

Does Human-Induced Habitat Modification Influence the Impact of Introduced Species? A Case Study on Cavity-Nesting by the Introduced Common Myna (*Acridotheres tristis*) and Two Australian Native Parrots

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Abstract Introduced species pose a major threat to biodiversity across the globe. Understanding the impact of introduced species is critical for effective management. Many species around the world are reliant on tree cavities, and competition for these resources can be intense: threatening the survival of native species. Through the establishment of 225 nest boxes, we examined the relationship between tree density and the abundance and nesting success of three bird species in Canberra, Australia. The common myna (*Acridotheres tristis*) is an introduced species in Australia, and the crimson rosella (*Platycercus*

elegans) and eastern rosella (*Platycercus eximius*) are native species. We then investigated the impact of common myna nest box occupation on crimson rosella and eastern rosella abundance. Tree density significantly influenced the abundance and cavity-nesting of all three species. Common myna abundance (birds per square kilometer) was greatest at low tree density sites (101.9 ± 22.4) and declined at medium (45.4 ± 10.1) and high (9.7 ± 3.6) tree density sites. The opposite pattern was observed for the crimson rosella, with greater abundance (birds per square kilometer) at high tree density sites (83.9 ± 9.3), declining over medium (61.6 ± 6.4) and low (31.4 ± 3.9) tree density sites. The eastern rosella was more abundant at medium tree density sites (48.6 ± 8.0 birds per square kilometer). Despite the strong influence of tree density, we found a significant negative relationship between common myna nest box occupancy and the abundance of the crimson rosella ($F_{1,13} = 7.548$, $P = 0.017$) and eastern rosella ($F_{1,13} = 9.672$, $P < 0.001$) at some sites. We also observed a slight increase in rosella nesting interruptions by the common myna at lower tree densities (high: $1.3 \% \pm 1.3$, medium: $6.6 \% \pm 2.2$, low: $12.7 \% \pm 6.2$), although this increase was not statistically significant ($F_{2,40} = 2.435$, $P = 0.100$). Our study provides the strongest evidence to date for the negative impact of the common myna on native bird abundance through cavity-nesting competition. However, due to the strong influence of habitat on species abundance and nesting, it is essential to investigate the impacts of introduced species in conjunction with habitat variation. We also suggest one component of introduced species management could include habitat restoration to reduce habitat suitability for introduced species.

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Introduction

Introduced species and habitat modification pose major threats to biodiversity across the globe (Clavero and García-Berthou 2005; Levin and Crooks 2011; Pimentel and others 2005; Ruhren 2012; Westphal and others 2008). Introduced species can affect native species through predation, competition, herbivory, habitat alteration, disease, and hybridization (Davis 2003; Gurevitch and Padilla 2004; Kumschick and Nentwig 2010; Nentwig and others 2010; Pimentel and others 2005; Ruhren 2012). However, some introduced species can have a devastating impact while others are relatively benign (Davis and others 2011; Shine 2010). Furthermore, an introduced species may have a significant negative impact in one environment and little or no impact in another (Davis and others 2011).

Demonstrating the impact of an introduced species is a complex task, especially when it occurs alongside human-habitat modification (Didham and others 2005; Gurevitch and Padilla 2004; MacDougall and Turkington 2005). Understanding the different impacts on native species, and the interactions between these impacts, is critical for effective native species conservation (Davis and others 2011). For example, introduced species management may not assist threatened species recovery if habitat destruction is the major cause of species decline (Didham and others 2005). Additionally, understanding the impact of a species is essential for managing limited conservation resources (Kumschick and others 2012).

Species distribution and abundance is predominantly determined by resources that are critical for their survival (Elton 1927). Therefore, habitat features can have a large impact on species abundance and distribution (Bradshaw and others 2007; Clergeau and others 1998; Crooks and others 2004; Gardali and Holmes 2011; Munro and others 2009). For example, the availability of tree cavities can be a critical resource for some species (Aitken and Martin 2008; Gibbons and others 2002; Goldingay and Stevens 2009; Newton 1994; Wiebe 2011).

Human modification of landscapes (e.g., habitat clearing, tree removal for public safety) and fire can lead to reductions in cavity availability (Harper and others 2005a; Newton 1994; Wiebe 2011). This reduction can then limit the breeding success and the abundance of native species (Aitken and Martin 2008; Brazill-Boast and others 2010; Wiebe 2011), especially for species that cannot excavate their own cavities (Goldingay and Stevens 2009). In some landscapes, removal of trees with cavities may exceed natural replenishment (Goldingay and Stevens 2009; Lindenmayer and others 2012). As such, there is widespread concern about tree cavity decline, threatening the survival of numerous cavity-nesting species (Goldingay and

Stevens 2009; Harper and others 2005a; Lindenmayer and Wood 2010; Newton 1994; Wiebe 2011).

Nest cavity availability can be further reduced by the introduction of new species that compete for these limited resources (Czajka and others 2011; Newson and others 2011; Newton 1994; Strubbe and Matthysen 2009; Wiebe 2011). For example, in the Netherlands, the introduced common starling (*Sturnus vulgaris*) can dominate nest cavities and reduce the population density of great tits (*Parus major*) (van Balen and others 1982). Similarly, the introduction of the ring-necked parakeet (*Psittacula krameri*) in the United Kingdom is believed to cause reductions in nuthatch (*Sitta europaea*) abundance (Strubbe and Matthysen 2009).

In Australia, competition for nest cavities can be especially intense (Gibbons and Lindenmayer 2002). Over 300 species in Australia depend on tree cavities (Gibbons and Lindenmayer 2002) and the development of new cavities takes many years (Lindenmayer and others 2011). No Australian species create tree cavities, so cavity development is dependent on slow-acting processes of rot and decay (Lindenmayer and others 2000; Lindenmayer and others 2003; Mackowski 1984; Saunders 1979). In conjunction with slow replenishment, existing cavities are often destroyed through human-habitat modification (Harper and others 2005a; Soderquist and Mac Nally 2000). As such, competition from introduced species can have substantial impacts on native cavity-dependent taxa (Gibbons and Lindenmayer 2002; Lindenmayer and others 2009). Despite this, most research on cavity-nesting competition comes from the Northern Hemisphere (Brazill-Boast and others 2010; Czajka and others 2011; Goldingay and Stevens 2009; Newson and others 2011; Newton 1994; Strubbe and Matthysen 2009; van Balen and others 1982; Wiebe 2011).

One introduced species believed to compete with native species for cavity-nest sites is the common myna (*Acridotheres tristis*) (Dhami and Nagle 2009; Harper and others 2005b; Pell and Tidemann 1997a, b). The species has been listed as one of the world's worst invasive species (ISSG 2000). There is global concern that the common myna displaces native species through competitive domination of nest cavities, displacing birds from nest sites and destroying eggs (Byrd 1979; Dhami and Nagle 2009; Feare and Craig 1998; Harper and others 2005b; Pell and Tidemann 1997a, b; Watson and others 1992). The common myna can outcompete the native crimson rosella (*Platycercus elegans*) and eastern rosella (*Platycercus eximius*) in aggressive encounters during the breeding season in Canberra, Australia, potentially reducing their breeding success (Pell and Tidemann 1997b). Harper and others (2005b) found the common myna occupied 37.5 % of nest boxes over a breeding season from late September to March in Melbourne, Australia, possibly limiting the availability of

nesting sites for native species. The common myna can also build nests in multiple cavities, potentially deterring native species from using them (Pell and Tidemann 1997b).

Despite the above examples, there is no conclusive scientific evidence that domination of nest cavities by the common myna reduces the *abundance* of native species. Additionally, our previous research indicates that tree density may influence the abundance and impact of the common myna (Garrock and others 2013).

Many studies have found a strong influence of habitat suitability on species abundance (Didham and others 2005; MacDougall and Turkington 2005; Parsons and others 2006; Ruhren 2012). The common myna is abundant in modified urban landscapes and tends to avoid high-density native woodland areas (Garrock and others 2013). Therefore, in low tree density areas the common myna may become abundant and compete for resources with native species.

Our study investigated the influence of cavity-nesting of the introduced common myna on two native parrot species, the crimson rosella and eastern rosella. Due to the influence of habitat on species abundance, we initially examined variation in the abundance, levels of cavity occupancy and nesting success of these three species, across areas characterized by different tree density. We then investigated the impact of common myna nest box occupation on crimson rosella and eastern rosella abundance. To conduct our investigation, we used artificial nest boxes as a proxy for natural cavities. Artificial nest boxes provide a standardized and repeatable measure of cavity-nesting that can be representative of natural cavity nest use (Beyer and Goldingay 2006).

We developed a series of hypotheses (Table 1). Broadly, we hypothesized that tree density (high, medium, and low) would influence the abundance, rate of cavity-nesting, and nesting success of our three study species. We also hypothesized that common myna nest box occupancy would have a negative impact on the abundance of the crimson rosella and eastern rosella at low tree density sites.

Materials and Methods

Survey Sites

We selected survey sites around Canberra, Australia to investigate cavity-nesting occupancy by the common myna and native rosella species. Each site was located in a nature reserve next to an urban area (residential suburb). Nature reserves ranged from dense woodlands to open grassy woodlands and were dominated by *Eucalyptus* species. Sites extended for 250 m into reserves and followed the

suburb edge for 1 km (Fig. 1). We insured adjoining suburbs had been constructed more than 20 years ago so the vegetation was well established. Sites were located at least 2 km apart as the common myna rarely travels further than 2 km from its territory (Dhami and Nagle 2009; Feare and Craig 1998). These criteria limited the potential study sites to 23.

We further refined sites based on tree density, due to the influence of habitat on species abundance (Didham and others 2005; MacDougall and Turkington 2005; Parsons and others 2006; Ruhren 2012). We estimated tree density in the 23 potential sites by walking a 1-km transect through nature reserves and scoring the vegetation cover at 20 m intervals (Fig. 1). We allocated one point for tree cover overhead or zero points for no tree cover. We selected the five sites with the highest vegetation score (>40), the five sites with a medium vegetation score (between 31 and 36) and the five sites with the lowest vegetation score (<26) (Fig. 1). We used an analysis of variance (ANOVA) to test if mean nature reserve tree density varied significantly among the three categories (high, medium, and low) (Fig. 1a).

Nest Box Surveys

We constructed 225 nesting boxes from 15 mm plywood. Boxes had an internal volume of 19 l, and were fitted with a 65-mm diameter entrance hole in the front panel. In July–August 2008, we established 15 nesting boxes in each of the 15 sites. The crimson rosella, eastern rosella and common myna are known to prefer cavities with an entrance diameter of 50–80 mm but will use up to 120 mm (Goldingay and Stevens 2009).

We randomly selected nest box placement by dividing each site into 5 m grid cells. Grid cells were numbered from one to 10,000 and we used a random number generator to select the grid cell location for each nest box. Nest boxes were placed in the tree closest to the center of a selected grid cell. If there were no trees located in the grid cell, we placed the nest box in the closest tree in any direction. Nest boxes were only placed in *Eucalyptus* tree species that had a diameter greater than 20 cm at breast height. We never placed more than one box in a single tree. However, on occasion (if randomly selected), boxes were placed in trees within 5 m of one another. Nest boxes were mounted 3–4 m above the ground on the southern side of trees to insure they were protected from the summer sun.

To check nest boxes we used a bullet-camera surrounded by five light-emitting diodes (32 mm in diameter), that allowed color viewing in total darkness. We mounted the camera on the end of a 3-m pole and connected it to a video camera via a 5-m coaxial cable. To check nest boxes, we placed the camera at the entrance hole of each box, viewing and recording the images on a video camera (Fig. 2). If no

Table 1 Hypotheses for our study on cavity-nesting occupation of the introduced common myna (*Acridotheres tristis*) and the native crimson rosella (*Platycercus elegans*) and eastern rosella (*Platycercus eximius*) in Canberra, Australia

Literature/rationale	Hypothesis
1 Studies indicate that common myna abundance and nesting are strongly influenced by habitat, with numbers and nesting success increasing as tree density declines (Crisp and Lill 2006; Garrock and others 2013; Lowe and others 2011; Pell and Tidemann 1997a, b; Tracey and others 2007; White and others 2005). However, many native bird species are more abundant and exhibit increased nesting success in dense woodland (Blair 2001; Case 1996; Clergeau and others 1998; Crooks and others 2004; Deng and Gao 2005; Gardali and Holmes 2011; Munro and others 2009; Newton 1994; Sewell and Catterall 1998)	We hypothesized that tree density (high, medium and low) would influence the abundance, rate of cavity-nesting and nesting success for the common myna, crimson rosella and eastern rosella. Specifically, we hypothesized that common myna abundance, rate of cavity-nesting and nesting success would be greater in low tree density sites than in medium and high sites, while crimson rosella and eastern rosella abundance, rate of cavity-nesting, and nesting success would be greater in high tree density sites
2 Artificial nest boxes provide a standardized and repeatable measure of cavity-nesting that can be representative of natural cavity nest use (Beyer and Goldingay 2006; Pell and Tidemann 1997b). Because we used nest boxes as a proxy for natural cavities, we wanted test whether bird abundance was related to nest box occupancy. We used correlations between species nest box occupancy and abundance to determine whether observed trends in nest box occupancy were related to species abundance	We hypothesized that there would be a significant positive relationship between species abundance and nest box occupancy, with greater nest box occupancy by each species in areas where they are more abundant
3 Research suggests that rosella species tend to prefer natural cavities, while the common myna will readily use artificial cavities (Lowe and others 2011). Therefore, we avoided directly comparing nesting rates of common myna to nesting rates of rosella species as these relationships might have been due to preferences for natural cavities over nest boxes. Instead we compared common myna nest box occupancy with rosella abundance. Due to the potentially confounded relationship between species abundance and tree density we investigated the relationship between common myna nest box occupancy and rosella abundance separately over each of the three tree density categories	We hypothesized that there would be a negative impact of common myna nest box occupancy on the abundance of the crimson rosella and eastern rosella at low tree density sites
4 The impact of an introduced species can often increase in severity as it becomes more abundant (Choquenot and Parkes 2001). Therefore, if nest cavities are limited, increases in common myna numbers could lead to greater competition for cavities with native species	We hypothesized that in areas where the common myna is abundant a greater proportion of native birds would be evicted from nest boxes

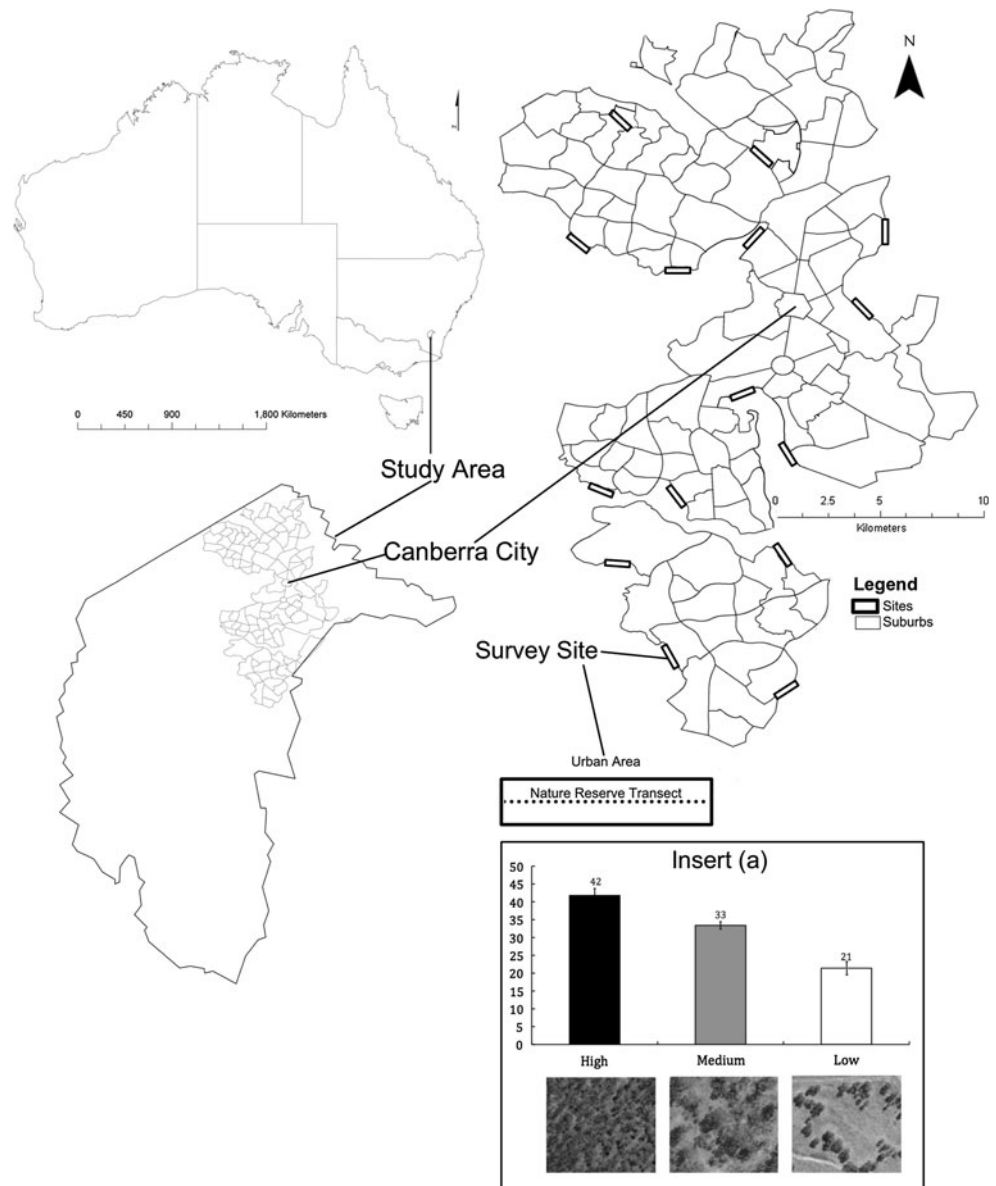
bird was present, or an adult bird was on the nest potentially obscuring eggs or chicks, we monitored the box for a period of 5–10 min from approximately 20 m away. This enabled us to identify birds when they returned to the box or the number of eggs/chicks present if the adult vacated the box. The procedure was fast and effective, resulting in minimal disturbance to nest box occupants and enabled us to identify the species and the number of eggs in each nest box.

Nest boxes were checked every 4 weeks throughout the breeding season (October–March), over 3 years (2008–2009, 2009–2010, and 2010–2011). The breeding season for many species in Canberra starts later than in other areas of Australia due to the altitude (approximately 605 m above sea level) and comparatively cold weather (Gibbs and others 2011; Lenz 1979). Before each nesting season, we checked and replaced damaged boxes.

We classified nest boxes as ‘occupied’ if a bird was observed using the box with nesting material and/or eggs at some stage during the breeding season. We classified an

egg as ‘successful’ if it produced a chick that hatched successfully (i.e., no evidence of a dead chick in, or surrounding, the box). However, due to the 4-week survey schedule, on some occasions it was difficult to determine if the eggs hatched successfully as we either did not observe the eggs or the chicks fledged before we returned. Therefore, in the analysis we only included data where we observed eggs on one visit and then observed chicks or unsuccessful eggs (e.g., broken or abandoned), in the following visit. We classified a nesting attempt as ‘interrupted’ if, after initial inspection, a box was ‘occupied’ by a native species and the following inspection revealed that the common myna had taken over the box. However, we were careful to avoid identifying an interruption as occurring if the initial species had chicks that were close to fledging and, therefore, may have vacated the box prior to the common myna using it. Using this conservative approach, it is likely that we underestimated the number of native species that were interrupted by the common myna.

Fig. 1 Study area and location of the 15 survey sites within nature reserves surrounding Canberra, South East Australia. At each site we randomly placed 15 nest boxes and set up a 1-km long and 100-m wide line transect survey. We scored vegetation cover at 20-m intervals along each transect. We then categorized nature reserved as having high, medium or low tree density (\pm SE) (see inset *a*). Tree density varied significantly among tree categories ($F_{2,12} = 12.5$, $P = 0.001$)



Bird Abundance Surveys

At each of our 15 sites we established a transect survey that was 1 km in length and 100 m wide (Fig. 1). We surveyed bird abundance every second month in the breeding season (November, January, March) from November 2008 to March 2011. Bird observers with more than 20 years bird watching experience identified birds by both sight and call. Observers attempted to sight all birds heard calling to minimize the chance of double counting. We assigned each observer a group of three sites (six transects) to survey. Observers walked transects for 20 min, within 3 h of sunrise. Surveys were only undertaken in good weather conditions when there was little or no rain or wind. During every survey month, each transect was walked two to three

times. Fifteen observers completed a total of 310 transect surveys.

Analysis

We used JMP 10[®] (SAS Institute Inc 2012) statistical software package to complete all statistical analysis. As we found no significant yearly variation in nesting or abundance, we then investigated the effect of tree density. Using the data from the 310 transect surveys we calculated the average number of birds per square kilometer per transect for each year. We also calculated the proportion of nest boxes occupied by each species at each site per year. This produced 45 measures of abundance and nest box occupancy for each species (15 sites over 3 years).

We investigated the influence of tree density on species abundance and nest box occupancy using one-way ANOVAs (Hypothesis 1, see Table 1).

We calculated the proportion of successful eggs from each box where we were able to clearly determine the fate of the eggs. Egg success for each species over the different tree densities was then evaluated using a one-way ANOVA (Hypothesis 1, see Table 1). We also used a one-way

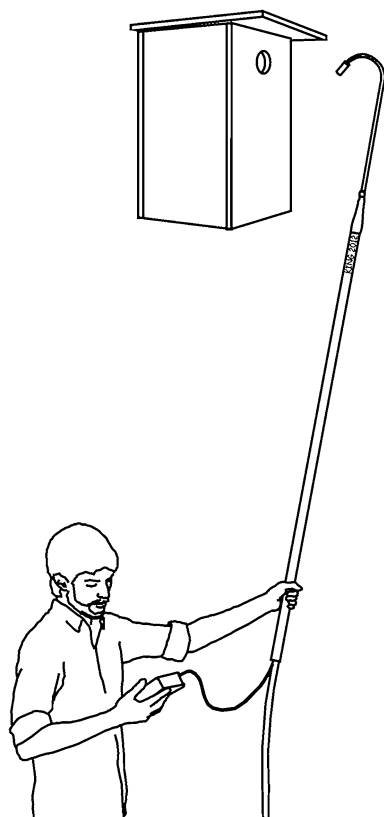


Fig. 2 Diagram of the bullet-camera we used to identify the species and the number of eggs in each nest box. We placed the camera at the entrance hole of each box, viewing and recording the images on the video camera. This procedure was fast and effective, resulting in minimal disturbance to nest box occupants (image credit Daryl King)

ANOVA to test if the average number of common myna eggs laid per clutch was significantly influenced by tree density.

We then used linear regression to analyze the relationship between abundance and nest box occupancy, for each species, over the 15 sites for 3 years (45 data points). We wanted to insure there was a significant relationship between bird abundance and nest box occupancy (Hypothesis 2, see Table 1) as we used nest boxes as a proxy for natural cavities.

We investigated the relationship between common myna nest box occupancy and rosella species abundance using linear regression (45 data points). We then investigated this relationship separately over each of the three tree densities (15 data points per tree density) (Hypothesis 3, see Table 1). This helped us to determine if significant correlations were due to habitat preferences between different species or if they were due to nest box competition by the common myna.

Finally, we examined the relationship between tree density and the number of common myna interruptions to rosella nesting using a one-way ANOVA (Hypothesis 4, see Table 1).

Results

Common Myna

The common myna occupied an average of 26.5 % (± 3.5) of nest boxes throughout the survey period (averaged over all sites). The common myna also build apparent 'fake' nests in an additional 6.8 % (± 1.0) of boxes that were not used for egg laying and minimal nesting material was placed in these boxes (Harper and others 2005b). In two nest boxes, we observed that crimson rosella nesting was interrupted and covered over by 'fake' common myna nests. We observed that 'fake' nests built by the common myna had a different appearance to nests built for egg laying. 'Fake' nests were constructed of a thin flat layer of

Table 2 Common myna abundance and nesting in nature reserves surrounding Canberra, Australia

Tree density	Number of nest boxes added	Common myna abundance (birds per km ²)	Nest boxes used by the common myna (%)	Common myna egg success (%)	Average eggs per clutch	Common myna interrupt rosella species nesting (% of boxes)
High	75	9.7 \pm 3.6	9.3 % \pm 2.1	56.3 % \pm 22.7	4.5 \pm 0.3	1.3 \pm 1.3
Med	75	45.4 \pm 10.1	27.1 % \pm 2.8	90.0 % \pm 4.0	4.3 \pm 0.2	6.6 \pm 2.2
Low	75	101.9 \pm 22.4	43.1 % \pm 8.0	91.1 % \pm 1.8	4.2 \pm 0.1	12.7 \pm 6.2
Significance		$F_{2,42} = 10.51$, $P < 0.001^*$	$F_{2,42} = 11.29$, $P < 0.001^*$	$F_{2,28} = 6.24$, $P = 0.006^*$	$F_{2,28} = 0.24$, $P = 0.787$	$F_{2,42} = 1.79$, $P = 0.179$

Analysis of variance was used to test if there was a significant difference in abundance, nest box occupancy, nesting success or nest box interruptions over three tree densities (high, medium, and low)

Significant differences are indicated with an asterisk

twigs and often a large amount of rubbish (e.g., plastic bags, chocolate bar wrappers). Common myna nests built for egg laying had a thick, bowl-shaped layer of twigs with only small pieces of rubbish. We also observed that the common myna placed a layer of green *Eucalyptus* leaves into the nest 2–3 days before laying eggs.

We found that the number of common myna birds per square kilometer declined rapidly with increasing tree density ($F_{2,42} = 10.51$, $P < 0.001$) (Table 2). A similar pattern was observed for common myna nest box occupancy, with higher numbers observed in low tree density sites and observations declining as tree density increased ($F_{2,42} = 11.29$, $P < 0.001$) (Table 2).

The common myna laid one to seven eggs per clutch, with an average of 4.3 (± 0.1) eggs per clutch. Egg success (proportion of eggs laid that hatched) was greater in the low and medium tree density sites than in the high tree density sites ($F_{2,28} = 6.24$, $P = 0.006$) (Table 2). However, we found no significant relationship between the average number of eggs laid per clutch by the common myna and tree density ($F_{2,28} = 0.24$, $P = 0.787$) (Table 2).

We found a significant positive relationship between common myna abundance and the proportion of nest boxes occupied by the species ($F_{1,43} = 131.71$, $P < 0.001$) (Fig. 3).

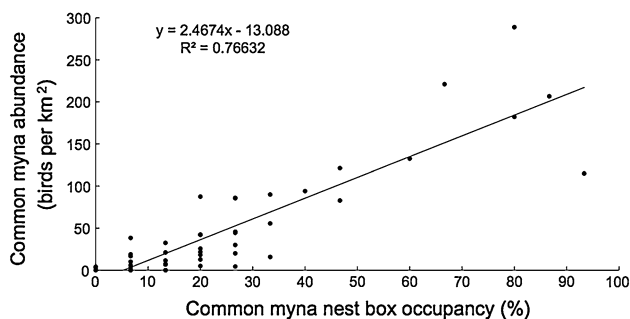


Fig. 3 Relationship between common myna abundance and the proportion of nest boxes occupied by the species ($F_{1,43} = 131.71$, $P < 0.001$)

Crimson Rosella

We observed that crimson rosella abundance at low tree density sites was significantly lower than at medium and high tree density sites ($F_{2,42} = 14.65$, $P < 0.001$) (Table 3).

The crimson rosella occupied an average of 24.3 % (± 2.1) of nest boxes throughout the survey period (averaged over all sites). Crimson rosella box occupancy increased with greater tree density ($F_{2,42} = 3.55$, $P = 0.038$) (Table 3).

Crimson rosella egg success (proportion of eggs laid that hatched) in high tree density sites was greater than egg success at medium or low tree density sites ($F_{2,38} = 4.04$, $P = 0.026$) (Table 3). There was also a significant relationship between crimson rosella abundance and the proportion of nest boxes occupied by the species ($F_{1,43} = 18.48$, $P < 0.001$) (Fig. 4).

Eastern Rosella

We found that eastern rosella abundance at medium tree density sites was higher than eastern rosella abundance at low or high tree density sites ($F_{2,42} = 5.79$, $P < 0.001$) (Table 4). The eastern rosella occupied an average of 8.9 % (± 1.2) of nest boxes throughout the survey period (averaged over all sites). We observed no significant relationship between eastern rosella egg success (proportion of eggs laid that hatched) and tree density ($F_{2,29} = 0.72$, $P = 0.495$) (Table 4). However, eastern rosella nest box occupancy was lower in the high tree density sites than in the medium or low tree density sites ($F_{2,42} = 3.75$, $P = 0.032$) (Table 4). We did not find a significant relationship between eastern rosella abundance and the proportion of nest boxes occupied by the species ($F_{1,43} = 1.75$, $P = 0.192$) (Fig. 5).

Impact on Rosella Nesting

We observed that the common myna interrupted crimson rosella nesting in 14 nest boxes and the eastern rosella in two nest boxes. The number of nest box interruptions by the common myna was slightly higher at sites with lower

Table 3 Crimson rosella abundance and nesting in nature reserves surrounding Canberra, Australia

Tree density	Number of nest boxes added	Crimson rosella abundance (birds per km ²)	Nest boxes used by the crimson rosella (%)	Crimson rosella egg success (%)
High	75	83.9 \pm 9.3	28.9 % \pm 3.0	65.7 % \pm 4.0
Med	75	61.6 \pm 6.4	25.8 % \pm 3.0	46.1 % \pm 5.1
Low	75	31.4 \pm 3.9	18.2 % \pm 4.3	44.6 % \pm 8.5
Significance		$F_{2,42} = 14.65$, $P < 0.001$ *	$F_{2,42} = 3.55$, $P = 0.038$ *	$F_{2,38} = 4.04$, $P = 0.026$ *

Analysis of variance was used to test if there was a significant difference in abundance, nest box occupancy or nesting success over three tree densities (high, medium, and low)

Significant differences are indicated with an asterisk

tree density; however, this relationship was not significant ($F_{2,42} = 1.79$, $P = 0.179$) (Table 2).

There was a significant negative relationship between the proportion of nest boxes occupied by the common myna and the abundance of the crimson rosella ($F_{1,43} = 26.057$, $P < 0.001$) (Fig. 6a). Further investigation revealed this negative relationship was significant at low tree density sites ($F_{1,13} = 7.548$, $P = 0.017$) (Fig. 6c) and high tree density sites ($F_{1,13} = 9.226$, $P < 0.001$) (Fig. 6b), but not at medium tree density sites ($F_{1,13} = 3.256$, $P = 0.094$) (Fig. 6c). At high tree density sites, an increase in the proportion of nest boxes occupied by the common myna, from 10–25 %, was related to a sharp decrease in crimson rosella abundance (Fig. 6b). At low tree density sites the relationship between common myna nest box occupancy and reduced crimson rosella abundance appeared to be less dramatic (Fig. 6d).

We also observed a significant negative relationship between common myna nest box occupancy and eastern rosella abundance ($F_{1,43} = 5.101$, $P = 0.029$) (Fig. 7a). However, further investigation revealed this relationship was only significant at low tree density sites ($F_{1,13} = 9.672$, $P < 0.001$) (Fig. 7d).

Other Species

Other species observed using nest boxes included the European honey bee (*Apis mellifera*), sugar glider

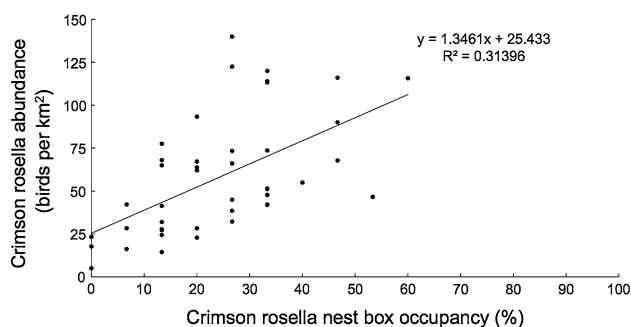


Fig. 4 Relationship between crimson rosella abundance and the proportion of nest boxes occupied by the species ($F_{1,43} = 17.85$, $P < 0.001$)

(*Petaurus breviceps*), common brushtail possum (*Trichosurus vulpecula*), red-rumped parrot (*Psephotus haematonotus*), Australian owl-nightjar (*Aegotheles cristatus*), and common starling. The European honey bee occupied 9.9 % (± 1.8) of nest boxes throughout the survey period. However, we found no significant relationship between European honey bee nest box occupancy and tree density ($F_{2,42} = 0.16$, $P = 0.849$). Nest box occupancy by other species was low (<5 % of boxes) and data were insufficient to allow for statistical analysis.

Discussion

Study Overview

To the best of our knowledge, this study provides the strongest evidence to date of the negative impact of the common myna on native bird *abundance*, through cavity-nesting domination. The key findings of our study were:

- (1) The abundance and nesting of the common myna, crimson rosella and eastern rosella were strongly influenced by tree density.
- (2) Nest box occupancy for the common myna and crimson rosella was strongly related to their abundance. This indicates that nest boxes provided a good proxy for species cavity-nesting.
- (3) Despite the strong influence of tree density on species abundance, at low tree density sites, common myna nest box occupancy had a negative influence on crimson rosella and eastern rosella abundance. At high tree density sites the negative relationship between common myna nest box occupancy and crimson rosella abundance appeared to be more severe.

We did not attempt to quantify the rate of natural cavity-nesting in the study sites. However, nest boxes can provide a standardized and repeatable measure of cavity-nesting (Beyer and Goldingay 2006). Additionally, we believe nest boxes in our study area were representative of natural

Table 4 Eastern rosella abundance and nesting in nature reserves surrounding Canberra, Australia

Tree density	Number of nest boxes added	Eastern rosella abundance (birds per km ²)	Nest boxes used by the eastern rosella (%)	Eastern rosella egg success (%)
High	75	34.5 \pm 3.9	4.4 % \pm 1.2	63.3 % \pm 13.5
Med	75	48.6 \pm 8.0	11.1 % \pm 2.1	46.8 % \pm 10.1
Low	75	22.6 \pm 3.0	11.1 % \pm 2.4	46.3 % \pm 7.5
Significance		$F_{2,42} = 5.79$, $P = 0.006^*$	$F_{2,42} = 3.75$, $P = 0.032^*$	$F_{2,29} = 0.72$, $P = 0.495$

Analysis of variance was used to test if there was a significant difference in abundance, nest box occupancy or nesting success over three tree densities (high, medium, and low)

Significant differences are indicated with an asterisk

cavity nest use for the common myna and crimson rosella, due to correlations between nest box use and abundance.

The common myna may show a preference for using nest boxes over natural cavities (Lowe and others 2011) and therefore, our observed occupancy and nesting success may be overestimated. The opposite may occur for the crimson rosella with evidence suggesting that they may prefer natural cavities to nesting boxes (Lowe and others 2011).

We have not been able to incorporate all causal variables into our analysis with some unexpected results observed. For example, eastern rosella abundance was not correlated with nest box use. The study species are likely to be influenced by other factors such as potential territorial exclusion by the native noisy miner (*Manorina*

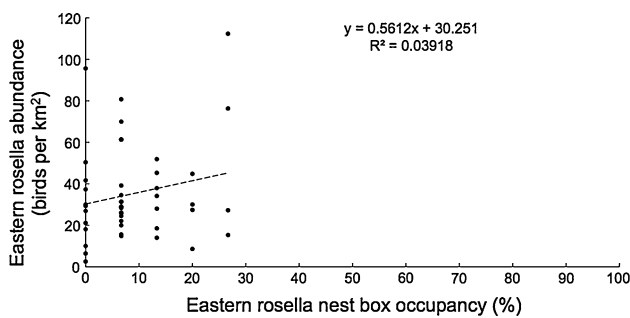


Fig. 5 Relationship between eastern rosella abundance and the proportion of nest boxes occupied by the species ($F_{1,43} = 1.75$, $P = 0.192$)

melanocephala), predation from the introduced domestic cat (*Felis catus*), land use practices in adjoining suburban areas and the abundance of natural cavities. Additionally, there may be detectability issues across the different observers and different tree densities, with it easier to observe birds in low tree density sites compared to high tree density sites. However, we believe the general trends observed in our study, over replicated sites, provide a firm basis from which to gain an understanding of the influence of habitat and the common myna on two native Australian parrots.

Influence of Tree Density on Species Abundance and Nesting

Many species are strongly influenced by habitat quality and are more abundant in high quality habitat than low quality habitat (Kajzer and others 2011). These variations in species abundance may occur due to increased breeding success and survival in high quality habitat (Xirouchakis and others 2011). However, high quality habitat for one species may not constitute high quality habitat for another species (Didham and others 2005; Farnsworth 2004; MacDougall and Turkington 2005). For example, the common myna is thought to prefer low tree density areas, while the crimson rosella tends to thrive in higher tree density forests and woodlands (Krebs 1998; Garock and others 2013; Pell and Tidemann 1997a). In our study tree density significantly influenced the abundance, nest box occupancy, and nesting

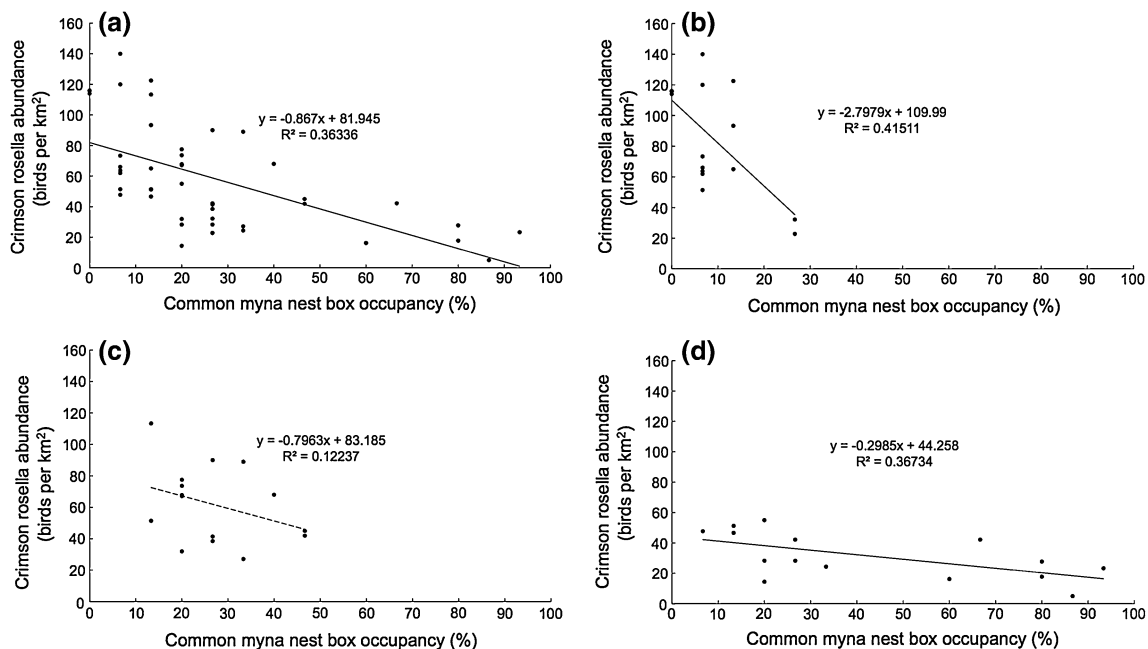


Fig. 6 Relationship between the proportion of nest boxes occupied by the common myna and the abundance of the crimson rosella. **a** The relationship over all sites of differing tree density ($F_{1,43} = 26.057$,

$P < 0.001$), **b** high tree density sites only ($F_{1,13} = 9.226$, $P < 0.001$), **c** medium tree density sites only ($F_{1,13} = 3.256$, $P = 0.094$), and **d** low tree density sites only ($F_{1,13} = 7.548$, $P = 0.017$)

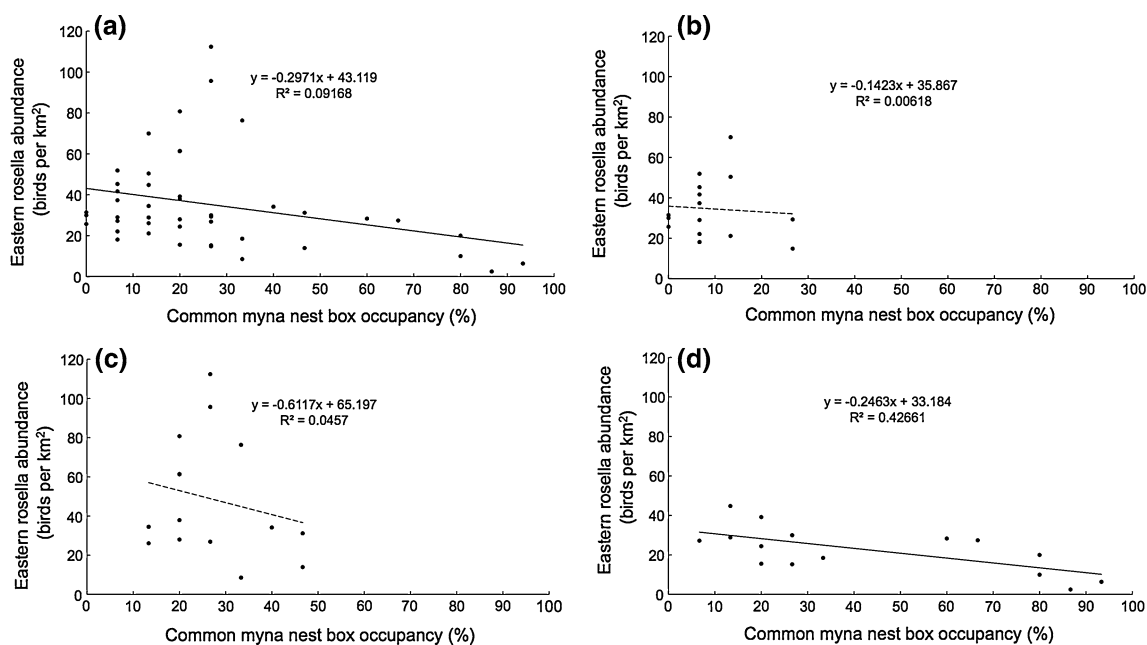


Fig. 7 Relationship between the proportion of nest boxes occupied by the common myna and the abundance of the eastern rosella. **a** The relationship over all sites of differing tree density ($F_{1,43} = 5.101$,

$P = 0.029$), **b** high tree density sites only ($F_{1,13} = 0.081$, $P = 0.781$), **c** medium tree density sites only ($F_{1,13} = 1.216$, $P = 0.290$), and **d** low tree density sites only ($F_{1,13} = 9.672$, $P < 0.001$)

success of the common myna and the crimson rosella in opposite ways. Eastern rosella abundance and nest box occupancy were also significantly influenced by tree density. These results supported Hypothesis 1 (see Table 1) that tree density would influence abundance and rate of cavity-nesting of all three study species.

The common myna appeared to prefer low tree density sites, occurring in greater abundance, occupying more nest boxes and having a greater egg success than in other areas (Table 2). The success rate of common myna eggs in low tree density sites was over 90 %. This success rate is very high for a cavity-nesting bird species; however, we were not able to determine the success rate of fledglings. In a review of cavity-nesting species, Nice (1957) found an average egg success rate of 66 %. Therefore, even in high tree density sites, where common myna egg success rate dropped to approximately 56 %, egg success was still relatively high. Low tree density sites may represent high quality habitat for the common myna. These habitats are probably similar to their natural environment in India and central and southern Asia (Feare and Craig 1998; Pell and Tidemann 1997a). Open grassland with low tree density may offer suitable ground foraging areas for the common myna, while providing the species with cavities for nesting.

The crimson rosella appeared to prefer high tree density sites, occurring in greater abundance and nesting in more nest boxes than in other areas (Table 3). We also observed greater egg success rates of 66 % in high tree density sites, while in low tree density sites the egg success rate was

45 %. These egg success rates are similar to the 50 % success rate found in a study of the crimson rosella nesting in a high tree density reserve in Canberra, where the common myna was absent (Krebs 1998). This indicates that the common myna may not negatively impact native parrot egg success; rather the common myna may potentially ‘impact’ species through reducing the availability of cavities. Alternatively, our observation schedule (every 4 weeks) may not have been frequent enough to fully identify all cases of egg predation or egg failure.

The eastern rosella was more abundant in medium tree density sites, however, relatively high levels of nesting occurred over both medium and low tree density sites (Table 4). The species is known to prefer lightly wooded areas (Pizzey and Knight 2007) that may be representative of the medium and low tree density sites in our study.

Introduced Species Impact in Conjunction with Tree Density

Due to the strong influence of tree density on species abundance, it is essential to investigate the impact of introduced species in conjunction with changes in habitat (Didham and others 2005; Farnsworth 2004; MacDougall and Turkington 2005; Ricciardi 2003). Analysis that encompasses both habitat preferences and the impact of introduced species will assist with discrimination between these two key factors that influence the abundance of native species. This is essential for three reasons:

- (1) To clearly understand the impact of introduced species on native species and avoid mistakenly identifying an impact when there is none (negative correlations may be due to habitat preference alone).
- (2) To determine if the impact of introduced species on native species is more severe in particular habitats.
- (3) To help facilitate effective management and mitigation of the negative impacts of introduced species.

For example, when tree density was not factored into our analysis, we found significant negative relationships between common myna nest box occupancy and the abundance of the crimson rosella and eastern rosella. However, this correlation does not imply causation. We would expect a negative correlation between common myna nest box occupancy and crimson rosella abundance based on habitat preference alone.

When we investigated the impact of the common myna on rosella species separately over different tree densities, we were able to account for some of the influence of habitat on species abundance and nesting. The common myna appeared to have a negative impact on both the crimson rosella and eastern rosella at low tree density sites (Figs. 1d, 7d). This relationship is potentially due to the high number of boxes occupied by the common myna at low tree density sites (over 90 % at one site). This high rate of box occupancy by the common myna and the building of ‘fake’ nests may limit the availability of nest sites for other cavity-nesting species. We also observed a negative relationship between common myna nest box occupancy and crimson rosella abundance at high tree density sites (Fig. 6b). Indeed the impact of the common myna appeared to be more severe in high tree density sites. Therefore, management of the common myna may be required in these areas that represent ‘high quality’ habitat for native species, especially in areas where threatened species are nesting, such as the superb parrot (*Polytelis swainsonii*).

Our findings supported Hypothesis 3 (see Table 1), that there would be a negative impact of common myna nest box occupancy on the abundance of the crimson rosella and eastern rosella. We observed higher numbers of native rosella nesting attempts interrupted by the common myna at low tree density sites although this was not statistically significant (Table 2). This finding partially supported Hypothesis 4 (Table 1), that in sites where the common myna is more abundant (low tree density sites), a greater number of native birds would be evicted from nest boxes.

Cavity Limitation

A review of the literature on population limitation in cavity-nesting species by Newton (1994) concluded that evidence exists for cavity limitation in human-modified landscapes

but less so in mature, unmanaged forests. More recently, these conclusions have been supported by strong experimental evidence from the Northern Hemisphere (see Wiebe 2011 for a review). All of our sites were human-modified landscapes. Our results indicated that in combination, habitat quality and the common myna might substantially limit cavity nest sites for native species. Therefore, habitat restoration through natural regrowth and tree planting may be a suitable management strategy to increase habitat quality for native species and in the longer-term increase the number of nest cavities. Habitat restoration is also likely to make the habitat less suitable for the common myna, potentially reducing their abundance (Grarock and others 2013).

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