Made to measure – building homes for bats, parrots and possums

Tina Hsu
Sydney Olympic Park Authority

Sydney Olympic Park Authority commenced a nest and roost box program in 2010 to provide supplementary habitat to the Red-rumped Parrot, microbats and possums, installing more than 60 boxes over the past 10 years. The Red-rumped Parrot population has increased almost three-fold as the parrots use the boxes for breeding each year. The bat boxes support three bat species, including a maternity group of Southern Myotis, Australia's only fishing bat and a threatened species. The Authority conducts regular inspections, ongoing management and habitat restoration to ensure the boxes continue to provide optimum habitat to fauna of conservation focus at the Park.

Hollows - what are they and why are they important?

More than 300 native Australian vertebrate species use tree hollows for breeding or shelter, including birds, microbats, arboreal marsupials, reptiles and frogs. Hollow-dependent fauna constitute approximately 15% of Australian vertebrate fauna (15% of birds, 31% of mammals, 10% of reptiles and 13% of amphibians), a far greater proportion of hollow-dependency compared to other continents (Gibbons and Lindenmayer, 2002). In NSW, at least 174 species (46 mammals, 81 birds, 31 reptiles and 16 frogs) are dependent on tree hollows; 40 of which are listed as threatened under the *NSW Biodiversity Conservation Act* 2016 (DPIE, 2019).

Tree hollows are cavities that develop in the trunk and branches of trees through natural processes such as damage by fire, wind or disease, and consumption by fungi or invertebrates such as termites (Goldingay, 2009; O'Connell and Keppel, 2016; DPIE, 2019). Tree hollows are common in myrtaceous trees, primarily eucalypts, and four broad types can be recognised – vertical spout, hollow in dead branch, hollow in live branch, and trunk hollow (Goldingay, 2009). The formation of tree hollows through natural processes typically requires more than 100 years but can take up to 400 years depending on tree species (Ridgeway, 2015; O'Connell and Keppel, 2016). While the minimum size-class at which trees consistently contain hollows varies with species and environmental conditions, in general, large old trees provide a greater density of hollows and hollows of a larger size, with eucalypts containing large hollows rarely less than 220 years old (Gibbons and Lindenmayer, 2002; DPIE, 2019). Unlike primary hollow users that can create cavities such as woodpeckers in Europe, North and South America, Australian animals are secondary hollow users that rely on pre-existing hollows (Goldingay, 2009). The existence of large, hollow-bearing trees, both dead and alive, is therefore of critical importance to hollow-dependent fauna, particularly larger species.

Extensive clearing since European settlement has removed and fragmented native vegetation including hollow-bearing trees across large swathes of NSW; for example, 70% of native vegetation has been cleared from the NSW sheep-wheat belt, the tablelands of the Great Divide and the coastal plain (DPIE, 2019). Clearing of native vegetation and loss of hollow-bearing trees are both listed as Key Threatening Processes under the *NSW Biodiversity Conservation Act* 2016, however, clearing has continued apace in NSW. The continual loss of hollow-bearing trees to land clearing is exacerbated by other factors such as clearing for development, public safety and asset protection; tree senescence and lack of recruitment; poor health and shorter lifespan of isolated tree/s; removal of dead wood and dead trees (also a Key Threatening Process); weeds; arson, and suppression of abiotic processes such as fire that may promote natural hollow development, leading to projections of hollow shortage across urban, rural and forested landscapes in large numbers of studies (Lindenmayer and Wood, 2010; Davis et al., 2013; Saunders et al., 2014; Leary, 2015; DPIE, 2019).

As hollow-bearing trees form a critical resource for many species, including critically endangered fauna such as the Swift Parrot and Leadbeater's Possum (Commonwealth *Environment Protection and Biodiversity Conservation Act* 1999), the provision of artificial hollows has become an important interim solution to address their continual loss.

Artificial hollows as supplementary habitat

Artificial hollows are manufactured simulations of tree hollows for the purpose of providing habitat for hollow-dependent fauna; these can be made out of various materials including PVC pipe, plastic drum or salvaged hollows, however, the majority are boxes made out of hardwood, softwood or plywood (Goldingay et al., 2018).

Within Australia, published information on artificial hollows date back to the late 70s, although studies have been slow to accumulate in the following decades. A review by Goldingay and Stevens (2009) found documented information on artificial hollows for just 15 of 114 hollow-using bird species and 8 of 41 hollow-using microbat species. These early reports were small in scale and often not well documented, although some were highly valuable as they demonstrated the potential for artificial hollows to meet the ecological needs of hollow-dependent fauna. For example, bat boxes installed in Organ Pipes National Park in Victoria facilitated the establishment of bat populations within regenerating forest in the park; the number of bats increased from 15 bats per check in 1994-95 to more than 100 bats per check in 2004-05. Artificial hollows have also been used for decades as supplementary nesting habitat for the critically endangered Orange-bellied Parrot.

As artificial hollows have been identified as an interim solution to the ongoing loss of hollow-bearing trees, their use has become more prevalent over time, appearing in Council reserves, National Parks, rehabilitating mine sites, as well as suburban backyards. DIY nest and roost box manuals are feely available online from various conservation and government agencies (e.g. Greater Sydney Local Land Services, 2016). Research on this topic is growing, and findings suggest much remains to be learned about species-specific roost ecology and artificial hollow design preferences. For example, while artificial hollows have been found to be useful to a population of Carnaby's Cockatoo, providing 45% of available hollows and raising the number of breeding attempts in the study area by 112% between 2011 and 2018 (Saunders et al., 2020), Rueegger et al. (2018) reported few bat species used boxes in their study; although introduction of a new box design markedly increased box usage, some species used boxes infrequently and maternity roosting was rare.

For land managers who wish to use artificial hollows to maintain long term viable populations of hollow-dependent fauna, research on natural and artificial hollow occupancy have identified many factors for consideration. However, it is important to recognise that the hollow requirements of most species are still poorly understood and only broadly described. Continual learning of the target species' natural hollow requirements and preferences, in conjunction with a commitment to assess artificial hollow performance through regular monitoring to inform adaptive management, is critical to the development and implementation of a successful, long-term artificial habitat provision strategy (Leary, 2015).

What do hollow-dependent fauna want in a home?

Many factors influence hollow occupancy, beginning at the landscape scale. Occupancy is dependent on hollow availability, which is related to tree species, age and size and strongly influenced by land management practices past and present. For example, in agricultural and pastoral landscapes, tree hollows are often confined to isolated paddock trees, dead trees and small remnants; artificial hollows installed in such areas are likely to have a different occupancy rate compared to areas with a high abundance of natural hollows (DPIE, 2019).

Within the pool of available hollows, only a fraction are suitable. Species select hollows for multiple, specific characteristics as the use of hollows with suboptimal characteristics can adversely affect survival and reproductive success (DPIE, 2019). Characteristics that influence hollow occupancy include:

- The hollow-bearing tree's **position and spatial configuration** in the landscape, with some species preferring hollows near riparian habitat or foraging areas (DPIE, 2019).
- **Territoriality** of the species under investigation. Strongly territorial species need spacing between hollows to minimise interspecific conflict; conversely, species that nest colonially (e.g. Superb Parrots) or in clusters across the landscape need a local abundance of hollows (DPIE, 2019).
- An **entrance size close to body width** is favoured by most species to avoid predation by or competition from larger species (DPIE, 2019); Goldingay and Stevens (2009) cites one study where predation of Crimson Rosella chicks by Pied Currawongs ceased after the artificial hollow entrance was modified into a 10cm spout.
- **Safety from predation** is critical to survival, and additional measures may need to be used if exclusion is not achievable, e.g. sensor-operated nest boxes that close the door at night were deployed to protect the critically endangered Swift Parrot from predatory Sugar Gliders.
- **Adequate hollow volume** to suit specific needs. Animals that roost communally or raise large litters need hollows with small entrances but large internal dimensions (DPIE, 2019); for example, studies have found some bat species chose roost trees that are significantly larger than available trees in the area (Goldingay, 2009). Hollow requirements can also differ within species; Rueegger et al. (2012) reported female Brown Antechinuses showed strong preference for large plywood boxes compared to smaller boxes of plywood and other materials. Hollow volume and depth are known parameters for avian breeding success (Goldingay, 2009). For example, Saunders et al. (2014) found nesting attempts by Carnaby's Cockatoo in shallow hollows (<400 mm) were less successful than those in deeper hollows (>1000 mm).
- **Protection from the elements.** Flooding of vertical spouts have been implicated in nest abandonment by the Red-tailed Black Cockatoo and loss of Eclectus Parrot clutches of between 12% to 20% over 4 years (DPIE, 2019).
- **Multiple hollows** are required by some birds, microbats, reptiles and arboreal marsupials to reduce parasite load, minimise risk of predation, obtain appropriate thermal microclimates, and allow efficient access to foraging areas as a function of their home range size. For example, the Brush-tailed Phascogale has a home range of 41-106ha, and individuals have been found to use up to 38 hollows over a year (Goldingay et

al., 2018; DPIE, 2019). In a study by Goldingay et al. (2018), Phascogales were found in 9% of functional boxes over 4000ha, but another 48% of boxes contained their distinctive nests, bringing total box usage to 57%.

- **Optimal microclimate**. The thermal property of a hollow is related to hollow height, entrance size, hollow width, tree diameter, aspect, and foliage mass near hollow. Tree hollows have a high capacity to buffer extreme temperatures, which is important for many species. O'Connell and Keppel (2016) recorded lower maximum day temperatures and higher minimum night temperatures in tree hollows, and a maximum buffering of 15.1°C below ambient temperatures. In contrast, nest boxes are usually poorly insulated and less temperature stable due to thinner walls and greater area to volume ratio, which could be detrimental to its users. Studies have found even small variation in internal nest temperature can have an effect on behaviour, reproductive performance and development in birds (Larson et al., 2018), and Burcher (2015) found Eastern Pygmy Possum breeding success in salvaged timber hollows was twice as high as that in poorly insulated PVC boxes. Thermoregulation is important to bats and they may select roosts that are heated by the sun to facilitate passive rewarming from daily torpor; studies have found species-specific preferences for aspect (Goldingay, 2009), as well as seasonal differences in preference for timber box thickness and aspect for some microbat species (Leary, 2015).
- Preferred **hollow height** varied among species, however, most bird and bat species reviewed by Goldingay (2009) would use hollows within 5m from ground. Leary's study on artificial bat box use by Cumberland Plain microbats (2015) found different occupation rates with box height (3-3.5m, 6m, 9m) with lower boxes more frequently occupied, and evidence of some species-specific height preference.
- **Stability and longevity** of hollows. Natural tree hollows can provide valuable habitat to fauna for decades, even when the tree is no longer alive. For example, Musk Lorikeets and Little Lorikeets have been reported to use the same hollows for close to 3 decades (Goldingay, 2009). Artificial hollows can also provide long-term habitat if made to last. Squirrel Gliders have been found to occupy and breed in nest boxes over a 10 year period, with individuals occupying boxes for up to 7 years (Goldingay et al., 2017), and Brush-tailed Phascogale and Sugar Glider boxes can remain functional despite infrequent maintenance for 20 years, depending on attachment method and tree species (Goldingay et al., 2018)
- Since suitable hollows are difficult to come by, i**nter- and intraspecific competition** can be fierce when hollows are scarce (Davis et al., 2013); competition between hollow-nesting parrots have led to nest usurpation and direct loss of eggs and nestlings (Goldingay, 2009). Displacement by the introduced Common Myna, Common Starling and European Honeybee are well documented (Goldingay et al., 2018), with

'Competition from feral honey bees (*Apis mellifera L.*)' listed as a Key Threatening Process under the *NSW Biodiversity Conservation Act* 2016. Goldingay et al. (2018) reported infestation rates from 9% to 57%; however, bees may depart after 1-2 years and management may not be required where large numbers of boxes are installed and infestation rate is low.

For artificial hollows to approximate the habitat value of suitable tree hollows, the abovementioned factors and the target species' ecological requirements need to be addressed and reflected in the design, material, placement (height and orientation), location and number of artificial hollows.

It is also important to recognise management success is not measured by hollow occupancy alone. In order to enable the persistence of viable populations over the long term, indicators of success should include the proportion of target fauna groups benefited by artificial hollows, evidence of reproductive success such as females with young, and increase in population over time (Leary, 2015).

These are discussed in greater detail in the Sydney Olympic Park Nest and Roost Box Project case study.

Fighting the housing shortage - a history of Sydney Olympic Park's nest and roost box project

Background

Nationally, 83 mammalian species are hollow-dependent; 46 occur in NSW, 14 of which have been recorded in Sydney Olympic Park (the Park). 114 Australian bird species are hollow-dependent; 81 occur in NSW, 19 of which have been recorded in the Park (Table 1). Some of these species or groups have been identified in the Sydney Olympic Park Authority's *Biodiversity Management Plan 2019* as priority species or groups for conservation focus due to ongoing, landscape-scale declines. These groups are microbats, woodland birds, and the Red-rumped Parrot in particular, as this species is at the eastern limit of its range at Sydney Olympic Park.

Table 1. Hollow-dependent species recorded in Sydney Olympic Park since 2000. Species with confirmed breeding records are denoted with *; threatened species are denoted with ^.

Mammalian hollow users – microbats	Avian hollow users
Chocolate Wattled Bat	Australian King Parrot
Eastern Bent-wing Bat^	Australian Owlet-Nightjar
Eastern Broad-nosed Bat	Barn Owl
Eastern False Pipistrelle	Crimson Rosella
Gould's Wattled Bat	Dollarbird*
Greater Broad-nosed Bat^	Eastern Rosella
Large Forest Bat	Galah*
Lesser Long-eared Bat*	Laughing Kookaburra*
Little Bent-wing Bat^	Little Corella*
Ride's Free-tailed Bat	Little Lorikeet
Southern Myotis*^	Long-billed Corella
White-striped Free-tail Bat*	Musk Lorikeet
Mammalian hollow users – arboreal marsupials	Powerful Owl^
Common Ring-tailed Possum*	Rainbow Lorikeet*
Common Brush-tailed Possum*	Red-rumped Parrot*
	Sacred Kingfisher*
	Scaly-breasted Lorikeet
	Southern Boobook*
	Sulphur-crested Cockatoo*

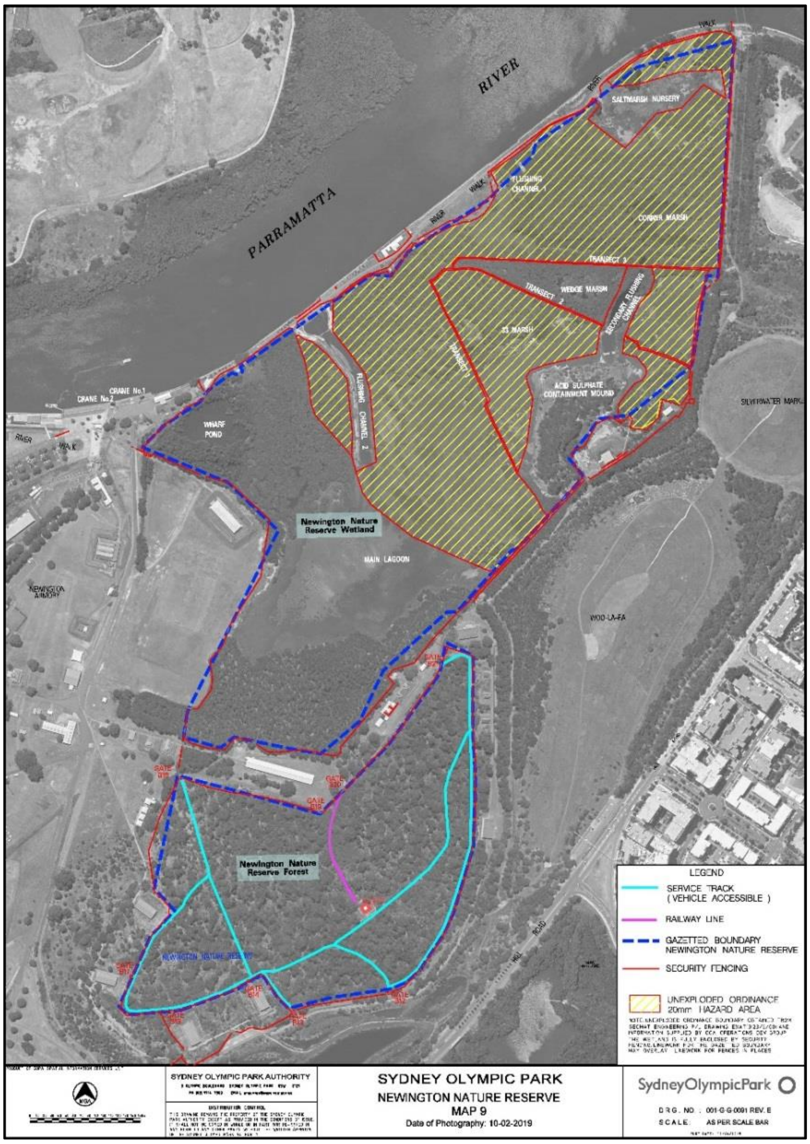

Figure 1. Newington Nature Reserve in Sydney Olympic Park contains a 13ha remnant of Sydney Turpentine Ironbark Forest with many large hollow-bearing trees

Figure 2. (left) Newington Nature Reserve forest contains large mature trees of the critically endangered Sydney Turpentine Ironbark Forest community; (right) Eucalypts planted across the Park for the 2000 Olympic and Paralympic Games are too young to have hollows

The majority of hollow-dependent animals live in Newington Nature Reserve forest (the Reserve, Figure 1), which contains a 13 hectare remnant of Sydney Turpentine Ironbark Forest, a critically endangered ecological community. The forest and surrounding lands were formerly part of the Royal Australian Navy Armament Depot, Newington. Military use excluded public access and exploitation of the forest for more than 100 years, allowing trees to grow and develop a multitude of hollows (Figure 2).

Since Sydney Olympic Park was constructed for the 2000 Olympic and Paralympic Games, trees planted for the Games are too young to have formed natural hollows. As hollows are a limited resource isolated to the Reserve, the need for supplementary habitat was recognised early. The first nest and roost box project ran for three years from 2003 to 2006; 53 boxes were installed – 20 for birds made from marine ply, 30 for bats made from hardwood and 3 for possums made from marine ply. Only the possum boxes were successful in attracting the target species; Common Mynas, Common Starlings and feral honey bees occupied many boxes. By 2009, most boxes were not functional, being in disrepair, fallen from the tree or missing (Figure 3). Less than one-third of boxes – and only those made from hardwood - were in reasonable condition for reuse.

The first project, though unsuccessful, taught us the importance of box material, design and installation method. Learnings from this project include:

- Hardwood boxes were more durable than boxes made from marine ply
- Waterproofing is required to increase box longevity
- Trial different box heights (boxes were mounted to 3-4m due to safety concerns and for ease of inspection)
- Stable attachments that go around the tree trunk and allow for tree growth are essential. Attaching boxes by nailing mounting strips to the sides of trees and looping wire over small branches were inadequate
- Entrances should be clear. Branches and growing shrubs obscured some box entrances which may have contributed to lack of success
- Anti-myna baffles did not deter Common Mynas on all occasions but this may be due to the positioning of a perch at some entrances, allowing Common Mynas to land there.

Figure 3. Common problems with artificial hollows from the Authority's first nest and roost box project; a) bat box entrance obscured by branches; b) bat box attached to a small branch, with lid missing; c) marine ply possum box with poor attachment and in disrepair; d) marine ply bird box with missing panels; attachment does not allow for tree growth

Current project – an overview

Armed with past lessons and increasing industry knowledge of nest box design, and in consultation with an experienced fauna ecologist licenced to work at heights, the current nest and roost box project commenced in October 2010 with 25 boxes installed around Newington Nature Reserve and in forest grids in Bicentennial Park. These are:

- 10 possum boxes
- 5 natural salvaged branch hollow for parrots
- 5 microbat boxes modified from the first project
- 5 new open-bottom microbat boxes, followed by
- 3 large microbat boxes customised for the threatened Southern Myotis, installed in bridge culverts over a wetland in June 2011

All of these original boxes were designed by Narawan Williams and made from hardwood (SOPA, 2020), and installed at approximately 5-6m from the ground. Regular half-yearly inspections began in October 2011, to determine if the boxes were being used by target fauna and to conduct box maintenance and repairs as required. Inspections are scheduled annually for October to determine box usage and breeding activity in spring, and April to determine box usage as the weather cools.

Inspections are done from a ladder with the aid of an inspection camera, and a torch with red light when inspecting microbat boxes; inspections of Red-rumped Parrot boxes are done through side hatches incorporated into the box design to access the back of the box while minimising distress to the animal.

The project is continually informed by new information, from Ecological Consultants Association conferences, published literature, expert advice as well as in-house research. For example, the Authority observed hollow competition between parrots in Newington Nature Reserve and conducted a study on hollow usage over 2011 and 2012; the study found intense competition for hollows and constant displacement of the smaller Red-rumped Parrot by Rainbow Lorikeets. Despite the large number of unused hollows available in the Reserve, two pairs of Red-rumped Parrots were found nesting nearby in Homebush Bay, in the posts of a disused wharf surrounded by open water (Figure 4). As the species' population was declining in the Park, likely due in part to hollow competition, customised boxes of different material and dimensions were made specifically for the Red-rumped Parrot to provide them with more suitable nesting sites and arrest population decline.

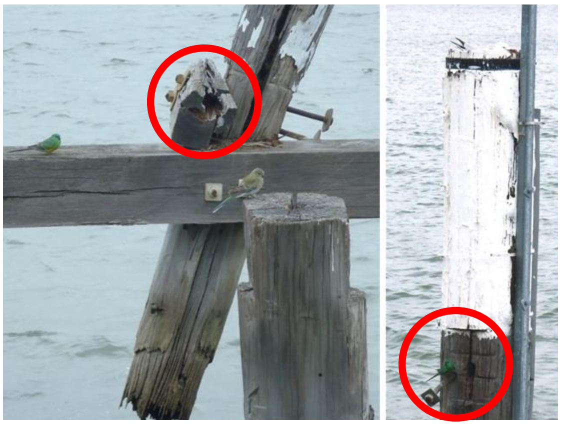

Figure 4. Two pairs of Red-rumped Parrot nesting in disused wharf posts in Homebush Bay; nest hollows are marked with red circles

Just as the plight of the Red-rumped Parrot was identified by Authority staff through observations in the field, observations by Park users have also informed the provision of supplementary habitat for other species. For example, the Authority have responded to reports of Brush-tailed Possums in heritage buildings by installing possum boxes to support relocated possums, as possums must not be released more than 150m from point of capture due to potentially lethal territorial disputes. Similarly, possum boxes have been installed in response to community reports of Brush-tailed Possums in unsuitable locations; three of the Park's possum boxes were donated to the Authority by concerned public and a wildlife rehabilitation group to provide habitat for the Brush-tailed Possum. In the case of microbats, direct observations are rare; the Authority uses data from four-yearly population studies conducted with ANABAT detectors to inform bat box placement.

Regular inspections have facilitated adaptive management in response to hollow occupancy. From 2013, boxes that were unsuccessful in attracting target species for more than 2-3 years were modified and/or relocated almost annually based on expert advice and in-house research. Regular inspections have also allowed relocation of boxes from unstable and potentially unsafe trees, e.g. due to termite activity, to safer locations. Inspections to date have found all boxes continue to be in excellent condition, only requiring infrequent minor repairs and wire adjustments in response to tree growth. Box placement has not included the use of nails or screws in live wood to prevent damage to tree tissue, but has successfully relied on careful site selection where branches are used to support boxes up to 35kg.

The original boxes have been successful with occupancy by target species. However, the Authority continues to trial new artificial hollow designs and new methods to increase the rate of occupancy, and to support ecological needs not supported by existing boxes. For example, microbats roost in groups of varying sizes; following the success of small-chambered microbat boxes, the Authority installed the 'Bat Mansion' in 2014 to provide roosting habitat for larger groups and/or multiple species (Figure 5). In June 2015, the Authority engaged arborists to create hollows inside live trees, to assess whether or not these would be favoured by microbats and birds. In November 2019, the Authority collaborated with the conservation arm of the Avicultural Society of NSW (ASNSW) to provide nest boxes for Red-rumped Parrots along the Parramatta River; to date, 16 Red-rumped Parrot boxes from ASNSW have been installed in Sydney Olympic Park, and Red-rumped Parrots have been observed inspecting these boxes (Figure 6).

Figure 5. The 'Bat Mansion' has much greater internal volume than original boxes and was installed to provide habitat for larger groups or multiple species of microbats. A heavy box like this should be installed with 3-5mm wire rope threaded through rubber hose for tree protection

Figure 6. A Red-rumped Parrot box donated by the Avicultural Society of NSW to support the species along the Parramatta River © Ivan Cindric

As at 2020, the Authority currently has a total of 66 artificial hollows, comprised of:

- 25 microbat roost boxes or logs
- 17 possum boxes, including 3 donated by the community
- 24 Red-rumped Parrot boxes, including 16 donated by the Avicultural Society of NSW

Salient findings from half-yearly inspections over the past 10 years are presented below.

10 years of artificial hollow monitoring

Microbat boxes

Microbat boxes compose the largest proportion of artificial hollows in the Park, and are more varied in design compared to hollows made for other species. The changes in microbat boxes over time illustrate adaptive response through informed experimentation with box design and placement.

The ten original microbat boxes installed near the Reserve in October 2010 are comprised of two designs (Figure 7). Half of the boxes were taken from the 2003-2006 project and modified to include the addition of naturalistic entries through a short length of hollowed branch (spout) and small slits at the side of the box.

Figure 7. The two main bat box designs are (left) closed bottom bat boxes modified from the first nest and roost box project, and (right) open bottom microbat boxes, later modified to emulate the more successful closed bottom design

Large chambers were split into several smaller chambers to suit bats of different sizes and in different numbers, and a cover was installed at the cavity base to help maintain a stable microclimate; this cover can be opened to allow for inspection without disturbing bats which usually cluster at the top of the cavity. Microbat boxes are approximately 50x20x10cm in size and mounted to different aspects (N, NE, NW, S and W) although there appears to be no difference in results. Leary's study on 150 bat boxes (2015) found seasonal differences in preference for aspect of closed bottom boxes for some bat species. The number of boxes at the Park may simply be too small for any species-specific preferences to be evident. All boxes have been used by microbats at one time (either Gould's Wattled Bat and/or Lesser Long-eared Bat), starting from six months to two years after the first inspection.

The other five boxes were a new design of multiple chambers with an open bottom, approximately 33x35x30cm in size. Only one was successful in attracting the Gould's Wattled Bat 1.5 years after the first inspection. Three boxes were taken down and modified in 2013 to emulate the initial design, i.e. adding attractive entries through a spout and slits at the box's side, partially covering the bottom of the box, and drilling a hole between two chambers at the far end from the entrance so bats can move between chambers. All three were taken up by bats after 1.5-2.5 years.

Inspections offer a snapshot in time, and occupancy is often based on the presence of fur and scats, not the actual animal. As droppings accumulate over the six-month period between inspections, it is difficult to determine whether season or aspect play a role in bat occupancy. However, one microbat box facing south consistently housed

Gould's Wattled Bat in April for five years (consecutive for 3 years, followed by a gap then another 2 years). Other boxes did not exhibit such a clear pattern.

Box designs known to be successful elsewhere were adopted for use, including the 'Inverse U' box designed by Narawan Williams for National Parks and Wildlife Service, with an internal volume approximately 4-5 times greater than common microbat boxes, able to support multiple species and large numbers (~157) of breeding microbats (Leary, 2015). The aptly named 'Bat Mansion' is a very large and heavy structure (~35kg), comprised of a horizontal section with two wings, each containing an internal box, allowing bats to move between sections and chambers of different width based on their thermal needs. It only took 1 year to be used by a Gould's Wattled Bat and a Lesser Long-eared Bat at the same time, and thereafter, by larger groups of Gould's Wattled Bat (~20), including the first sighting of a hairless juvenile in October 2017. It is the only box type to support female Gould's Wattled Bats with young in Leary's study of artificial hollow use by bats on the Cumberland Plain (Leary, 2015). At the October 2019 inspection, calls from adult and young Gould's Wattled Bats were heard in two small boxes of different designs, indicating this common species is benefiting from multiple boxes of different designs.

At any one inspection, about 3-4 boxes would contain live bats. However, unlike studies conducted in remnant forest reserves where up to seven species of microbats have been recorded in bat boxes (Leary, 2015), only the Gould's Wattled Bat and Lesser Long-eared Bat have been recorded in boxes installed near Newington Nature Reserve in the past 10 years. Evidence of breeding have been observed in both species.

Key findings and recommendations:

- It may take some years before boxes are occupied by the target species
- Occupancy may be improved by emulating successful designs
- There may be preferences for specific aspects by different species. Install boxes facing different aspects to facilitate roost selection
- Install boxes with larger internal dimensions to accommodate larger groups including maternity groups, an important component of microbat populations
- The boxes provided have not augmented habitat for species other than the common Gould's Wattled Bat and Lesser Long-eared Bat, and may have increased the relative abundance of these common species. Going forward, the abundance, distribution and hollow requirements of other microbat species in the vicinity needs to be investigated.

Australia's only fishing bat – the Southern Myotis

In June 2011, three large, multi-chamber, open bottom microbat boxes were placed in culverts over the freshwater Narawang Wetland to attract microbat species that prefer to roost in caves, tunnels and under bridges. Each box is approximately 80x40x30-40cm. The numerous vertical chambers of varying width were divided by timber ~ 15-25mm thick to create different microclimate. There are also two chambers above some of the vertical slots (Figure 8).

a)
b)
c)

Figure 8. a) Bat boxes installed in culverts over a wetland have been successful in attracting the Southern Myotis, a microbat species listed as vulnerable in NSW; b) the box is large with many chambers to accommodate different group sizes; c) the vertical chambers of varying width are flanked by timber of varying thickness

It took 1.5 years for microbat droppings to appear, and almost four years for the first group (6) of Southern Myotis to be recorded. The Southern Myotis is Australia's only fishing bat, and is listed as vulnerable under the *Biodiversity Conservation Act* 2016. The species' natural roost preferences are tree hollows and caves near water or directly over water if roosts are available. They also roost in tunnels and culverts, and under bridges and piers; bat boxes targeting the Southern Myotis have been successful in replacing roost sites lost during bridge upgrade (N. Williams, pers. comm.). The species has been found to select for cavities with smaller entrances compared to available, unused cavities in the area (Campbell, 2009).

After the first Southern Myotis sighting, adult Southern Myotis with young appeared in the same box six months later (October 2015); thereafter, the population began growing in number and has expanded to use other boxes. Juveniles were observed again in November 2019 and October 2020. At the time of writing, this is the only known maternity roost on the Parramatta River. Abundance continued to rise over time. The April 2020 count of 28 individuals across two boxes is the highest number recorded at this roost site.

Myotis were found to roost in the open bottom vertical chambers as well as the larger, horizontal cavities above these vertical chambers. The open vertical chambers are of different width, and are made by timber planks of different lengths and thickness. Based on the presence of Myotis and their scats, there may be a preference for the 'shorter' chambers, where the timber does not protrude too far from the side walls. Myotis scats are found in multiple chambers in each of the three boxes, indicating the bats visit more chambers than they are observed to roost in. One chamber has been continually used since the first Southern Myotis was observed, and this may continue to be the maternity chamber into the future.

In 2018, a round branch hollow with an open bottom was attached to one of the boxes to test their preference for naturalistic hollows that can accommodate larger groups; so far there has been no sign of microbats visiting or roosting in this hollow.

Key findings and recommendations:

- Understand the species' ecology and install boxes in appropriate locations
- It may take many years for the target species to be observed using the artificial roost
- Provide different microclimate by making chambers of different width and wall thickness, as well as open bottom chambers and closed cavities; record details to facilitate replication if a preference is identified.

Other microbat boxes

Following the success of the Myotis boxes in Narawang Wetland, the Authority installed Myotis boxes in the Brickpit, as ANABAT records suggest the Southern Myotis forage over the many large ephemeral and permanent freshwater ponds in the precinct. Three large, round timber hollow sections were selected to provide for communal roosting; a large metal sheet was placed over the top of these hollows to protect the bats from rats and other predators. Two other general microbat boxes were also installed in the Brickpit. Surprisingly, there has been no sign of usage such as scats since installation in October 2015. The precinct may contain sufficient numbers of suitable natural roost sites for microbats, or the positioning of the roost boxes was just not favourable. These boxes are being progressively relocated to new trial locations, selected based on the presence of suitable microbat foraging habitat but potentially lacking in suitable roosting habitat.

Key findings and recommendations:

- Hollow occupancy may not occur even if the target species is confirmed to be present and foraging ground is nearby
- Regular monitoring allows inactive hollows to be identified and relocated to other areas sooner, with potentially better results.

Red-rumped Parrots

In May 2012, eight boxes were custom made for this species, two from PVC, and six from hardwood. Two were installed near Newington Nature Reserve and six on timber posts at the Archery Centre, near a confirmed nesting site at an old wharf and also near a large expanse of turf where the birds were known to feed (Figure 9).

Figure 9. Red-rumped Parrot boxes installed on timber posts at the Archery Centre

The boxes have a landing platform with a ladder for climbing, internal ladder for young to climb out, a small entrance (45 to 60mm) to exclude non-target parrots, anti-myna baffle, peat moss for nesting, and a side hatch or removable lid for inspection. They were mounted at a height of 5 metres or above with the entrance facing north-east or east. Two of the hardwood boxes were 'vertical' i.e. 45cm in height (internal volume approx. 23x23x35cm) and four 'horizontal' i.e. 45cm in length (2 internal chambers each 12x15x20cm); two of the latter were mounted at 45 degrees. Only the nest boxes installed at the Archery Centre have been successful. The two boxes at the Reserve were relocated to another location adjacent to the parrot's known feeding ground in October 2015, before being relocated to the Archery Centre in April 2017 due to lack of occupancy.

The parrots inspected and used the boxes for breeding in the season following installation, and they used every box type, with eggs or fledglings found in each, i.e. PVC, hardwood horizontal, hardwood horizontal mounted at 45 degrees, and hardwood vertical. The same three hardwood boxes were used in the following seasons, with chicks successfully raised to fledging (Figure 10).

Successful recruitment has boosted the Red-rumped Parrot population; the annual Red-rumped Parrot surveys across the Park detected an increase from just over 30 birds in 2013 to more than 80 birds in 2018.

Unlike the hardwood boxes, the PVC box presented problems from the start – four unhatched eggs were found in the season following installation (April 2013). While a fledgling was seen in the box in October 2013, and another breeding attempt was made as suggested by egg shells and a chick skull seen in April 2015, the parrots stopped using the box. Lack of breeding success in the PVC box may be related to temperature, as the box presumably gets hotter than the hardwood boxes, particularly as the boxes are completely exposed to solar radiation. To test this theory, the other PVC box was taken down, covered in insulation material and returned to the same post as the uninsulated PVC box in April 2018. So far, the only bird attracted to the box was the Common Starling, which used it in the spring 2019 breeding season, suggesting a preference for the insulated PVC box to the uninsulated PVC box right above it. Since nest box installation in April 2012, this is the only non-target species to use the nest boxes, with one previous attempt in 2013.

To better understand the role of temperature on breeding success, 11 temperature and humidity loggers called I-buttons were installed in June 2019 on the inside of used and unused nest boxes,

Figure 10. (left) A pair of Red-rumped Parrots at a horizontal hardwood nest box mounted to 45 degrees; note the dampcourse over lid, anti-myna baffle and parrot ladder at the front, and a side hatch to facilitate inspection; (right) three Red-rumped Parrot chicks in a vertical hardwood box; note the grooves carved into the inside of the box to assist the young to climb out

and on the posts on which they sit (Figure 11). These temperature and humidity loggers will record data for one year before they are removed for data analysis.

Figure 11. An I-button temperature and humidity logger attached to the inside of a horizontal hardwood Red-rumped Parrot nest box

Key findings and recommendations:

- Inform installation location with field observations and known ecology of the species; locate boxes close to known foraging grounds
- Customise boxes to the target species; trial different materials, aspect and design where possible
- Temperature may have adverse impacts on reproductive success; locate boxes across different thermal gradients to allow choice, and use materials that provide greater insulation qualities.

Natural branch hollows for parrots

The Authority's study on hollow usage in Newington Nature Reserve identified a concentrated area of breeding activity by the Rainbow Lorikeet, Galah, Sulphur-crested Cockatoo, and Red-rumped Parrot. Available hollows are present outside this hotspot but not used. Five natural branch hollows for birds were installed in October 2010 in the perimeter area just outside the Reserve. Despite the proximity, these were never used by the target species. Instead, three of the five hollows were regularly used by rats.

After 3.5 years the hollows were removed, modified, and re-installed at Archery Centre (Figure 12). The expanse of turf at the edge of the Archery Centre shooting range provide excellent foraging grounds for the Red-rumped Parrot, and nest boxes installed here in 2012 for the species were quickly used to raise young successfully. It was thought that the natural hollows may provide additional nesting habitat, and also inform management of the species' preference in hollow type and structure. The salvaged hollows were capped at one end, and dampcourse was applied where water ingress may occur. As the hollows were installed on tall timber posts, metal strips and nails were used in addition to PVC-coated wire for attachment, as there was no concern of sap corroding the nails or the attachment harming the tree.

Since their installation in April 2014, all hollows have been used by microbats periodically based on the presence of bat scats, with up to two Gould's Wattled Bats seen in three hollows and a Lesser Long-eared Bat in another. No Red-rumped Parrots have used the capped natural hollows. The internal volume of the hollows may be more suited to microbats. Also, by this time, the Red-rumped Parrots have already shown a preference for a subset of the available hardwood nest boxes. These natural hollows have now been classified as bat roosts.

Figure 12. A salvaged branch hollow modified to provide nesting habitat for the Red-rumped Parrot was used by microbats instead

Key findings and recommendations:

- Artificial hollows need to be installed in known active breeding area of the target species
- Hollows of different types should be installed at the same time to test for preference

Possum boxes

Possum boxes are simple in design. The ten original hardwood boxes installed in 2010 are approximately 45x30x35cm with an entrance of 12x13cm; subsequent boxes are similar in size, but come with improvements such as a climbing stick near the entrance, and dampcourse to waterproof the lid (Figure 13).

Lack of a climbing stick in the original boxes did not hamper occupancy, as most boxes were occupied in the first inspection one year after installation, and have been occupied on a regular basis since; females with joeys have been seen in all but three of the original boxes. In the original design (Figure 13a), the front wall is comprised of two panels, and the small gap between the panels was not

Figure 13. a) original hardwood possum box installed in 2010; lack of climbing stick does not appear to affect uptake; b) Men's shed possum box donated by WIRES in 2016; c) Men's shed possum box with additional dampcourse on lid, installed in 2017; d) hardwood possum box with dampcourse on lid installed in 2018

considered a concern. However, in October 2017, an Australian Wood Duck nesting in one of the possum boxes died after its foot became stuck in the gap between the panels. The gap had become larger over time as the timber panels expanded and contracted in response to humidity and temperature. Subsequently, all the gaps were plugged to prevent similar incidents from occurring in the future, and design changes such as single-panel walls will be used in future boxes.

The time between box installation and occupancy differed with location, not with box design. Boxes installed near Newington Nature Reserve and in the forest grids of Bicentennial Park were occupied shortly after installation; however, it took six years for a box with the same design installed in Kronos Hill to be used, even though the box was installed in response to possum sightings, including a possum sleeping in a garbage bin, indicating lack of suitable shelter. Kronos Hill was planted with thick stands of eucalypts for the Games, with a sparse understorey dominated by the invasive grass kikuyu. Staged replacement of weeds with native shrub plantings commenced in the precinct in 2014. The development of a habitat with greater floristic and structural diversity may have created adequate food resources for the Brush-tailed Possum in what was once a movement corridor for the species.

Distance between boxes, as short as 10-50m in the case of the six possum boxes in Bicentennial Park, did not appear to affect occupancy or the condition of the occupants. At most inspections, five, or sometimes all six boxes would be occupied, with dependent young in some boxes. All animals have appeared to be in good condition to date.

Possums are adapted to the urban environment and will roost in roof spaces and other human structures. At Blaxland Riverside Park, a possum moved into a playground climbing tower, roosting underneath a protruding section of the structure about 15 metres off the ground (Figure 14). The sleeping possum could be seen from inside the climbing tower, and prompted numerous enquiries from concerned community members. Two boxes were donated by WIRES and installed near the tower in 2016 (Figure 13b). These were not occupied until one year after installation, and the possum in the climbing tower continued to roost there.

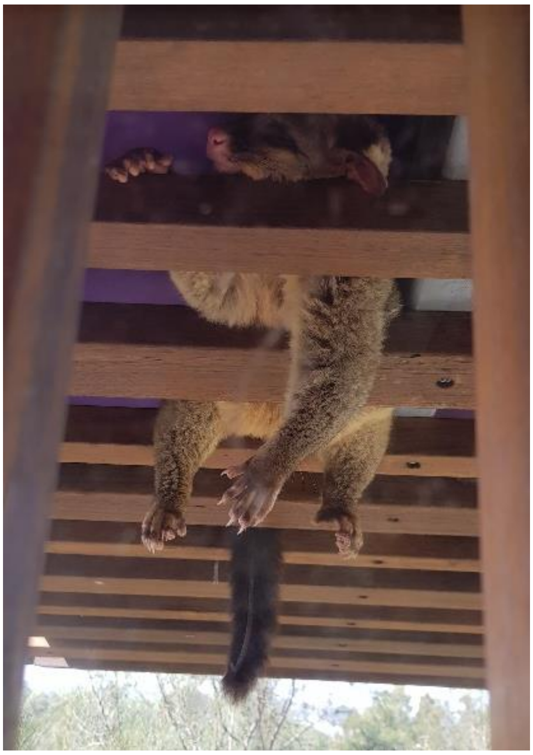

Figure 14. Brush-tailed Possum roosting in the climbing tower

The area encompassed by Newington Nature Reserve, Newington Armory and Blaxland Riverside Park appears to have a high possum population. Fights between possums, presumably over territory, have been observed, and Authority staff once rescued an injured possum sheltering in a skip bin. In response, two more possum boxes were installed in the area in 2018, and these were occupied within six months. Again, the possum in the climbing tower has not relinquished its roost; it was there at the April 2020 inspection, even though two of the possum boxes in the vicinity were unoccupied on the day.

Similarly, two possum boxes in Narawang Wetland were installed in January 2017 following public concern over a young Brush-tailed Possum being harassed by birds. Despite the lack of tree hollows in the area, and what appear to be abundant food resources, it took almost two years for one of the boxes to be occupied, and by a Common Ring-tailed Possum rather than a Brush-tailed Possum.

Apart from the Common Ring-tailed Possum, which has been found in three possum boxes to date, the Australian Wood Duck is the only other native fauna and the only avian species to use a possum box. Feral European honey bees have infested three possum boxes to date. Interestingly, feral honey bees have only been found in possum boxes, and not in boxes designed for other species. Unlike microbat boxes which have narrow internal cavities, the large internal cavity size of possum boxes appears to suit feral honey bees in establishing hives. The Red-rumped Parrot boxes, although of suitable cavity size, may be in a location that is not favourable for feral honey bees (N. Williams, pers. comm.).

Some studies suggest the bees are likely to move away on their own; however, the Authority actively manages this Key Threatening Process to prevent the bees from taking over natural hollows in the Reserve. Covering the entrance is one method to exterminate the bees without the use of chemicals, and has been used successfully. However, in light of the positive value of honey bees to the beekeeping industry, the Authority has since approached a licenced beekeeper to assist with bee removal, and one of the infested boxes was taken down and the bee colony relocated. The percentage of boxes affected is ~18% to date. Due to ongoing management, bee infestation has not occurred in more than one box at one time, so the infestation rate remains low at ~6% per inspection.

Key findings and recommendations:

- Have gap-free panels to avoid risk of injury or death to fauna
- Possum boxes located in high density areas may not be used if the animal already has preferred roosts
- Boxes may be installed in close proximity to each other without adverse effects
- Native and introduced fauna may occupy the box; devise management options for feral honey bees.

Habitat trees

At the Hollows as Habitat forum co-hosted by the Authority and Greater Sydney Local Land Services in May 2015, arborists demonstrated how to create hollows in trees with chainsaws. A faceplate is first taken off the tree, and the desired internal volume removed section by section; the faceplate is returned and secured, and an entrance hole of the desired diameter drilled into the faceplate. This method creates an approximation of a hollow made by natural processes, with the advantage of providing a hollow that is natural in looks and also potentially more favourable in terms of insulation properties.

This technique was subsequently trialled at the Park in 2015. Four trees were chosen for this trial, two *Corymbia* and two *Eucalyptus* trees, and each had two bird hollows and one bat hollow carved into the tree. The first inspection in

December 2015 found no activity and identified improvements, i.e. hollow should be smaller than faceplate, so that light doesn't penetrate after the faceplate shrinks, and that the bird hollows were too narrow and shallow for birds. A subsequent inspection in October 2017 found one *Corymbia* too unstable to inspect. A couple of bird hollows in the *Eucalyptus* trees may have been inspected by wildlife, based on the presence of unidentified scat in one hollow, and the other hollow having been scraped clear. Entrances to the bat hollows have become too small or sealed over.

Key findings and recommendations:

- It may be better to trial hollow creation on dead or senescing trees so that wounds don't seal over as is likely to happen in live trees
- Trial different cutting technique into live trees
- Account for faceplate shrinkage to ensure the cavity is adequately protected from light
- Provide sufficient internal volume for target species
- Use arborists experienced in this technique, or arborists guided by ecologist on fauna requirements.

Conclusion

Sydney Olympic Park Authority's nest and roost box project has provided supplementary habitat to the Common Brush-tailed and Ring-tailed Possum, Red-rumped Parrot, and microbats including the Southern Myotis, Gould's Wattled Bat and Lesser Long-eared Bat.

The effect of supplementary habitat on the Red-rumped Parrot has been the most clear and most successful. This species took up the customised nest boxes soon after installation and has raised young annually, increasing the population from a low of just over 30 birds across the Park in 2013 to a high of 87 birds in 2018. The successful boxes were positioned on the south east side of the posts, but box orientation did not matter. While other customisation likely assisted in increasing box uptake, the lack of success of the same boxes in two other areas suggest installation location is important. As the boxes are completely open to the elements, they are subject to predicted increase in temperature and extreme weather events due to climate change. As artificial hollows are less insulated compared to tree hollows due to thinner walls and larger surface area to volume ratio, future reproductive success or offspring development is likely to be negatively affected (Larson et al., 2018). Data from the temperature and humidity loggers will inform if there is temperature variation in used and unused boxes in close proximity to each other, and assist with future placement of nest boxes. Studies are being conducted on insulation products or methods to buffer artificial hollows from extreme temperatures, such as foil batts and paint (Griffiths et al., 2017; Larson et al., 2018); boxes with different thermal properties may need to be installed across different levels of canopy cover and aspect to provide suitable habitat to a range of species.

Although the Authority's trial with chainsaw hollows was not successful, research in this area is continuing apace. Mechanically created hollows have been used by birds, microbats and arboreal marsupials (Rueegger, 2017). Other research has found internal decay can occur in trees before access is developed e.g. though limb breakage, and it may be possible to add artificial entrances to developing voids to increase hollow availability in the landscape (Ellis, 2018). The Authority will keep abreast of developments in this field, as it has the potential to substantially increase the number of tree hollows with the insulation property of live trees across the Park.

The outcome of microbat boxes is equivocal. Studies have found microbat boxes can increase bat populations, but favour common species disproportionately (Leary, 2015), as has happened at the Park with bat boxes outside Newington Nature Reserve providing habitat to two common microbat species. In contrast, bat boxes installed above freshwater wetlands for the Southern Myotis have been a success. The boxes were located within the species' foraging ground, and were used for both roosting and breeding, suggesting the species' ecological needs were met. This is of significance as the species is listed as vulnerable in NSW and few maternity colonies are known. The box design may be replicated elsewhere to provide habitat for the Southern Myotis. Investigation into the habitat and ecological needs of other uncommon microbat species in the Park, particularly threatened species, and how to deliver supplementary habitat at a scale that is helpful, is the next task to address.

Based on reduced observations of Brush-tailed Possums roosting in inappropriate locations (roof spaces and bins), the provision of roost boxes may have contributed to easing the pressure of housing shortage. Without possum boxes, these possums may be roosting in roof spaces, or experience increased territorial disputes.

Tree hollows are a critical resource that cannot be easily replicated or replaced by artificial hollows. Much remains unknown about the attributes that hollow-dependent species rely on for their survival; many species do not use artificial hollows, and those who do may be lured into an ecological trap if the artificial hollows – installed for the purpose of attracting fauna to a resource that they become dependent on – are not made, maintained and monitored adequately into the long term. Ultimately, processes causing the continual loss of hollow-bearing trees need to be slowed, and halted where possible, and artificial hollow provision should be part of a holistic habitat restoration practice alongside replacement tree plantings, with the aim of providing suitable, long-term habitat for a full assemblage of fauna to ensure their continued survival.

Acknowledgements

Sydney Olympic Park Authority acknowledges Narawan Williams, fauna ecologist, for his expert advice and high quality boxes that has contributed to the success of the nest and roost box project; and the Avicultural Society of NSW for the donation and installation of Red-rumped Parrot boxes. Multiple SOPA staff participated in field inspections.

References

Burcher, Paul (2015). Eastern Pygmy-possums in Hornsby Shire. Hollows for habitat forum proceedings. Greater Local Land Services. http://greatersydney.lls.nsw.gov.au/__data/assets/pdf_file/0005/566627/hollows-for-habitat-proceedings.pdf

Campbell, Susan (2009). So long as it's near water: variable roosting behaviour of the large-footed myotis (*Myotis macropus*). *Australian Journal of Zoology* 57, 89-98. https://doi.org/10.1071/ZO09006

DPIE (2019). Loss of hollow-bearing trees - key threatening process listing. https://www.environment.nsw.gov.au/Topics/Animals-and-plants/Threatened-species/NSW-Threatened-Species-Scientific-Committee/Determinations/Final-determinations/2004-2007/Loss-of-Hollow-bearing-Trees-key-threatening-process-listing

Davis, Adrian & Major, Richard & Taylor, Charlotte (2013). Housing Shortages in Urban Regions: Aggressive Interactions at Tree Hollows in Forest Remnants. PloS one. 8. e59332. 10.1371/journal.pone.0059332.

Ellis, Murray (2018). The presence of heartwood decay, a precursor to hollow formation, within Eucalyptus camaldulensis in relation to stem size. Ecological Management & Restoration. 19. 10.1111/emr.12328.

Gibbons, Philip & Lindenmayer, David (2002). Tree Hollows and Wildlife Conservation in Australia. 10.1071/9780643090033.

Goldingay, Ross (2009). Characteristics of tree hollows used by Australian birds and bats. School of Environmental Science and Management. 36. 10.1071/WR08172.

Goldingay, Ross & Stevens, Jane (2009). Use of artificial tree hollows by Australian birds and bats. Ross L Goldingay. 36. 10.1071/WR08064.

Goldingay, Ross & Rueegger, Niels & Grimson, Matthew & Taylor, Brendan (2015). Specific nest box designs can improve habitat restoration for cavity-dependent arboreal mammals: Nest box designs favored by arboreal mammals. Restoration Ecology. 23. 10.1111/rec.12208.

Goldingay, Ross (2017). Does nest box use reduce the fitness of a tree-cavity dependent mammal?. Ecological Research. 32. 10.1007/s11284-017-1461-4.

Goldingay, Ross & Thomas, Karen & Shanty, Devi (2018). Outcomes of decades long installation of nest boxes for arboreal mammals in southern Australia. Ecological Management & Restoration. 19. 10.1111/emr.12332.

Greater Sydney Local Land Services (2016). Build your own wildlife nest box. A guide for Western Sydney. https://greatersydney.lls.nsw.gov.au/__data/assets/pdf_file/0006/656610/GS-LLS-Wildlife-Nest-Box-10-2017-Accessible.pdf

Griffiths, Stephen & Bender, Robert & Godinho, Lisa & Lentini, Pia & Lumsden, Linda & Robert, Kylie (2017). Bat boxes are not a silver bullet conservation tool. Mammal Review. 10.1111/mam.12097.

Larson, Eliza & Eastwood, Justin & Buchanan, Katherine & Bennett, Andrew & Berg, Mathew (2018). Nest box design for a changing climate: The value of improved insulation. Ecological Management & Restoration. 19. 39-48. 10.1111/emr.12292.

Leary, Tanya (2015). Why monitoring matters- Case study of hollow augmentation for microbats in Cumberland plain reserves. Hollows for habitat forum proceedings. Greater Local Land Services. http://greatersydney.lls.nsw.gov.au/__data/assets/pdf_file/0005/566627/hollows-for-habitat-proceedings.pdf

Lindenmayer, David & Wood, Jeff (2010). Long-term patterns in the decay, collapse, and abundance of trees with hollows in the mountain ash (*Eucalyptus regnans*) forests of Victoria, southeastern Australia. Canadian Journal of Forest Research. 40. 48-54. 10.1139/X09-185.

O'Connell, Chris & Keppel, Gunnar (2016). Deep tree hollows: Important refuges from extreme temperatures. Wildlife Biology. 22. 305-310. 10.2981/wlb.00210.

Ridgeway, Peter (2015). Augmenting hollows – worthwhile or just warm & fuzzy? Hollows for habitat forum proceedings. Greater Local Land Services. http://greatersydney.lls.nsw.gov.au/__data/assets/pdf_file/0005/566627/hollows-for-habitat-proceedings.pdf

Rueegger, Niels & Goldingay, Ross & Brookes, Lyndon (2012). Does nest box design influence use by the eastern pygmy-possum?. Australian Journal of Zoology. 60. 372. 10.1071/ZO12117.

Rueegger, Niels (2017). Artificial tree hollow creation for cavity-using wildlife – Trialling an alternative method to that of nest boxes. Forest Ecology and Management. 405. 404-412. 10.1016/j.foreco.2017.09.062.

Rueegger, Niels & Goldingay, Ross & Law, Brad & Gonsalves, Leroy (2018). Limited use of bat boxes in a rural landscape: Implications for offsetting the clearing of hollow-bearing trees: Bat boxes in an offset program. Restoration Ecology. 27. 10.1111/rec.12919.

Saunders, Denis & Mawson, Peter & Dawson, Rick (2014). Use of tree hollows by Carnaby's Cockatoo and the fate of large hollow-bearing trees at Coomallo Creek, Western Australia 1969–2013. Biological Conservation. 177. 10.1016/j.biocon.2014.07.02.

Saunders, Denis & Dawson, Rick & Mawson, Peter & Cunningham, Ross (2020). Artificial hollows provide an effective short-term solution to the loss of natural nesting hollows for Carnaby's Cockatoo *Calyptorhynchus latirostris*. Biological Conservation. 245. 108556. 10.1016/j.biocon.2020.108556.

Sydney Olympic Park Authority (2020). Quality and longevity in artificial hollows - how to design and install long-lasting boxes. Narawan Williams. AMBS Ecology and Heritage.