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Do woodland birds prefer to forage in healthy *Eucalyptus wandoo* trees?

Woodland birds and tree condition

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Globally, many forests and woodlands are in decline. The marked loss of canopy foliage typical of these declines results in reduced foraging resources (e.g. nectar, pollen, and insects) and, subsequently, can reduce habitat quality for woodland birds. In south-west Western Australia, patches of *Eucalyptus wandoo* woodlands have shown a decline in condition since at least 2002. We investigated how changes in *E. wandoo* condition affect the woodland bird community. Foraging activities of three bird species were recorded for 20 sites in Dryandra State Forest and Wandoo Conservation Park either by conducting watches on focal trees ('sitting' method), or following individuals through the woodland ('following' method). Condition assessments of trees used by the birds were compared with those for trees available at the study site. Weebills (*Smicrornis brevirostris*; canopy insectivore) displayed preference for healthy trees (low amounts of canopy dieback), whereas rufous treecreepers (*Climacteris rufa*; bark-foraging insectivore) preferred trees with a higher proportion of dead branches. Yellow-plumed honeyeaters (*Lichenostomus ornatus*; insectivore/nectarivore) foraged in older, larger *E. wandoo* trees having full canopies with few signs of tree decline. Tree declines, such as that happening in *E. wandoo*, alter the foraging resources and habitat available to woodland birds.

Additional keywords: foraging resources, habitat, tree condition, tree decline.

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Introduction

Around Australia, woodland birds are showing population declines (Bennett and Watson 2011; Ford 2011). These changes have been linked with habitat change at the landscape and microhabitat scales (Watson *et al.* 2004b; Doerr *et al.* 2011). Climate change, land clearing, agriculture, and tree decline alter the woodlands and foraging resources for many guilds of birds, through alteration in the habitat quality and resources. Changes in habitat and foraging resources can alter the foraging behaviour and activity of birds (Calver and Dell 1998; Ford *et al.* 2001; McGinness *et al.* 2010; Doerr *et al.* 2011; Ford 2011). For example, landscape alteration and a lack of connectivity between remaining fragments of native vegetation specifically restricts the foraging movement and behaviour of the brown treecreeper (*Climacteris picumnus*) in New South Wales (Doerr *et al.* 2011). On the other hand, the

activities of birds can also influence habitat condition. For example, several studies have investigated the relationship between canopy decline and bell miners (*Manorina melanophrys*). Territorial bell miners exclude insectivorous birds that would usually control the populations of sap-feeding insects (e.g. psyllids) that feed on and defoliate eucalypts; the absence of insectivorous birds therefore contributes to tree decline (Stone 1996; Bradstock *et al.* 2005; Haywood and Stone 2011). The interactions between habitat and birds are most likely species-specific, and highlight the need to understand the specific habitat and feeding requirements of bird guilds (Radford *et al.* 2005) to predict their vulnerability to habitat changes.

Declines in tree condition and increases in tree mortality are occurring worldwide on a massive scale (Reid and Landsberg 2000; Close and Davidson 2004; Allen *et al.* 2010). Jurskis (2005) reviews many studies on decline episodes from all States around Australia, several occurring in each state. The causes of these declines are sometimes simple; however, in most cases, there appears to be a complex interplay of persistent abiotic and biotic damaging factors and mechanisms (Manion 1991). For example, fire suppression (Close *et al.* 2009), bell-miner activities (Stone 1996), climate change (Allen *et al.* 2010), and *Phytophthora cinnamomi* 'dieback' (Shea *et al.* 1983; Tippett *et al.* 1985) are all factors linked to tree declines. The slow progressive death of trees results in highly visible symptoms (Stone 1999), including the death of the upper portions of the tree foliage and loss of tree branches, resulting in an overall reduction in crown density (Stone 1999; Jurskis and Turner 2002; Jurskis 2005; Carnegie 2007; Davidson *et al.* 2007; Robinson 2008; Whitford *et al.* 2008). These changes in tree condition are likely to affect the activities of some bird guilds. For example, a study investigating the role of tuart (*Eucalyptus gomphocephala*) decline on birds identified that some feeding guilds may benefit from tree decline and the associated changes in resources, while other guilds are disadvantaged (Wentzel 2010). Long-term tree declines are, therefore, likely to result in changes in avifaunal diversity due to altered habitat quality and foraging resources (Loyn and Middleton 1980; Gorrod 2006).

Eucalyptus wandoo is a smooth-barked eucalypt endemic to Western Australia that has shown signs of episodic decline in condition since the 1960s, with the most recent decline commencing in 2002 (Hooper and Sivasithamparam 2005; Wandoo Recovery Group 2006). Decline in *E. wandoo* manifests as heterogeneous changes across the landscape, where declining trees can often be directly adjacent to apparently healthy trees, no tree mortality is evident, and the trees may also recover after a period of canopy loss (Brouwers *et al.* 2012). This decline is therefore unlike decline in jarrah (*Eucalyptus marginata*) in response to drought and high temperatures, where the whole canopy of trees is lost over a short period for patches of trees across the landscape (Matusick *et al.* 2012), and more closely resembles the responses of these trees to the presence of disease (Shea *et al.* 1983; Dakin *et al.* 2010).

The objective of the present study was to determine how the condition of *E. wandoo* trees influenced the tree selection by three common bird species (which are present in sufficient numbers to

determine patterns of habitat preference). It was predicted that a declining canopy would lead to loss of food resources for several bird guilds (e.g. nectarivores, canopy-feeding insectivores and leaf gleaners). Epicormic growth is new flushes of growth in the canopy which is evident as trees recover (Landsberg 1985; Hobbs and Atkins 1988; Jurskis 2005). Epicormic growth may increase the foraging resources available to insectivores (e.g. weebills, *Smicrornis brevirostris*) (Arnold *et al.* 1987), as epicormic foliage may support more insects compared with established canopy (Landsberg and Wylie 1983; Landsberg 1988; Recher *et al.* 1996). Yellow-plumed honeyeaters (*Lichenostomus ornatus*) utilise foraging resources such as lerp, manna, and insects (Wilson and Recher 2001), which are found only in tree canopies and are likely to be absent for trees that have lost their canopy. *E. wandoo* trees showing a loss of canopy may therefore have fewer yellow-plumed honeyeaters foraging within them. Other guilds may benefit from an increase in foraging resources; for example, birds that make use of wood and dead branches as a foraging substrate (e.g. rufous treecreepers, *Climacteris rufa*) (Craig 2007) may benefit from the presence of trees in decline. The aim of this study was to test these predictions by comparing the condition of trees where birds were observed foraging with the condition of other trees available at the sites.

Methods

Site description

Study sites were located in *E. wandoo*-dominated woodlands in Dryandra State Forest (32°48'S, 116°53'E, 160 km south-east of Perth, Western Australia), and Wandoo Conservation Park (31°54'S, 116°27'E, 75 km east of Perth). *E. wandoo* woodlands once covered most of the wheatbelt region, but clearing for agriculture has resulted in only 40% of the original *E. wandoo*-dominated woodlands remaining (Mattiske Consulting Pty Ltd and Havel Land Consultants 1998; Doughty 2000). *E. wandoo* woodlands have an open canopy (~30% canopy cover) with a patchy understorey of small shrubs usually <1 m high, including *Gastrolobium* spp., *Macrozamia riedlei* and *Xanthorrhoea preissii* and a grassy herb layer (Yates and Hobbs 1997). Both reserves have histories of land clearing, stock grazing, harvesting (logging) and controlled fire management (Department of Conservation and Land Management 1980).

Observations were conducted at 20 sites in total, 10 each in Dryandra State Forest and Wandoo Conservation Park, with each site being a square 1-ha area. Sites were chosen using Vegmachine 2.0 (2010, CSIRO), which assesses changes in vegetation condition over a landscape through differences in its reflectance (Landsat imagery), classifying the vegetation as increasing, decreasing or stable. The times compared for this study were 1999 and 2009, as this was the period during which decline in *E. wandoo* had been noted (Mercer 2003; Whitford *et al.* 2008). Vegmachine was used to identify suitable sites at the desktop, and the exact location of sites and trees was determined by ground-truthing.

Surveying foraging woodland birds

Bird activity was recorded in order to determine the correlation between tree condition and the use of trees by foraging birds. The three bird species observed were the nectarivorous/insectivorous yellow-plumed honeyeater, and two insectivorous species: the weebill and the rufous treecreeper. The body size, diet and foraging ecology of these species differ and they utilise different parts of the *E. wandoo* trees (Table 1). These species are also commonly sighted in *E. wandoo* woodlands and therefore would be sighted often enough for adequate data collection and analysis. It was predicted that the foraging activities of each species would be influenced by different tree characteristics of the *E. wandoo* decline. Other species were recorded at these sites – striated pardalotes (*Pardalotus striatus*), red wattle birds (*Anthochaera carunculata*), and western wattlebirds (*Anthochaera lunulata*) – but sample sizes were inadequate for data analyses.

All observations were conducted by TLM using binoculars and recorded into a voice recorder for mornings (0600–1100 hours) and afternoons (1400–1600 hours) between July and October 2010. All 20 sites were visited each month (i.e. four surveys per site overall) and observations were carried out over eight days of each month to complete the recordings/data collection at all sites. The sites were returned to in random order to account for slight differences in the time of day.

The decline of *E. wandoo* woodlands is cyclic and patchy (Brouwers *et al.* 2012); no tree mortality is witnessed and healthy trees are often adjacent to declining trees. This made it difficult to work at a community level when, within a site, there is much variation in the condition of individual *E. wandoo* trees. In order to take this variation in *E. wandoo* condition into consideration when determining tree selection by the three bird species, the techniques observed the use of individual trees by birds. To ensure sufficient numbers of observations for analysis were made, two techniques were used for recording bird foraging and activity on individual trees. These methods were:

Method 1 The ‘sitting’ method entailed identifying which trees were either used or not used by birds during the survey period. The observer positioned herself in the centre of six *E. wandoo* trees (with a diameter >20 cm) closest to the centre of each site (hereafter called ‘site’ trees). Bird activity in these six trees was recorded over 20 min. These trees were subsequently categorised as ‘used’ or ‘unused’ during this time. One ‘use’ of a tree is defined as an individual bird making one foraging attempt at a resource (i.e. flower, foliage, branch or trunk) within a single tree. Repeat observations of the same bird on the same tree within one observation period (20 min) were not included to avoid pseudoreplication. An ‘unused’ tree was defined as a site tree in which no foraging attempt was made by any bird (of any species) during any of the four observation periods made at each site.

Method 2 The ‘following’ method commenced with the observer starting in the centre of the six site trees and moving to the closest bird activity (movement or calls) that could be heard or observed. These birds were then followed on foot from tree to tree while foraging behaviour was observed and recorded continuously for 20 min or until the birds could no longer be seen (whichever occurred first). Hence, this method included not only the site trees, but also trees away from the centre point of each site. The trees that the birds used

(hereafter referred to as 'selected trees') were marked and their location recorded with a GPS (Garmin eTrex H) to return to for analysis. These selected trees were compared against the 'unused' site trees identified using Method 1.

The following variables were recorded for each bird observation:

- (1) bird species;
- (2) foraging height [six categories: ground, lower trunk (lower half), upper trunk (upper half), lower canopy (lowest third), mid canopy (middle third), upper canopy (upper third)];
- (3) foraging substrate, or the type of food resource the individual was using (seven categories: flowers, foliage, live branches, hollows, dead branches, trunk/bark or leaf litter); and
- (4) foraging manoeuvres (probe, glean, hang glean, hawk, sally, hover probe).

Foraging height and substrate were compared between species (pooling data across both survey methods) by Pearson's Chi-square analysis (Microsoft Excel 2010), with expected values calculated assuming that an equal proportion of individuals of each species used each foraging height/substrate category.

Tree condition characteristics

A range of tree characteristics were visually assessed for each tree (Table 2). The Whitford tree condition measure (healthy–declining: 1–6) (Whitford *et al.* 2008) and Grimes tree condition measure (healthy–declining: 5–0) (Grimes 1987) assign each tree a value commensurate with its condition, based on a pictorial scale. These semiquantitative measures incorporate epicormic growth, crown density, the proportion of dead branches and crown dieback in their assessments. The USDA tree condition assessment (Schomaker *et al.* 2007) (originally designed for pine trees in the USA using a range of tree condition measures, some of which can appropriately be transferred to eucalypt trees), includes visual estimates of crown density (%), crown dieback (%) and uncompact live crown ratio (%) (Table 2). Other tree condition measures that have been found relevant when assessing fauna habitat in eucalypts (Wentzel 2010) are the proportion of dead branches (%) and epicormic growth (%) (Table 2). Canopy height (m) was also measured for each individual tree using a digital vertex (Vertex III and Transponder T3, Haglöf Sweden AB). Tree litter cover (%) was measured at the base of each tree using two 1-m² quadrats. The percentage variables were converted to proportions and arcsine-square-root transformed (Zar 1998).

Determining the correlations between tree characteristics and bird foraging

Logistic regression (negative binomial – due to the high number of zeros in the data) using 'R' 2.12.1 and Tinn-R was carried out to determine whether birds were selective in their foraging trees. Analysis was carried out for bird species for which sufficient observations were available ('sitting' and 'following' survey methods analysed separately for yellow-plumed honeyeaters; 'following' method only for weebills and rufous treecreepers). We compared trees that were used for foraging by birds

(sitting method surveys: 'used' trees; following method surveys: 'selected' trees) with the characteristics of trees not witnessed as used (site trees not identified as used by each of the target species during the 20-min sitting method surveys: 'unused' trees; note different numbers of 'unused' trees for each species). Location (Dryandra State Forest or Wandoo National Park) was present in all models as a random factor. Independent variables included Whitford tree condition measure (1–6), Grimes tree condition measure (5–0), crown density, crown dieback, epicormic growth, uncompact live crown ratio, proportion of dead branches, canopy height, and tree litter cover. A correlation matrix indicated that none of these factors were significantly autocorrelated ($r \geq 0.35$, $P > 0.05$).

Interpretation of the alternative logistic regression models was carried out by Akaike Information Criterion (AIC), corrected for small sample size (AIC_c). In total, 211 models were created for each dependent variable using various combinations of all the tree characteristics. The top models ($\Delta\text{AIC}_c < 2$) were considered a plausible fit for the data (Quinn and Keough 2002) and are considered well supported models to describe the dataset. The AIC_c model weight (w_i) was calculated for each of the top models: w_i values indicate the likelihood that each model is the best model of the model set to explain the dataset. We calculated a standardised β coefficient (indicating how much each parameter contributed to the model) and P values for each parameter in the model. The standardised β coefficients are the coefficients obtained if you had first standardised all of your variables to a mean of 0 and a standard deviation of 1; thus, the standardised β value allows direct assessment of the relative contribution of each independent variable (i.e. tree and habitat characteristics) in the prediction of the dependent variable.

Likelihood ratio test

A likelihood ratio test assesses the fit of a model. The test compares the alternate and null models to produce a log-likelihood ratio statistic (LL_c) and degrees of freedom (d.f.). In this case, models that included tree characteristics were compared with models without these tree characteristics included (the null-model) to determine whether the former were a better fit to the data. The P value is then determined from the binomial distribution using the LL_c and d.f. and the alternate model is proven or rejected in place of the null model.

Results

The three bird species (yellow-plumed honeyeaters, weebills, and rufous treecreepers) each used different parts of the trees (heights: Fig. 1a): yellow-plumed honeyeaters and weebills foraged in the mid–upper canopy, while rufous treecreepers more commonly foraged lower in the canopy and on the trunk more than the other species. They also differed in their use of foraging resources (substrates: Fig. 1b): live branches and foliage were the common foraging resources used by yellow-plumed honeyeaters and weebills, while rufous treecreepers foraged on branches more than the other two species. The foraging manoeuvres of each of the three common bird species were relatively consistent,

with >95% of the observations of yellow plumed honeyeaters and weebills recorded as gleaning, and >95% of observations of rufous treecreepers recorded as probing bark.

Live branches ($n = 205$ observations) and foliage ($n = 271$ observations) were the common foraging resources used by yellow-plumed honeyeaters (Fig. 1b). Dead branches ($n = 9$ observations), flowers ($n = 9$), tree litter cover ($n = 20$) and trunk/bark ($n = 54$) were also used. For each survey method, a single well supported model best explained the differences between trees that were not used, and trees that were used/selected by yellow-plumed honeyeaters. The adjusted R^2 value for the ‘sitting’ survey method was only 0.044, suggesting that there was poor explanatory power, probably because there were only $n = 12$ selected trees (compared with $n = 108$ unused site trees) for this method. For the ‘following’ survey method ($n = 73$ selected trees compared with $n = 108$ unused site trees), the best model indicated that yellow-plumed honeyeaters preferred to forage in taller trees that had a larger proportion of crown (uncompacted live crown ratio), with some dead branches (positive relationships with the proportion of dead branches) but overall minimal crown loss (negative relationships with crown dieback) (Table 3). Yellow-plumed honeyeaters therefore showed preference for larger *E. wandoo* trees with minimal canopy loss.

The insectivorous weebill primarily used foliage ($n = 116$ observations) and, to a lesser extent, live branches ($n = 34$), tree litter cover ($n = 2$), dead branches ($n = 2$) and flowers ($n = 9$) for foraging resources (Fig. 1b). A single model described data from the ‘following’ survey method ($n = 31$ selected trees compared with $n = 118$ unused site trees), which included positive correlations with uncompacted live crown ratio, canopy height, proportion of dead branches, and epicormic growth, but a negative correlation with crown dieback (Table 3). This indicates that weebills foraged in taller *E. wandoo* trees (with only a small amount of canopy loss or epicormic growth present).

Rufous treecreepers used dead branches ($n = 109$ observations), trunk/bark ($n = 22$), foliage ($n = 2$), tree litter cover ($n = 4$) and live branches ($n = 13$) for foraging substrates (Fig. 1b). Using the ‘following’ survey method ($n = 16$ selected trees compared with $n = 120$ unused site trees), there was a positive correlation between trees used by rufous treecreepers and uncompacted live crown ratio, canopy height, and proportion of dead branches, but negative correlations with crown dieback and epicormic growth. Treecreepers were therefore using taller trees with larger canopies but also more dead branches. Although the number of selected trees was small, the adjusted R^2 for this model was 0.463.

Likelihood ratio tests demonstrate that the models including the tree characteristics were a better fit to the data ($P < 0.05$) than the null models (without tree characteristics) (Table 3). The models including the tree characteristics therefore had better explanatory power to describe the selection of *E. wandoo* trees by these bird species than the models without tree characteristics.

Several tree condition measures and habitat features were not included in the top logistic regression models. These included Whitford tree condition, crown density, and tree litter cover. These results indicate that these measures were not strongly predictive of the activity of these three focal bird species in *E. wandoo* woodlands. Common variables in the best models (canopy height, crown dieback, uncompacted live crown ratio, proportion of dead branches, and epicormic growth) better described the dataset.

Discussion

It is important to identify factors that are likely to detrimentally influence woodland birds, as many woodland birds have been noted as currently undergoing serious population declines (Bennett and Watson 2011; Ford 2011). This includes the yellow-plumed honeyeater and rufous treecreeper, which have declined across their range in the farming region of Western Australia (Ford *et al.* 2001). Understanding the effects of woodland habitat and degradation upon birds is therefore an important aspect of managing these landscapes (Maron *et al.* 2011). This is particularly true for birds that are commonly found in the woodlands, as they may be the first to demonstrate observable relationships with the changes in habitat. The present study demonstrated that the relative size and density of the canopy influences the selection of *E. wandoo* trees by foraging birds. Canopy height and canopy size (i.e. uncompacted live crown ratio) contributed to models distinguishing between trees used by birds and those not observed as used. However, the condition of the trees was also an important factor, with the presence of dead branches, epicormic growth and crown dieback contributing to models describing tree selection by foraging birds. Generally, *E. wandoo* trees chosen by birds were taller and showed fewer signs of complete canopy loss, although dead branches were present in trees used as foraging resources by all three focal bird species. We discuss the results of this study in the context of the decline of tree condition in general.

Yellow-plumed honeyeaters, rufous treecreepers and weebills were each more likely to forage in larger trees with a higher canopy to trunk ratio. Similarly, yellow-plumed honeyeaters have previously been shown to prefer older, larger trees (Wilson and Recher 2001). Most observations of foraging by yellow-plumed honeyeaters were in mid- to upper-canopy on foliage and branches. These birds were rarely observed foraging on flowers, which supports previous studies showing that this principally insectivorous species forages on flowers <10% of the time (Recher and Davis 1998; Wilson and Recher 2001). Weebills largely foraged amongst foliage and branches, but were also observed foraging on flowers where these insectivores were likely retrieving insects. Although Arnold (1988) and Watson *et al.* (2004a) recorded positive relationships between the abundance of weebills and dense overstorey canopy, we recorded some preference for trees with dead branches, which may indicate some natural senescence of larger/older trees, or that early decline of *E. wandoo* canopy may be beneficial to weebills. Rufous treecreepers create territories in woodlands with larger, older trees possessing hollows (Luck 2002), which supports the positive relationships between treecreepers and

canopy height and uncompacted live crown ratio in the current study. Structurally complex, larger eucalypt trees, such as *E. wandoo*, support more invertebrate prey (Majer 1985; Recher *et al.* 1996) and would provide a greater range of foraging resources than smaller trees.

We had predicted that insectivores were more likely to make use of epicormic growth in *E. wandoo* since invertebrate abundance is higher in epicormic growth of various eucalypt species compared with older leaves (Landsberg and Wylie 1983; Marsh and Adams 1995). However, the relationships with epicormic growth were not strong, and in the case of rufous tree creepers were actually negative. While rufous tree creepers forage more commonly for invertebrates on branches and dead wood (Craig 2007), weebills and yellow-plumed honeyeaters use the invertebrate resources in canopy foliage and around live branches (Arnold *et al.* 1987; Wilson and Recher 2001). Robinson and Holmes (1984) outlined that the structure of the foliage will not only influence the abundance of invertebrate prey but also bird foraging behaviour (e.g. hawking or hovering). Dense new foliage (epicormic growth) may therefore be nutritionally superior, but may be a difficult foraging substrate for birds to access. Future studies quantifying the invertebrate prey in declining and healthy *E. wandoo* trees (particularly in and around epicormic growth) would indicate whether the observed relationships with bird foraging activities can be explained by invertebrate abundance.

We predicted that species that use dead wood would be more likely to benefit from decline in tree condition, which results in more dead branches in the canopy and on the woodland floor (Landsberg 1985; Hooper and Sivasithamparam 2005; Jurskis 2005; Davidson *et al.* 2007). Dead branches can benefit birds via the provision of invertebrate prey, and perching branches from which to pounce upon or sally for prey (Wentzel 2010). All three birds surveyed in the present study showed a positive correlation with the presence of dead branches. Rufous tree creepers commonly foraged on dead wood and trunk (i.e. bark); they were rarely observed on the ground. Similarly, Craig (2007) found that rufous tree creepers foraged on the ground only 7% of the time, compared with 83% of observations on standing vegetation and 9% on fallen logs and stumps. Yellow-plumed honeyeaters use dead branches not only for bark probing, but as perches to take off from to hover, snatch or hawk for invertebrate prey (Wilson and Recher 2001). Weebills primarily feed on insects within the foliage (Arnold *et al.* 1987); their relationship with dead branches may be linked with preference for older *E. wandoo* trees that naturally have more dead branches.

Both positive and negative correlations between yellow-plumed honeyeaters foraging and canopy height were recorded for the two survey methods. These conflicting results may be a consequence of the naturally open canopy of *E. wandoo* (Mercer 1991; Cousin and Phillips 2008) that is highly variable in the percentage of crown density, even between healthy trees. Differences in the results between the two survey methods may also reflect the dissimilar numbers of trees included in each. Remaining in the same location (the 'sitting' method) meant that there was time where the observer was watching focal trees but no bird activity was occurring. By contrast, the 'following' method

guarantees more data (as demonstrated by the higher number of observations on a higher number of trees). As a caveat, however, the ‘following’ method does not clearly identify when trees were not being used by birds.

Several tree characteristics and habitat features (Whitford tree condition measure, crown density, tree litter cover) were not included in the best models. A lack of inclusion of crown density in any of the best models may be a consequence of the open canopy of *E. wandoo* (Mercer 1991; Cousin and Phillips 2008) that has highly variable crown density values between trees. As the three focal bird species are largely canopy dwelling (Arnold *et al.* 1987; Wilson and Recher 2001; Craig 2007), it is not surprising that tree litter cover was not strongly correlated with any of the species’ tree selection.

Tree condition characteristics were included in the best models describing the foraging activities of birds, suggesting that the condition of *E. wandoo* plays a role in the choice of trees for foraging activities by these woodland bird species. The patchy nature of the decline means that birds would not have to travel large distances to find the foraging resources they require, whether the resources result from healthy or declining *E. wandoo* trees. A more widespread long-term decline that results in tree mortality or at least severe loss of canopy, in addition to a warming climate and fewer rainfall events has the potential to significantly affect bird populations. Without understanding the aetiology of *E. wandoo* decline, it is difficult to predict the long-term effects of changes in tree condition upon birds.

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Fig. 1. Numbers of observations of weebills (*Smicrornis brevirostris*; $n = 164$ observations), rufous treecreepers (*Climacteris rufa*; $n = 150$ observations) and yellow-plumed honeyeaters (*Lichenostomus ornatus*; $n = 566$ observations) broken down according to (a) foraging height, or (b) foraging substrate. Data collected using both the ‘sitting’ and ‘following’ survey methods are pooled. Significance of Chi-square tests are indicated as *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.005$.

Table 1. Characteristics of the three focal bird species examined in this study (Pike et al. 2008; Vernes et al. 2001) and the foraging substrate and tree health characteristics predicted to influence each

Sufficient observations were made for analysis of yellow-plumed honeyeaters (both survey methods), weebills (‘following’ method only) and rufous treecreeper (‘following’ method only)

Bird species	Body size (cm)	Feeding guild	Preferred foraging resource	Influence of tree condition characteristics on foraging activities		No. of observations (individual trees)	
				Predicted	Observed correlations	‘Sitting’ method	‘Following’ method
<i>Lichenostomus ornatus</i> (yellow-plumed honeyeater)	15–17	Insectivore, nectarivore	Foliage, flowers	Crown density, crown dieback, epicormic growth	Taller trees with healthier, relatively larger proportion canopy, and trees that had more leaf litter at their bases (Whitford tree condition measure), also a high proportion of dead branches. Conflicting data: crown density.	79 (12)	487 (73)
<i>Smicrornis brevirostris</i> (weebill)	8.5–9.5	Insectivore	Foliage (high in the canopy)	Epicormic growth	Trees with proportionally larger, dense canopy, but with dead branches present in the canopy.	27 ^A	164 (31)

<i>Climacteris rufa</i> (rufous treecreeper)	15–17	Insectivore	Dead branches, wood and/or bark	Proportion of dead branches, crown dieback	Taller trees with proportionally larger, dense canopy, with little epicormic growth but dead branches present in the canopy.	2 ^A	150 (16)
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^AInsufficient data for statistical analyses – observations completed on too few trees to allow distinction of habitat preferences.

Table 2. Tree condition characteristics measured on all trees (site, unused and selected trees)

All tree condition measures were completed at an approximate distance of half the height of the tree in question. These assessments were conducted twice on each tree at 90° from each other. In addition to these independent measures of tree characteristics, the continuous variables were incorporated together as a single measure by Principal Components Analysis (PCA) for each tree. The dimensions of these analyses captured a holistic measure of tree health; correlations with these dimensions are shown for each variable included (*r*). The Grimes and Whitford tree condition measures were not included as they were highly correlated with other tree characteristics in the analysis

Tree characteristic	Definition	PCA 1 ^A	PCA 2 ^B
Whitford tree condition measure	Measures overall tree condition on a scale from C1 to C6, where C1 is healthy crown and C6 is a dead tree. This measure captures epicormic growth, crown density and crown dieback (Whitford <i>et al.</i> 2008).	–	–
Grimes tree condition measure	Measures overall tree condition on a scale from 0 to 5 where 0 is a dead tree and 5 is a healthy tree with a complete canopy. This measure captures epicormic growth, crown density and crown dieback (Grimes 1987).	–	–
Crown density (%)	Percentage of crown containing foliage, branches, and reproductive structures (Schomaker <i>et al.</i> 2007).	<i>r</i> = –0.499	<i>r</i> = –0.513
Crown dieback (%)	Percentage of crown that has undergone recent dieback, often an early indication of stress (Schomaker <i>et al.</i> 2007).	<i>r</i> = 0.799	<i>r</i> = 0.141
Uncompacted live crown ratio (%)	Ratio of live crown length to above-ground tree length. Uncompacted means crown length is not reduced to compensate for gaps between base of live crown and live top of the tree.	<i>r</i> = –0.056	<i>r</i> = 0.895
Epicormic growth (%)	Percentage of epicormic growth (growth from buds beneath the bark) observed in canopy (Podger 1980; Stone 1999).	<i>r</i> = 0.781	<i>r</i> = –0.074
Proportion of dead branches (%)	Percentage of all major branches (diameter >20 cm; counted for the whole tree) that are senescent.	<i>r</i> = 0.810	<i>r</i> = 0.160
Canopy height (m)	Highest point of tree that is live. Completed three times and averaged.	–	–
Leaf litter cover (%)	Recorded at the base of each tree (site and selected trees) as close as possible to the trunk for two 1-m ² quadrats and averaged to create a value per tree. Greater litter cover could reflect greater canopy size or declining health.	–	–

^AFor PCA 1, eigenvalue = 2.231, % of total variance = 44.62.

^BFor PCA 2, eigenvalue = 0.996, % of total variance = 19.92.

Table 3. Logistic regression (negative binomial) describing the differences between trees that were either not observed as being used as foraging resources (‘unused’ trees) or used by weebills (*Smicrornis brevirostris*), rufous treecreepers (*Climacteris rufa*) or yellow-plumed honeyeaters (*Lichenostomus ornatus*)

The surveys were carried out using two methods (the ‘sitting’ and ‘following’ methods; see text for description) at 20 sites in Dryandra State Forest and Wandoo National Park, Western Australia (*n* = number of observations made using each method). A total of 211 models were created and assessed by

Akaike Information Criterion (AIC) for each dependent variable; only models with $\Delta AIC_c < 2$ are shown. For each independent variable used in each model, the standardised β coefficient and P values are shown. For each model, the adjusted R^2 value demonstrates the explanatory power of each model and the w_i indicates the weight of evidence that these models, of all 233 models created for each dependent variable, was the best fit of the data. The log-likelihood statistic (LLc), the fit of each model and d.f. are shown for each model. Whitford tree condition measure, crown density, and tree litter cover were not included in the top models used to describe foraging activities of these bird species

Method	Yellow-plumed honeyeater		Weebill	Rufous treecreeper
	'Sitting'	'Following'	'Following'	'Following'
	<i>n</i> = 79 observations <i>n</i> = 12 used trees	<i>n</i> = 487 observations <i>n</i> = 73 selected trees	<i>n</i> = 164 observations <i>n</i> = 31 selected trees	<i>n</i> = 150 observations <i>n</i> = 16 selected trees
Factors included in the model				
Adjusted R^2	0.044	0.065	0.174	0.463
Grimes tree condition measure	-0.17 (0.01)	-	-	-
Canopy height	-0.14 (0.05)	0.19 (0.00)	0.21 (0.00)	0.35 (0.00)
Crown dieback	-	-0.25 (0.00)	-0.07 (0.40)	-0.09 (0.13)
Uncompacted live crown ratio	-	0.12 (0.00)	0.33 (0.00)	0.44 (0.00)
Proportion of dead branches	-	0.07 (0.24)	0.17 (0.03)	0.28 (0.00)
Epicormic growth	-	0.06 (0.39)	0.05 (0.59)	-0.07 (0.12)
w_i	0.99	1	1	1
LLc	-118.31	-273.68	-152.74	-100.89
d.f.	3	7	7	7

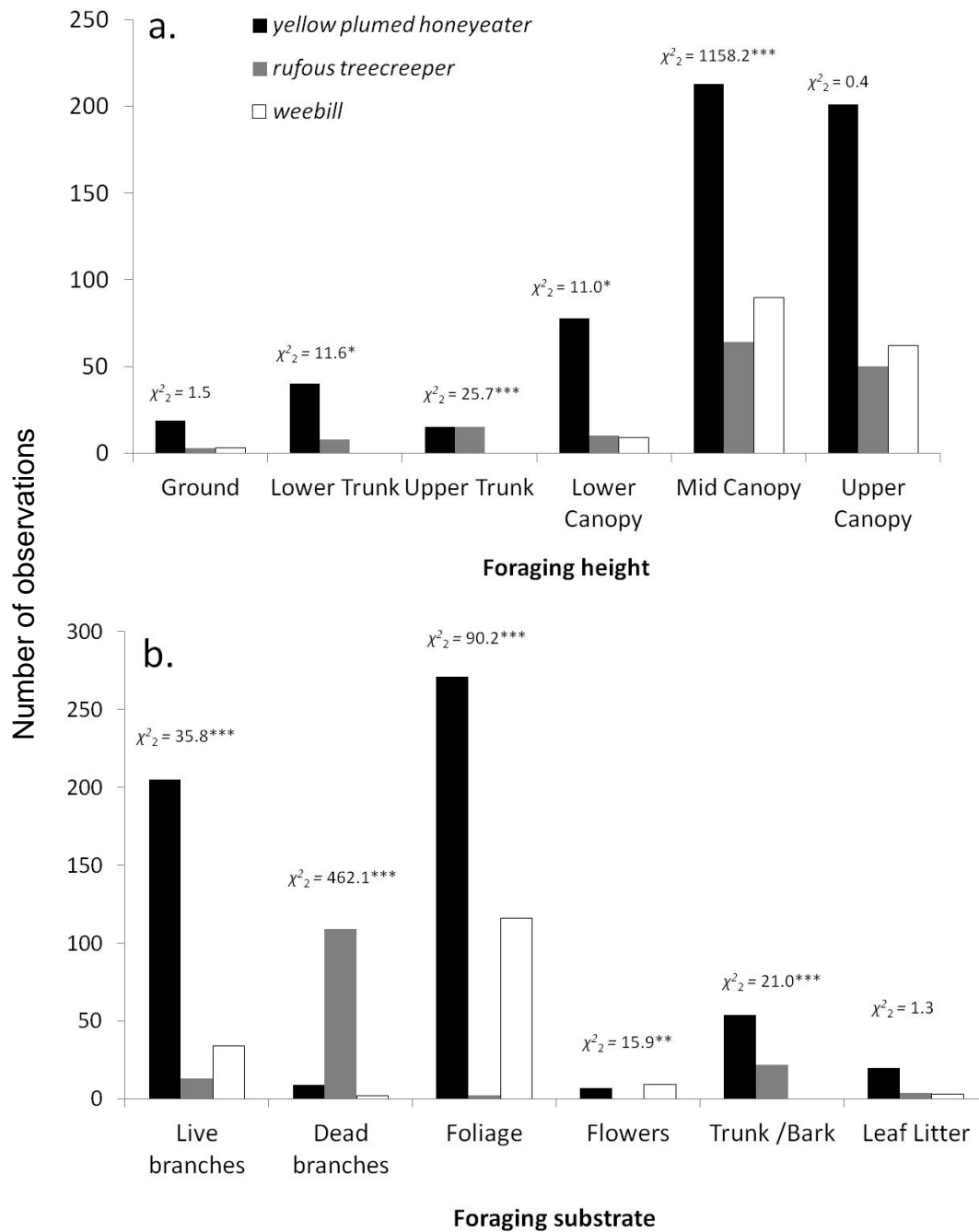


Figure 1: Numbers of observations of weebills (*Smicrornis brevirostris*; n=164 obs), rufous treecreepers (*Climacteris rufa*; n=150 obs) and yellow-plumed honeyeaters (*Lichenostomus ornatus*; n=566 obs) broken down according to a) foraging height, or b) foraging substrate. Data collected using both the ‘sitting’ and ‘following’ survey methods are pooled. Significance of χ^2 tests are indicated as * P < 0.05, ** P < 0.01, *** P < 0.005.