Hollow futures? Tree decline, lag effects and hollow-dependent species

Adrian D. Manning†
The Fenner School of Environment and Society
The Australian National University
Canberra, ACT 0200
Australia
adrian.manning@anu.edu.au
Telephone: +61 2 6125 5415
Fax: +61 2 6125 0757

Philip Gibbons
The Fenner School of Environment and Society
The Australian National University
Canberra, ACT 0200
Australia
philip.gibbons@anu.edu.au

Joern Fischer
Leuphana Universität Lüneburg
Scharnhorststraße 1
D 21335 Lüneburg
Germany
joern.fischer@leuphana.de

Damon Oliver
Biodiversity Conservation Section, Office of Environment and Heritage, Department
of Premier and Cabinet
Level 3, 11 Farrer Place
PO Box 733
QUEANBEYAN
NSW 2620
Australia
Damon.Oliver@environment.nsw.gov.au

David B. Lindenmayer
The Fenner School of Environment and Society, ARC Centre of Excellence for
Environmental Decisions, National Environmental Research Program
The Australian National University
Canberra
ACT 0200
Australia
david.lindenmayer@anu.edu.au

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† Corresponding author
Abstract

Tree hollows are a critical breeding resource for many organisms globally. Where hollow-bearing trees are in decline, population limitation can be a serious conservation issue. A particular problem in addressing hollow limitation is the long time that hollows take to form. This means there can be a significant lag time between detecting a species’ population decline, and arresting the lack of hollows through reducing tree mortality and increasing regeneration. Once underway, declines of hollow-dependent species therefore can be difficult to halt. It is imperative that we identify and anticipate such future problems before they occur, and implement conservation action in advance. In this study, we use a novel application of an established modelling method to explore this issue and illustrate an ‘early warning’ approach, focusing on a case study of the vulnerable superb parrot (*Polytelis swainsonii*) from south-eastern Australia. The species is dependent on hollow-bearing trees for nesting that have a very long generation time (>120 years). Potential nest trees for the superb parrot are on a trajectory of decline. We modelled the future hollow resource for this species under different management scenarios including: (a) business-as-usual – i.e. no further specific conservation action; (b) and (c) waiting until considerable further reductions (90% and 70%) in hollows before implementing conservation actions to replace hollow-bearing trees; and (d) implementing enhanced conservation actions now to redress loss of hollows. We found that all scenarios except (d) ‘conservation action now’, resulted in substantial declines in potential nest trees, and came at significant opportunity cost in terms of reducing tree mortality and increasing tree regeneration. Delaying conservation action will greatly increase the long-term risk of extinction of hollow-dependent species. Predicting and slowing the decline in available hollows by early by early intervention and restoration
management is critical, even if hollow-dependent species populations may appear to be secure in the short-term.
Introduction

Tree hollows provide a critical breeding resource for many organisms globally. For example, across Europe, North America, Southern Africa and Australia, 18% of birds use hollows for nesting, and 11% are obligate users (Newton, 1994). In situations where tree populations are in decline, the associated reduction in hollow availability has been associated with a decline in hollow-using species (Newton, 1994, Gibbons & Lindenmayer, 2002, Marsden & Pilgrim, 2003, Aitken & Martin, 2008, Heinsohn et al., 2009).

Reversing the decline in hollow-bearing trees population is complicated by ‘lag effects’. These describe the delay between initiation of actions to halt and reverse tree decline, and the time needed for trees to be old and large enough to produce suitable hollows (>120 years) (Manning et al., 2004, Gibbons et al., 2008). Lag effects have serious implications for threatened, hollow-dependent species (Saunders et al., 2003, Maron, 2005), potentially resulting in an extinction debt (Tilman et al., 1994), that is, a future commitment to extinction from action (or inaction) now. Delay in beginning tree protection and restoration risks producing increasingly long, hollow-scarce population bottlenecks in the future, due to the long time it takes for hollows to form (Manning et al., 2004, Gibbons et al., 2008). This has direct, long-term implications for populations of hollow-dependent species.

Here, we explore the role of lag effects on the availability of potential nest trees of an obligate hollow using species, namely the vulnerable superb parrot (*Polytelis swainsonii*) in south-eastern Australia. A key challenge in planning conservation action for hollow-dependent taxa is to predict which species will be at risk from future hollow scarcity. Population estimates and simple extrapolation of trends based on passive monitoring can sometimes have limited predictive power.
To predict long-term conservation risk, some understanding of ecological processes affecting critical resources that limit populations of a given species is essential. We examined a key ecological process by modelling recruitment and mortality of populations of potential nest trees for the superb parrot. Our aim was to explore the possible risks of delaying conservation actions to protect and restore hollow-bearing trees. We used an established method for modelling scattered tree populations (Gibbons et al., 2008, Fischer et al., 2010, Gibbons et al., 2010), to simulate and predict future hollow scarcity under different conservation scenarios. Our key questions were:

1. What is the effect of current management practices on potential nest trees if these practices continue into the future?
2. What is the effect of delaying tree conservation and restoration actions until potential nest tree populations drop substantially (by 70% to 90% of current levels)?
3. What is the effect of immediately acting to reduce potential nest tree mortality and increase recruitment?

Our analysis provides an ‘early warning’ approach that can be adapted to other obligate hollow nesting species.

Materials and Methods

Study species

The superb parrot (weight 130 – 160 g, wingspan 53 – 57 cm, length approximately 40 cm), occurs in a restricted range in south-eastern Australia (Webster, 1988, Webster & Ahern, 1992, Higgins, 1999). It nests in hollows in branches and tree trunks, and breeds between September and December (Webster, 1988, Webster & Ahern, 1992, Manning et al., 2004).
Across a significant part of its range, the superb parrot breeds in agricultural landscapes with scattered hollow-bearing trees (Manning et al., 2004). These trees are remnants from temperate eucalypt woodlands that have been converted for cultivation and livestock grazing. While the superb parrot persists in these landscapes, the regeneration of the trees on which it depends for nest hollows has largely ceased due to suppression of tree regeneration from livestock grazing, cultivation, exotic plants and other human-induced disturbances (Fischer et al., 2009, Weinberg et al., 2011). Because mortality among existing trees is also high (Ozolins et al., 2001), the number of trees with hollows is declining (Gibbons et al., 2008).

Study area

The study area is a major breeding area of the superb parrot, located on the South–West Slopes of New South Wales (33° 25’–35° 18’S; 147° 41’–149° 24’E, approximately 24,740 km²; Manning et al. 2004). The vegetation type used by the superb parrot in this region is box-gum grassy woodland dominated by yellow box (Eucalyptus melliodora), Blakely’s red gum (E. blakelyi) and white box (E. albens), often in conjunction with other species such as apple box (E. bridgesiana), mealy bundy (E. nortonii), red box (E. polyanthemos), candlebark (E. rubida), brittle gum (E. mannifera) and red stringy bark (E. macrorhyncha) (Benson, 1991, Benson, 1999, NSW NPWS, 2002). These woodlands once covered an extensive area of south-eastern Australia (Beadle, 1981, Department of Environment and Heritage, 2006). However, over 92% of woodland has been cleared, and what remains is highly modified (Threatened Species Scientific Committee, 2006), mostly consisting of small remnant patches and scattered paddock trees (Gibbons & Boak, 2002, Manning
et al., 2004). Consequently, box-gum grassy woodlands are listed as a critically endangered ecological community (Department of Environment and Heritage 2006).

Predicting the availability of potential nest trees for the superb parrot

We used a simulation model described by Gibbons et al. (2008) and populated it with datasets from within our study area to predict the future availability of potential nest trees for the superb parrot under different conservation scenarios. This simulation model tracks the mean diameter at breast height (DBH) and mean number of trees with hollows in stands through time with recruitment and mortality applied at pre-defined rates. The simulation model is stochastic in the sense that parameters in the model (e.g. tree mortality) can be entered as random values within a range of observed or likely values. The model is then run as many times as there are random values so predictions for any single scenario are calculated as a range of values from multiple runs of the model. The different steps in the simulation modelling and data used to populate each step are described below.

1. Populate the simulation model with tree diameter distribution data

The first step was to populate the simulation model with data for existing trees in the study area. We calculated the mean number of trees in 10 cm DBH classes (i.e., 0-10 cm, 11-20 cm, etc.) for each tree species and health class (i.e., living or dead), based on data collected at 48 separate 2 ha sites in the agricultural matrix within our study area (the range of diameters recorded in the 48 x 2ha sites was 1cm – 232cm DBH).

2. Identify potential nest trees for the superb parrot
Second, we predicted the proportion of trees that are potential nest trees for the superb parrot. Manning et al. (2004) observed that 98% of 136 nest hollows used by the superb parrot had a minimum entrance width ≥5cm, so we recorded a tree as a potential nest tree for the superb parrot if it contained ≥1 hollow with an estimated minimum entrance width ≥5cm. Hollows ≤1m above the ground, in cut stumps and in fire scars at the base of trees were not recorded.

We recorded the presence/absence of hollows with minimum entrance width ≥5cm, DBH and tree species in all living and dead trees ≥5cm DBH at 513 50m × 20m plots. These plots were part of a different study than the 48 sites described in step 1, but were located in the same study region. In these 513 plots, we recorded 2665 living trees (Blakely’s red gum, yellow box, white box, red box, mealy bundy and apple box) and 192 dead trees. We predicted the proportion of living trees that are potential nest trees for the superb parrot by fitting a Generalised Linear Model (GLM) with a logit link to these data in which the presence/absence of at least one hollow potentially suitable for the superb parrot in a tree (p_l) was the (binary) response variable and DBH and tree species the explanatory variables. This model was:

$$\logit (p_l) = -4.1129 + (0.0718 \times DBH) - 2.3761 \times \text{Species group}$$  

where Species group was a factor with two levels (Species group 1 is white box, red box, mealy bundy and apple box. Species group 2 is yellow box and Blakely’s red gum). The relationships between DBH and the probability of hollows suitable for the superb parrot were not significantly different between the tree species in each group. The area under the Receiver Operating Characteristic curve (AUC) for this model was 0.93 indicating the model had “excellent” discriminating ability (Pearce & Ferrier,
The model used for predicting the proportion of dead trees that are potential
nest trees for the superb parrot ($p_d$) was:

$$\text{logit} (p_d) = -3.4715 + (0.0809 \times \text{DBH})$$  \hspace{1cm} \text{Equation 2}

The AUC for this model was 0.83, indicating the model had “good” discriminating
ability (Pearce & Ferrier, 2000).

### 3. Recruitment of new potential nest trees over time

To simulate the development of new potential nest trees for the superb parrot over
time, we developed a relationship between tree age and DBH for the two groups of
tree species used in Equation 1 to predict potential nest trees. However, data on the
relationship between age and DBH only exist for one tree species in our study area
derived the following relationship to predict the ages of yellow box trees:

$$\text{Age} = 0.019714 \times \pi \times (\text{DBH}_{\text{standardized}}/2)^2$$  \hspace{1cm} \text{Equation 3}

Where $\text{DBH}_{\text{standardised}}$ is the “yellow box equivalent diameter” for each tree as
explained below.” To also predict the ages of trees of other species, we followed the
procedure outlined by Fischer et al. (2010) and calculated a ‘yellow box equivalent
diameter’ for each individual tree of the various other eucalypt species. The procedure
assumed that all eucalypt species in our study area follow an identical growth curve
relative to their maximum attainable diameter, and have the same approximate life-
span as yellow box. DBH values for all tree species were initially standardised to a
value between zero and one, as a proportion of the maximum attainable diameter (i.e. the maximum diameter observed in the field). Those values were then multiplied by the maximum diameter observed for yellow box to obtain a ‘yellow box equivalent diameter’. Equation 3 was then used to estimate the ages of these trees. We acknowledge that this procedure is unlikely to give precise age estimates, but it is a pragmatic solution given the paucity of data available for trees in our study area.

To determine how many new potential nest trees were recruited over time, we: (1) standardized DBH values for each cohort (DBH class) to “yellow box equivalents”, (2) predicted age from DBH for each cohort using Equation 3, (3) added the number of years equivalent to each time-step in the simulation, (4) used the inverse of Equation 3 to predict the DBH of the cohort at the end of this time-step, and (5) converted standardized DBH values back to raw values for each tree species. These final DBH values were then used to predict what proportion of trees will be potential nest trees in the future, using Equation 1 for living trees, or Equation 2 for dead trees.

The time-step in the simulation model was equivalent to the period between regeneration events (i.e. when new eucalypts become established). The mean age of trees in the smallest DBH classes (0-20cm DBH) recorded at the 48 sites was approximately 5-12 years. We used the most optimistic (shortest) period of 5 years between regeneration events in all scenarios representing business as usual (i.e. current management approaches continue into the future). This means that the model is a ‘best case scenario’ when regeneration is more limited. Gibbons et al. (2008) found that the number of scattered trees perpetuated over the long-term is sensitive to the number of trees recruited during each regeneration event. Therefore, for
simulations representing business-as-usual, we recruited trees at the mean (±SE) rate of 0.02±0.01 per ha for species group 1 (yellow box, Blakely's red gum) and 0.22±0.18 per ha for species group 2 (white box, mealy bundy, apple box), which is the mean (±SE) number of trees we recorded in the smallest DBH classes (0-20cm DBH) at the 48 sites. These data were entered stochastically. That is, a random value for the number of trees (per ha) recruited every time-step was selected from a normal distribution with a mean (±SE) equivalent to the estimates obtained for each tree species group.

4. Mortality of trees

We included two sources of mortality in our model. We calculated annual mortality from data collected on changes in the densities of scattered trees between 1964 and 1994 within the study area (Cowra 8630 map sheet, Geoscience Australia) (Ozolins et al., 2001). The mean (±SE) for annual mortality was 0.013±0.005. Gibbons et al. (2008) found that the numbers of scattered trees in these landscapes was highly sensitive to annual mortality, so we populated the simulation model with these data stochastically. For each run of the simulation model, we selected mean annual mortality randomly from a normal distribution with a mean±SE of 0.013±0.005. We also set, at 500, the maximum number of years that trees will remain living or standing, which is based on longevity estimates for yellow box reported by Banks (1997). There were no other data from which this estimate could be derived and Gibbons et al. (2008) report that the number of scattered trees is not sensitive to this parameter in simulations of this type.

5. Predictions from the simulation model
For each scenario, we predicted the mean (±95% prediction interval) numbers of potential nest trees for the superb parrot at each time-step, or at the end of each recruitment event, over 100 runs of the simulation model.

Simulated Scenarios

We simulated four alternative scenarios for conserving potential nest trees of the superb parrot. We use scenarios because they provide decision-makers with a broad range of management options to consider. Further, we know that persistence of tree hollows is most sensitive to mortality and recruitment (Gibbons et al. 2008), and different scenarios allow us to explore the effects of altering these key parameters. We include one scenario that is no further conservation action (a), and two based on the IUCN criteria for listing species ((b) and (c); IUCN, 2002). We did this because (1) these scenarios relate to the percentage decline in a given population needed to meet the criteria for two IUCN status levels (Critically Endangered and Endangered), and (2) a link between superb parrots populations and nest hollow availability is highly likely in the study area (see Discussion). The final scenario (d) relates to immediate conservation action to improve current levels of mortality and recruitment.

(a) No further conservation actions. Under this scenario, we commenced the simulation using current potential nest tree densities in the agricultural matrix (3.9 per ha), which is, conservatively, half of the mean density of potential nest trees that occurs in relatively unmodified remnants dominated by yellow box and Blakely’s red gum (Gibbons et al., 2008). Current rural land management practices are assumed to continue, so no action is taken to increase existing tree landscape-scale tree recruitment or reduce existing tree mortality.
(b) Wait until 90% reduction in potential nest trees. We used the IUCN criterion of a 90% population decline (though not its rate) as a guide to trigger for conservation actions—this would equate to ‘Critically Endangered’ status if considering a species (IUCN, 2002). Under this scenario, we allowed potential nest tree density to drop to 0.8 per ha or approximately 10% of pre-clearing levels, before landscape-scale tree recruitment at the rate of one new tree per ha planted every 10 years and reduction of annual tree mortality to half current levels.

(c) Wait until 70% reduction in potential nest trees. We used the IUCN criterion of a 70% reduction (though not the rate) as a guide to trigger conservation actions—this would equate to ‘Endangered’ status if considering a species (IUCN, 2002). Under this scenario, we allowed the potential nest trees density to drop to approximately 30% of pre-clearing levels (2.4 per ha), before there was landscape-scale tree recruitment at the rate of one new tree per ha planted every 10 years and reduction of annual tree mortality to half current levels.

(d) Implement enhanced conservation actions now. Under this scenario, we immediately implemented landscape-scale tree recruitment at the rate of one new tree per ha planted every 10 years and reduced of tree mortality to half current levels.

Scenario (a) represents the most likely (i.e. business-as-usual) scenario. Scenarios (b) and (c) were chosen to represent the implications of waiting until there are further reductions in populations of the superb parrot before triggering a higher threat status and therefore increased conservation efforts. Scenario (d) represents the
case where decline in potential nest trees to date triggers an immediate increase in conservation resources to redress the major factors causing the decline of potential nest trees. This is the least likely scenario.

Results

(a) No further conservation actions. Under this scenario, our modelling indicated that the density of potential nest trees would continue to decline from the current estimate of 3.9 per ha, which is approximately 50% of the original (pre-clearing) estimate (8 per ha), over the 200 year simulation period (Figure 1a). The predicted mean density of potential nest trees declined to 6% of the original (pre-clearing) estimate by the end of the simulation period (200 years).
Figure 1. Predicted numbers (mean ± 95% prediction interval) of potential nest trees (per ha) for the superb parrot over 200 years under scenarios of (a) business-as-usual (no further conservation actions); (b) wait until 90% reduction in potential nest trees before implementing conservation actions; (c) wait until 70% reduction in potential nest trees before implementing conservation actions; and (d) implement enhanced conservation actions now.

(b) Wait until 90% reduction in potential nest trees. Under this scenario, we waited until a 90% decline in the density of potential nest trees relative to an original
(pre-clearing) estimate (8 per ha) before implementing restoration actions. A predicted 90% decline in the mean density of potential nest trees relative to the original (pre-clearing) density occurred after 135 years. After initiation of restoration actions (reducing tree mortality and increasing tree recruitment), the predicted mean density of potential nest trees began to increase (Figure 1b), but reached only 29% of the original (pre-clearing) mean density by the end of the simulation period (200 years).

(c) Wait until 70% reduction in potential nest trees. Under this scenario, we waited until a 70% decline in potential nest trees relative to the original (pre-clearing) estimate (8 per ha) before taking action. A predicted 70% decline in mean potential nest trees density relative to original (pre-clearing) density occurred after 40 years. After initiation of restoration actions (reduced tree mortality and increased tree recruitment), the predicted mean density of potential nest trees began to increase (Figure 1c). By 200 years, the mean density of potential nest trees had reached 3.6 per ha, still below the current mean density, and 45% of the original (pre-clearing) mean density.

(d) Implement enhanced conservation actions now. Under this scenario, we immediately initiated restoration actions (reducing tree mortality and increasing tree recruitment). The predicted mean density of potential nest trees remained relatively stable over the simulation period. The predicted mean density of potential nest trees declined from the current mean density of 3.9 per ha to 3.6 per ha at 60 years before increasing to a mean of 4.1 per ha at the end of the simulation period (200 years), which is slightly above the current density (Figure 1d).
Discussion

Conservation of hollow-dependent species in woodland and forest is a global issue (Saunders et al., 1982, Newton, 1994, Newton, 1998, Gibbons & Lindenmayer, 2002, Lindenmayer et al., 2011). We have used one species, the superb parrot, to illustrate the universal problem of lag effects in managing potential nest trees of hollow-dependent species. To do this, we examined the effect of different conservation scenarios on potential nest trees for an obligate hollow using species to illustrate the risk associated with lag effects. Our results show that it is essential to anticipate future hollow-limited bottlenecks as a result of long-term tree decline.

In three out of four scenarios ((a) to (c)), the number of potential nest trees was predicted to decline substantially. Even where a delayed response eventually took place ((b) and (c)), potential nest trees did not recover to current levels within 200 years. Under Scenario (a) (“no further conservation action”), the potential for eventual local extinction of the superb parrot within the study area, as potential nest trees decline to very low densities, is evident. Although scenarios (b) and (c) did eventually begin to reverse the decline in potential nest trees, the risk is that society at that time may not choose, or be able to, act. Furthermore, if our predictions prove to be overly optimistic, e.g. because our models were too conservative (see Material and Methods), or if tree clearing accelerates (see below), the possibilities to act effectively in the future may be severely constrained. The only scenario that resulted in the predicted number of potential nest trees remaining stable over the next 200 years was Scenario (d) (“implement enhanced conservation actions now”). This indicates that immediate action to reduce tree mortality and enhance tree regeneration within the
study area will be essential to avoid serious impact on hollow-availability for at least
200 years.

The mortality of scattered trees where they occur around the world is often
increased by the intensification of agricultural production (Manning et al., 2006a). For
example, cultivated land expanded by 75% in our study area between the 1960s and
1990s (Ozolins et al., 2001). Global food demand is predicted to increase by 70 to
100% by 2050 (Godfray et al., 2010). In our study area, the growth of cultivated land
is predicted to increase (Zhang et al. 2006; Grain Research and Development
Corporation 2010). In recent years, the majority of permits issued to clear native
vegetation in this region have been associated with either converting pastoral land to
cultivation, or introducing technologies (e.g., pivot irrigators, control-traffic farming)
to increase productivity in cultivated land. Many of these applications can have a
detrimental impact on the superb parrot. For example, in New South Wales over a
three-year period from 2008-2011, 114 applications to clear native vegetation
(including 85 applications to clear scattered paddock trees) had the superb parrot
listed a likely to occur on the site. Of these, 49 applications were within our study
area (NSW Office of Environment and Heritage, 2011). Our results clearly
demonstrate that any actions that undermine or delay conservation efforts to reduce
tree mortality and increased recruitment (i.e. Scenario (d)) should be avoided.

Artificial nest boxes have been suggested as a possible approach to overcome
hollow scarcity (McComb & Noble, 1981, Twedt & Henne-Kerr, 2001). However,
recent monitoring of 3200 nest boxes placed along a major four-lane highway that
crosses superb parrot breeding areas, has not found a single breeding event in these
artificial structures (D. Lindenmayer et al., unpublished data). It is also not clear that
nest boxes could be placed in sufficient numbers, at a landscape scale, and be
maintained continuously for the recovery periods indicated by this study. Current knowledge suggests that the maintenance and perpetuation of hollow-bearing trees is the most plausible solution for the conservation of the superb parrot.

In interpreting all scenarios, we assumed a positive relationship between the density of potential nest trees and populations of the superb parrot. This relationship is widely reported for hollow-dependent birds (Newton, 1994, Gibbons & Lindenmayer, 2002, Marsden & Pilgrim, 2003, Murphy et al., 2003, Saunders et al., 2003, Heinsohn et al., 2009), and has been shown experimentally (Brawn & Balda, 1988, Aitken & Martin, 2008). However, the level at which hollow availability limits populations of the superb parrot is unknown. As with other hollow-dependent species, this will vary spatially, and in relation tree and hollow availability and competition from other species (Newton, 1998, Manning et al., 2004).

It has been postulated in a study of potential nest trees in roadside vegetation that hollows were unlikely to be limiting for the superb parrot (Davey & Purchase, 2004). It is highly unlikely such a conclusion (which is speculative only) could validly be extrapolated to the trees in the agricultural matrix that we modelled. This is because: (1) Roadside vegetation is among the most undisturbed native vegetation in this part of Australia (van der Ree & Bennett, 2001) and empirical research within the study areas has shown considerable differences in tree density between travelling stock reserves and adjacent paddocks (Lentini et al. 2011). Lentini et al. (2011, unpublished data) found that travelling stock reserves has on average 90.7 stems per ha (±25.85) compared to 5.6 stems per ha (±1.51) in adjacent paddocks. Furthermore, exotic 4.1 (±1.49), wheat 2.2 (±0.43), canola 1.6 (±0.53), and Lucerne or clover paddocks 1.5 (±0.37) had even fewer stems per ha. As such land uses are the majority in landscapes used by the superb parrots, this has profound implications for the
relative amount of hollows available (see below), and process-based prediction of population sustainability. (2) There is greater level of threat from clearing, spray drift and fertilizers to trees in the agricultural matrix (Manning & Fischer, 2010) compared to trees in roadsides. (3) Roadsides represent a small proportion of the landscape compared to the agricultural matrix (the area we have modelled) where the majority of superb parrots occur (Manning et al., 2006b). Scattered trees and small remnants (<1ha) of the agricultural matrix represent 54% of the total area remaining of this woodland (Gibbons and Boak 2002). (4) Hollow availability in box-gum grassy woodland with very low tree densities (< 6 per stems ha over 15cm DBH), supports very low numbers of hollows potentially suitable for superb parrots (11 hollows over 5cm diameter per ha) compared to low density (6 – 10 stems per ha and 31 hollows), medium density (11 – 50 stems and 74 hollows per ha, and high density (51 – 100 stems and 111 hollows per ha) (L. Rayner, unpublished data). Low density scattered trees are typical of the landscapes occupied by the superb parrot in the study area. Manning et al. (2004) found most (60%) of superb parrot nest trees in the study area were surrounded by only 1 – 5 trees within 50 metres. Manning et al. (2006b) found most superb parrots occurred where there was low density woodland. Therefore, we believe that it is reasonable to assume that as tree populations continue to decline in the agricultural matrix (as we have predicted), hollow availability will further limit the population size of the superb parrot (see Newton 1994; Newton 1998). Critically, it is the inexorable trend observed in our modelling that should be of serious concern to conservation decision-makers. Failure to identify and respond appropriately to lag effects in restoration of nest hollows will place many dependent species at increased risk of extinction in the future. The predicted effects of lag times on tree hollow-dependent species are now beginning to be documented (e.g. Saunders et al., 2003,
Maron, 2005). Not only does waiting to act increase extinction risk and reduces future response options, but it is also is likely to cost more (i.e., more trees will need to be regenerated) and potentially will be less successful due to synergistic processes affecting small populations such as inbreeding and stochastic events (Lindenmayer & Fischer, 2006). Our novel application of an established modelling method provides an early warning approach that conservation managers can use to identify species at risk from longer-term ecological trends so that they can initiate vigorous conservation measures now. Without such approaches, there is a serious risk that species facing future bottlenecks in key resources, such as those dependent on hollows, will always be disadvantaged by classification systems that assign conservation threat level based on past population trends.

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