The occurrence of potential tree hollows in the dry eucalypt forests of south-eastern Tasmania, Australia

*Sarah Munks[1], Mark Wapstra[1,6], Ross Corkrey[2,7], Helen Otley[1,3], Georgia Miller[1,4], Bernard Walker[5]

[1] Forest Practices Authority, 30 Patrick Street, Hobart, Tasmania.

[2] University of Aberdeen, Lighthouse Research Station, George Street, Cromarty, Ross-shire, IV118YJ, United Kingdom.

[3] Present address: C/- Fisheries Department, FIG, Stanley, Falkland Islands, United Kingdom

[4] Present address: 85 Duncan St, Maroubra, New South Wales

[5] 84 Knocklofty Terrace, West Hobart, Tasmania

[6] Present address: ECOtas, 28 Suncrest Avenue, Lenah Valley, Tasmania

[7] Present address: Tasmanian Institute of Agricultural Research, University of Tasmania, Newtown Research Laboratories, 13 St John Avenue, Newtown, Tasmania

*To whom correspondence should be addressed: sarah.munks@fpa.tas.gov.au

ABSTRACT

The relationship between environmental variables and the occurrence of potential hollows and hollow-bearing trees in three dry forest types (dry *Eucalyptus delegatensis* forest, *E. pulchella - E. globulus - E. viminalis* grassy/shrubby forest and dry *E. obliqua* forest) in south-eastern Tasmania, was examined using generalised linear modelling.

The number of trees with potential hollows and the number of potential hollows was significantly higher in dry *E. obliqua* forest, compared with the other two forest types. The number of potential hollows per tree was best explained by tree species, tree form, degree of burn damage and the interaction between burn damage and tree species. There was no significant relationship between the number of trees with potential hollows per site and the environmental variables measured. However, the number of potential hollows per site was best explained by several environmental variables: vegetation type (highest in dry *E. obliqua* forest); topographic position; amount of dead trees on the ground; the age of the stand; the average total basal area of all trees; the height of the overstorey vegetation and various interactions between these variables and other variables, such as understorey cover.

A model developed using a subset of the environmental variables measured was coupled with GIS data to develop a map of the predicted occurrence of trees with potential hollows throughout the study area. The use of such a predictive map for landscape level planning, in particular to assess the implications of land use scenarios on the hollow resource, is illustrated.

Key words: Tree hollows, forest management, Tasmania, modelling

Introduction

Tree hollows provide important habitat for many species. There is a positive correlation between the number of available hollows and the diversity and abundance of hollow-dependent fauna (Saunders *et al.* 1982, Kavanagh *et al.* 1985, Smith and Lindenmayer 1988). In Tasmania, up to forty five vertebrate species have been recorded using tree hollows for nesting or shelter (Table 1). These species include endemics (at the species or subspecies level) and five are listed in the schedules of the Tasmanian *Threatened Species Protection Act 1995* and/or the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (Table 1). In addition, a wide range of invertebrate species are likely to opportunistically use hollows as hibernation and aestivation sites while other species will use the wood mould or humus within tree hollows as breeding substrate (Grove pers. comm.).

Land clearing for agriculture and plantation establishment has resulted in the depletion of hollow-bearing trees in extensive parts of Australia. Gibbons and Lindenmayer (2002) concluded that without significant changes to land-use practices hollow-bearing trees and their associated fauna will continue to decline in areas managed for wood production and agriculture. Legislation, policies and prescriptions that aim to cater for the maintenance of the hollow resource have been adopted by most forest management agencies in Australia.

Tasmania's *Regional Forest Agreement* (Commonwealth of Australia and State of Tasmania 1997) recognises hollow-dependent fauna as a priority fauna group to be protected by "existing mechanisms". The "existing mechanisms" refer to the actions prescribed in the Tasmanian *Forest Practices Code* (Forest Practices Board 2000) for the retention of hollow-bearing trees. In the absence of information on the hollow resource and its associated fauna in Tasmania, these prescriptions were developed predominantly from studies conducted on mainland Australia on only one taxonomic group (i.e. arboreal marsupials) (Taylor 1991). It has been noted, however, that estimates of the number of hollow-bearing trees and use of hollows by fauna are not readily transferable from one site to another

Table 1 Vertebrate fauna known to use hollows in standing trees (dead and alive) in Tasmania. This list includes both obligate hollow users and species that may be described as opportunistic hollow users. Species (e.g. eastern quoll) only recorded using C type** hollows are not included. (Information sources: Bell et al. 1997; Brereton et al. 1997; Brereton 1997; Brown 1986; Brown 1989; Bryant 2002; Duncan 1995; Duncan and Taylor, 2001; Flegg and Madge 1995; Gibbons and Lindenmayer 2002; Green 1993; Haseler and Taylor 1993; Munks et al. 2004; Rhodes 1996; Rounsevell 1984; Taylor 1991; Taylor et al. 1987; Taylor and Haseler 1993; Taylor and Savva 1988; Thomas 1979, 1980; Wapstra et al. 2000; Watts 1999; Wilson and Rounsevell 1984; Woinarski 1979; Spencer pers.comm. N. Mooney pers. comm., S. Bryant pers.comm.).

Taxonomic group	Species	Conservation status*	Hollow type**
Amphibians	Brown tree frog, *Litoria ewingii*	-	A,C
Reptiles	Pretty skink, *Niveoscincus pretiosus*	T	A,B,C,D
	Metallic skink, *Niveoscincus metallicus*	-	A,C
Birds	Green rosella, *Platycercus caledonicus*	T	A, D
	Eastern rosella, *Platycercus eximius*	-	A,B
	Swift parrot, *Lathamus discolor*	Ee	A,B
	Orange-bellied parrot, *Neophema chrysogaster*	MCRe	A,B
	Blue-winged parrot, *Neophema chrysostoma*	M	A,B
	Musk lorikeet, *Glossopsitta concinna*	-	A,B
	Yellow-tailed black cockatoo, *Calyptorynchus funereus*	-	A,B
	Sulphur-crested cockatoo, *Cacatua galerita*	-	A,B
	Striated pardalote, *Pardalotus striatus*	M	A,B,D
	Forty-spotted pardalote, *Pardalotus quadragintus*	TEe	A,B,D
	Masked owl, *Tyto novaehollandiae castanops*	Te	A,B
	Southern boobook owl, *Ninox novaeseelandiae leucopis*	T	A,B,D
	Australian owlet-nightjar, *Aegotheles cristatus*	-	A,D
	Australian shelduck, *Tadorna tadornoides*	-	A
	Australian wood duck, *Chenonetta jubata*	-	A,B
	Grey teal, *Anas gracilis*	-	A,C
	Chestnut teal, *Anas castanea*	-	
	Tree martin, *Hirundo nigricans*	M	A,B,C,D
	Flame robin, *Petroica phoenicea*	-	A,C,D
	Dusky robin, *Melanodryas vittata*	T	A,C,D
	Dusky woodswallow, *Artamus cyanopteris*	M	A,C, D
Birds (Australian natives exotic to Tasmania)	Galah, *Cacatua roseicapilla*	-	
	Long-billed corella, *Cacatua tenuirostris*	-	A,B
	Little corella, *Cacatua sanguinea*	-	A,B
	Laughing kookaburra, *Dacelo novaeguineae*	-	A,C,D
Birds (introduced)	Common starling, *Sturnus vulgaris*	-	A,B,C,D
	House sparrow, *Passer domesticus*	-	A,B,D
Mammals	Southern forest bat, *Vespadelus regulus*	-	D,C,A
	Little forest bat, *Vespadelus vulturnus*	-	D
	Large forest bat, *Vespadelus darlingtoni*	-	D,C,A
	Lesser long-eared bat, *Nyctophilus geoffroyi*	-	D,C,A

Taxonomic group	Species	Conservation status*	Hollow type**
	Greater long-eared bat, *Nyctophilus timoriensis*	-	D
	Chocolate wattled bat, *Chalinolobus morio*	-	D,C,A
	Goulds wattled bat, *Chalinolobus gouldii*	-	D,C
	Eastern falsistrelle, *Falsistrellus tasmaniensis*	-	D,C
	Common brushtail possum, *Trichosurus vulpecula fuliginosus*	-	A,B
	Common ringtail possum, *Pseudocheirus peregrinus convoluter*	-	A,B,D
	Sugar glider, *Petaurus breviceps breviceps*	-	A,B,D
	Eastern pygmy possum, *Cercartetus nanus*	-	A,C,D
	Little pygmy possum, *Cercatetus lepidus*	-	A,C,D
	Echidna, *Tachyglossus aculeatus*	-	A,C
	Spotted-tailed quoll, *Dasyurus maculatus maculatus*	Vr	A,C,D

M = migratory, T = Tasmanian endemic, CRE and e = Critically endangered and endangered under Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC) and Tasmanian *Threatened Species Protection Act 1995* (TSPA), respectively. V and v = vulnerable under EPBC and TSPA, respectively. R and r = rare under EPBC and TSPA, respectively. **As Gibbons and Lindemayer, 2002, i.e. A, hollows in main stem, or a short section of residual branch that connects to a pipe in the main stem. B, hollows occurring in living and dead branches of the crown. C, fire scars, basal or butt hollows at the base of tree. D, fissures or cracks in branches or main stem with vertical entrances.

due to the difference in forest types, environmental conditions and hollow-dependent fauna present (Gibbons and Lindenmayer 1997). This may particularly be the case in Tasmania where much of the State supports forests dominated by endemic eucalypt species or subspecies, and the hollow-dependent vertebrate fauna is distinctly different to mainland Australia (Table 1).

Gibbons and Lindenmayer (1997) identified information on the distribution and use of hollow-bearing trees as important for the development of prescriptions for the maintenance of the hollow resource. Such information is limited in Tasmania compared with that available for other State's (Lamb *et al.* 1998). There have been no detailed studies into the distribution of hollow-bearing trees within production forest in Tasmania, apart from an estimate of the density of hollows in *E. amygdalina* and *E. obliqua* dry sclerophyll forest in the north-east of Tasmania by Taylor and Haseler (1993).

In this paper we examine the distribution and density of hollow-bearing trees in dry forest used for production forestry in south-eastern Tasmania. Much of the dry sclerophyll vegetation in south-eastern Tasmania has been altered since European settlement (Duncan 1999). Agriculture and forestry practices have resulted in the removal, or modification of the structure and composition of these forests resulting in a depletion of the hollow resource. Duncan (1999) notes that this disturbance is likely to continue into the forseeable future with the lowland forests with grassy understoreys being cleared for grazing and forests with shrubby understoreys targeted by the timber industry. Firewood harvesting may also have an impact on these forests and their fauna (Bryant 2002). To maintain populations of hollow-dependent fauna in these areas it is critical that land managers have access to information on the characteristics, extent and spatial distribution of hollows and hollow-bearing trees in order to assess the consequences of various land management options. The key questions addressed in this paper are what are the characteristics of hollow bearing trees in dry forests important to the forest industry in south-eastern Tasmania, and what are the characteristics of the sites where they occur.

Methods

Study Area and Climate

The study area encompassed an extensively forested tract of public and private land on the east coast of Tasmania (Figure 1). The area is characterised by flat terrain adjacent to the coast, behind which a series of steep hills dissected by complex stream systems rise to a broader upland tier system. Altitude varies from sea level to 975 m asl.

Vegetation is largely influenced by the degree of insolation with exposed ridges and slopes supporting dry scleromorphic vegetation and sheltered slopes and streams systems supporting wet sclerohyll forest, relict rainforest and dense riparian vegetation. The area is within the humid warm/ moist subhumid warm climatic zones (Gentilli 1972) characterised by a mean annual rainfall varying from 500 to 600mm and temperatures ranging from 6 - 17°C. Much of study area has been subject to various forestry activities for over 100 years, with extensive areas of higher productivity forests (e.g. those dominated by *E. obliqua* and/or *E. delegatensis*) supporting regeneration of various ages resulting from clearfell, burn and sow, shelterwood removal or intensive selective logging silviculture, and most of the lower productivity sites (e.g. those supporting peppermint species) being selectively logged either commercially for pulp or firewood. The study area is characterised by frequent wildfires, with fire frequency highest in the drier, less productive forests and lowest in the moister higher productivity or higher altitude forests.

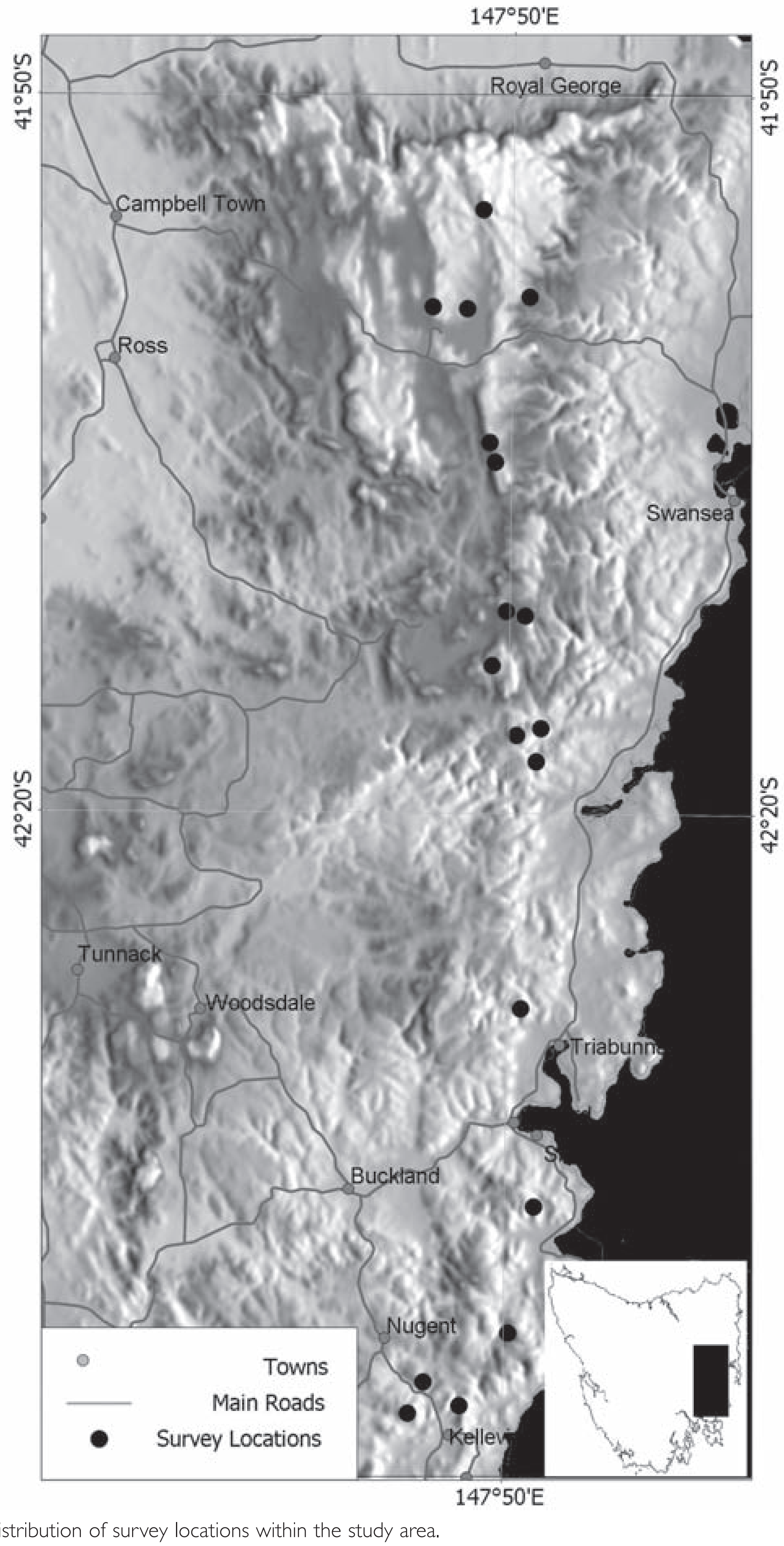

Figure 1. Distribution of survey locations within the study area.

Forest Type and Study Site selection

Three broad forest types were chosen as the primary unit of initial study site stratification based on vegetation mapping produced during the Tasmanian *Regional Forest Agreement* (Tasmanian Public Land Use Commission 1996): dry *Eucalyptus delegatensis* forest, *E. pulchella - E. globulus- E. viminalis* grassy/shrubby dry forest and dry *E. obliqua* forest. These are three of the dominant forest types throughout the study area, and represent the range of forest types used by the forest industry on the State's east coast.

Within each forest type, 50 to 71 replicated sites (a total of 189) were sampled between August and December 2000. Sites were grouped at 18 survey locations selected to cover the widest possible geographic area covered by the particular forest type (Figure 1). The area covered by these survey locations was defined primarily by logistical constraints on access (most locations were on public land) and distance from base. In addition, survey locations were selected to ensure approximately similar climate conditions, geology (i.e. Jurassic dolerite) and soil fertility (i.e. soil fertility index ranging from 4.8 – 7.7, as Nix *et al.* 1992).

At each survey location, up to four sites were haphazardly selected from the available topographic positions (ridge top, upper slope, mid-slope, lower slope/gully). Each site was at least 200 m away from another site. All sites were on dolerite and the majority had a soil fertility index (as Nix *et al.* 1992) of 7.7 with only four sites having a soil fertility index of 4.8.

The location of each site was recorded using a Geographic Positioning System with and accuracy of 30 m or from a 1:25000 map of the area. All sites had been burnt at some stage in the past and although none of the sites had been logged by commercial forestry operations in recent history, there was evidence of light selective logging at some, probably from firewood collection.

Hollow Survey

At each site a circular plot of 0.25 ha (radius 28.2 m) was established. Each plot was systematically searched on foot for trees (>10 cm diameter at breast height over bark, DBH, as Taylor and Haseler 1993) with potential hollows (visible with binoculars from the ground). The number of trees (>10 cm DBH) with hollows observed and the number of hollows observed were recorded. Hollows recorded included all those observed greater than approximately 3 cm in diameter in branches and trunk and fissures in the trunk greater than about 3 cm in width.

Other studies have shown that the number of hollows seen in standing trees from ground level may be different from the actual number present (e.g. Gibbons and Lindenmayer 2002; Mackowski 1987; Sodequist and Lee 1994). Therefore the use of ground-based observations in this study probably resulted in inaccurate estimation of the number of trees with hollows and the number of hollows actually present at a particular site. Time and safety considerations excluded a close examination of all possible hollows in trees in this study. We have assumed that the degree of inaccuracy in our estimates was the same for each site surveyed. This is because the same observers were used at all sites throughout the study and the ease with which the hollows could be observed was similar for each of the forest types. The numbers used are regarded, therefore, as an index of hollow tree, and hollow, availability (or potential availability in the case of mistaken 'blind' entrances) and not actual numbers present.

All other trees over 10 cm DBH, without potential hollows, in each plot were also recorded. A total of 7782 trees were sampled across all sites.

Tree Characteristics and Habitat Variables

Tree species (*Eucalyptus pulchella, Banksia marginata, E. delegatensis, E. viminalis, E. amygdalina, E. obliqua, E. globulus*) and form, as described in Table 2 (modified from Smith and Lindenmayer 1988), of each tree over 10 cm DBH in each 0.25 ha plot were recorded. All dead standing trees over 10 cm DBH were also recorded.

The degree of burn damage to each tree was recorded as: 0 = no damage, 1 = presence of burnt bark, 2 = cambium of the tree showed clear signs of effects from fire, 3 = presence of large hollow or arch burnt through base of tree.

Habitat variables (described in Table 3) recorded at each site were chosen for their anticipated value as predictors of hollow-bearing tree distribution and for the ease with which they could be collected.

Table 2. Tree form categories recorded at each site for each tree over 10 cm DBH.

Tree form category	Description
F1	Regrowth or medium growth tree (regrowth =10-20 cm DBH, medium = 20-60 cm DBH) with no major branches off trunk.
F2	Regrowth or medium growth tree with major branches off trunk, but no major dead limbs.
F3	Large tree (DBH> 60 cm) with no major branches off trunk (dead or alive).
F4	Large tree (DBH > 60 cm) with major branches off trunk, but no major dead limbs.
F5	Regrowth, medium or large tree with dead limbs (apart from one or two live straggly branches).
F6	Dead tree with most branches still intact.
F7	Dead tree with 0-50% of top of branches broken away.
F8	Dead tree with >50% of top of branches broken away.
F9	Hollow stump.

Table 3. Habitat variables recorded at each site.

Variable	Description
Geology	Recorded from Tasmanian Department of Mines (1975).
Altitude	Metres above sea level, recorded from 1: 25 000 topographic map.
Vegetation cover and height	Estimate of projected canopy cover (%) and height of canopy and observed understorey vegetation layers (dry sclerophyll forest is characterised by a multi-aged canopy dominated by eucalypt species underlain by one to several shrub layers of various composition, usually as a result of successive fires).
Age of stand	Regrowth, 0-20 cm DBH; poles, 20-60 cm DBH; mature, >60 cm DBH
Total basal area (TBA):	The average cross sectional area in square metres of all trees (taller than 1 m) on the 0.25 ha plot (as Braithwaite et al. 1989). Estimated using the Angle Count Sampling or "Sweep" method (Goodwin 1995) from three points in each plot.
Vegetation age structure	Photographic interpretation (PI) of the vegetation age structure within each plot obtained from Forestry Tasmania's PI type maps (Stone 1998).
Forest type	The forest type was recorded at two scales: (1) the broad classification of forest types used in the Tasmanian *Regional Forest Agreement* (Tasmanian Public Land Use Commission, 1996) and, (2) the finer-scaled classification of forest types as defined by Duncan and Brown (1985), which essentially defines dry sclerophyll forest types based on the dominant eucalypt species in the canopy and the understorey characteristics (e.g. shrubby, heathy, grassy, sedgy).
Slope	A measure, allocated to categories of the steepness of terrain at each plot (0=flat, 0-3^{O} slope; 1 = gently undulating, 3-6^{O} slope; 2 = undulating/hilly, 7-13^{O} slope; 3 = steep, > 13^{O} slope).
Aspect	A measure, allocated to categories of the slope direction (0 = no aspect; 1 = north, NW to NE; 2 = E, NE to SE; 3 = S, SE to SW; 4 = W, SW to NW).
Topographic position	Position of the plot in the landscape (i.e. ridge, upper slope, mid-slope,lower slope/gully)
Distance from a stream/river	Distance of the plot to the nearest creek-bed (0 = creek runs through plot, 1 = creek is < 100 m away; 2 = creek is between 100 m and 1 km away; 3 = creek >1 km away).
Leaf litter cover	Estimated % of plot area covered in leaf litter (1 = 0-25%;2 = 25-50%; 3 = 50-75%; 4 = >75%).
Rock cover	Estimated % of plot area covered in rocks (1 = 0-25%; 2 = 25-50%; 3 = 50-75%; 4 = > 75%).
Occurrence of fire	A record of fire history and the type of burn (i.e. low or high intensity) collected from forestry records.
Logging history and disturbance class	Evidence of previous logging from observations or forestry records (i.e. virgin stand, current logging, 2 – 3 past logging events, 3 – 4 past logging events and fire, recent or historic wildfire, all dead stems, past roading).
Dead trees on ground	Abundance measure (i.e. low, 1-3 trees; medium, 3-6 trees; high >6 trees)

Statistical analysis

The abundance of trees with potential hollows and abundance of potential hollows, for sites for each broad forest type and each finer-scaled forest type (see Table 3) were tested for equality using Generalised Linear Modelling (GLM) (McCullagh and Nelder 1989). Observed number of trees with hollows and observed number of hollows were seperately calculated. A log link function and Poisson distribution were assumed for both measures. The models were fitted after adjusting for over-dispersion where required. Levels of statistical significance were set at 0.01 unless otherwise stated.

The relationship between the observed number of potential hollows per tree and recorded tree characteristics (tree form (Table 2), species, burn damage) was also analysed using a GLM (McCullagh and Nelder 1989). Tree forms 3 and 9 were excluded due to insufficient data. Log-linear analysis was used to model the number of hollows using the explanatory variables tree form, species and burn damage.

The relationship between the occurrence of trees with potential hollows, and the occurrence of potential hollows, and all the recorded environmental variables for each site (Table 3) were also analysed using a GLM (McCullagh and Nelder 1989). Observed number of trees with potential hollows and number of potential hollows were seperately calculated. A log link function and Poisson distribution were assumed for both measures. The models were fitted after adjusting for over-dispersion where required. Levels of statistical significance were set at 0.01 unless otherwise stated.

To explore the use of the data in developing a map that could be used to predict the occurrence of trees with hollows at the landscape scale a model was developed using a subset of the environmental variables. The variables chosen were those for which spatial (GIS) information was available (i.e. vegetation community, vegetation age structure, slope, aspect, distance to stream, altitude and age of stand). A log-linear model was fitted with the count of trees with potential hollows as the dependent variable. Only sites with trees with potential hollows were included in this analysis. This model for occurrence of trees with potential hollows was then coupled with the appropriate GIS data for each 75 m (approximately 0.6 ha) grid square within an area of approximately 6,300 square kilometres in the south east of Tasmania encompassing the forest types examined. This produced a map of the predicted occurrence of trees with potential hollows. GIS data for the significant habitat variables were extracted from the TASVEG vector GIS coverage (vegetation community) (Anon 2001) a 75 m

Digital Elevation Model (slope) constructed for the study area using 1:25000 contour maps (from the 'LIST' data, Department of Primary Industry, Water & Environment, Information and Land Services Division, Tasmania) and the vector coverage of "Growth Stage" derived from Forestry Tasmania's Photographic Interpretation mapping (Stone 1998). The general approach in the development of the map was to calculate a raster (grid cell) surface where the value of each grid cell represents the predicted number of trees with hollows. Models were constructed using the raster GIS package IDRISI (IDRISI32 V2 Clark Labs, The Idrisi Project http://www.clarklabs.org) to carry out layer reclassification and arithmetic. Each pixel could only have one value for each of slope, vegetation type and age. Any pixel not having a valid code for each of the three explanatory variables was given the status unclassified and ultimately deleted from the final layer.

A smoothing algorithm was applied that averaged each grid cell value with the values of its surrounding eight cells.

No independent data was available to verify the map predictions. As a preliminary analysis predicted values for each grid cell (prior to smoothing) were compared with the original observed field data. Spearman correlation coefficients (S) were calculated for the observed and predicted values for the number of trees with hollows. Spearman correlation coefficients were used since these do not make any distributional assumption. Statistical significance was set at 0.05.

Results

Forest type and the occurrence of potential hollows

Standing trees with potential hollows were found in all of the forest types surveyed. Only thirteen of the 189 sites surveyed did not have trees with potential hollows. The number of trees with potential hollows, and total number of potential hollows, were significantly higher in the dry *E. obliqua* forest compared with the other two broad forest types i.e. dry *E. delegatensis* forest and *E. pulchella - E. globulus - E. viminalis* grassy/shrubby forest (Table 4). For example, dry *E. obliqua* forest had 1.478 (95% CI:1.193, 1.830) times as many trees with potential hollows per site as the *E. pulchella - E. globulus - E. viminalis* grassy/shrubby forest. Similarly, dry *E. obliqua* forest had 1.636 (95% CI: 1.265, 2.114) times as many potential hollows per site as the *E. pulchella - E. globulus - E. viminalis* grassy/shrubby forest.

The mean number of trees with potential hollows observed per 0.25 ha plot was 3.94 $\pm$ 2.80 (n = 71) for dry *E. delegatensis* forest, 4.72 $\pm$ 2.95 (n = 50) for *E. pulchella - E. globulus - E. viminalis* grassy/shrubby forest and 7.09 $\pm$ 4.45 (n = 68) for dry *E. obliqua* forest. The mean number of potential hollows observed per 0.25 ha plot was 6.38 $\pm$ 6.17 (n = 71) for dry *E. delegatensis* forest, 8.20 $\pm$ 7.03 (n = 50) for *E. pulchella - E.globulus - E. viminalis* grassy/shrubby forest and 13.41 $\pm$ 8.67 (n = 68) for dry *E. obliqua* forest.

Similarly, the number of trees with potential hollows, and the number of potential hollows, differed significantly between the more finer-scaled forest type definitions (Duncan and Brown 1985) (Table 5). The number of trees with potential hollows, and number of potential hollows, were highest in the grassy *E. obliqua* and shrubby *E. obliqua* forest types (Table 5). The mean number of trees with potential hollows observed per 0.25 ha plot ranged from 3.40 $\pm$ 3.35 (n=10) for grassy *E. delegatensis* to 8.33 $\pm$ 5.47 (n = 3) for grassy *E. obliqua* forest. The mean number of potential hollows observed per 0.25 ha plot ranged from 5.90 $\pm$ 7.47 (n=10) for grassy *E. delegatensis* to 14.67 $\pm$ 12.38 (n = 3) for grassy *E. obliqua* forest.

Tree characteristics and the occurrence of potential hollows

There was a significant relationship between the number of potential hollows per tree and the measured tree characteristics (Table 6). The number of potential hollows was best explained by tree species, tree form, type of burn damage, and the interaction between burn damage and tree species. The number of potential hollows was higher in the trees that fitted the description of Form 4 (large tree with major branches off trunk) and where trees had burn damage, particularly where the cambium had been exposed through burn damage (burn damage category 2). The occurrence of hollows was highest in dead trees. Out of the living trees, the number of potential hollows was highest in *E. obliqua*. For example, *E. obliqua* had 3.5801 (95% CI:1.8978, 6.7531) times as many hollows as *E. globulus*. The number of potential hollows was lowest in *E. amygdalina*. *E. pulchella* also had significantly fewer hollows, especially when the bark was burnt.

Table 4. Regression model coefficients for broad vegetation types (Tasmanian Public Land Use Commission 1996) versus abundance of trees with potential hollows and potential hollows per site.

Vegetation Community	Estimate	Standard error	Pr>ChiSq
No. trees with hollows model coefficients *Overall P<0.0001*			
Intercept	1.6221	0.0892	<0.0001
Dry *E. obliqua forest*	0.3907	0.1091	0.0003
Dry *E. delegatensis*	-0.1725	0.1216	0.1561
E. pulchella-E. globulus-E.viminalis grassy/shrubby forest	0.0000	0.0000	-
No. hollows model coefficients *Overall P<0.0001*			
Intercept	2.1041	0.1088	<0.0001
Dry *E. obliqua*	0.4920	0.1309	0.0002
Dry *E. delegatensis*	-0.2509	0.1501	0.0946
E.pulchella-E.globulus-E.viminalis grassy/shrubby forest	0.0000	0.0000	-

Table 5. Regression model coefficients for finer-scaled vegetation types (Duncan and Brown 1985) versus abundance of trees with potential hollows and potential hollows per site.

Vegetation Community	Parameter estimate	Standard error	Significance
No. trees with hollows model coefficients ***Overall P=<0.0009***			
Intercept	1.7492	0.1706	<0.0001
Grassy *E. delegatensis*	-0.5254	0.2969	0.0768
Grassy *E. obliqua*	0.3711	0.3308	0.2620
Grassy *E. pulchella*	-0.0892	0.2080	0.6679
Heathy *E. pulchella*	-0.0264	0.3175	0.9337
Heathy *E. obliqua*	-0.1398	0.4037	0.7292
Shrubby *E. delegatensis*	-0.2351	0.1927	0.2225
Shrubby *E. obliqua*	0.2254	0.1839	0.2205
Shrubby *E. pulchella*	0.0000	0.0000	-
No. hollows model coefficients ***Overall P<0.0001***			
Intercept	2.2634	0.2030	<0.0001
Grassy *E. delegatensis*	-0.4884	0.3585	0.1731
Grassy *E. obliqua*	0.4222	0.3979	0.2886
Grassy *E. pulchella*	-0.1172	0.2490	0.6378
Heathy *E. pulchella*	-0.1839	0.4124	0.6556
Heathy *E. obliqua*	-0.1039	0.4893	0.8319
Shrubby *E. delegatensis*	-0.3581	0.2319	0.1226
Shrubby *E. obliqua*	0.2979	0.2180	0.1718
Shrubby *E. pulchella*	0.0000	0.0000	-

Table 6. Results of model fit for measured tree characteristics versus observed number of potential hollows per tree.

Explanatory Variable	DF	Chi-Square	Overall probability
Form (F)*[1]	6	1248.49	<.0001
Burn damage (BD)*[2]	3	32.37	<.0001
Tree Species*[3]	6	104.27	<.0001
Burn damage x Tree species	18	64.38	<.0001

No. Hollows per tree = exp (-3.3202 + (F1)*0.1478 + (F2)*1.5837 + (F4)*3.2038 + (F5)*2.3476 + (F6)*1.1528 + (F7)*0.9817 + (BD0)*-0.6679 + (BD1)*0.0301 + (BD2)*0.0517 + (Species = E.p)*0.9257 + (Dt)*1.9553 + (Species = E.d)*0.7070 + (Species = E.v)*0.0585 + (Species = E.a)*-0.9740 + (Species = E.o)*1.2754 + (BD0)*(Species = E.p)*-0.1151 + (BD0)*(Dt)*-0.1402 +(BD0)*(E.d)*-0.2405 + (BD0)*(Species = E.v)*0.8382 + (BD0)*(Species = E.a)*0.0287 + (BD0)*(Species = E.o)*-0.4356 + (BD1)*(Species = E.p)*-1.0748 + (BD1)*(Dt)*-0.4247 + (BD1)*(Species = E.d)*-0.5204 + (BD1)*(Species = E.v)*-0.3083 + (BD1)*(Species = E.a)*0.9619 + (BD1)*(Species = E.o)*-0.1495 + (BD2)*(Species = E.p)*-0.6071 + (BD2)*(Dt)*-0.3744 + (BD2)*(Species = E.d)*-0.1266 + (BD2)*(Species = E.v)*0.1497 + (BD2)*(Species = E.a)*1.2439 + (BD2)*(Species = E.o)*-0.3966)

*[1] See Table 2 for Form category descriptions.

*[2] Burn damage categories: BD0 = No damage, BD1 = presence of burnt bark, BD2 = cambium of the tree showed clear signs of effects from fire, BD3 = presence of large hollow or arch burnt through base of tree.

*[3] E.p = *Eucalyptus pulchella,* E.d = *E. delegatensis*, E.v = *E. viminalis*, E.a = *E. amygdalina*, E.o = *E. obliqua*, E.g = *E. globulus* and Dt = dead trees.

Relationship between the occurrence of potential hollows and environmental variables

There was no significant relationship between the number of trees with potential hollows per site and any of the environmental variables measured. However, the number of potential hollows varied significantly with a number of the environmental variables.

The number of potential hollows per site was best explained by broad vegetation type, topographic position, number of dead trees on the ground, the occurrence of *Callitris rhomboidea* (a pyramidal native conifer), the age of the stand, the average total basal area of all trees, the height of the overstorey vegetation and various interactions between these variables and other variables, such as the presence of *Cyathodes glauca* (a low compact understorey shrub) and understorey cover (Table 7).

The number of potential hollows was significantly higher in the dry *E. obliqua* forest on lower, middle and upper slopes compared with the *E. pulchella - E. globulus - E. viminalis*

Table 7. Results of model fit for measured environmental variables versus number of potential hollows per site.

Explanatory Variable	DF	Chi-Square	Overall probability
Vegetation type (RFA definition) (VR)*[1]	2	26.43	<0.0001
Topographic position (TP)*[2]	3	14.20	0.0026
Dead trees on the ground (DG) *[3]	2	20.85	<0.0001
Presence of *Callitris rhomboidea* (Cr)	1	20.20	<0.0001
Age of stand (Age)	1	12.89	0.0003
Total basal area (TBA)	1	12.30	0.0005
Overstorey height (m) (Os)	1	43.77	<0.0001
Vegetation type (RFA definition)x Topographic position	6	43.50	<0.0001
Total basal area x Vegetation type (RFA definition)	2	17.37	0.0002
Topographic position x Dead trees on the ground	6	53.34	<0.0001
Total basal area x Topographic position	3	22.94	<0.0001
Understorey cover (%) (Uc) x Topographic position	3	49.09	<0.0001
Cyathodes glauca cover (Cgc) x Dead trees on the ground	2	21.02	<0.0001
Age of stand x Dead trees on the ground	2	16.79	0.0002
Overstorey height (m) x Dead trees on the ground	2	30.65	<0.0001

No. Hollows = exp (2.7165+ (VR1)* -1.7502+ (VR2)* -1.8716+ (VR3)* 0+ (TP1)* -0.7058+ (TP2)* 0.415+ (TP3)* 0.6824+ (TP4)* 0+ (DG1)* -1.9978+ (DG2)* -2.8838+ (DG3)* 0+ Cgc * -0.0918+ Cr * 1.2316+ AGE * 0.1297+ TBA * 0.0243+ Os* -0.1014+ Uc * 0.0231+ (VR1)*(TP1)* 0.1717+ (VR1)*(TP2)* -0.0957+ (VR1)*(TP3)* 0.3447+ (VR1)*(TP4)* 0+ (VR2)*(TP1)* 1.2415+ (VR2)*(TP2)* 0.8881+ (VR2)*(TP3)* 1.2856+ (VR2)*(TP4)* 0+ (VR3)*(TP1)* 0+ (VR3)*(TP2)* 0+ (VR3)*(TP3)* 0+ (VR3)*(TP4)* 0+ TBA *(VR1)* 0.0489+ TBA *(VR2)* 0.0481+ TBA *(VR3)* 0+ (TP1)*(DG1)* 2.4695+ (TP1)*(DG2)* 1.7878+ (TP1)*(DG3)* 0+ (TP2)*(DG1)* 1.0463+ (TP2)*(DG2)* 0.4935+ (TP2)*(DG3)* 0+ (TP3)*(DG1)* 0.8307+ (TP3)*(DG2)* -0.1498+ (TP3)*(DG3)* 0+ (TP4)*(DG1)* 0+ (TP4)*(DG2)* 0+ (TP4)*(DG3)* 0+ TBA *(TP1)* -0.0527+ TBA *(TP2)* -0.0543+ TBA *(TP3)* -0.0504+ TBA *(TP4)* 0+ Uc *(TP1)* -0.0494+ Uc *(TP2)* -0.0049+ Uc *(TP3)* -0.0191+ Cgc *(DG1)* 0.1912+ Cgc *(DG2)* 0.4065+ AGE *(DG1)* 0.3582+ AGE *(DG2)* -0.0940+ Os *(DG1)* 0.0182+ Os *(DG2)*0.1003)

*[1] VR1 = dry *E. delegatensis*, VR2 = dry *E. obliqua,* VR3 = *E. pulchella – E. globulus - E. viminalis* grassy shrubby forest.

*[2] TP1 = Lower slope/gully, TP2 = Middle slope, TP3 = Upper Slope, TP4= Ridge

*[3] DG1 = 1-3 trees, DG2 = 3-6 trees, DG3 = >6 trees.

grassy shrubby forest, at all topographic positions, which formed a homogeneous group with all the other non-significant forest types at all topographic positions. The number of hollows increased significantly with increasing total basal area (TBA, see Table 3) in the different forest types and for different topographic positions. The rate of increase with increasing TBA was significantly higher in dry *E. delegatensis* and dry *E. obliqua* forest compared to the *E. pulchella – E. globulus - E. viminalis* grassy shrubby forest and significantly lower on the lower, middle and upper slopes compared to ridges.

There was a significant difference in the number of potential hollows observed at different topographic positions with different amounts of dead trees on the ground. For example, higher number of potential hollows were observed on lower slopes than on upper slopes where the amount of dead trees on the ground was low. Overall, the number of potential hollows was significantly lower in areas where there was a low or moderate amount of dead trees on the ground compared to areas where the number of dead trees on the ground was high.

The number of hollows did not vary significantly with age of the stand, however it did marginally increase with age of the stand, in areas where fallen trees were found.

In general, the number of potential hollows decreased with increasing overstorey height and increased with increasing understorey cover. The rate of decrease with increasing overstorey height, however, differed according to the different levels of dead trees on the ground.

Development of predictive maps

The model for hollow tree occurrence, constructed using the subset of the environmental variables measured, for which spatial (GIS) information was available, consisted of the following variables that together best explained the data collected:

Number of trees with potential hollows per site = constant + Broad vegetation type + Slope + Age

The number of trees with potential hollows per site was highest in dry *E. obliqua* forest compared to the other forest types. For example, dry *E. obliqua* had 1.3476 (95%CI:1.0977,1.6543) times the number of trees with hollows (in a site) as the *E. pulchella – E. globulus - E. viminalis* grassy/ shrubby forest. The number of trees with potential hollows increased with the age of the stand but decreased with increasing slope (Table 8).

Table 8. Model coefficients for subset of the environmental variables measured, for which spatial (GIS) information was available, versus measures of hollow tree occurrence.

Parameter	Parameter estimate	Standard error	Significance
Number of trees with hollows per site coefficients			
Intercept	1.0669	0.1691	<0.001
Dry *E. obliqua* forest	0.2983	0.1047	0.0044
Dry *E. delegatensis* forest	-0.2501	0.1141	0.0284
E. pulchella-E. globulus-E. viminalis grassy/shrubby forest	0.0000	0.0000	.
Slope	-0.0137	0.0049	0.0055
Age of stand	0.3222	0.0682	<0.0001

Fitted model: No. Trees with hollows = exp(pred)

Where, pred = 1.067–0.2501*(dry *E. delegatensis*)+ 0.2983*(dry *E. obliqua*)+ 0.000*(*E. pulchella-E. globulus-E. viminalis*)–0.0136*(slope)+ 0.3222* Age

Figure 2 illustrates the map derived from the relationship between the environmental variables measured, for which spatial (GIS) information was available, and the number of trees with potential hollows per site. This map illustrates the patchy distribution of areas with a high number of trees with hollows. Preliminary analysis of the map comparing the values predicted for each 75m^2 grid cell (prior to smoothing) with the observed original field data indicated that there was a significant correlation between the observed and predicted values for the number of trees with hollows per site (0.25 ha) (S=0.221, p=0.014, n=123).

Discussion

The results of this study indicate that dry *E. obliqua* forest supports the highest number of potential hollow-bearing trees per hectare (28/ha), compared to other forest types examined. This estimate is at the higher end of the range reported in studies of different native forest types in Australia (0-27/ha) (summarised in Gibbons and Lindenmayer 2002). It is less than the 48/ha recorded in Taylor (1991) for dry *E. obliqua* forest in the north-east of Tasmania, but is similar to the mean number of hollow-bearing trees per hectare for forest dominated by *E. obliqua* in Victoria (26.9/ha), recorded by Fox *et al.* (2001). The relatively low mean occurrence of potential hollow-bearing trees in the dry *E. delegatensis* forest (16/ha) compared to dry *E. obliqua* forest was also found by Fox *et al.* (2001), who reported 6.2 hollow-bearing trees/ha for *E. delegatensis* forest.

Other studies have found that the tendency of eucalypts to form hollows varies between tree species (e.g. Lindenmayer *et al.* 1993, Sodequist and Lee 1994, Gibbons 1999, Fox *et al.* 2001, Whitford 2002). Differences in growth form, growth rates, morphology, wood properties (hardness, decay rates, etc.), incidence of timber defects and fire susceptibility between species have all been suggested as explanations for this variation (Fox *et al.* 2001; Gibbons and Lindenmayer 2002). Most hollows in eucalypts occur in branches and studies suggest that tree species with a propensity to grow large branches, that persist even when decayed are more likely to develop hollows (Marks *et al.* 1986, Gibbons and Lindenmayer 2002). Differences in growth rate and persistence of branch stubs may explain the difference in hollow occurrence between *E. obliqua* and *E. amygdalina* observed in this study. *E. amygdalina* is known to grow more slowly and as a result self-prune branches more cleanly than *E. obliqua* (Neyland pers. comm.). Differences in age of the stand, however, may explain the observed differences in hollow occurrence between the *E. obliqua* and *E. globulus* sampled in this study. Stands where *E. globulus* occurred were generally younger (dominated by regrowth or poles) than stands where *E. obliqua* was dominant.

The occurrence of trees with potential hollows was high in two of the finer-scaled *E. obliqua* dominated vegetation communities, grassy *E. obliqua* forest and shrubby *E. obliqua* forest, when compared with the other eight finer-scaled vegetation communities. However, the occurrence of trees with potential hollows was relatively low in heathy *E. obliqua*. This indicates that tree species may not be the sole factor influencing hollow occurrence for a particular tree. Tree form, burn damage, and the interaction between tree species and burn damage, were also found to influence the occurrence of hollows in a particular tree. Trees were more likely to have hollows if they were large (>60 cm DBH) with major branching off from the trunk and where wood had been exposed through burn damage. The relationship between these tree attributes and the incidence of hollows have been recognised in other studies (e.g. Inions *et al.* 1989, Taylor and Haseler 1993, Lindenmayer *et al.* 1993, Gibbons 1999, Gibbons and Lindenmayer 2002). The lower occurrence of trees with hollows in heathy *E. obliqua* forest may be explained by the dominance of regrowth *E. obliqua* trees at these sites (67% of the *E. obliqua* trees in this forest type, for which form was recorded, were of Form 1 or 2). Heathy understoreys, as opposed to denser shrubby ones, are generally created and maintained through more frequent fires. Although burn damage can encourage hollow formation, the frequency and intensity of fires in the heathy *E. obliqua* sites appear to have resulted in a younger stand, resulting in a lower occurrence of hollows. Heathy understoreys are also associated with poorer soils and hollow formation may take longer in trees growing in such soils.

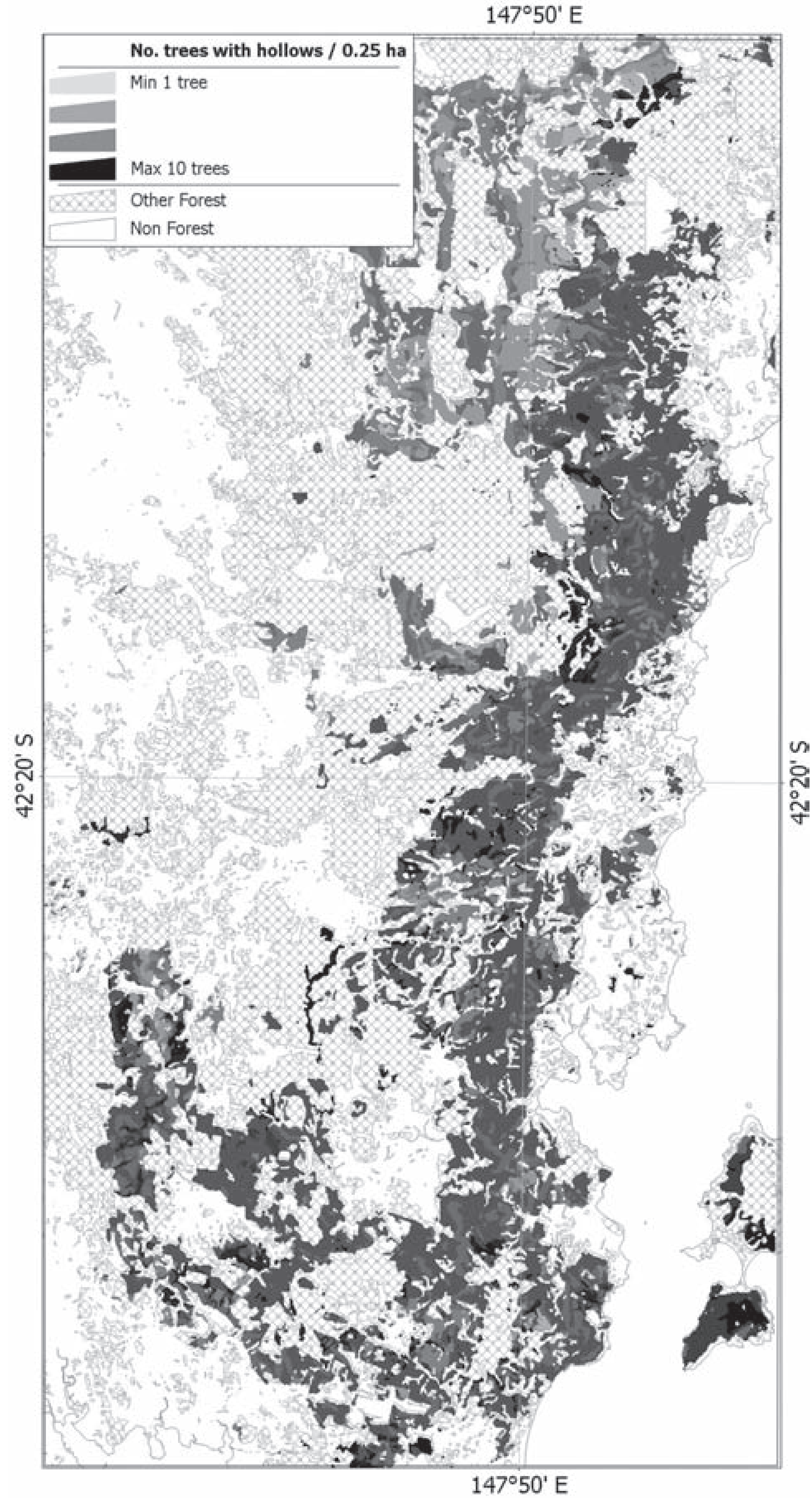

Figure 2. Map derived from the relationship between the environmental variables measured, for which spatial (GIS) information was available, and the number of trees with potential hollows per site.

Previous studies suggest that factors operating beyond the tree-level also influence the occurrence of hollows resulting in the large variation in the numbers of trees with hollows across the landscape. Such factors include, age of the stand, topographic position, levels of logging disturbance, the number of large stems in a stand, mean annual rainfall, size-class distribution of trees, productivity of a site, fire and land use history (summarised in Gibbons and Lindenmayer 2002). As well as broad vegetation type, variation between the sites examined at in this study appeared to be associated predominantly with factors that reflected the age and structure of the stand and topographic position. The positive relationships between the presence of hollows in trees and stand basal area and age of the stand, seen in this study, are well established in the literature (Lindenmayer *et al.* 1991; Bennett *et al.* 1994; Gibbons *et al.* 2000). The importance of a mature, relatively undisturbed, dry forest stand is also indicated by the positive relationship, found in this study, between the presence of hollows in trees with the presence of dead trees on the ground. The number of potential hollows was inversely related to the height of the overstorey. This may be related to the morphology of the trees in the stand, with lower overstorey height generally associated with larger trees with greater crown area. Crown area and form has been associated with a greater number of hollows in other studies (Fox *et al.* 2001, Gibbons 1999, Lindenmayer *et al.* 2000). Lindenmayer *et al.* 1991 found a higher number of trees with hollows in gullies and on flat terrains in Victorian montane ash forest. In this study hollow occurrence was generally highest in areas with a low to moderate slope. This influence of topographic position on the incidence of hollows could be related to wind exposure, fire effects and/or site productivity all of which may directly affect hollow formation.

Studies in mainland Australian forests have identified factors that influence the incidence of hollows (e.g. Lindenmayer *et al.* 1991; Lindenmayer *et al.* 1993, Bennett *et al.* 1994, Gibbons 1999), however researchers have found that the models developed in these studies have limited predictive ability. Insufficient data and at several spatial scales and inappropriate statistical methodology have been identified as causing the poor precision of these previous predictive models (Fox *et al.* 2001). In this study, the sampling design used to collect the data from which the predictive models were built incorporated stratification on the basis of both environmental variability and spatial scale. Replicate forest types were sampled over as wide a geographic area as logistically possible, and clusters of sites were sampled within each replicate forest type. Preliminary analysis indicated that the simplified trees with hollows model coupled with GIS data may have moderate predictive ability, however, an evaluation dataset independent of the original model needs to be collected to enable a more rigorous test. The effect of possible within-tree correlations on the analysis will also be a subject of future work, which will be approached within a Bayesian framework.

Within a particular area of forest not all available hollows are used. The type of hollow used varies between species (Table 1). Factors that have been found to influence the occupancy of hollows include, hollow characteristics (e.g. entrance width, depth of chamber, aspect), numbers of hollows in a tree, tree health, tree size, tree species, tree location and tree spacing (studies summarised in Gibbons and Lindenmayer 2002). The only published estimate for the number of hollow-bearing trees occupied by fauna in dry eucalypt forest in Tasmania is 0.4 per hectare for four species of birds in dry *E. obliqua* forest in the north-east of Tasmania (Taylor and Haseler 1993). Up to 45 of Tasmania's vertebrate hollow users (Table 1), including the bird species studied by Taylor and Haseler (1993), use hollows in the area looked at in this current study. To estimate the hollow demand by this full complement of fauna, information on the density at which the species occurs, the number and type of hollows that an individual requires, and the average number of suitable hollows per tree, is needed. Collection of such information requires considerable resources and is currently unavailable. Using a range of data collected for eucalypt forests and woodlands (predominantly mainland Australia), Gibbons and Lindenmayer (2002) estimated the proportion of all hollow-bearing trees that are occupied by vertebrates to be between 43% and 57%. Since the Tasmanian hollow-dependent vertebrate fauna (Table 1) is dominated by migratory breeding birds and lacks the diversity of arboreal marsupials characteristic of much of eastern and southern Australian forests; the proportion of occupied hollow-bearing trees may be less in Tasmania. However, in the absence of information on hollow occupancy by Tasmanian fauna, the requirement for hollow-bearing trees in the study area may be tentatively estimated using these proportions. The broad forest types looked at in this study contained between 16 – 28 potential hollow-bearing trees per hectare, so hollow-bearing trees in these forests in the south east of Tasmania can be estimated to be occupied by vertebrates at a rate of around 7 – 15 hollow-bearing trees per hectare. Estimates like these, however, may be poor because of multiple den use and changes in use over time (Gibbons and Lindenmayer 2002).

At the landscape scale hollow-bearing trees are retained throughout the study area, across all land tenures, within a network of informal reserves (e.g. streamside reserves, areas retained for other special values, unloggable areas) and formal reserves. These are largely protected areas where natural hollow development processes will continue into the future. Outside of these areas, where dry forest harvesting operations occur (on all land tenures), current Tasmanian *Forest Practices Code* prescriptions to assist the maintenance of habitat for hollow dependent fauna are applied. This includes the retention of uncut forest 100 m in width every 3-5 km (wildlife habitat strips) and patches of mature forest, containing a minimum of 2 – 3 hollow-bearing trees, every 5 ha (wildlife habitat clumps) (Forest Practices Board 2000). The overall retention rate, however, in any harvest area may actually be greater since some hollow-bearing trees are retained as part of the silvicultural system employed (Wilkinson 1989). Such retained trees, however, are typically isolated individuals with a high mortality rate due to windthrow, mechanical damage (Wapstra and Taylor 1998) and firewood harvesting (Bryant 2002).

Figure 3 shows the predicted scenario, for a forest block within the study area, if all planned coupes were harvested in a period too short to get adequate recruitment of hollow-bearing trees. Such a significant reduction in abundance of trees with hollows in areas outside the reserve system would be expected to impact most on the gregarious species (e.g. green rosella, eastern rosella, blue-winged parrot, musk lorikeet, sulphur-crested cockatoo and threatened swift parrot) that prefer to nest in areas where there is a wide choice of hollows (Bryant pers. comm., Brereton unpublished data). This 'worst case' scenario illustrates the inadequacy of the reserve system alone to retain the hollow resource for maintenance of populations of hollow dependent fauna across their range, and highlights the importance of effective 'off-reserve' management prescriptions to complement the reserve system.

Summary

The results of this study indicate factors that are associated with hollow occurrence at both the tree and site level in dry forest types in south-eastern Tasmania. Put simply, the largest available trees (>60 cm DBH if available) with major branching off the trunk, and trees where the cambium has been exposed through burn damage, should be retained. Aerial photos may be useful to assist location of such trees within a proposed logging coupe.

The site-level models in this study suggest that a higher occurrence of hollows can be expected in dry *E. obliqua* forest, in areas with a low to moderate slope and areas with older age stands. Following testing, using an independent dataset, the map of predicted occurrence of trees with hollows, produced in this study may be useful when identifying areas at the landscape scale important for conservation of habitat for hollow dependent fauna and for assessing the impacts of different land-use scenarios.

If the aim is to maintain populations of hollow dependent fauna throughout their range then there may be a need to revise current prescriptions for the retention of hollow-bearing trees in 'off-reserve' areas. The rate of retention, spatial application of retention prescriptions and application of measures to ensure recruitment of hollow-bearing trees needs to be addressed, particularly in areas important for threatened hollow dependent fauna. The results of current work (Koch pers. comm.) on the occurrence of hollow-bearing trees actually used by fauna, is required to further inform decisions on particular trees to retain and appropriate hollow tree retention rates for fauna in Tasmania's forests.

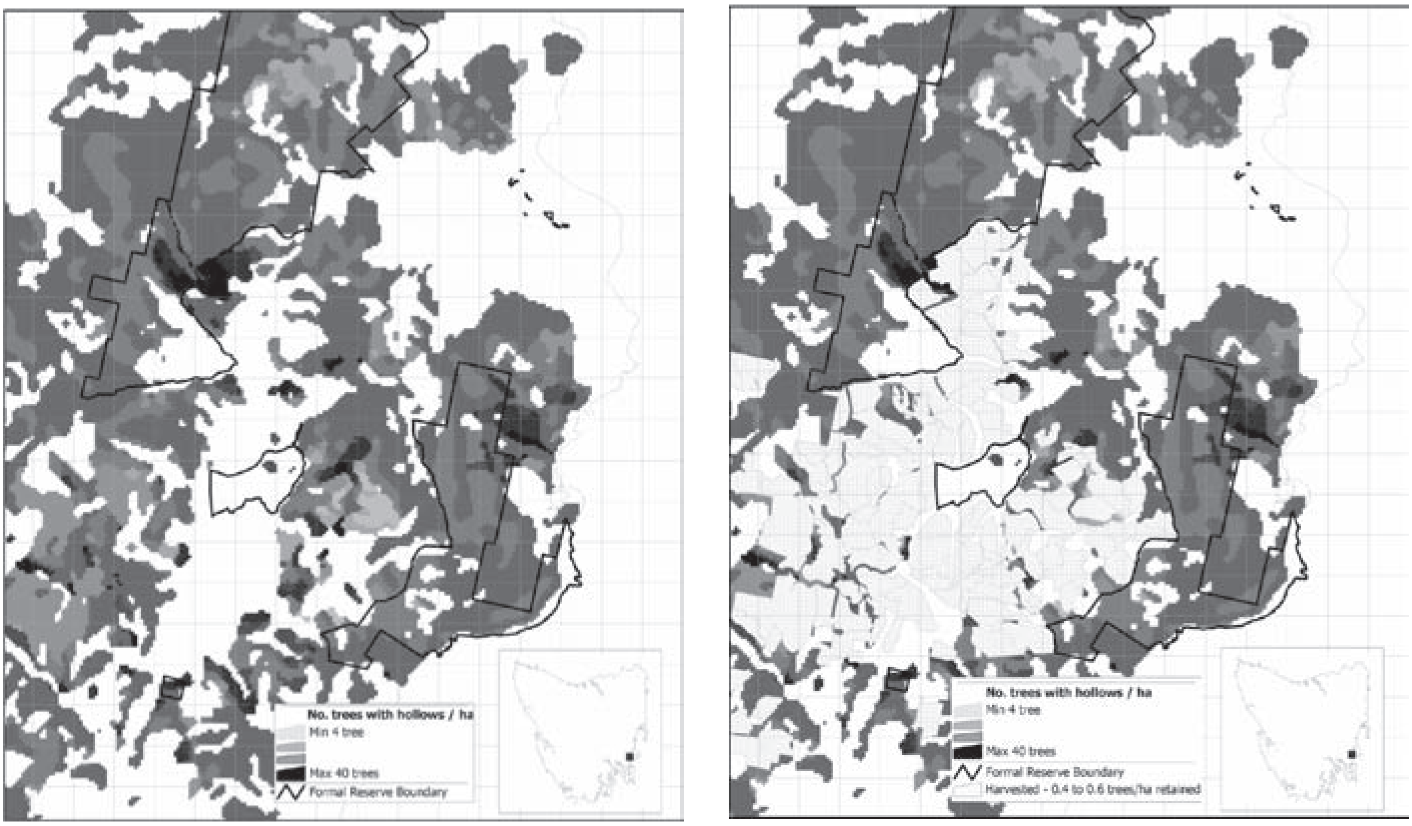

Figure 3. The predicted number of trees with potential hollows/ha for a forest block within the study area (a) prior to harvesting of planned State forest coupes (Forestry Tasmania as of February 06) and (b) after all planned State forest coupes have been harvested. Note that white areas include areas where trees with hollows are not found, other forest types not surveyed in this study and non forest vegetation types, including cleared land. Grid = 1km^2

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