Trapping and collaring are effective ground based methods for pinpointing the location of arboreal fauna, and the hollows they occupy. There is a large range of trapping techniques, which can be considered as captive and non-captive methods (Kehl & Borsboom, 1984; Henry & Craig, 1984). Most non-captive methods such as hairtubing and electronic detection provide information about the animal, which can be hard to relate to hollow location (Goldingay & Kavanagh, 1991). Mark-recapture surveys usually require captive methods such as elliot and pitfall trapping, providing an opportunity to track an animal to it's hollow after release. Success is more likely if radio-tracking equipment is utilized (Dickman, 1991, Richards, 1991. Fitzgerald *et al*, 2002).

Most detailed hollow measurements have resulted from inspection of hollows in fallen trees, the cavity being exposed with chainsaws (Gibbons *et al*, 2000, 2002). Assessment of felled trees is considered the most cost-efficient method of studying a large number of hollows (Gibbons & Lindenmayer, 2002). This methodology enabled Whitford (2001) to develop a graphical methodology relating hollow dimensions to occupation by fauna, in southwest

Western Australia. It is necessary for the researcher to liaise with forestry managers to co-ordinate the cavity inspection with a felling operation (Mackowski, 1984). The limitations of this technique are that non-silvicultural forest types are likely to be under-represented in survey data. In addition, there is considerable damage done to fragile hollows when the tree is actually felled.

Techniques that allow a researcher access to a prospective hollow, commonly utilize modern equipment and methods.
Ladders are commonly used to access hollows, roosts, and nest-boxes up to a height of approximately 14m (Calder *et al*, 1983). The height restriction involved with ladders may create a source of bias in research. Nest box research programs have involved placement of nest boxes, via ladder, at height of 5-10m (Ambrose, 1982, Moncrieff, 1985, Sharp & Goldingay, 1998, Ward, 2000). These authors did not evaluate hollows and nest boxes at increased height due to the limitations of the method.

Mechanized access systems are routinely utilized to access the tree canopy. Equipment such as elevated work platforms, cranes (Azarbayani *et al*, 1999; Richardson *et al*, 1999) and, floating gondolas are standard equipment used in arboriculture and research institutions where budget is available.
A rope access system is the commonly used term to describe a method of using climbing and caving equipment to access the upper parts of a tree. Specifically, the equipment used includes special purpose ropes and harness with additional rope grab and descending hardware. This system is the most widespread access option for tree canopy researchers (Henry, 1984; Inions et al, 1989, Taylor & Haseler, 1993, Harper, 2002), and government agencies (Aubry & Raley, 2002).

2.2 Tree hollow typology

As a construct, a tree hollow is subject to a wide range of interpretation within the literature. The variation in understandings, to some degree, reflects author-specific concern with particular taxa or methodology. Overall, hollow typology is designed in relation to the requirements of higher order vertebrate fauna (Gibbons *et al*, 2002). This is significantly related to the comparative ease of observing and researching larger and more visible fauna, and tree hollows. A fundamental issue within the literature appears to be the development of the contextual framework in which cavity-type features are recognized as being hollows (Gibbons & Lindenmayer, 2002). This recognition is the basis of observers agreeing upon what they are seeing, and a format for future researchers. The lack of a cohesive hollow typology increases the potential for contextual and perceptual error in the observer group (Harper, 2002). Perceptual error is defined by other authors (Marr, 1982), as an interrelation between cognitive understanding and actual environmental properties of vision such as shading, gradients, textures and, surface contours.

There has not been a systematic approach to tree hollow classification, in the order of a taxonomic method. However, many authors have outlined a

structured approach to describing tree hollows (Ambrose, 1983; Mackowski, 1984; Whitford, 2001).
The principal terms for describing tree hollows derive from synonyms for hole such as crevice, cavity, fissure and, hollow. There is also the potential for the tree hollow to be labeled in relation to its location in the tree (e.g. crown hollow, butt hollow); or in relation to the suspected cause of the hollow forming event (e.g. fire scar hollow, stress crack).

2.2.1 Hollow cavity definitions

Visual assessment of the hollow cavity beyond the hollow entrance is potentially a difficult exercise. In this respect, there is evidence to suggest that hollow development within species and forest types may follow similar development paths (Florence, 1996). In maturing eucalypts the cavities increasingly extend towards each other, ultimately forming a single hollow complex (Ambrose, 1982, Mackowski, 1984).

Hollows generally do not have an agreed minimum depth in the literature. Early studies suggested that 3 cm was an adequate guideline as to a functional, minimum hollow depth (Ambrose, 1982; Calder *et al*, 1983). Harper (2002) describes a functional hollow depth of 5 cm, and notes that the functionality is diminished as the hollow entrance size increases. Reduced hollow depth may limit the roosting and nesting opportunities for larger fauna. The systematic approach to hollow cavity definition as proposed by Whitford (2001), follows on the complex hollow measurements of Ambrose (1982) and Calder *et al* (1983). These authors have highlighted the requirement to think about, and measure, hollows three-dimensionally. Research by Ambrose (1982), Calder *et al* (1983*),* Mackowski (1984), and others, investigated internal hollow characteristics in detail, noting parameters related to planar orientation, cavity thermoregulation, drainage, and landscape orientation.

The relationship between cavity dimensions and hollow entrance measurements has been the subject of considerable research. A weak association between minimum entrance width and hollow depth has been noted (Gibbons *et al*, 2000), and a stronger association between hollow depth and paired entrance dimensions has been demonstrated (Whitford, 2001). However, there is no evidence for a correlation between entrance dimensions and internal cavity volume (Gibbons & Lindenmayer, 2002*)*. Hence, hollow entrance dimensions are only a guide to the fauna, which are able to fit within the minimum hollow dimension (Abbot & Whitford*,* 2002), and not an indication of the actual hollow volume or occupancy. Gibbons et al (2000) defined a hollow as having a minimum entrance width of 2 cm. However, Menkhorst (1984), Ward (2000) and others, have consistently noted fauna utilizing hollows with entrance widths less than 2 cm (e.g., *Acrobates pygmaeus, Antechinus stuartii*). Soderquist *et al* (2002) classified hollows by averaged entrance diameter, with categories for small (2-5 cm), medium (5-10 cm), large (10-20 cm) and very large (>20 cm).

Lindenmayer *et al* (1991) defined any opening in the trunk >4 cm in diameter as a hole, and a branch was considered to be a hollow if the opening was >4

cm in diameter. This author later revised this aspect of hollow classification (Lindenmayer et al, 2000) (Fig 5). Clearly, most cavity descriptions are actually, hollow entrance classifications, based upon vertebrate associations.

2.2.2 Hollow types

Hollow entrances are commonly stratified to reflect functional usage by animals of different sizes (Gibbons & Lindenmayer, 1997), based upon a loose agreement on hollow terms amongst authors (*Figs 2.4; 2.5*).

Typically, tree hollows may be stratified into trunk hollows, or branch hollows, based upon their location. Bole or butt hollows describe a type of trunk hollow occurring at the base of a tree (Ambrose, 1982). Crown hollows are those that occur in the broken upper portion of a tree trunk (Lindenmayer *et al*, 2000). Soderquist and Mac Nally, (2000) measured all hollows from the ground up, classifying them as canopy hollows if over 1.3m above the ground and, base hollows if lower than 1.3m.

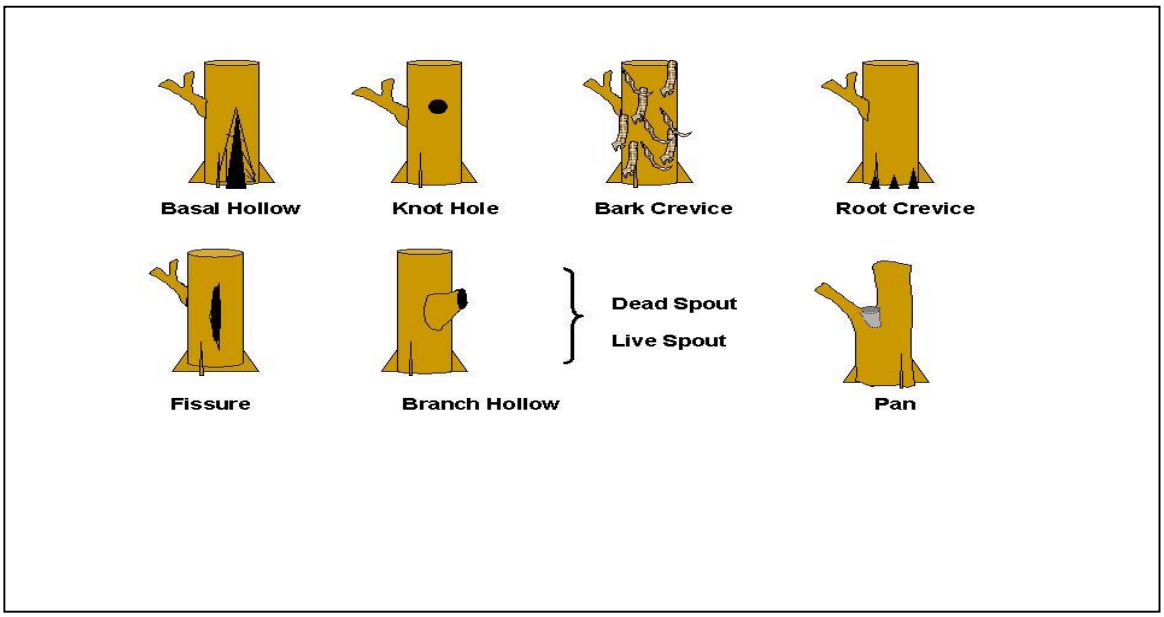


Figure 2.4, Cavity types
(Redrawn from Ambrose, 1982)

The importance of cracks and fissures as hollow types have only begun to be assessed (Lumsden *et al*, 1994). Lindenmayer *et al* (1991,p291) defined a fissure as “any narrow crack in the tree trunk >1.5 cm in diameter and >3 cm long”. Many hollows are shallow or blind. They may be a depression or pan that may hold water, and are potential habitat for amphibians or arthropods (How & Kitchener, 1983), or they may provide a protected drinking station for other arboreal fauna (Gibbons & Lindenmayer, 2002*).*

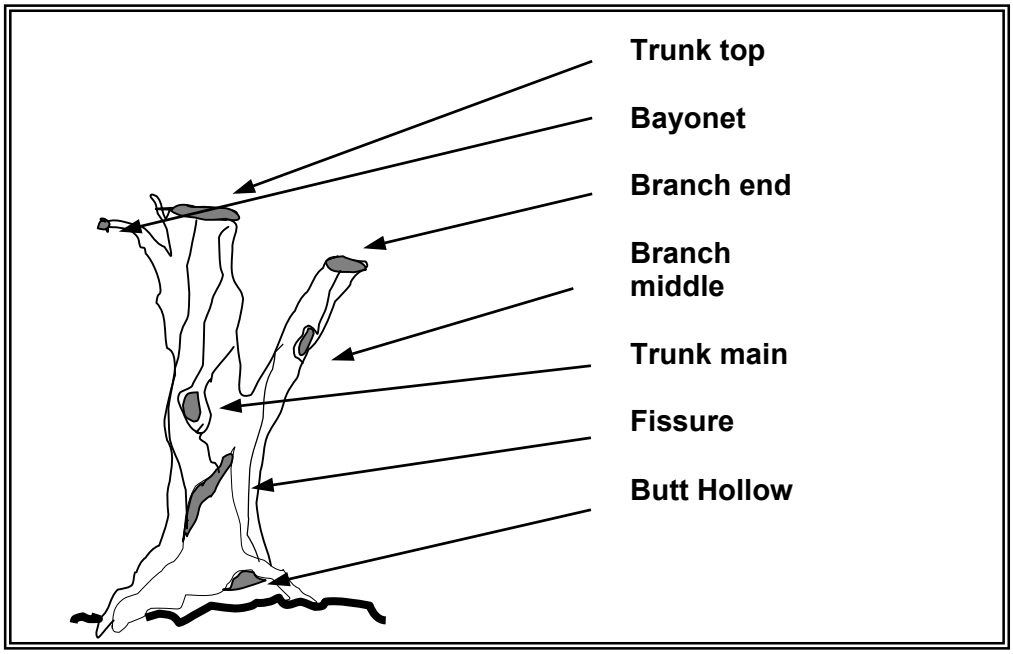


Figure 2.5, Cavity types
(Redrawn from Lindenmayer et al, 2000)

2.3 Tree Hollow Morphology

The formation of hollow cavities in trees is a part of the natural disturbance ecology of forests (Jacobs, 1955). Hollow formation can be considered as an essential stage in the dead wood cycle, hastening the structural breakdown of the stag tree into forest litter (Voller & Harrison, 1998). In terms of forest structure, hollow occurrence is mostly associated with large, old trees, which are past maturity and entering the senescing stage of growth (Scotts, 1991, Lindenmayer *et al*, 1993). The proportions of hollow types and sizes are known to alter as the tree ages, and there is evidence for an exponential decrease in hollow frequency with increasing hollow size (Abbot & Whitford, 2002). There are a considerable range of factors, which influence hollow development within a tree, and within the landscape. It is generally considered that within the life of a tree, a range of integrated factors that ultimately result in hollow development (Hobbs & Yates, 2000). Tree hollows may take several hundred years to form as the tree grows and decays into forest litter.

2.3.1 Tree structure and response

Lindenmayer *et al* (2000) noted specific relationships between hollow occurrence and forest structure, and this has been confirmed by other researchers (Calder *et al*, 1983; Lindenmayer *et al*, 1993; Gibbons & Lindenmayer, 1997; Wormington & Lamb, 1999; Gibbons *et al*, 2000, 2002, Fox *et al*, 2001). In this respect, evidence suggests that hollow occurrence is strongly correlated with tree characteristics such as the diameter, form, and height of trees (Lindenmayer *et al*, 1993, Gibbons *et al*, 2000*).*

The specific growth stage of individual trees is also related to hollow development (Mackowski, 1984; Gibbons *et al*, 2000). These authors noted that trees with the least growth defects had the lowest likelihood of containing hollows for all values of tree diameter, and that the most deliquesced tree forms had the highest probability of containing hollows. Collapse is a term used to describe a component of the deliquescence process by which a tree stem breaks in response to decay and environmental factors such as wind and fire (Lindenmayer *et al*, 1993). The collapse of hollow bearing trees is an ongoing process, with collapse mortality of between 3 –5 % per year recorded in Mountain Ash forest (Lindenmayer *et al*, 1997). Collapse mortality was not restricted to the most advanced individual tree forms; collapse was recorded across all tree forms.

Old growth trees are positively associated with hollow abundance, however senescing (advanced age) and stag trees had lower numbers of hollows overall. Hence, tree diameter is correlated with hollow abundance up to a point. The largest oldest hollow bearing trees have reduced numbers of hollows in the smaller entrance categories, and an increased proportion of large hollows. In a sample of live hollow bearing trees in East Gippsland, Gibbons *et al* (2000) recorded a mean diameter of 118 cm and a range of 30-308 cm while Calder *et al* (1983) noted hollows in trees with diameters of 20-30 cm within the Wombat forest.

Branch shedding describes the process of occlusion in which the limbs of trees are gradually shed and the resulting wound heals over (*Plate 2.1*). This process varies between tree species. In general; branches have a greater to tendency to be shed if they are large and old (Ambrose, 1982). Branches may be induced to fall or to be broken by a range of climatic and mechanical disturbances such as lightning strike or an adjacent tree fall. Lindenmayer *et al* (1993) note that Mountain ash (*E. regnans*) and Alpine ash (*E. delegatensis*) are self-thinning and self-pruning. The self-thinning mechanism is prevalent in *eucalypt* species (Marks *et al*, 1986); however variation in efficiency of the mechanism can cause variable success in the occlusion of branches (Gibbons & Lindenmayer, 2002). The formation of a brittle zone at the base of primary branches (Shigo, 1979), and on second and third order laterals was found to assist branch shedding in *E. regnans* and *E. sieberi* (Marks *et al*, 1986). These authors also noted the incidence of decay and other defects increased with the diameter of the occluded branch.



Plate 2.1, Branch occlusion process in Candlebark (E.rubida)

2.3.2 Species variation

Within the Australian landscape, Eucalyptus spp. predominates at the overstorey level in most forest types. Eucalypts have species-specific responses to infection, decay, fire, and infestation (Jacobs, 1955; Gill, 1974; Ambrose, 1982). Similar results have been recorded from non-eucalypt species in other countries (Hennon *et al*, 2002). Heartwood compounds were found to be correlated with resistance to decay.

Ryan and Yoder (1999) argue that tree growth and structural form are related to factors including, nutrient availability, maturation switches in the tree genetic profile and, hydraulic limitations to photosynthesis.
Ambrose (1982) suggests factors affecting hollow formation are growth habits of the host tree, resistance to injury and decay, tree spacing and climate. Other authors have noted that there are a considerable range of responses to disease, and disease susceptibility, amongst eucalyptus species (Potts & Pederick, 2000*).*

Wormington & lamb (1999) found that in a dry eucalypt forest in SE Queensland, hollows developed when the trees were approximately 100 years. These authors noted that species-specific growth rates create a mosaic of hollow formations across temporal scales. Calder *et al* (1983) argued that there was an increased occurrence of hollows in the smooth barked eucalypts (Symphomyrtus) relative to hollow occurrence in ‘barked’ species. Gibbons *et al* (2000) did not validate this across 1500 trees in East Gippsland. It takes

300 years for hollows to develop in jarrah, and 200 years in marri, in Western Australian forests, (Inions *et al*, 1989, Wardell-Nicholls & Johnson, 1991).

Wormington and Lamb (1999) noted interspecies variation in hollow numbers in Queensland trees, and related this to the growth rates of the particular species. Thus hollows had formed more readily in Blackbutt (*E. pilularis*) than in Tallowwood (*E. microcorys*) or Scribbly gum (*E. signata*). Hollows were found in over 50% of Blackbutt with diameter of 100 cm, and in over 50% of Tallowwood and Scribbly gum with a diameter of 80 cm. Lindenmayer *et al*, (1993) noted considerable interspecies variation in the numbers of holes, fissures, and hollow branches, reflecting differences in timber properties and rot susceptibility. It is important to note that senescent hollow bearing trees of all species are prone to complete collapse (Lindenmayer *et al*, 1997).

There is little available data on the development of tree hollows in non-eucalypt species, within Australia. Ambrose *(*1982*)* suggests that there is decreased probability of hollow development in non-eucalypt mid-storey trees such as Acacia spp, due to reduced trunk and branch volume, along with increased fire susceptibility. Hollows have been seen to occur in species such as Blackwood (*Acacia melanoxylon*) (Plate 5.4), Myrtle Beech (*Nothofagus cunninghamii*) and, Tree Ferns (*Dicksonia antarctica*) (pers.obs). Tropical forests have a wide range of non-eucalypt species that can potentially form tree hollows.

2.3.3 Mechanical excavation

External environmental forces have a significant role in hollow formation. Climate has a variable influence on a forest stand, depending upon geographical position, altitude, and site microclimate factors (Wardell-Johnson & Nichols, 1991*)*. The main climatic forces involved in tree decay are sun, rain and, wind. In combination with other environmental parameters such as geology and disease, they provide the ongoing daily and seasonal limitations to growth for each species, and within each forest type. The interrelated effects of climatic components on forest structure can best be seen when forest edges are created (Franklin & Forman, 1987). The exposure to isolated or fragmented forest stands may result in a range of responses termed dieback (Reid & Lansberg, 2000). This decline may result from physiological climatic stress such as drought (Old, 2000). Pathogenic disease may also cause hollow formation in individual trees or patch associated trees (Florence, 1996).

Variations in rainfall and solar radiation contribute to forest species and forest stand variation across the landscape. Individual trees are disposed to a growth pattern related to the bio-climatic envelope at that site (Lindenmayer *et al*, 1993). Latitude, slope and, stand age are also important in hollow development, again providing an interrelation effect upon the site microclimate. Mackowski (1984) also noted that drainage patterns within the

hollow were important as a mechanism of excavation and a precursor for fungal decay.

2.3.4 Fire

With specific reference to Australian forests, Eucalypt species evolved in association with fire regimes, creating a significant vector of hollow formation within the Australian environment (Gill, 1974; Wardell-Johnson & Nichols, 1991; Florence, 1996). The actual effect of a fire event on tree health is variable, the most common event being fire scar formation (Gill, 1974), particularly on the leeward side of the tree bole (dry side), (*Plate 2.2*). The most important aspect of this paper was the demonstration of fire effects around a tree bole and the variable response in fire behavior and wound formation. High intensity fires scorch and weaken crowns, cause malformations to the boles and dry sides, and deepen previous fire scars (Florence, 1996). Fire scar formation is considered a primary factor in the development of tree hollows, particularly in dry forests (Adkins, 2003). The scar site presents an opportunity for infection and further decay from insect attack. The scar site may also be successfully occluded and healed.

Fire has been shown to alter the forest structure within Mountain Ash forests (Lindenmayer *et al*, 1990) leading to an even arrangement of hollow bearing trees throughout the fire-affected area. Inions *et al* (1989) found that intense fire destroyed 38% of originally occurring possum den trees and that existing dead hollow bearing trees were the worst affected. High-intensity fire was found to be a primary excavator of new hollows reducing the mean tree age of hollow formation.

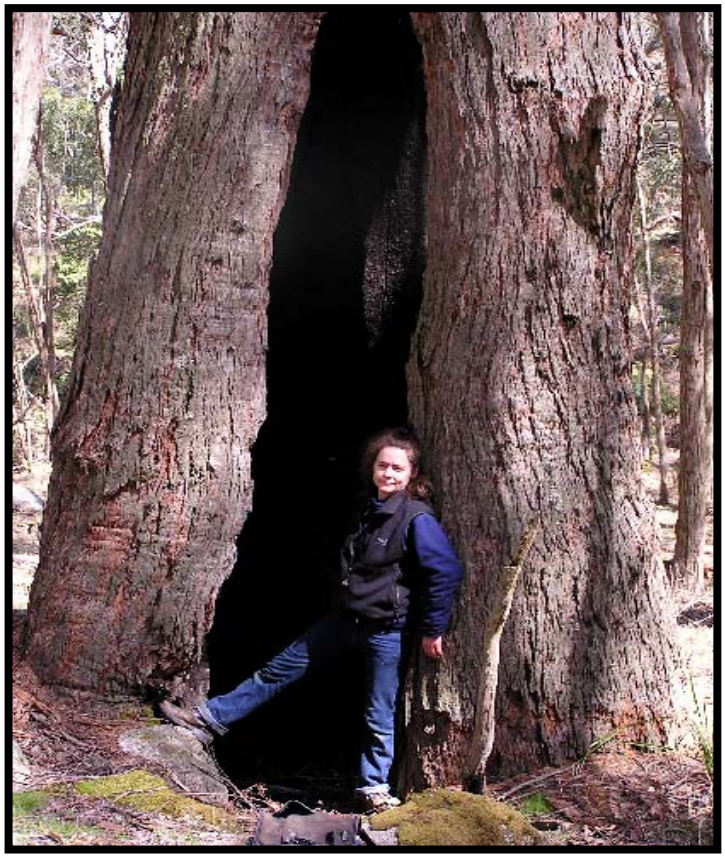


Plate 2.2, Fire scar in old growth messmate (E. obliqua)

2.3.5 Biotic excavation

There are several causal factors involved in tree decay, deliquescence and, collapse. Apart from mechanical disturbance, biological sources of hollow creation are a significant factor in the Australian environment.

2.3.6 Fungal decay

Fungal infection is a key process in hollow formation (Kile & Johnson, 2000). Infection may take place in *Eucalyptus spp.* when heartwood and sapwood are exposed (*Plate 2.3*). These authors note that over 75% of the eucalypt heart rot species are associated with white rot or white pocket rot. Species of "*Phellinus* and *Inonotus* are the most commonly implicated in Australia, and *Phellinus* and *Stereum* elsewhere" (p307). In 3 species of *eucalyptus* from southeast Queensland, Wormington and Lamb (1999) found that hollow development is primarily initiated by fungal infection entering through dead branches and branch stubs, rather than from fire scars. The fungal decay of the tree fiber (cellulose) is largely a combination of hydrolysis and oxidation, with the proportions of non-decay and decay fungi changing over time.

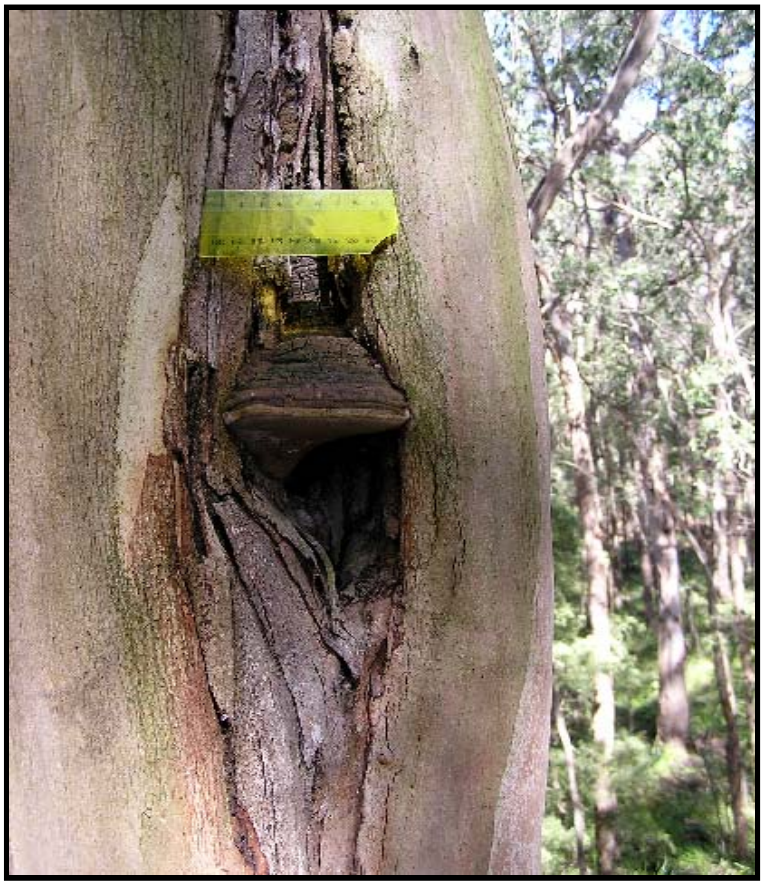


Plate 2.3, Fungal infection in Candlebark (E.rubida)

2.3.7 Invertebrate decay

There are several species of invertebrates that are involved in the hollow formation process within the Australian environment. Some invertebrates complete all or part of their life cycle within a living or dead tree (Creffield, 1996). These invertebrates advance hollow development in association with pathogenic fungi and other physiological stresses (Wormington, 1996). In effect, obligate tree dwelling invertebrates are hollow creators and hollow dwellers in the same manner as higher order arboreal fauna. Typically, they create their own micro-hollows throughout living and dead trees. The presence of termites is seen as a primary correlate of hollow development (Ambrose, 1982). Principal termites are *Coptotermes* and *Porotermes (Isoptera*). Theses species usually enter previous sapwood injuries and enlarge them. The combined actions of fungal attack and termite decay cause the heartwood to become soft and friable, increasing the likelihood of hollow formation.

In addition, chronic insect herbivory by sapsuckers and woodborers also affects hollow formation (Old, 2000). This may be further complicated by dysfunctional activity at the root-mycorrhiza complex (Richards, 1991), and through regional vertebrate associations, such as Bell-miner dieback (Stone, 1996).



Plate 2.4, Termite decay in Manna Gum (E.viminalis)

2.3.8 Vertebrate excavation

Australia does not have primary hollow excavators, such as the woodpecker (Aubrey & Raley, 2002). However, many higher order fauna are active in modifying hollow shape and size, and may indirectly advance hollow formation by a variety of mechanisms.

The Brush-tailed possum is known to chew at and enlarge hollow entrances (Menkhorst, 1984; Gibbons & Lindenmayer, 2002). Similar behaviour has been recorded amongst parrots and kingfishers (Ambrose, 1982).
In addition, insectivorous arboreal vertebrates are attracted to arthropod populations as a food source and may further excavate embryonic hollows or decorticate peeling bark. There is some evidence that the *Echidna (Tachyglossus aculeatus*) is also responsible for hollow excavation/utilisation in Australian forests (Wapstra and Thompson, 2000).
Vertebrate over-foraging has been cited as a potential hollow creation mechanism (Neyland, 1996; Stone, 1996*)* with effects related to dieback.

2.4 Tree hollow ecology

Hollows are recognized as being of specific importance as habitat to Australian native animals (Tyndale-Biscoe & Calaby, 1975). It is estimated that 304 species (15%) of all Australian vertebrates use tree hollows (Gibbons & Lindenmayer, 2002). It is likely that this is an underestimation, when consideration is given to amphibians, reptiles and invertebrates (Fitzgerald *et al*, 2002; Gibbons & Lindenmayer, 2002). It is difficult to assess the behavioral aspects of hollow using fauna due to issues of hollow detectability and accessibility (Menkhorst, 1984).

There is some evidence of resource partitioning of hollow bearing trees among arboreal marsupials (Lindenmayer *et al*, 1991), and that the hollow bearing tree resource may be shared with spatial or temporal partitioning of usage. There is a tendency for most arboreal and scansorial species to utilize multiple hollows within their home range (Henry & Craig, 1984). Kehl and Borsboom (1984) found evidence for preferential selection of tree species for denning and roosting by arboreal mammals. However, most arboreal species appear to select a variety of tree species for denning throughout their geographic range (Gibbons & Lindenmayer, 2002)

Hollow abundance alone is not the only factor responsible for maintaining arboreal species diversity and richness in eucalypt forests. The structural complexity and species richness of the mid-storey and understorey are known to be prime correlates of fauna abundance (Davey, 1984), and the spatial arrangement of hollow bearing trees ultimately has a bearing on occupancy (Saunders et al, 1982, Lindenmayer *et al*, 1990)

Not all hollow users are obligate. Some species are opportunists. Many opportunistic ground-dwelling mammals utilize hollows as a feeding resource, and as an occasional nesting site (Dickman, 1991). This author noted that tree species such as ribbon gum (*E. viminalis*) are favored by insectivorous, scansorial (climbing) mammals such as *Antechinus stuartii* and *Phascogale calura*. In Western Australia, Inions *et al* (1989) found there was no evidence that possums selected den trees on the basis of tree species.

Within Victoria, 23 species of bat are known to roost or forage in tree hollows (Lumsden *et al*, 1994), and 11% of Australia's land birds are obligate hollow-nesters (Scotts, 1991).

Many invertebrates undergo significant parts of their life cycles within a living or dead tree (Kitching *et al*, 1993). This creates an additional food resource for higher order species. Little information is available on the use of hollows by snakes, although preliminary research (Fitzgerald *et al*, 2002) found that the Stephens Banded snake (*Hoplocephalus stephensii*) used between 5 and 30 shelter trees within a significant area.

Lack of hollows was suggested as a limiting factor to distribution of some species within the Box-Ironbark region (Traill, 1991, Bennet *et al*, 1994), and these issues are also important in other parts of the country (Smith & Lees, 1998). Specifically, species high in the food chain such as the Powerful Owl (*Ninox strenua*) were found to be most at risk from habitat fragmentation and loss of hollow bearing trees within this region (Soderquist *et al*, 2002). This owl is rarely a hollow user, however, essential food resources are often hollow dependent.

Revegetation for habitat reconstruction, and species persistence in agricultural districts is often cited as the principal conservation imperative facing Australia (Reid & Landsberg, 2000). Management of the hollow resource for arboreal species is a significant environmental objective in Australian forests. There is an implied importance of tree hollows as a bio-diversity indicator for natural resource management (Smith & Lindenmayer, 1988, Ross, 1999).

There is evidence that large old trees and, hollow bearing trees are important surrogate measures for the densities of arboreal mammals and the predators that feed on them (Burgman & Lindenmayer 1998, Soderquist *et al*, 2002, Gibbons *et al*, 2002). However there is some concern over the accuracy of tree dating methodologies (Calver, 1997), and management interpretation of the results. This has led to disputes regarding the age of forest stands, and the rates of growth expected (Anderson, 2003).

The correlation of tree size and occupancy is not straightforward. Gibbons *et al* (2002) found that retention of large diameter hollow bearing trees will impact upon the availability of hollows with small entrance sizes, as small hollows were not associated with increasing tree size. It is apparent that clearfelling of Mountain Ash forests produced hollow bearing tree stands with a clustered spatial distribution (Lindenmayer *et al*, 1990), with a significantly lower probability of occupation by arboreal marsupials. In East Gippsland, 43% of all hollows had evidence of occupation (Gibbons *et al*, 2000), larger hollows having the greater likelihood of occupancy.

Higher order vertebrate fauna (i.e., *T. vulpecula*) can be considered as a surrogate measure of large hollow density at small spatial scales (Abbot & Whitford, 2002). There is evidence for the retention of dead stag trees as an immediate fauna resource (Moloney *et al*, 2002). The installation of nest boxes has occurred as an intermediary measure to provide a hollow resource where hollow bearing trees are scarce or absent *(*Ambrose, 1982; Calder *et al*, 1983; Menkhorst, 1984; Ward, 2000).

Hollows are a structural limitation to tree health, and may alter the overall tree form and structure (Shigo, 1979). In terms of forestry science, hollows are considered as a wood defect, by diminishing the quality or quantity of merchantable timber. Current defect mapping methodologies use tree profiling systems to record defects such as dry spikes, green limbs, stem openings, and swellings (DNRE, 1997). For this reason there has been a significant silvicultural selection process to reduce the numbers of structurally unsound

and, un-merchantable trees. This stand improvement process has reduced the number and spatial arrangement of hollow bearing trees throughout managed forests (Ambrose, 1982; Franklin & Forman, 1987; Gibbons & Lindenmayer, 1997). Current forestry practices have specific guidelines for retaining hollow bearing, or habitat trees, within the current silvicultural systems employed within general management zones (DNRE, 1996). It is necessary to consider the abundance and distribution of tree hollows at a range of spatial scales to include specific types of hollow formations across different species (Lindenmayer & Franklin, 2002)

The application of principles of bio-diversity conservation to plantation forests is a relatively new concept. Forest managers are considering mechanisms for retention of hollow bearing trees amongst plantation landscape mosaics and, within adjacent remnant vegetation (Lindenmayer *et al*, 2003).
There has been increased attention to the maintenance of permanent inventory plots throughout Australian production forests (Moloney *et al*, 2002). This will enable ongoing assessment of silvicultural practices in relation to forest ecology.

2.4.1 Tree hollow management within the Wombat forest

Timber production is cited as a major influence in the creation of Australian forest structures (Frawley, 1991). Historical patterns of timber production have been similar, starting in accessible areas and progressively moving into more difficult country. Frawley (1991) notes that timber production was significantly boosted during the gold rush era.

The Wombat forest has been utilized for timber extraction since 1850. Settlement, agriculture and the developing gold mining industry claimed a significant proportion of timber until the establishment of forest management in 1900 (Flett, 1979*)*. Extensive fires burnt through the forest in 1885 and 1886 destroying large numbers of trees. Agricultural clearing and firewood collection continued unabated throughout the early 20th century, despite the dwindling resource (W.F.S., 2003). In 1945, sawlog felling was re-commenced, peaking at 84 000 cubic meters in 1952. Forestry developed stand improvement measures began in 1955, ending in 1966. Throughout this period, defective and undesirable trees were systematically removed to improve regeneration potential of emerging seedlings (Calder et al, 1983). Establishment of clearfelling practices in the 1970's accompanied a more coordinated management of the resource, resulting in a mosaic of age classes of tall straight trees. By this stage the hollow resource had been largely removed from almost all areas under silvicultural regime (Anderson, 2003). Roadside remnant vegetation and a few spaced reserves are now considered to be the most significant stands of hollow bearing trees.

The protection of habitat is cited as a key issue, raised through the public consultation process of the West Victoria- regional forest agreement (WFIP,

2000). This panel noted that the lack of Old growth forest impacted upon the limited distribution of hollow- bearing trees. A general proposal to mange this issue was not resolved, in default, action statements were developed to manage threatening processes for a limited list of endangered species such as the Powerful Owl.
The selection process for retained habitat is predicated upon the need for suitable habitat for dispersal, relocation and, re-colonisation by fauna.
The Wombat forest has been designated as planning unit within the Midlands forest management area (D.N.R.E, 2002). The management prescriptions developed for this area have specific requirements for retaining habitat trees (maximum of 3 trees/ha) with a preference for the retention of gum species as habitat trees.

Landscape approaches to habitat retention involve complex interrelationships between habitat unit sizes, proximity to reserves and, the population integrity of species within the unit area. With specific relation to the Wombat forest, a wildlife habitat prescription has been developed (D.N.R.E, 2001). Specific indicator species have been nominated that encompass habitat requirements for most other species.

The Midlands - Forest Management Plan (DNRE, 1996) states that critical components of biodiversity conservation include;

a) **3.1** *Ecosystem Diversity*- Structural Diversity-" the presence of relatively large, dead, standing and fallen trees, which often contain hollows".

b) **3.2** *Management of Threatening processes*-Actions-"Develop a habitat tree prescription for state forest in the Midlands FMA, by June 1997 which considers, - requirements and sensitivity of hollow using wildlife, also – the particular need to protect veteran hollow bearing trees."

c) **9.1** *Research and Education*-Actions- " Improve knowledge about forest ecosystems and management activities, and their interaction".

d) **11.3** *Monitoring-Actions*-"Develop and progressively implement criteria and indicators for forest biodiversity"

A biodiversity assessment of Western Victoria has been undertaken as a part of the requirement for a comprehensive regional assessment (CRA) of biological diversity (DNRE, 2000) and in part fulfils national JANIS criteria for representative reserves. Notably, arboreal mammals were surveyed only as an adjunct to an intensive forest owl survey. Hence, the official census figures only recorded five arboreal species over the entire region. This result does not correspond with the stated arboreal mammal survey intensity of 902 visits (p15) over the period 1998 – 1999.

A review of other authors (Gibbons & Lindenmayer, 2002; Calder et al, 1983) and of SFRI data sets; indicated that 18 species of hollow dependent mammal and 34 species of hollow dependent bird were known from the Wombat forest (Table 2.1).

Table 2.1, Hollow using fauna of the Wombat forest

Common name	Species name
Mammals	
Greater Glider	*Petauroides volans*
Yellow Bellied Glider	*Petaurus australis*
Feathertail Glider	*Pygmaeus acrobates*
Sugar Glider	*Petaurus breviceps*
Ringtail Possum	*Pseudocheirus peregrinus*
Brushtail Possum	*Trichosurus vulpecula*
Mountain Brushtail Possum	*Trichosurus caninus*
Brown Antechinus	*Antechinus stuartii*
Dusky Antechinus	*Antechinus swainsonii*
Bush Rat	*Rattus fuscipes*
Brush tailed phascogale	*Phascogale tapoatafa*
White striped Freetail bat	*Tadarida australis*
Chocolate Wattled Bat	*Chalinolobus morio*
Goulds Long-eared Bat	*Nyctophilus gouldi*
Lesser Long-eared Bat	*Nyctophilus geofroyi*
Little Forest Bat	*Vespadelus vulturnus*
Goulds Wattle Bat	*Chalinolobus gouldii*
Fat-tailed Dunnart	*Sminthopsis crassicaudata*
Hollow Raiding Mammals	
Echidna	*Tachyglossus aculeatus*
Reptiles	
Jacky Lizard	*Amphibolurus muricatus*
Lace Monitor	*Varanus varius*
Carpet Python	*Morelia spilota*
Marbled Gecko	*Christinus marmoratus*
White's Skink	*Egernia whitii*
Goulds Goanna	*Varanus gouldii*

Table 2.1, Hollow using fauna of the Wombat forest (continued)

Birds	
Gang Gang Cockatoo	*Callocephalon fimbriatum*
Major Mitchell Cockatoo	*Cacatua leadbeateri*
Sulphur Crested Cockatoo	*Cacatua galerita*
Yellow tailed Black Cockatoo	*Calyptorynchus funereus*
Long billed Corella	*Cacatua tenuirostris*
Diamond Dove	*Geopelia cuneata*
Black Duck	*Anas superciliosa*
Pink-eared Duck	*Malancorynchus membranaceus*
Peregrine Falcon	*Falco peregrinus*
Sacred Kingfisher	*Todiramphus sanctus*
Laughing Kookaburra	*Dacleo novaeguineae*
Little Lorikeet	*Glossopsitta pusilla*
Musk Lorikeet	*Glossopsitta concinna*
Purple-crowned Lorikeet	*Glossopsitta porphyrocecephala*
Fairy Martin	*Hirundo ariel*
Tree Martin	*Cecropsis nigricans*
Spotted Owlet Nightjar	*Aegotheles cristatus*
Barking Owl	*Ninox connivens*
Barn Owl	*Tyto alba*
Southern Boobook Owl	*Ninox novaeseelandiae*
Masked Owl	*Tyto nvaehollandiae*
Powerful Owl	*Ninox strenua*
Buff Banded Rail	*Gallirallus philippensis*
Hooded Robin	*Melandodryas cucullata*
Scarlet Robin	*Petroica multicolor*
Crimson Rosella	*Platycercus elegans*
Eastern Rosella	*Platycercus eximius*
Grey Teal	*Anas gracilis*
Buff-rumped Thornbill	*Acanthiza reguloides*
Red browed Treecreeper	*Climacteris erythrops*
White browed Treecreeper	*Climacteris affinis*
Dusky Wood-swallow	*Artamus cyanopterus*
Masked Wood-swallow	*Artamus personatus*
Australian Kestrel	*Falco cenchroides*
Hollow Raiding Birds	
Grey Butcherbird	*Cracticus torquatus*
Grey Currawong	*Strepera versicolour*
Pied Currawong	*Strepera graculina*
Australian Raven	*Corvus coronoides*
Little Raven	*Corvus mellori*

(Source: Calder *et al*, 1983, Gibbons & Lindenmayer, 1997, 2002, Whitford, 2001, W.F.S., 2003)

3. METHODS

3.1 Study area

Field studies were undertaken within the Wombat state forest, in the Central Victorian Uplands bioregion. The boundaries of the study area are within the 1:25 000-map sheet of Bullarto 772332, (*Fig 3.1*).

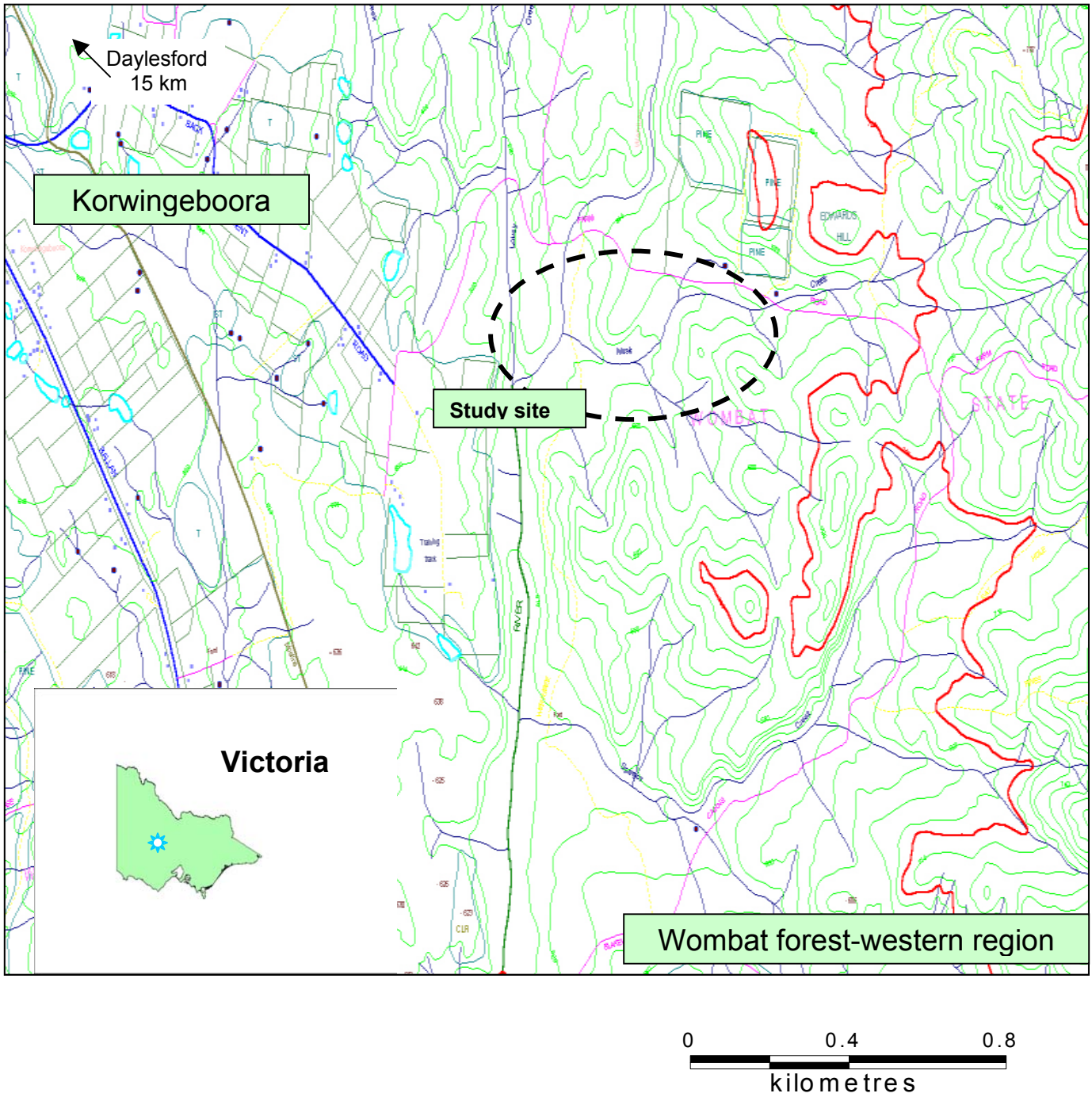
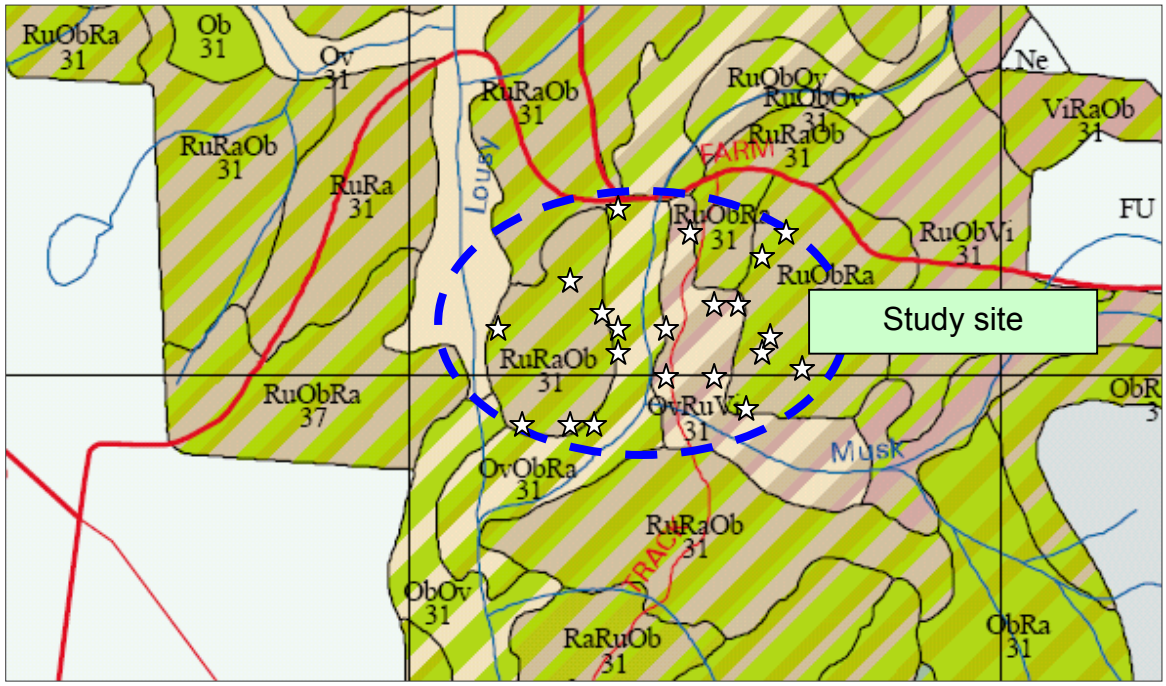


Figure 3.1, Study area location

Survey data was collected in mature forest of the headwaters of the Werribee River, 15 km SSW of Daylesford, Victoria.

The forest mosaic at the site consists of Dry foothill forest (EVC 29) dominating the ridges and midslopes; merging into a Damp/ Riparian forest complex (EVC 45/18). In terms of speciation, the Monocalypts *E. obliqua, E. radiata* and*, E. dives* dominate the dry forest canopy above a sparse mid-storey and groundcover. The Symphomurtus, *E. rubida, E. viminalis* and, *E. ovata* are more dominant in the Riparian/ Damp forest canopy over a complex understorey and *Acacia* dominated mid-storey.
The previous review of literature indicated that hollow bearing trees are more abundant in old forest, and the primary association for site selection was to locate the most mature forest stands. An evaluation was made of the data sets available within the Statewide Forest Resource Inventory (SFRI), available in GIS format. Data sets were located pertaining to eucalypt species present, crown cover projection, crown form class, and height class (Figure 3.2). These were packaged with additional supporting data layers in CD format for *Map Info*, called *Wombat Explorer* (DSE, 2003). The final site selection of Musk Creek was made on the basis of a location containing mature forest, within a cost-effective distance from the Ballarat research centre. In addition, a previous fire effects study had mapped some hollow bearing trees near this location (Tolhurst, 1992).



Key

Ra-*E.radiata* / Ob-*E.obliqua* / Di-*E.dives*
Ov-*E.ovata* / Ru-*E.rubida* / Vi-*E.viminalis*

☆ Survey trees

 # Note that colour hatching represents various logging histories

Figure 3.2 GIS Forest stand height and eucalypt species present
(Source: DSE, 2003.)

In order to maximise the variation in the parameters to be measured at the level of the hollow, the survey line traversed sections of forest with differentiated stand heights. The survey line traversed the two dominant forest types creating further variation in the obstruction value of associated vegetation.

This study focused on tree hollows within the Symphomurtus, specifically *E. rubida* or Candlebark. *E. rubida* is well represented throughout the Wombat forest and is considered a significant habitat tree (MacLean, 2003) and is therefore regularly retained in logging operations. This study excluded hollow formations within the Monocalyptus to reduce the potential for inter species bias, and t improve interpretation for the *E. rubida* sample set. *Eucalyptus rubida* has an increased range of tolerance to soil quality and water stress than its relative's *E. viminalis* and *E. ovata* (Tolhurst, 1992). Therefore, *E. rubida* could be sampled across a wide range in topography, and within different forest types.

The transect bound of 800m x 300m was extensively ground surveyed by two researchers. When increased search time did not locate further hollows, the initial ground survey was ended. All hollow bearing trees were marked and tree details recorded.

3.2 Climbing survey

The requirements for safe work at height were investigated and available techniques were examined (Appendix 1). All designated trees from the initial ground survey were climbed and assessed using Industrial Rope Access systems (AS4488). A work method was developed along with a job safety analysis to control risk during the climbing survey (Appendix 2). Hollows with a depth of less than 5cm, and with an entrance diameter of less than 1cm were excluded from this survey (Harper, 2001) on the basis that these hollows had reduced potential for utilization. All hollows were counted, mapped with GPS, and specific parameters measured (Table 3.1). Surveys were undertaken in fine weather during the months of September and October 2003.

Table 3.1,Tree and hollow parameters measured

Tree Measures	Measurement units	Reference
DBHOB	In cm	
Species	After Kostermans	Kostermans, 1967
Aspect	N,NE,NW,S,SE,SW,E,W	
Height	In metres	
Hollow Measures		
Aspect	As a compass bearing	Calder *et al*, 1983
Height	In metres	
Planar	In degrees	Ambrose, 1982
Potential field of view	In degrees	
Obstruct	Notional scale	
At 5m	scale 1 – 4	
At 10m	scale 1 – 4	Robel et al, 1969
At 20m	scale 1 – 4	
Entrance dimensions	In cm x cm	Whitford, 2001
Hollow surface area	In cm squared	Gibbons *et al*, 2002
Hollow type	Hole or fissure	Lindenmayer *et al,* 2000
Hollow position	Five location choices	Ambrose, 1982
Hollow occupied or maintained	Y/N	

Evidence of occupancy was also recorded for future research. Trees were classified to species level based upon fruit, and leaves.

Standard ground survey techniques for the detection of tree hollows are prone to several sources of bias. This project examined the relationship between detection success and four key parameters of hollow development, hollow height, hollow planar orientation, hollow obstruction and, paired entrance dimensions or hollow surface area.
The existing understandings for presence/ absence detection surveys, is that there are four possible variations in the response of an observer to the detection process (Wintle et al, 2003). In relation to tree hollow surveys, a true positive describes the situation where an observer has successfully detected a tree hollow that actually occurs. A false positive describes the situation where an observer has falsely detected a hollow that does not actually occur. A false negative is when the observer does not detect a hollow that actually occurs. A true negative is when the observer correctly concludes that there is no hollow where no hollow exists.

Detection success is defined here as the proportion of tree hollows correctly identified by the observer as a proportion of the true number of actual hollows in the survey set. Detection success should not be confused with observer overall count figures, which potentially include a component of false positive error.
Within the survey method developed for this project, it was possible to establish the total count of actual hollows that could be located by a ground observer. With this figure known, the quantity of false negatives could also be determined. It was apparent that a ground observer might return overall count

figures both lower and higher than the actual amount possible. The occurrence of higher than possible counts indicates that false positive survey error is a significant component of overall bias.

In order to estimate the false positive figure, the survey data entry system listed specific location and form data that were compiled by individual ground observers. This information was crosschecked, on a hollow-by-hollow basis, against the form and location data of the climbing survey.

3.2.1 Hollow height

The distance between an observer and a specific hollow has been shown to be a significant factor in the determination of detection success (Harper, 2001). All hollows located during the climbing survey were measured for height. This measurement was completed at the hollow using a 30m tape measure.

3.2.2 Hollow planar orientation

The angle of presentation of the hollow entrance has been discussed within the literature (Ambrose, 1982) as a likely source of bias in hollow detection. The planar orientation describes the angle of projection of the hollow entrance independently of the hollow aspect or compass bearing. This orientation describes whether the hollow is facing upwards or downwards and to what degree. Measurement was undertaken at the hollow using a hand held clinometer. The clinometer was held against an imagined flat surface which best typified the hollow orientation. The divergence was noted in degrees.

3.2.3 Hollow Obstruction Index

Unimpaired visual access is central to success in locating tree hollows within a given search environment. Dependent upon forest type and mid-storey density, there is the potential for adjacent vegetation to obscure the hollow from detection. This study considered that the degree of obstruction was measurable in a standard method that would allow comparison between forest types. The method examined the spatial arrangement of associated vegetation, to see how this affected hollow detection success.

In the three dimensional space of the forest, tree hollows have a volume and a location which are not readily observable. It is assumed here, that the chance of detection success is a function of the planar orientation of the hollow entrance in relation to the viewing spectrum of the observer, (Fig 3.3). In this diagram, Hollows A and B are typical trunk hollows and are readily visible. It is evident that some hollows will not be detected regardless of the orientation of the ground observer around the tree (Fig 3.3 – hollow C).

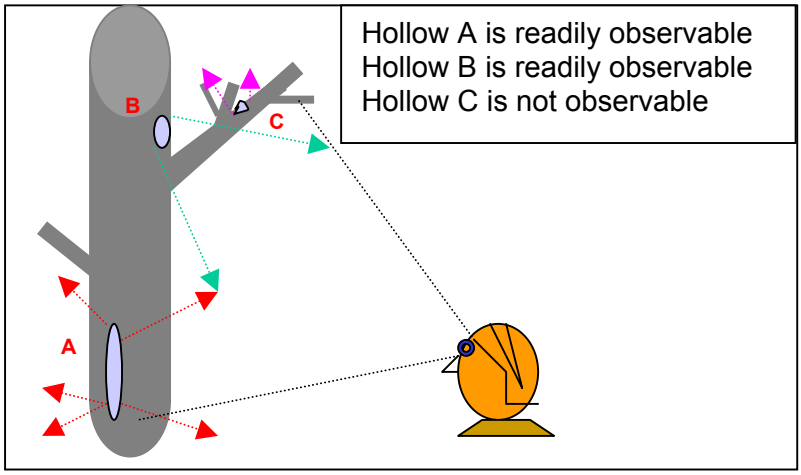


Figure 3.3, Relationship between hollow planar aspect and observer viewing spectrum

In fig 3.3, it is evident that tree hollows open towards a particular aspect, or **field of view**; and that the initial layer of obstruction is where the hollow bearing tree itself obscures the hollow from view. By extension, this **potential field of view** can be described two dimensionally, as an arc of a potential viewing field for an observer, at eye level, (Fig 3.4).

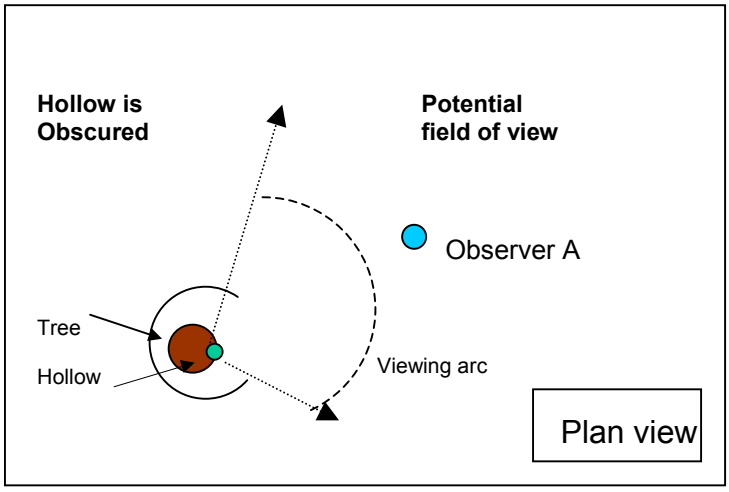


Figure 3.4, Tree hollows; the potential field of view

These examples are based upon the field of view of an observer at ground level. There are available methods (eg climbing) to present different fields of view, and changes in topography (i.e. steep slopes) will present progressive fields of view as the observer approaches the hollow.

Additional vegetative screening of sections of this field may further obscure the potential field of view. In a forest environment, this screening effect will vary in relation to the position of the observer within the potential field of view.

For example, a leaf assemblage may obscure the hollow from detection at 5 metres, but not at 10 metres (Fig 3.5).

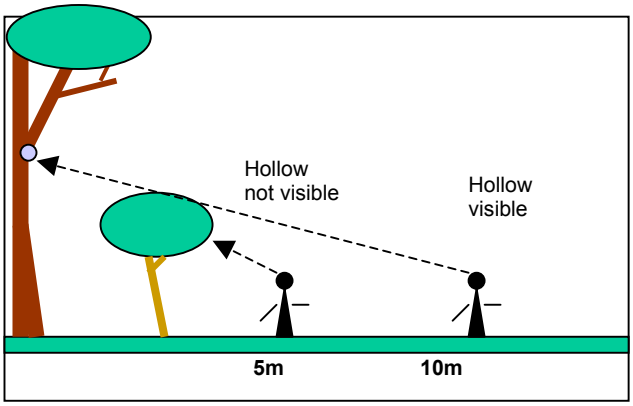


Figure 3.5, Vegetative screening varies with distance

The effect of adjacent tree trunks is to obstruct a small segment of the view over an extended distance. A forest of trees will compound this effect at distance increases.
In result an **actual field of view** can be envisaged for a particular hollow that is complex in its variation over distance. The visual acuity of the observer is an obvious limitation in preventing the observation of all sizes of hollow over long distances. It was observed that a search - circle around a nominated tree was in general, around 20-40m in diameter. This describes the area traversed by ground surveyors as they search a specific tree.
It is possible to measure the potential field of view, which is a fixed arc regardless of the observer position on flat ground. To sample the degree of obstruction within the potential field of view, systems was devised to section up the field of view, and record the degree of obstruction at stations on each section (Fig 3.6).

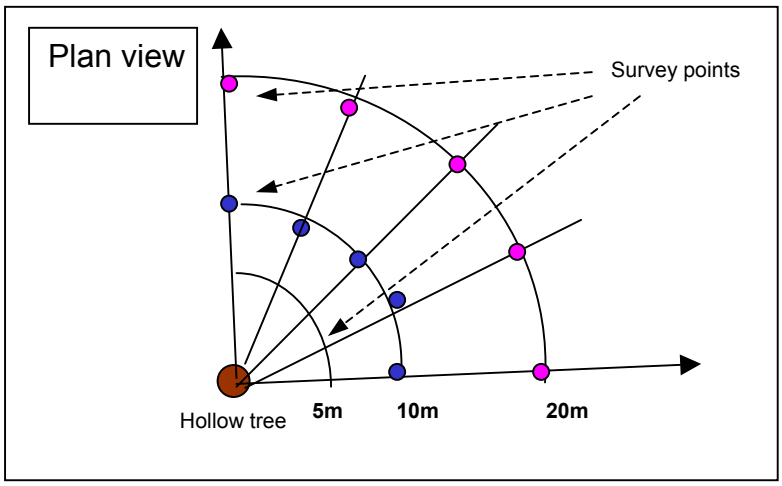


Figure 3.6, Sampling the degree of obstruction

For any designated field of view, the arc is sectioned by dividing the arc in half, and halving the halves. This will always create four segments regardless of the initial arc angle. This also creates five ray arms dividing the segments.

The procedure involves fixing the centre of a string line to the tree trunk, directly under the hollow being measured (at a height of 1.3m). The outliers of the potential field of view are fixed by eye and the string line ends are tied along the line of the outliers. In result, the string line projects from the tree trunk, producing an arc angle, which can be measured with a protractor describing the overall potential field of view.

A viewing station is nominated at a fixed point along each ray arm. At each location, the degree of obstruction is noted as one of the following classes;

Class 1 Hollow is not obscured by vegetation (100% visible)
Class 2 Hollow is partially obscured – (50 -100% visible)
Class 3 Hollow is mostly obscured – (0 – 50% visible)
Class 4 Hollow is totally obscured – (0% visible)

The four variable classes are given a weighted value (i.e. Class 1 = 1, Class 4 = 4) such that the five station entries could total between 5 and 20. That is 5 for a viewing arc that is unobstructed, and 20 for a viewing arc that is fully obstructed.
With this method it is possible to describe the average obstruction factor as a percentage at each distance. That is, data collected across the five viewing stations at the 5m distance is totalled and divided by the sample size to give the mean level of obstruction. The same process can then occur at other distance designations.
For this study, viewing stations were initiated within the PFV arc at 5m, 10m and 20m distance from the tree trunk. This creates sets of figures, which allow an assessment of the change in obscuration over distance. A final pooled figure can be calculated which describes the mean level of obstruction for a hollow across 15 survey stations at 3 distance designations.

3.2.4 Paired entrance dimensions- surface area

Previous research has demonstrated the value in stratifying hollow entrance sizes into entrance classes, based upon the likelihood that particular sizes of animal will utilise those entrance classes (Gibbons & Lindenmayer, 1997). Paired entrance dimensions (Whitford, 2001) were converted into a hollow entrance surface area. This surface area describes the extent of the hollow opening, and relates to the total hollow area available to be viewed by an observer.

3.3 Ground survey

3.3.1 Observer set

The eight participants in the ground survey were self-selected, having responded to a tree survey flyer. The 4 females and 5 males were assessed

on the basis of experience and qualifications and assigned an observer experience ranking between 1 and 9.
Participants were given a 15-minute induction into the project, outlining the project aims and objectives. Hollow examples were viewed and related to the data entry sheets provided for the survey.
Data entry sheets were designed to record information in relation to hollow form, location and, orientation.
Observers were required to complete data entry prompts in relation to hollows that had been located.
This information provided the comparison data set for the climbing survey information

3.3.2 Tool kit

Ground observers were given a 15-minute induction to the project based upon a pre-designed key, which explained the data entry process for the observer.
The observer group were equipped with the following;

a) Observer data entry sheet (Appendix 3)
b) Binoculars (10 x 25) to reduce observer error due to distance
c) A 2m measuring pole. Observers used the pole to estimate the height of individual hollows.

3.3.3 Data Analysis

Preliminary co linearity between variables was initially assessed using correlation analysis.
Evaluation of significant differences in-group means was undertaken using the student's T- test.
Further analysis of variable interactions in relation to detection success were examined using ANOVA
Variable relationships were examined using the SPSS statistical software package. This enabled an assessment of the main and interaction effects between the measured hollow variables and the levels of detection success recorded.

4. RESULTS

4.1 Climbing survey of hollow bearing trees

4.1.1 The hollow set

In total, 49 tree hollows were examined and selected parameters were measured and recorded.

Table 4.1, Pairwise attributes for tree size and hollow distribution

	Hollow location					
DBHOB	Trunk base	Trunk mid	Trunk top	Branch end	Branch mid	Total
40 –60 cm	0	11	2	0	0	**13**
60 –80 cm	0	2	3	0	0	**5**
80 – 100 cm	6	5	4	5	2	**22**
100 - 120 cm	1	3	1	1	1	**7**
120 cm +	0	0	0	2	0	**2**
Total	**7**	**21**	**10**	**8**	**3**	

Within this survey, hollows were more commonly found in the mid trunk region. Overall, trunk hollows comprised 78% of all hollows located. Most hollows were found in trees with a diameter of 80 – 100 cm. These figures cannot be interpolated across the survey area, or elsewhere, due to the low number of sampled trees overall (n=17).
Paired entrance dimensions were converted into a hollow entrance surface area. This surface area describes the extent of the hollow opening, and relates to the total hollow area available to be viewed by an observer.

Table 4.2, Pairwise attributes for hollow distribution and hollow surface area

Surface area	Trunk base	Trunk mid	Trunk top	Branch end	Branch mid	Total
0 – 9 cm2	0	0	2	0	0	**2**
10 – 99 cm2	3	8	4	6	2	**23**
100 – 999 cm2	3	10	4	1	1	**19**
Over 1 m2	1	3	0	1	0	**5**
Total	**7**	**21**	**10**	**8**	**3**	

47% of all hollows had a surface area of less than 100 cm2. This is equivalent to ranges of paired entrance dimensions within a limit of 10 x 10 cm. 39% of all hollows had a surface area of between 100 cm2 and 1000 cm2. This equates to paired entrance dimensions up to 33 cm x 33 cm.

The opening aspects of the tree hollow set did not indicate any particular trend towards specific compass bearings. That is, hollows were located opening towards all compass bearings except southeast. In total, 11 hollows

or 29% of the total were found to be occupied, and another 14 showed evidence of occupation such as nesting material and hollow maintenance.
Of the 14 occupied hollows, 13 were nest/den sites for arboreal marsupials, and Kookaburras occupied one hollow.

4.1.2 Hollow variables

a) Hollow height
The height of surveyed hollows ranged between 0 and 25 m with a mean hollow height of 12m ± 6.6m; (mean ±SE).

b) Hollow planar orientation
Planar orientation ranged between –25 and 85 degrees with a mean orientation of +15 degrees ± 24 degrees. A hollow with a negative orientation can be described as pointing downwards. The average orientation was +15 degrees, indicating that most hollows have a component of upward inclination in their form.

c) Hollow obstruction
Hollow obstruction was measured at radial arcs of 5, 10 and 20m from the outer bark. At each arc 5 survey stations were located, and obstruction measurements taken. The pooled mean obstruction was 2.4 ± 1.0.
Comparison of obstruction data between the 5m, 10m and, 20m stations indicated that obstruction increased significantly as distance from the tree increased. The average obstruction at 20m was significantly higher than at 10m and 5m (One way ANOVA, F=3.27,df=48, p=. 006); and the difference between obstruction at 10m and 5m was also significant (One-way ANOVA, F=7.07, df=48, p= .000).
Figure 4.1 affords a perspective of variation in obstruction over distance that illustrates the gradual increase in obstruction over that distance.

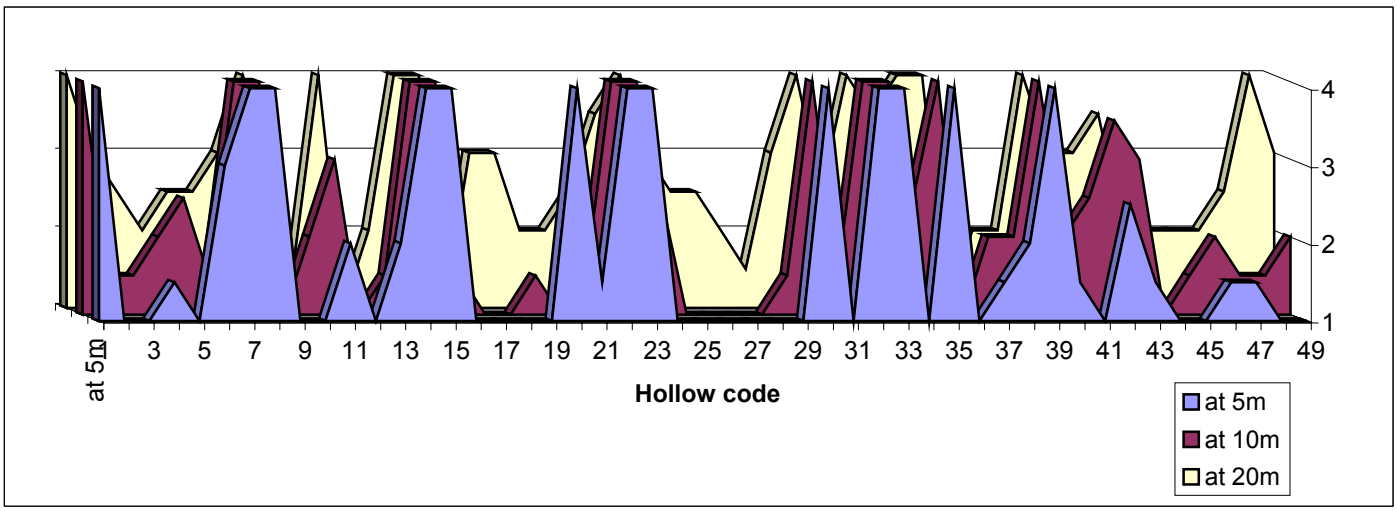


Figure 4.1, The distribution of obstruction scores at 5m, 10m and, 20m

d) Surface area

The paired entrance dimensions of the hollow set ranged from 5cm2 up to 3600cm2. The mean hollow surface area was 354cm2 -+ 762cm.

e) Hollow variable inter-relationships

A correlation matrix of all hollow variables indicated that the value of some parameters varied in relation to changes in other hollow variables. Planar orientation was significantly correlated with obstruction (r = .601), and with hollow height (r = .528), but not with surface area (r = -.257). Obstruction data was also significantly correlated with hollow height (r = .538), but not with surface area (r = -.216). All correlations are significant at the .01 level.

There is significant co linearity between hollow height, obstruction and, planar orientation, and a more variable relationship with hollow surface area. The direction of correlation indicates that increases in the value of one variable, will be accompanied by increases in the value of related variables, however the nature of the interaction is unclear.

4.2 Ground survey of hollow bearing trees

4.2.1 Detection success

Initially, it is important to distinguish between the overall counts obtained by individual observers and, the true count obtained via the climbing method. The proportion of hollows successfully identified in relation to the true count, constitutes detection success. The ground observer group detected on average, 31(63%) of the 49 hollows present to be detected. Detection success ranged from 47% to 71% ± 9%. (Figure 4.2).

The overall count of hollows ranged from 25 to 63, with a mean figure of 42 ±12. The overall count was on average 128 % of the true count, ± 17 %.

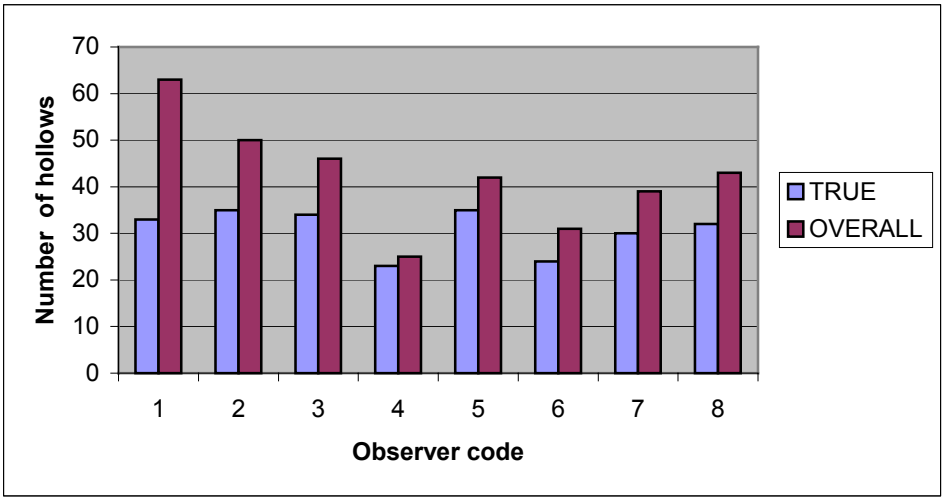


Figure 4.2, Differentiating overall count from the true count

4.2.2 Observer experience

There was a significant correlation between observer experience and detection success, indicating that experienced observers had an improved ability to detect hollows in relation to inexperienced observers (Fig 4.3).

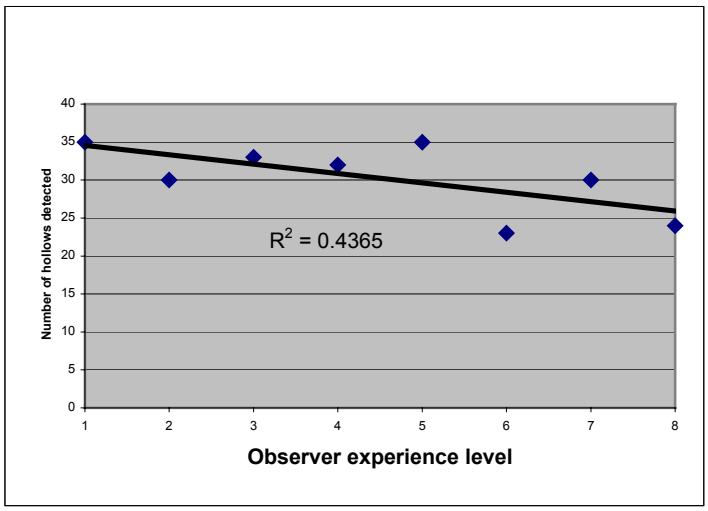


Figure 4.3, The relationship between detection success and observer experience

4.2.3 False negative survey bias

The false negative component of the survey result is the quantity of hollows that exist, but were not located by the observer set. The false negative component is a dependent source of bias, it's value predicated upon knowledge of the true total. Hence, there is a limit to the total false negative error in its relation to the true total.

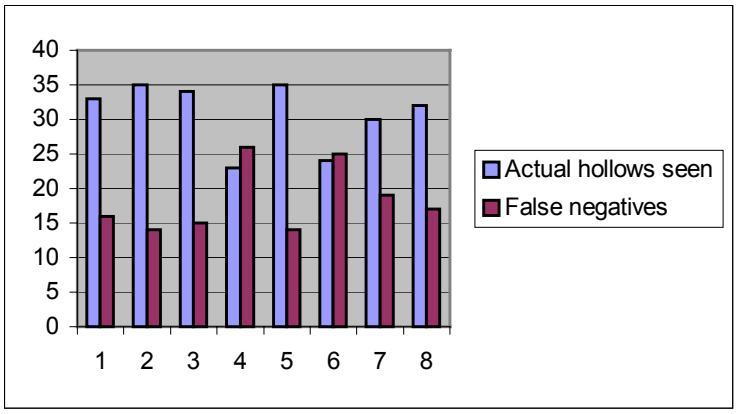


Figure 4.4, The relationship between actual hollows seen and actual hollows not seen

Figure 4.4 demonstrates the two components of an overall actual total. These are component a- the number of actual hollows seen plus component b- the number of actual hollows not seen. Within this survey method, the total quantity of actual hollows occurring in the survey set was known. Under normal survey conditions, only the final observed total is known. The relationship between these two final figures is illustrated in Table 4.3

Table 4.3, False negative error in relation to observer count and true total

Observer	False negative error as a % of detection success	False negative error as a % of the observed total
1	49	33
2	40	29
3	44	31
4	113	53
5	40	29
6	104	51
7	63	39
8	53	35
Mean	**64%**	**38%**

The false negative error can be expressed as a proportion of the true count of hollows that occur in the survey set, or as a proportion of the total number of hollows observed. This ratio describes the number of hollows that exist but were not seen by the observer, in relation to the number of actual hollows seen. Thus, for every 5 actual hollows seen, 3 hollows were missed.

The mean false negative error rate averaged 64% of the true total detected, and 38% of the observed total. Two observers (#4 and #6) achieved error rates in excess of their detection success scores. As outliers in the data set, these two scores pulled the average false negative error rate from 48% up to 64%. In relation to the observed total, the false negative error rate averaged only 38%. This reduced error ratio reflects that observers located and recorded more hollows than actually existed. The effect is to dilute the false negative error. The appearance is of a decreased level of error, but a more thorough analysis indicates that the overall error is actually increased due to the effect of false positive bias.

4.2.4 False positive survey bias

The false positive component of the survey result is the quantity of hollows that were recorded as present, but were found not to occur / exist in the course of the climbing survey (*Fig 4.5*). The false positive component of bias is independent of the true total and the false negative component. There is no maximum value that can be achieved.

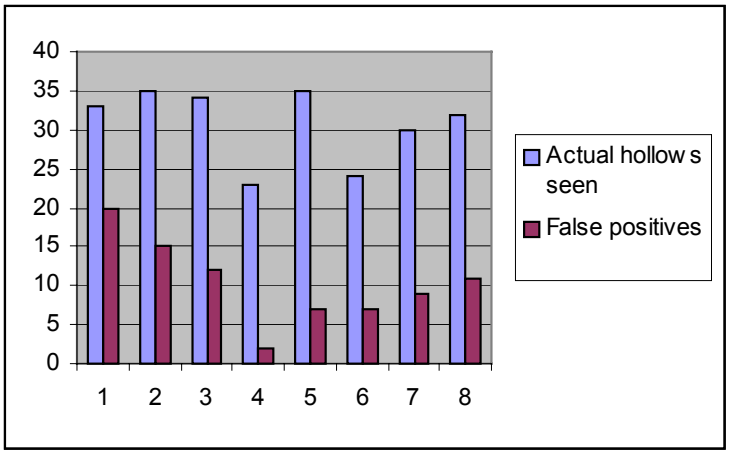


Figure 4.5, The relationship between actual hollows seen and non-hollows seen (false positives)

False positive error ranged from 9% to 61% as a proportion of the true count with a mean score of 33% (Table 4.4). Hence, false positive error occurred at a ratio of 1/3. That is, for every 3 actual hollows accurately located, an additional false hollow was found.
In relation to the observed total, the false positive error averaged 21%. This indicates that 1 false hollow was found for every 5 observed hollows.

Table 4.4, False positive error in relation to observer count and true total

Observer	False positive error as a % of detection success	False positive error as a % of the observed total
1	61	41
2	43	31
3	35	25
4	9	4
5	20	14
6	29	14
7	30	18
8	34	22
Mean	**33%**	**21%**

4.3 The relationships between detection success, survey bias and, hollow variables

The levels of detection success recorded were compared with variation in the values of the parameters a) Hollow height, b) Hollow planar orientation, c) Hollow obstruction and d) Hollow surface area. Initial correlation analysis indicated a significant negative relationship between detection success and hollow height, planar orientation and, obstruction. These relationships were examined further to assess the contribution of variables and variable combinations to changes in detection success.

4.3.1 Hollow height

Hollow height was significantly correlated with detection success (r = -.642). The negative basis of the relationship indicates that increased hollow height will be associated with reduced detection success (Fig 4.6). The sub-set of hollows that were not detected at all (n=5), were amongst the highest hollows surveyed, averaging 20 metres in height. Hollows that were always detected (n=11) were grouped around a significantly lower average height of 8m. Hollows that were detected frequently (over 50% of the time) were significantly lower than hollows that were detected infrequently (less than 50% of the time), (t=3.62, df=15,p=. 003). N equals 33 hollows and 16 hollows respectively.

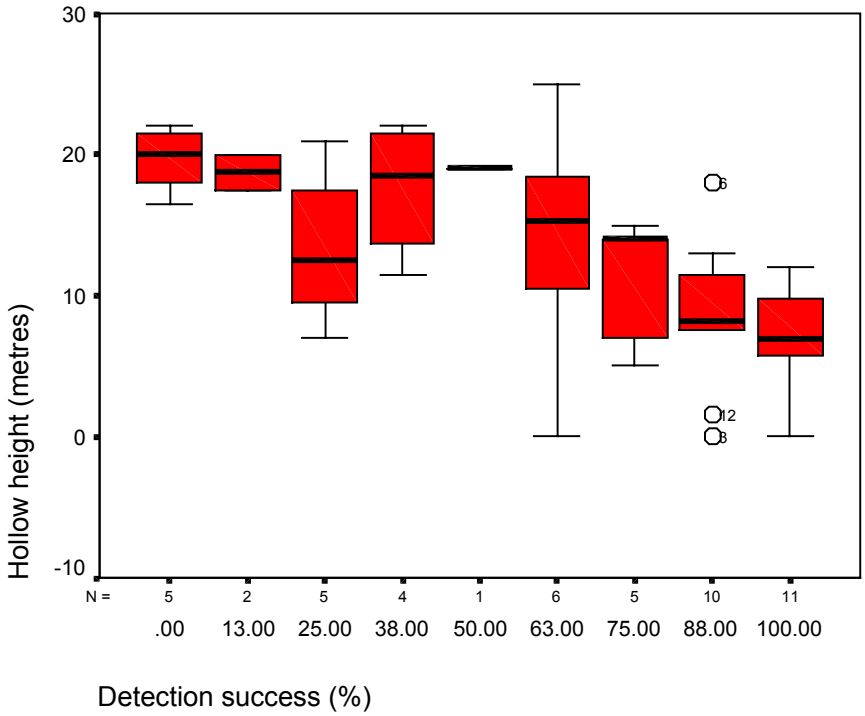


Figure 4.6, The relationship between detection success and hollow height

4.3.2 Hollow Planar Orientation

Hollow planar orientation was significantly correlated with detection success (r = -.641). The negative basis of the relationship indicates that increased planar orientation is associated with reduced detection success (Fig 4.7).

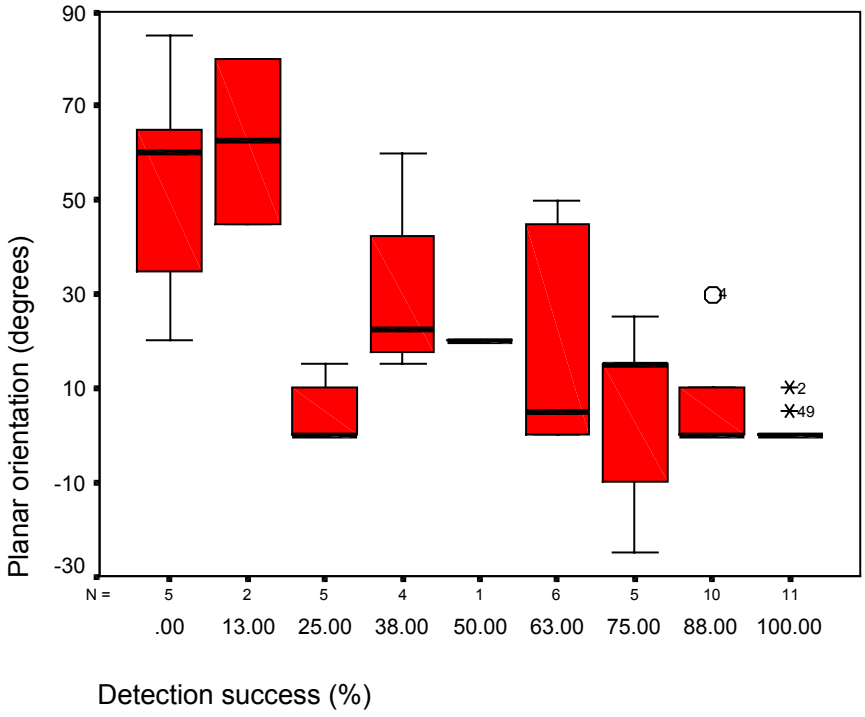


Figure 4.7, The relationship between detection success and planar orientation

Hollows that were frequently detected (n=33) had a significantly lower mean planar angle, averaging 8 degrees; compared to hollows that were infrequently detected (n= 16) which averaged 33 degrees (t=3.309, df= 15, p= .005).

4.3.3 Hollow obstruction

Pooled hollow obstruction is also significantly correlated with detection success (r = -.678). Again, the negative basis of the relationship indicates that increased obstruction scores (Fig 4.8) are associated with reduced detection success.

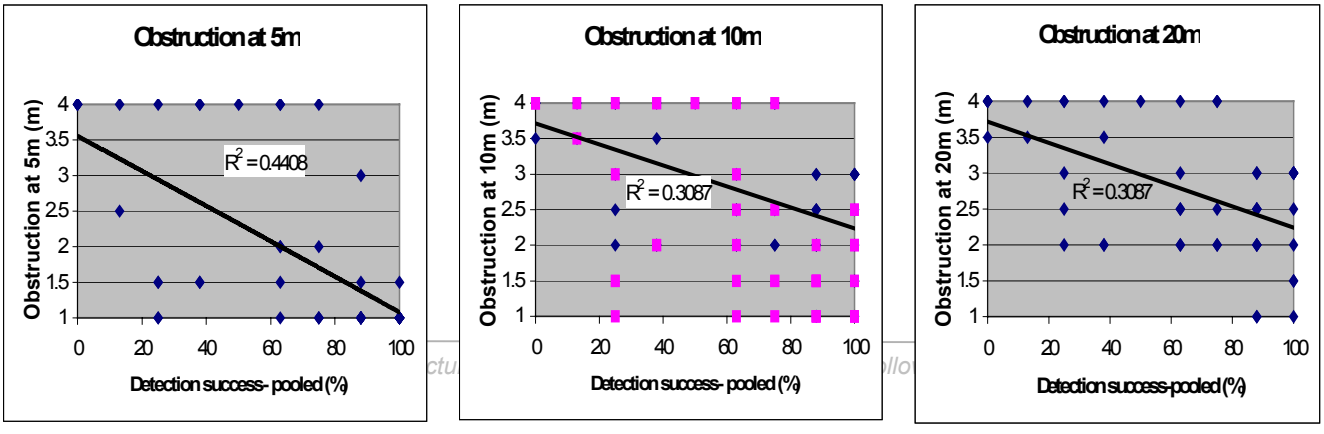


Figure 4.8, The relationship between detection success and obstruction over distance

Hollows that were frequently detected had a significantly lower level of recorded obstruction (average = 2), compared with hollows that were infrequently detected (average = 3), (t= 3.782, df= 15, p= .002) (Fig 4.9).

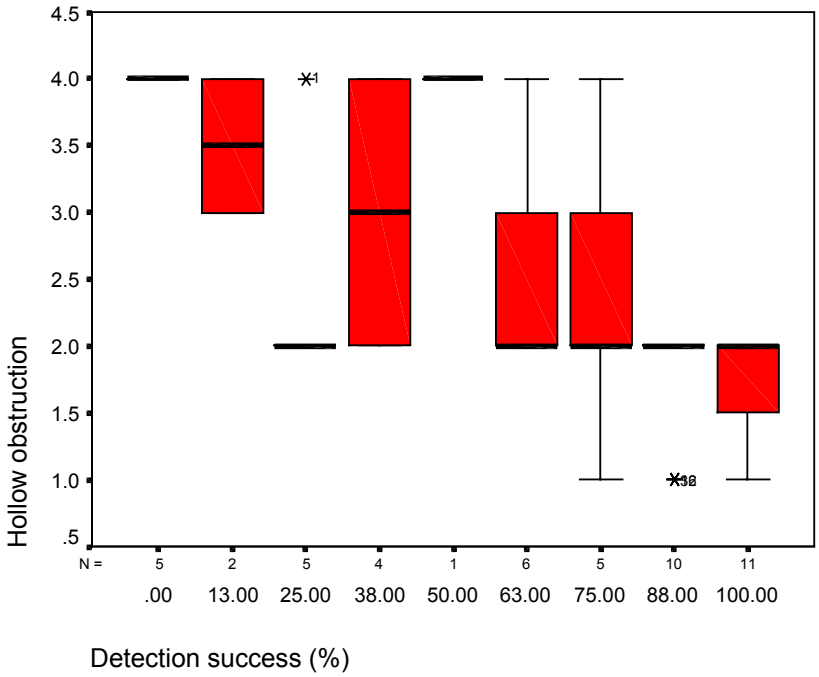


Figure 4.9, The relationship between detection success and pooled obstruction

4.3.4 Hollow entrance dimensions (Surface area)

Paired entrance dimensions were converted into a hollow entrance surface area. Surface area data was not significantly correlated with detection success at the 95% level of confidence. There was no significant difference between the surface area of frequently detected hollows and infrequently detected hollows. (t= .810, df = 15, p= .431).

With respect of the hypotheses postulated at project inception, the results indicate that the null model be rejected for the first four stated hypotheses. That is, there is a significant difference between the results of tree hollow surveys undertaken using tree climbing and ground survey methods. The experience of observers significantly affects the survey results recorded. The height, planar orientation and, obstruction of a tree hollow significantly affect the likelihood of detection success.
The final null model was accepted, that tree hollow entrance size does not affect detection success.

5. DISCUSSION

5.1 Hollow variables and detection success

Ground surveys of tree hollows are subject to variation in the detection success achieved (Harper, 2002). This variation in detection success is significantly correlated with the height, planar orientation and, associated vegetative obstruction, of the particular hollow under study. Although it might be expected that hollows with large entrances are more easily detected, this study did not support that assumption. Hollows of all entrance sizes regularly escaped detection. Variation in detection success was significantly related to three of the four hollow measures assessed. Analysis of measured hollow parameters showed a range of associations between the variables height, planar orientation, obstruction, and detection success. The paired entrance dimensions, expressed as a hollow surface area, did not indicate a significant correlation with other hollow variables, or with detection success.

Previous research (Harper, 2002) established that the distance between an observer and a tree hollow was an important factor in detection success. This argument was tested in this study, analysing the variable, hollow height, and a significant relationship with detection success was confirmed. Hollows in the highest part of a tree are more likely to escape detection. This study found that hollows close to the ground also escape detection, indicating that other factors play a role in detection success. The observer group utilized binoculars and various ground observers detected some of the highest of hollows. This suggests that hollow height, or distance from observer, is important but not the critical determinant in detection success.

Analysis of planar orientation data indicated that most hollows have a positive planar orientation, and that positive planar orientation is significantly associated with reduced detection success. Tree hollows with the highest angles of orientation are least likely to be detected, however hollows with high angles of orientation that were close to the ground, were regularly detected. This relationship is most likely based on the effect that increased hollow orientation has on the available hollow entrance to be viewed by an observer. Further, this issue is essentially a function of the position of the observer relative to the hollow. Climbing survey methods allow an observer to access all viewing planes, enabling a downward view into the tree structure. In this situation, planar orientation is not a factor in hollow detection.

The obstruction of a tree hollow is a significant indicator of the likelihood of that hollow being detected. The screening effect of associated vegetation contributes to the obstruction of a hollow from detection. In the forest environment, the effect of vegetative screening is compounded over distance as potential sighting angles to the hollow are reduced. Some observers

located hollows that were deemed to be un-detectable in the obstruction measurement process, and it is not clear by which process this was achieved. It is the case that the process of obstruction measurement as described, does not fully encompass all viewing positions available to the actual observer, but a sample of those positions.

The evidence of false positive detection error suggests that observers may also detect hollows based off visual cues unrelated to actual observable information. Simply, a broken branch with no actual hollow contains all the structural features of other branch stubs, which have been seen by the observer to be hollow bearing. The decision to note that stub as a hollow relates back to unclear hollow typology definitions and survey methods, as there is no significant agreement on how much of a hollow is required to be seen before it can be designated as a hollow.

The size of the visible area of a tree hollow entrance (hollow surface area) is not an accurate indicator of the likelihood of a particular hollow being detected by a ground observer. It is evident that small hollows may be regularly located despite the size of the hollow. Similarly, some large hollows may not be detected, and this analysis suggests that the reasons are due to a range of effects on the perceptive abilities of an observer.

In the first instance, the variation in perceptive ability may be due to the contextual framework in which the observer does or does not fully comprehend the range of hollows that it is possible to locate. In this respect, many hollows were located during the ground survey that did not fit the standard criteria of tree hollows (Plate 5.1). This relates to the experience and/or qualifications of the individual observer within various forest types. In this study, this variation was measured as observer experience, and detection success was positively correlated with increased levels of experience and qualification. There is sufficient variation in the respondent scores to suggest that the association is not a simple relationship, and that other factors of the survey may affect the ability of observers to detect tree hollows.



Plate 5.1, Micro – hollow development in Candlebark branch

Hollow size – 4mm x 8mm

5.2 Error and bias

The contribution of false negative error to overall bias indicates that three out of every ten hollows that occur in the forest environment of the survey site are likely to remain undetected. Further, there is no significant advantage in multiple ground searches to detect the residual hollows. Hollows that remained undetected could be characterised as high in the tree, or with a significant upward orientation, or heavily obstructed by vegetation. Of the sub-set of hollows that were never, or rarely, detected, there was some variation in the hollow forms that were measured.

The contribution of false positive error to overall bias indicates that a false hollow is located for every three actual hollows located. At the outset, the designation of a tree feature as a false hollow is an arbitrary decision. As noted, parameters of the survey design may ultimately determine hollows that will be excluded from analysis. This study did not anticipate false positive error, and it is not adequately described in other research. Thus, the researcher was forced to go back and review those trees where ground observers had noted too many hollows. Although, the hollow size parameters had been designated in the pre-survey induction, on the ground it was a difficult process for the observer to determine the actual hollow depth, and an estimate was required. In result, some tree scars and discolorations were marked as hollows by the observer set (Plate 5.2).



Plate 5.2, Typical false hollow detail in Candlebark (E. rubida)

Within the observer group totals, it was apparent that some observers had detected more hollows than were found in the climbing survey. The resultant overall count is therefore made up of components of false negative error and false positive error. Clearly, the solution is to know the actual count figure to

determine the contribution of each error component. False positive bias therefore relates differently to the overall count figure. In this study, false positive error was only 21% of the overall count, compared with 33% of the actual count. For every five hollows recorded by the observer overall, an additional false hollow is described.

5.3 Applying a correction factor for bias in ground survey

It is most likely that a survey team will not have access to determining the actual hollow count for a nominated survey site. The survey will produce a number of overall counts from the observer set, for analysis. In relation to the overall counts achieved in this study, it is possible to describe two correction factors that minimise survey error in relation to false positive and false negative records. This analysis found a 38% false negative error rate, and a 21% false positive error rate; in respect of the pooled overall count figures achieved. To correct for this bias in future research, it is necessary to make transformations of the pooled overall count figure;

A) Average Overall x .38 = Actual hollows, falsely not detected

B) Average Overall x .21 = False hollows, falsely detected

C) Accurate Detection total = Average overall – B

D) Actual total = C + A

5.4 Relationship between survey environment and ground survey success

It is difficult to accept the application of correction factors, developed for one forest environment, when arbitrarily applied to another environment. This study indicated that it was variation in hollow parameters that explained most of the error in hollow detection. Hence, it is likely that other forest types may contain distributions of tree hollows with unique characteristics in terms of hollow form, location, orientation and, associated vegetative obstruction. In this event, new correction factors will certainly be applicable. For example, Harper (2002) noted a stronger correlation between ground survey counts and climbing counts than was described in this study. That study occurred in a forest type (Yarra Bend – Melbourne) with significantly more branch hollows, and more hollows that were of a lower height. Lindenmayer *et al* (1991) noted that Mountain Ash forests were very tall with few lateral branches low on the tree trunk. In result, it might be expected that hollow height would be a more

significant factor in detection success, and that false negative, and false negative error would be larger in value.
In conclusion, the stated error rates are an adequate starting point to examine detection success in the forest environment.

The ecological significance of bias in tree hollow detection is poorly understood. Current understandings contend that the ground survey method is only requiring a set of correction factors to enable an accurate picture of hollow information. The assessment of tree hollow types from this survey environment, indicated that specific types of hollow regularly escaped detection. Three out of forty-nine hollows, or 6% of the total hollow set, could be described as tree pans (How & Kitchener, 1983; Gibbons & Lindenmayer, 2002). Tree pans detected in this study were always toward the top of their respective tree and had a significant positive planar orientation (Plate 5.3).



Plate 5.3, Tree pan hollow in Candlebark

The hollow identified in Plate 5.3 contained several litres of water when located, the only discernable water supply within 200m. In addition, there was extensive evidence of wear and tear (maintenance) around the pool. Another example is shown in Plate 5.4, where a pan hollow in Blackwood had filled with water, and was occupied by invertebrate larvae.



Plate 5.4, Tree pan hollow in Blackwood

It is likely that hollows of this type systematically escape detection during ground surveys, and that these hollows have a poorly documented ecological function.

The forest policy of the Victorian government includes a specific requirement to inventory natural resources (DSE, 1997). Inventory procedures in relation

to hollow bearing trees are based upon TREEMAP stem profiling techniques. A review of these techniques indicates that there is a systematic bias in relation to describing the full complement of utilizable hollow types in a given forest environment. There is not an adequate description of the species most likely to use tree pans, and how the resource may be partitioned.

The review of government information (D.N.R.E., 1996, 2001) indicates that there is a gap in the existing information relating to the distribution and abundance of tree hollows and arboreal species within the Wombat forest. Further, it is likely that renewed ground survey effort will provide biased results.

Burgman & Lindenmayer (1998) note “studies of the reliability, repeatability and biases of systems used to measure and classify the threat faced by species are all to rare” (p64).

Additional diagnostic keys have been developed to assess the quality of native vegetation (Parkes *et al*, 2003). By definition, a ‘habitat hectares’ approach is intrinsically related to quality of native vegetation as **habitat.** However, the ‘habitat hectares’ approach does not include a mechanism to assess the contribution of hollow bearing trees towards high quality natural

environments. The development of standardised procedures to assess hollow distribution and abundance may improve the existing approach. Recognition of Australia's prolific arboreal fauna speciation would make these changes to the technique a priority (Norton & Lindenmayer, 1991).

5.5 Conclusion on limitations of ground survey method

The future development of tree hollow survey techniques requires a focus on the quality of information recorded. Ground survey techniques do not provide essential information relating to hollow cavity characteristics and occupying fauna (Whitford, 2001). Gibbons et al (2002) stated that ". the number of occupied hollows in a tree is a more appropriate response variable than a binary variable based on presence/ absence to predict those trees suitable for retention" (p 10).

It has been suggested that "the only way to resolve this problem would be to complete similar measurements… and then fell and dissect the measured trees" (Lindenmayer et al, 2000, p 143).

Harper (2002) showed that the efficiency of other survey systems (such as tree climbing) were related to the accuracy of the survey results, as well as the costs of survey. This author suggested that tree climbers should assess one in every eight trees surveyed. The current study did not make a comparison of the efficiency of the two types of survey methodology on the basis that the outcomes would not resolve the issue of quality of information.

The main conclusion out of this study is that ground surveys of tree hollows are not an appropriate technique for describing all the information that is required by forest managers. Ground survey techniques are appropriate for establishing general abundance and distribution of a hollow set, assuming that error and bias are being corrected for. Current management practice compiles data sets in this way, however the spatially organized data is transferred to GIS programs, and management decisions are made. Clearly, these data sets are not an accurate estimation of hollow abundance, distribution, or ecological association.

Within the Wombat forest, there is a priority to assemble an accurate representation of tree hollows and their associated fauna. Existing map sets do not describe critical tree hollow information. Successful landscape scale management of connectivity processes is predicated on the quality of this information. A targeted survey design that combines tree-climbing surveys with ground surveys is likely to improve the quality of data collected, and the management decisions made in respect of this information.

There is considerable potential for further research in this area. Preliminary data from this and other studies (Harper, 2001), suggests that actual hollow distributions may vary considerably from initial understandings developed out of ground survey techniques. False positive bias is poorly described in the literature, and is possibly as significant a source of error as false negative bias. The development of correction factors for different forest types may go

some way towards improving the quality of information gathered, and provide an idea of how detection success varies across forest types in respect of these two sources of bias. Variation in observer skill base is a significant issue. The development of a taxonomic guide to tree hollow characterization (forms, locations, orientations) may help standardize observer responses, and permit cross comparison of observer results.

Providing quality ecological information is a primary requirement of a field survey technique. Tree pans are not the only type of hollow likely to be overlooked using a ground survey method. Clarification of the role of fissures and micro-hollows in the ecological system will influence the development of a taxonomic guide, and provide insight into the utilization of these spaces by fauna.

There is very little information available on the spatial arrangement of tree hollows and subsequent use by fauna. It is possible that the interconnectedness of forest architecture components, such as hollows, is a significant correlate of utilization by fauna. The arrangement of mid-storey and understorey components in a forest environment, may provide mobilization pathways between hollows. Factors such as this may be a critical determinant in whether a hollow is utilized or not.

Bias within the climbing survey method was not assessed. Future projects should control for the potential of climbing survey bias with a second independent climbing assessment. This will examine the likelihood that the tree-climbing surveyor routinely overlooks specific hollows.

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7. PERSONAL COMMUNICATIONS

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Andrew MacLean. (2003). Senior Forest Officer D.N.R.E. Ballarat Division).

Appendix 1

A guideline to safe work at height

Appendix 2

Tree Hollow Survey Project 2003

Operational Outline & Risk Management Strategy

Background

This project involves an assessment of tree hollows in a selected stand of mature trees within the Wombat forest. This is part of an honours research project for a candidate at the University of Ballarat.
The main objective is to locate and measure a selection of tree hollows using a tree-climbing method. This hollow set will later be the subject basis for a ground survey.
In result, we will have an improved understanding of the precision and accuracy of ground survey methods.

Operational Details

Schedule

The table below details the survey dates planned over an 8-week period. Scheduled days may be lost due to bad weather; these may not necessarily be made up.

Schedule	Dates	Days
Week 1	30/09/03 – 04/10/03	5
Week 2	07/10/03 – 11/10/03	5
Week 3	14/10/03 – 18/10/03	5
Week 4	21/10/03 – 25/10/03	5
		20 day

Reporting Structure

The project researcher is Darren Holloway. The project is completed under the auspices of The School of Science & Engineering at the University of Ballarat. The supervising staff member is Barry Kentish.

Logistics

Darren Holloway can be contacted on 0418 395 734

Competency requirements

At the outset, individuals involved in this type of project require competency in specific areas. Tree climbing skills and safe work at height procedures are key competencies. There are many institutions offering short and long course modules in these skills. At least one member of the supporting ground crew is required to

have competency in this area, so that a climbing rescue may be effected if required.

Climbing Requirements
Specifically, operatives will work within the recommended practices for the amenity tree industry with additional conformance to AS 4488 (Industrial Rope Access).

Risk Management System

Risk Management is part of the obligation to provide a safe workplace. Operatives are required to work safely through awareness of potential hazards. Following, is documentation relating the types of risks to be aware of and how we will manage them. Throughout the project the climbing team will meet to discuss work methods or any incidents that may have occurred.

Risk Identification

For clarity, risks have been structured into the following:

- Issues relating to remote environments.
- Issues relating to site selection and set up.
- Issues relating to the survey process.

Issues relating to remote environments

ACTIVITY	HAZARD	CONTROL MEASURE
Exposure to the elements	Too hot	Stop work > 30^0 C
		Sun hat and cream provided
	Dehydration	Ensure regular fluid intake
	Too cold& wet	No climbing work on wet wood
		Wear appropriate clothing
Bushwalking	Rocky terrain	Sturdy boots essential
		Eyes on the ground when walking
	Easy to get lost	Keep map and compass
		Stay together
		Keep your own idea on car location
	Insects, snakes and leeches	Sturdy boots, gaiters & repellent
Vehicles	Too fast	Say something – say slow down
	Load not secured	Team to stow equipment well

Issues relating to site selection and set-up.

ACTIVITY	HAZARD	CONTROL MEASURE
Vehicles		
Too far from vehicle	Easy to get lost	Mark out walk-in with tape
Too close	Falling wood & animals	Park at least 30m from tree
Topography		
Mine workings	Injury to team	Crew to discuss if site is suitable
Tree selection		
Tree is dead	Dead wood falling	Dead trees will not be climbed
Tree is structurally unsound	Tree may fall	Trees will not be climbed Integrity examined by climber
High dead wood in tree	Dead wood may fall	Climb only if dead wood can be avoided
Survey Equipment		
Carry in gear	Something may be forgotten	Make a checklist Double check your equipment before heading out & returning to vehicles.

Issues relating to the survey process

ACTIVITY	HAZARD	CONTROL MEASURE
Planning the survey	Roles are not clear	Always discuss the survey plan
Set the exclusion zone	Falling objects	Survey team only in exclusion zone
Setting the ropes	Throw-line is cast	Everyone outside exclusion zone
Work Positioning	Work at height	Correct equipment to be worn

		No access to area under climber
Secondary tree inspection	Dead wood	Climber to notify ground crew of dead wood position
Survey in process		
	Someone is injured	Stop survey. Apply first aid
	Climber is unconscious	Stop survey. Implement Rescue Plan

First Aid Plan

The first aid plan is to be enacted in the event that any crewmember is injured. A first aid kits will be positioned within the vehicle. If the survey site selected is 'remote', i.e. > 100m from the vehicle, a first aid kit must be carried. If an injury has occurred all work must stop and assistance given. The requirement for further evacuation is a decision for the first aid officer. All injuries are to be brought to the immediate attention of the University of Ballarat OH & S representative, and an entry is to be made in the Incident Log. All injuries will be reviewed within 48 hrs of occurrence; or prior to recommencing work with a similar risk potential.

Rescue Plan

In the event that a climber is rendered unconscious in the tree, an immediate rescue must occur. All survey operatives must have received specific training in how to affect such rescues. It is important that the rest of the survey team know what is occurring and how they can help. The climbing operative must be within a reasonable proximity to other team members (i.e. 100m) at all times when a survey is in process, with all equipment, so any required rescue is **immediate.** Critical to the success of a fast rescue, is that the climbing operative has their work rope and safety rope in place when in the tree. Ground crew are to respond to the requests from the climber performing the rescue; and to be alert for any falling material.

Method Statement

Relevant legislation and Standards

The method is designed to be compliant with all relevant sections of the Recommended practices for the amenity tree industry, 2001. In addition, risk at height is managed using the methodology of industrial rope access. The safe work procedures used on this project are primarily guided by the following government legislation, technical standards, Australian standards and recommended practice guidelines:

- AS/NZS (Part 1 & 2) - 1997. Industrial rope access systems.
- AS 4142.1 – 1993. Fibre ropes.
- AS/NZS 1891.1 –1995. Industrial fall arrest devices – safety belts & harnesses.
- AS/NZS 1801 – 1997. Occupational protective helmets.
- Occupational Health and Safety Act 1985.
- Code of Practice - First Aid in the Workplace 1995.

- Victorian WorkCover Authority “Working Safely With Trees” 2001.
- Draft Regulations-Occupational Health & Safety (Prevention of falls) Regulations 2002

Risk management leading to a safe workplace is required under the Occupational Health & Safety Act 1985. There is no requirement for plant, machinery, or hazardous substances within the scope of the project.

Operational Review

The following work method is guided by the requirements of the standards noted above, and the risks and control measures developed through the risk management process. The procedures detailed are specific to the climbing operative, but have a corresponding action required from the ground crew. It will take a short while for teamwork to develop and this is related to the ground crew understanding the process the climber must go through. Note that non-climbing personnel are not to be involved in the setting of ropes. Methods and procedures are subject to review and change. This will be as a result of effective communication. Risks, methods, and procedures will be covered through an induction process.

Access to site

Access to specific survey sites will be on foot from the vehicle. When the team arrives at a location, this area is named as **the survey-site**. The public is excluded from this area of operations. From a parked vehicle the team will walk in, through the bush to the tree chosen for survey.

- All climbers will carry rope access equipment in packs to each survey site.
- Ensure essential personal protective gear and survey items are carried in and out.
- Approach the survey site carefully and quietly so as not to disturb wildlife.
- In thick bush mark out a trail with marker tape. Remove on the walk out.
- Carry first aid kit and sufficient water.

Site set up

The first factor to consider when setting up the survey site is recognising any potential hazards, and that the typical hazards have been identified and control measures put in place. Upon arrival at the survey site, an effective **exclusion zone** is to be delineated and marked out. The size of the exclusion zone is hereby set at 20m diameter, measurable with the 30m tape. A circle of this diameter effectively allows for deadfall from the survey tree itself. All persons who are not part of the survey team are to be excluded from this area while the climber is in the tree.

- Visually and verbally agree on the major hazards and how they will be avoided.
- Use the tape measure as a guideline for the size of your exclusion zone.
- Always wear a helmet within the exclusion zone.

- If necessary, climb the tree adjacent to the survey tree for a safer position.

Tree Integrity

Every tree must be inspected before work begins. The inspection checklist is noted below. Only Manna Gum, Blackwood and, Candlebark are to be climbed within the scope of operations. If the nominated survey tree is found to be structurally unsound by the climber, this will be communicated to the ground crew and a new site nominated. Each team will have at least one operative with specific experience of climbing, and assessing the integrity of the nominated tree species. Dead wood higher in the tree is not necessarily a reason to abandon the site, although it is of sufficient risk that the climber shall not be under it when in their final survey position.

Tree integrity inspection checklist

ASPECT	HAZARDS TO BE NOTED
Species	Ensure you have a Manna Gum, Blackwood, or Candlebark. Are they reliable to climb?
General Health	Is the tree alive or dead?
	Is the tree stable in the ground.
Tree Bole	Is the bole intact, hollow, burnt out.
Tree trunk	Is the trunk fractured, hollow, leaning?
Branches	Are branches notably dead and still intact?
	Are dead branches hung up over the crown?
	Are living branches collaring?
Wildlife	Are there hollows likely to contain wildlife?

Installation of Fall Arrest System

When the survey team is satisfied as to the integrity of the chosen tree, the ropes may be set. Prior to this step the climber is to alert the ground crew that a line is about to be thrown and clear the exclusion area of all persons. The first step in this process is to cast the throw-line up and through a major structural fork in the tree. This light line may be hand thrown or slingshot. The ends of the two work ropes are clove hitched into the end of the throw-line, and the throw-line is then hauled back over the fork, towing the work ropes with it. The throw-line is then detached. The two work ropes are now ready to be set.

Each work rope is independently set as a ‘pull through’. This is a method whereby the line may be retrieved later. A loading knot (Fig 9 knot) is tied in the length of rope on one side of the tree fork. A steel D karabiner is clipped into the knot and into the free running length on the other side of the tree fork. The line can be hauled into position with the knot and karabiner firmly up against the tree fork. The second rope is set the same way. The ropes should now be firmly anchored and ready to climb.

In one variation to this, the two work ropes are anchored to an adjacent tree suitable to the task. Method of attachment is with the loading Fig. 9 knot from each rope, and steel D karabiner through a crane sling. Note that all anchors should have an estimated 1.2 ton of ultimate loading strength to comply with AS 4488.

Work Positioning

The climbing operative ascends utilizing the equipment and methodology of AS 4488. One rope, 'the live rope' is ascended using purpose designed rope grabs (Petzl Jumar & Croll). The other rope, 'the safety rope" is connected to the climber using a fall arrest device (Petzl Shunt). The climber wears an integral chest and waist harness. Steel D karabiners and maillon rapides provide the connection point between harness, lanyards, and rope clamp devices. The climber ascends the rope to a designated position, preferably the crook of a branch where stability may be improved.

In one variation to this, (the aiding technique) the climber may be required to ascend to the top of the rope and move into the tree at a prominent fork. The rope is ascended in the usual manner to just below the knot. A minimum of two slings are then attached to prominent limbs within reach using a 'larksfoot' knot. The objective is for the climber to move off the live rope by detaching the chest safety (Petzl Croll) allowing unrestricted movement up into the fork. At this point the climber is still attached to their fall arrest device (Petzl Shunt) and to two independent slings in the tree structure. The distance moved is generally no more than 2m. A foot sling is usually positioned to enable an easy transition. The ropes must now be repositioned higher to enable an easy descent and to permit a quick rescue.

In a second variation, the climber may be required to ascend the main trunk of the tree from the ground, without the use of ropes. This is often the case with Blackwood and occasionally so with Manna Gum and Candlebark. This is usually because the foliage of the tree is too thick to permit setting of the throw-line. This is done by the use of two larksfoot slings set around the tree main trunk. They are both appropriately connected to the climbers harness via lanyards. Using a foot sling the larksfoot slings are progressively slid up the trunk, the climber moving in short stages. The work ropes are always taken up with the climber and 'set' once in the survey position. Descent is made via a purpose designed descent device (Petzl Stop) on the live line, in conjunction with the fall arrest 'shunt' on the safety line. Helmets are to be worn at all stages of the survey procedure. One exception is for the climber setting the throw-line. During a throw process the perceptive abilities of this individual may be hampered by the helmet, so they should proceed with caution.

Survey Procedure

When the operative is in position, they will communicate readiness and the ground crew may finalize their positions and the survey begun. The climber will be handling lightweight survey equipment including camera and GPS. Note the falling object hazard for the ground crew.

Site Dismantle

The team is not to consider the job finished at that survey site until the climber is down. The descending climber must be aware of any spike hazards during the descent. The climbing ropes may be easily pulled back down from the ground. Ensure that all required information is recorded on the data sheet. Check your climbing rope for damage as you pack up. Remove all litter and marking tape on your way out.

Communication and Review

The survey team is encouraged to discuss all aspects of the process. Any suggestions may be given to the principal researcher at any time. Suggestions related to the climbing work method will be discussed in an induction process.

Hours of Work

All survey works are planned to occur in good daylight. Hence, surveys will generally occur between 9am and 3pm.

Equipment

The principal researcher will provide all necessary access equipment and a pack for carrying it. A helmet is included. The condition of the equipment will be monitored periodically. It is the operative's responsibility to ensure that the kit is kept clean and packed at the end of each day. Protective work wear will also be provided.

Insurance

The University of Ballarat will maintain $10, 000,000 public liability insurance.

Appendix 3



Tree Hollow Survey Form

Name:

Date:

Tree ID	Hollow 1	Hollow 2	Hollow 3	Hollow 4	Hollow 5	Hollow 6
Examp	T F L O 1 2 NW m	B F L O 2 1 SE m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m
1	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m
2	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m
3	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m
	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m
5	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m
6	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m
7	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m
8	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m
9	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m
10	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m	F L O m
11	F L O	F L O	F L O	F L O	F L O	F L O	F L O	F L O