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Diamond Firetails (*Stagonopleura guttata*) preferentially nest in mistletoe

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Abstract. More than two-thirds of the terrestrial avifauna of Australia have been reported to use mistletoe as a nest substrate. Despite the prevalence of this behaviour, no previous research has measured nest-site selection relative to mistletoe availability. Thus, no species has been found to preferentially select mistletoe as a nesting substrate. We conducted a comprehensive search of a 365-ha woodland near Holbrook, New South Wales, for Diamond Firetail (*Stagonopleura guttata*) nests and recorded the nesting substrate. We also quantified the number of mistletoe plants in the study area and estimated their area as a percentage of the total canopy. Although mistletoe conservatively accounted for ~2.3% of the canopy, 13 of 43 (30%) Firetail nests in the study site were in mistletoe. More Firetail nests were found in mistletoe than expected by chance. This finding provides the first evidence for nest-site preference in mistletoe. We predict that nests placed in mistletoe have a selective advantage owing to increased nesting success, although this was not tested in this study, as all nests were inactive. We propose that the dense evergreen foliage of mistletoe provides a good structure for efficient nest building, a favourable microclimate and high levels of nest concealment that may reduce predation risk.

Introduction

Bird–mistletoe interactions have attracted considerable research. Most studies on bird–mistletoe interactions have focused on birds as pollinators and seed dispersers of mistletoe (Calder 1983; Reid 1986; see also Watson 2001 and references therein). Many birds also use mistletoe as sites for nesting and roosting, but until recently, this type of interaction has received little attention. Watson compiled published records of 43 bird families with species recorded nesting or roosting within mistletoe, and drew attention to the widespread nature of this phenomenon (Watson 2001). Although this behaviour is common within some groups (especially the Musophagidae, Accipitrinae, Ptilogonatidae and Ptilonorhynchidae), the widespread frequency of this behaviour has, to date, not been fully acknowledged or investigated in detail.

In a review of the nesting substrate of Australian birds, Cooney *et al*. (2006) found that 215 species of Australian birds in 28 families have been recorded nesting in mistletoe. This represents 65% of Australian birds that nest above the ground in the foliage of trees – adding a further 13 families to the global list of families known to nest in mistletoe. For 15 families, more than half the Australian species have been recorded nesting in mistletoe, including all Australian members of the Cuculidae, Corvidae, Pomatostomidae, and all but one of the Australian species in the Artamidae and Ptilonorhynchidae (Cooney 2004; Cooney *et al*. 2006). Despite the apparent widespread use of mistletoe as a nesting substrate, preference for mistletoe as a nest site has not been demonstrated for any species worldwide.

Mistletoe is widespread in all wooded habitats in mainland Australia (Calder 1983) and the opportunity to nest in mistletoe will arise purely out of chance for any species that places its nest in the branches of trees. The random occurrence of nest placement in mistletoe will vary between different habitats, as well as within a habitat, owing to the patchy distribution of mistletoe across the landscape (Turner 1991). For example, a study of an arid woodland found *Amyema quandang* at an average density of 5.5 plants per *Acacia papyrocarpa* shrub (Reid and Lange 1988), whereas a study in a dry sclerophyll forest in south-eastern Australia found a density of 1.7 mistletoe plants per tree (Turner 1991). Furthermore, mistletoe is more abundant near edges and in fragmented landscapes than in the middle of patches and in unfragmented landscapes (Turner 1991).

Many autecological studies have documented the incidence of mistletoe nesting. In Australia, up to a third of all nests of some species are placed in mistletoe (Bridges 1994; Geering and French 1998; Ford 1999). Oliver (1998) demonstrated that Regent Honeyeaters (*Xanthomyza phrygia*) nested in areas with a higher density of mistletoe at a local scale (50 m plots) than surrounding areas, but did not demonstrate a preference by Regent Honeyeaters for placing their nests in mistletoe. These studies could not demonstrate a preference for mistletoe nesting sites because they did not

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quantify the number of potential mistletoe and non-mistletoe nesting sites that were available to the birds.

Here we examine the nest-site selection of a bird that regularly nests in mistletoe (Diamond Firetail (*Stagonopleura guttata*)) and quantify the proportion of nests found in mistletoe compared with its availability in the birds' habitat. This comparison will test whether Diamond Firetails show a preference for nesting in mistletoe. Although the nesting ecology of Firetails is well known from aviculture (Immelmann 1965; O'Gorman 1980; Trott 1994), less work has been undertaken on these birds in the wild. Indeed, apart from the early work undertaken by North (1906) and Immelmann (1965), the only recent quantitative research on wild Diamond Firetails is an honours thesis that included Diamond Firetails in a study of three firetail species in South Australia (Read 1987). Therefore we also present data on other characteristics of Firetail nests to develop a clearer picture about nest-site selection in this species.

Materials and methods

Study site

The study was conducted in a patch of privately owned remnant woodland and forest called Morgan's Ridge (35°42.4′E, 147°24.0′S), located 9 km east of Holbrook in the south-western slopes region of New South Wales (NSW), Australia. Covering an area of ~2600 ha, Morgan's Ridge is one of the largest remnants of the dry foothill forest community and grassy box woodland community in southern NSW (Cooney 2004).

The fieldwork took place on the eastern side of Morgan's Ridge in a 365 ha patch of woodland at the base of the ridge, known as Wybalena (Cooney 2004). Although this area has been grazed and used for timber production in the past, the current owner has not grazed this area since 1989 and much of the understorey and ground cover has returned to a natural state (Cooney 2004). The canopy is dominated by Blakely's Red Gum (*Eucalyptus blakelyi*), Red Stringybark (*E. macrorhyncha*) and Red Box (*E. polyanthemos*), with patches of regrowth and dense thickets of Silver Wattle (*Acacia dealbata*). Other canopy trees include Yellow Box (*E. melliodora*), Apple Box (*E. bridgesiana*), Long-leaf Box (*E. goniocalyx*), White Box (*E. albens*), Currawang (*A. doratoxylon*) and Kurrajong (*Brachychiton populneus*). The understorey is open and grassy, dominated by native and introduced grasses, interspersed with Austral Bracken (*Pteridium esculentum*), Rock Fern (*Cheilanthes* sp.) and thickets of small shrubs including Common Fringe Myrtle (*Calytrix tetragona*; Cooney 2004). Two species of mistletoe occur at Morgan's Ridge, increasing in abundance near the edges of the patch. Box Mistletoe (*Amyema miquelii*) is more abundant, parasitising *Eucalyptus* species, while it in turn is occasionally parasitised by Fleshy Mistletoe (*Amyema miraculosum*).

Study species

Diamond Firetails are an ideal candidate for learning more about mistletoe nesting, given that they regularly nest in both mistletoe and *Eucalyptus* plants (North 1906; Lord 1956; Immelmann 1965) both of which are relatively common in our study area. Diamond Firetail nests are large bulky structures built in the forks of trees, shrubs and mistletoes (Immelmann 1965; Read 1987) that are easily identified and sufficiently large to ensure that all nests in the area were located. It is important to find all the nests in the study area so as not to bias the experiment by only finding conspicuous nests while missing those that are better concealed. This oversight might happen if a species with a smaller or less obvious nests were studied, whose nest could get lost in the dense foliage of mistletoe, especially if placed high above the ground. Diamond Firetail nests also persist for several seasons (O'Gorman 1981), which allowed us to gather a larger sample size by including nests of previous years in our analysis of nest-site selection. Diamond Firetail nests superficially resemble nests of babblers (*Pomatostomus* spp.) and Red-browed Finches (*Neochmia temporalis*), both of which are found at the study site. Babbler nests, however, are grassier and more ovoid in shape, whereas nests of Red-browed Finches do not have a bottle-neck entrance, which makes identification of Diamond Firetail nests possible. Determining the identity of cup nests, however, is rarely possible without an attendant parent owing to their less distinctive appearance.

Firetails build large nests that average 300 mm in length and 200 mm in height and width (Immelmann 1965). They are ovoid with a long entrance tunnel up to 150 mm long and made of fine grass, and occasionally twigs, and lined with very fine grass and feathers (North 1906; Immelmann 1965). Firetails typically build their nests in *Eucalyptus* trees (55% of nests in one study; Read 1987), but a range of other trees and shrubs are also used (Read 1987). Firetails usually nest within 4.5 m of the ground (Read 1987), although some nests have been recorded at heights above 20 m (North 1906; Immelmann 1965). Some trees carry more than one nest, and one tree in western Victoria had four nests in it, three of which were in use (O'Gorman 1981). Nests are also occasionally built in the base of the large stick nests of eagles and other large raptors (Immelmann 1965; Birds Australia Nest Record Scheme (NRS) reference 652/55). Nests built in mistletoe are limited to one per clump, with the nest chamber wall abutting the haustorium (O'Gorman 1981). These nests usually face away from the centre of the tree and are inclined slightly downward (O'Gorman 1981).

Diamond Firetails, like other estrildid finches, also build a roosting chamber that is not used for laying eggs. Roost-nests may be a previous year's brood-rearing nest (brood nest) or may be purpose-built for roosting (O'Gorman 1981). A roost-nest is not lined and is usually occupied by just one pair of birds (Immelmann 1965; O'Gorman 1981). Roost-nests may also be built in the lower part of a tree and are often more closely spaced than brood nests (O'Gorman 1981).

Diamond Firetails are listed as Vulnerable in NSW (Schedule 2 of the *Threatened Species Conservation Act 1995* (NSW); NSW National Parks and Wildlife Service 2004). They are a declining species that has disappeared from parts of its former range (NSW National Parks and Wildlife Service 2004). These declines are considered to be a result of land clearance, fragmentation of habitat, and overgrazing of the grassy understorey by stock (Ford *et al*. 2001; NSW National Parks and Wildlife Service 2004). Therefore, understanding the nesting requirements and preferences of Diamond Firetails could assist future conservation efforts.

Parameters measured to determine nest-site selection in Diamond Firetails

To determine the characteristics of Firetail nest sites and to identify any preference for nesting in mistletoe, we conducted a comprehensive search for Firetail nests over the entire 365-ha study area to ensure that all nests were found. When a nest was located, we recorded the type of plant in which the nest was situated. We also recorded the height of the nest and height of the tree in which the nest was placed, using a Suunto clinometer (Suunto Oy, Vantaa, Finland) accurate to ± 0.5 m, and the quadrant of the tree in which the nest was located using a compass. The height of the nest in relation to the height of the tree (relative height) was calculated by converting the nest height into a percentage of the tree height. Because the search was conducted during the non-breeding period, it was not possible to differentiate between brood nests and roost nests.

To measure nest-site availability, we assessed the relative amounts of each potential nesting substrate in the study area. From 50 random points generated in ArcView 9, 43 suitable points were determined within the study area to pair with the 43 actual Firetail nests. We classified trees that were >2 m in height as forming the canopy and a random site was considered suitable if it had partial canopy cover. A random site that did not have any canopy cover therefore was considered not suitable.

At each random point and at each of the 43 Firetail nest sites, a circle of 11.3 m radius (0.04 ha) was marked using a tape measure attached to a centrally located peg. This area is called the nest-patch level (after Steeger and Hitchcock 1998; Siepielski *et al*. 2001). Within this circle, the area of the canopy cover was visually estimated and the percentages of each vegetation type (categorised as mistletoe, *Eucalyptus* or other) determined. Combined, these allowed evaluation of whether or not nests were placed randomly or if a preference was being displayed in relation to floristic composition or vegetation density or both. It also allowed analysis of the structural composition of the habitat across the entire study area to determine broader patterns of nest placement within the vegetation cover.

Finally, to determine the number of potential mistletoe nest-sites in relation to other potential nest-sites, two randomly selected points were marked within each random quadrat. At each of these marks, the vegetation immediately above the mark was recorded as mistletoe, *Eucalyptus* or other. This measurement allowed evaluation of whether or not the actual nests were being built in mistletoe by chance, or if one substrate was being chosen more often than expected.

Statistical analysis

A two-tailed Fisher's exact test was used to compare the frequency of nests placed in mistletoe with the frequency of random points that encounter mistletoe. Two sample *t*-tests were used to compare the means of the nest-site variables (nest height, tree height, relative height and orientation), with mistletoe as the grouping variable. A paired *t*-test was used to examine differences between nests placed in mistletoe and eucalypt at the wider, nest-patch level. All statistical analyses were considered significant at $P < 0.05$. Below, means are presented ± standard deviation unless indicated.

Results

A total of 43 Diamond Firetail nests was found, of which 13 (30.2%) were in a clump of mistletoe and 30 in *Eucalyptus* trees (Fig. 1). When the composition of the canopy was measured using random points within nest-patch circles, only two of the 86 points (2.3%) occurred beneath mistletoe plants. On this measure there is a significantly greater number of nests in mistletoe than expected by chance (two-tailed Fisher's exact test, $P < 0.001$).

Most Firetail nests were in *E. blakelyi* ($n = 37$), although there were three nests in *E. melliodora* and one each in *E. bridgesiana*, *E. goniocalyx,* and *E. polyanthemos*. All of the 13 mistletoe nests were in *A. miquelii*. The host trees for the mistletoe nests were *E. bridgesiana*, *E. polyanthemos* and *E. melliodora*, which each hosted one nest, with the remaining ten nests in *E. blakelyi* trees. There were no nests in any other tree species, despite a small number of other structurally similar plant species, such as *B. populneus* and *Acacia dealbata*.

Nests were located primarily in the south-eastern quadrant of the host tree (154.2 ± 70.7°; Fig. 2), but the location did vary significantly by plant substrate ($t = -2.02$, d.f. = 41, $P = 0.05$). *Eucalyptus* nests were placed in the south-eastern quadrant of the plant (140.3 ± 64.03°), whereas mistletoe nests were placed closer to the southern quadrant (186.2 ± 77.52°) and varied more in orientation than nests in *Eucalyptus* trees.

Mean height of nest trees was 7.97 ± 3.24 m, although the nests placed in mistletoe were in significantly taller trees than those that were placed in *Eucalyptus* foliage ($t = -4.44$, d.f. = 41, $P < 0.001$; Fig. 3). The mean height of all Firetail nests was 4.26 ± 1.89 m. The mean height of nests in *Eucalyptus* was 4.05 ± 1.99 m, whereas mean height in mistletoe was 4.75 ± 1.59 m, though this difference was not significant ($t = -1.13$, d.f. = 41, $P > 0.05$). Nests were placed approximately half-way up the trees (54 ± 0.15% total height), with relative height of nests in *Eucalyptus* significantly lower than those in mistletoe nests ($t = -4.44$, d.f. = 41, $P < 0.001$).

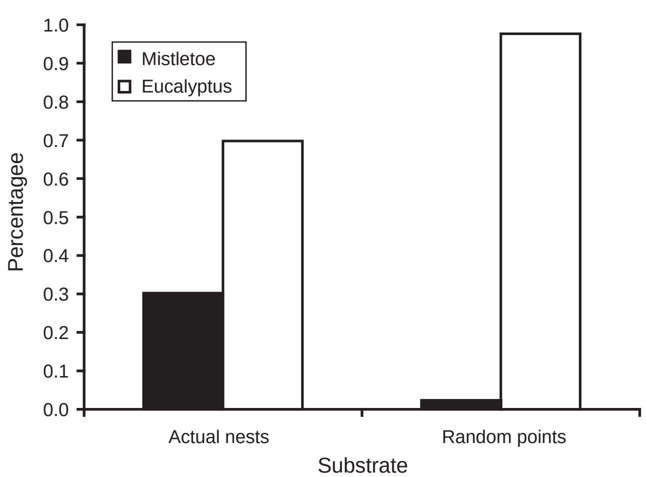

Fig. 1. Actual nest sites and potential nest sites, by substrate, for Diamond Firetail at Morgan's Ridge, Holbrook, NSW, 2004.

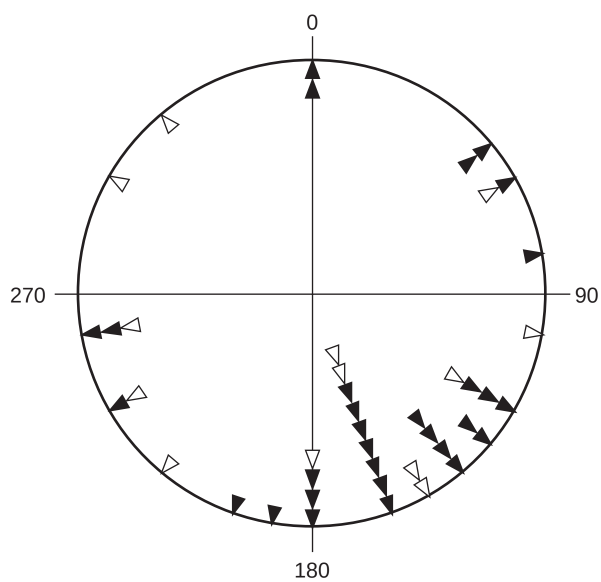

Fig. 2. Compass rose showing the aspect, in degrees, of 43 Diamond Firetail nests in *Eucalyptus* (solid) and mistletoe (outline) plants at Holbrook, NSW, 2004.

At the nest-patch level, for 43 nest sites and 43 random sites, mistletoe was present at 0.025 m m^{-2}, whereas *Eucalyptus* trees represented 0.43 m m^{-2} of the total area. The result is a medium open-forest, according to Specht's classification of Australian forest types (Fox and Recher 1986) with the canopy covering less than half of the total area. There was little difference in the amount of mistletoe from measurements taken at the nest-patch level of both actual nest sites and random sites (t = 0.44, d.f. = 42, P > 0.05), but there was significantly more canopy coverage at random sites than at the sites where Firetails nest (t = –3.76, d.f. = 42, P < 0.001).

Discussion

Evidence for nest-site preference in mistletoe

Diamond Firetails in this study showed a clear preference for nesting in mistletoe. This study is the first to report on nesting preference in mistletoe for any bird species. As indicated in Fig. 1, Firetail nests are built in mistletoe far more often than would be expected by chance. Furthermore, this estimate is a conservative approximation of the number of mistletoe nest sites that would be found in this habitat. Although we only measured a two-dimensional footprint of the canopy, a measure of the total volume of the canopy would greatly increase the difference between the number of potential mistletoe and *Eucalyptus* nest sites. Diamond Firetails did not, however, nest in the tips of trees or at the ends of branches (S. J. N. Cooney, personal observations), so the two-dimensional model provides an adequate, yet conservative, measure of mistletoe availability.

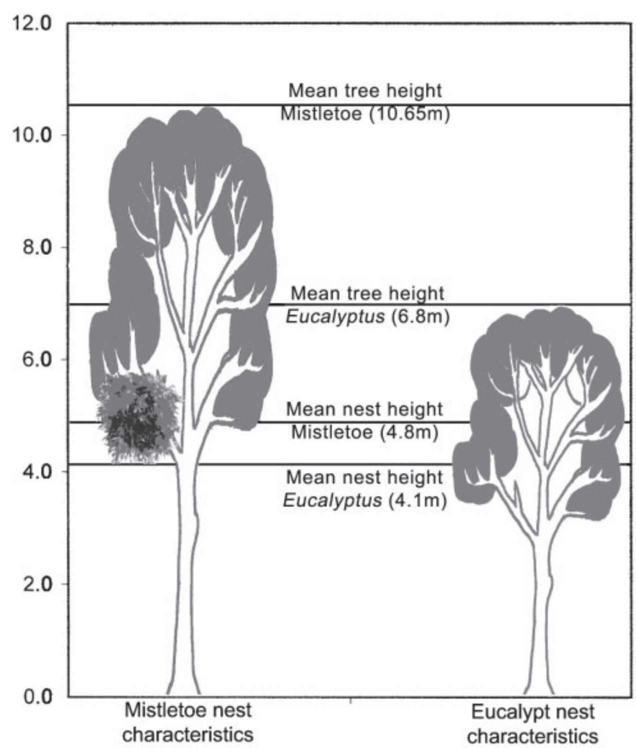

Fig. 3. Mean height of tree and nest (m), by nesting substrate, for 43 Diamond Firetail nests at Morgan's Ridge, Holbrook, NSW, 2004.

Mistletoe is a well known nesting substrate for Diamond Firetails and was first documented by North (1906: p. 270), who noted that a Firetail built its nest 'in a *Loranthus* growing on a *Eucalyptus* fully fifty feet from the ground'. Other authors have subsequently recorded the use of mistletoe as a nest site for Firetails (Lord 1956; Immelmann 1965; O'Gorman 1981) and 10 of the 89 (11%) records in the NRS state that the Firetail nest was built in mistletoe. None of these researchers quantified the amount of mistletoe in their study sites, so a preference for mistletoe as a nest site could not be demonstrated until now.

Firetail nests were built on the south-eastern side of the nest tree, although location of nests in mistletoe varied more than nests in *Eucalyptus* trees (Fig. 2). The south-eastern location of Firetail nests is nearly opposite that favoured by White-winged Fairy-wrens (*Malurus leucopterus*; north-eastern side) and Superb Fairy-wren (*M. cyaneus*; northern side) in semi-arid NSW (Tidemann and Marples 1988). Both this study and that of Tidemann and Marples (1988) found that the birds built their nests in the eastern, rather than western hemisphere of the nest plant. Nests built on the eastern side of a tree will avoid the heat of the afternoon sun that sets in the west and benefit from the warming effects of the morning sun.

Several bird species orient their nests to avoid heat stress through insolation (Ricklefs and Hainsworth 1969; Walsberg 1985) or desiccation from strong winds (Peterson and Best 1985). Locating the nest in a favourable position can increase the success of a nesting bird by 24% (Austin 1974). The greater variation in nest-site location for mistletoe nests may be because nests in mistletoe are not so constrained by the pressure of avoiding the heat of the sun by affording the bird better insulation from heat than nests placed in *Eucalyptus* trees. This flexibility may allow Firetails to nest in otherwise unviable sites in relation to the sun.

The height of Firetail nests in this study (overall mean of 4.26 m) is comparable with that found by Read (1987) in SA, who reported an average nest height of 4.3 m, and with the NRS, which was 4.11 m. There was no significant difference in the height of nests that were placed in mistletoe compared with those placed in *Eucalyptus* trees. There was a difference in the height of the host trees, which may relate more to the conditions required by mistletoe, rather than to the nests themselves. Trees must be a certain size and age to host a mistletoe plant large enough to support a Firetail nest. Trees that hosted nests in this study were ~7.9 m tall, compared with 7.4 m in Read's (1987) study and 6.3 m in the NRS. Although the nest site is not known for most of the NRS records, Read (1987) encountered many Firetail nests in shrubs, reducing the average height. Firetails nest higher in the vegetation than two sympatric finch species, the

Beautiful Firetail (*S. bella*) and the Red-browed Finch (Read 1987). Relative heights of the nests in this study (53%) varied slightly compared with that found by Read (1987; 58%), but this variation can largely be attributed to differences in nest-tree height; relative nest height from the NRS was 65%.

Most (86%) of the Firetail nests were in *E. blakelyi* and all of the mistletoe nests were in *Amyema miquelii*. This finding is not surprising as these two plants are the dominant representatives of their plant type at Morgan's Ridge. It is noteworthy that no plant other than a *Eucalyptus* hosted a nest, despite the use of other types of vegetation accounting for up to 45% of nest sites in SA (Read 1987). Immelmann (1965: p. 35) further states that the site of the nest 'varies considerably', which raises the question of the generality of the findings of this study for nest-site preferences in Diamond Firetails across Australia.

Why do Diamond Firetails prefer to nest in mistletoe?

Predator avoidance is an important component of nest-site selection (Hogstad 1994), but a range of other selective forces also influence design and location of nests. These include insulation (Kern 1984), stability (Wilson and Cooper 1998), brood parasitism (Burhans and Thompson 1998), nestling safety (Slagsvold 1982), resource acquisition (Siepielski *et al*. 2001) and phylogeny (Winkler and Sheldon 1993). The choice of mistletoe as a nest site for Firetails, or any other bird, will similarly be a trade-off between some or all of these factors.

Enhanced levels of concealment, such as those afforded by the dense foliage surrounding mistletoe nest sites, may reduce the risk of predation by hindering the development of a search image in predators (Martin 1988). As a primary cause of nesting mortality (Ricklefs 1969), nest predation can be a strong selective force sculpting the life-histories of birds (Martin 1987). Dense vegetation can also impede the movement of mammalian predators through the canopy (Larivière and Messier 1998) and reduce the foraging efficiency of avian predators (Sugden and Beyersbergen 1986). In Ponderosa pine forests in North America, concealment was considered to be a key factor in nest-site selection of up to 50% of mistletoe nesting birds in that habitat (Bennetts *et al*. 1996).

Our findings also suggest that microclimate may be an important selective force on Diamond Firetail nest-site selection. O'Gorman (1980) found that captive Firetails modified their incubation behaviour according to the ambient temperature, spending less time in the nest as ambient temperatures increased. Species that are smaller or incubate intermittently, such as Diamond Firetails, will be limited in nest design and behaviour by incubation thermodynamics and therefore their nest design would be expected to maximise thermodynamic benefits at the expense of other functions (Hilton *et al*. 2004). The extra level of predator concealment that may be afforded by mistletoe, might allow larger nests with more insulation to be built, without sacrificing concealment and risking increased levels of predation.

In this study we analysed nest-site location for all nests encountered. None of the nests was active, and the age and status (e.g. brood *v.* roost nest) of the nests were not known. Thus we cannot conclude if there was a difference in nest site between roost and brood nests. Brood nests and roost nests are known to differ from each other in respect to height and lining (Immelmann 1965; O'Gorman 1981), but we were unable to differentiate between the two in relation to their occurrence in mistletoe. It is also possible that the vegetation surrounding the nests has changed since its construction. Such changes may mask the original importance of the surrounding vegetation to the nest's microclimate. Furthermore, again because the nests were from a previous nesting attempt, the influence of the season on nest site is not known. It may be that all the nests in mistletoe were built early or late in the season or in an unusually dry season or wet season and therefore may provide a better nest site at these times than at others.

As a final cautionary note on interpretation of the findings, it is possible that nests placed in mistletoe persist for longer than those in *Eucalyptus* trees. The dense structure of the mistletoe may be more resistant to the impact of wind or may simply provide a more rigid scaffold that stops the nest material from falling away. This potentially increased persistence of nests in mistletoe would bias our results in favour of a higher estimate of nesting occurrence in mistletoe.

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