Restoring the restoration: bringing back woodland birds

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Sydney Olympic Park is a large urban park containing both remnant and constructed landscapes that underwent significant restoration in preparation for the 2000 Olympic Games. The initial landscape design and plant species selection resulted in a landscape with low structural complexity dominated by maturing canopy trees and a simple grassy understory. Woodland birds are a component of the Park's biodiversity that are sensitive to and have declined as a result of this initial landscape design as well as adjacent urban development. The results of a 2005 monitoring program focusing on woodland birds led to a change in landscaping strategies to include increased vegetative structural complexity. This study measured changes in vegetation structure and bird composition from 2003 to 2019. The study found that diversity of woodland birds was correlated with high shrub cover, low tree density and the distribution of the aggressive Noisy Miner *Manorina melanocephala*. The most recent surveys in 2019 found that increases in both woodland bird abundance and richness occurred in quadrats that were part of a shrub-planting program suggesting that suitable woodland bird habitat can be achieved in urban parks.

Background

Birds are one of the most recognised and popular elements of urban biodiversity (Fuller *et al.* 2007), but they are directly threatened by urbanisation (Watson *et al.* 2002) and populations of woodland birds in particular are declining across a range of urban environments including Sydney (Parsons *et al.* 2006). Factors contributing to this decline are generally assigned to land development (Ford 2011) resulting in fragmentation, edge effects, increased generalist species, simplified habitats, and reductions in bird diversity (Marzluff 2001). Over one-third of Australia's land birds are woodland dependent and as a consequence of these changes at least one in five of these species is now threatened (Birdlife Australia). Retaining small birds in urban landscapes is a challenge for landscape designers and land managers juggling the demands of recreation and conservation in finite urban green spaces.

Sydney Olympic Park covers approximately 640ha and forms a suburb of Sydney, Australia, located 14 km west of the central business district. The Park was developed for the 2000 Sydney Olympic Games and involved significant rehabilitation of 435ha of parkland through the remediation of contaminated land, restoration of remnant bushland areas and landscaping while accommodating a number of sporting, entertainment and leisure facilities (Darcovich and O'Meara 2008 and O'Meara and Darcovich 2014).

Remediated and landscaped areas were designed to form linear and structurally simple shapes in order to provide for both active and passive recreation (Hassel 1997). The planting design sourced mainly eucalyptus species or *Casuarina glauca* with grassy understory species selected for their fast growth, tolerance of poor soils and aesthetics. These landscaped habitats are dissected by pathways and open spaces for use by the public. A remnant bushland patch (13 ha) of critically endangered Sydney Turpentine Ironbark Forest is located in the Newington Nature Reserve. Dense areas of woody weeds dominated by Lantana *Lantana camara* and Bone Seed *Chrysanthemoides monilifera* were present in several pockets (35ha total) forming a dense shrub understorey.

Woodland birds at Sydney Olympic Park are defined as species that are dependent on woodland and forest remnants, excluding urban generalists such as Australian Raven, Magpie-lark and Willie Wagtail. Aggressive species such as the Grey Butcherbird *Cracticus torquatus* and Noisy Miner *Manorina melanocephala* whose behaviour excludes other species have also been excluded because they impact the diversity and numbers of smaller woodland birds. Sydney Olympic Park supports a high diversity and abundance of woodland birds, despite being relatively isolated from other remnant bushland habitats in surrounding suburbs. Species such as the Superb Fairy-wren *Malurus cyaneus* or Red-browed Finch *Neochmia temporalis* are resident and common; however, the Park is an important refuge for other species that occur only in comparatively small numbers or are vagrant and migratory, using the Park as a stepping stone during large landscape scale movements. Woodland birds require structurally complex habitat comprising a mix of groundcover, shrub and tree species to provide a high volume and variety of food, dense thickets for shelter and nest sites.

In recent Australian studies, the presence of Noisy Miners has been shown to be a

major threat to the diversity of small woodland birds within remnant patches (Maron 2007, Robertson *et al.* 2013 and Thompson *et al.* 2015). This species exhibits 'aggressive despotic behaviour' that has shaped avian assemblages in woodlands of eastern Australia (MacNally *et al.* 2012). The changes to landscape that result in fragmentation, loss of vegetation structure, dominance of Eucalyptus and loss of species richness contribute to the formation of habitat that favours the Noisy Miner (Munro *et al.* 2007 and NSW Scientific Committee 2013). Studies have found that the presence of Noisy Miners can reduce the richness and abundance of smaller birds (less than 63g) by 50% through aggressive exclusion (Clarke and Oldland 2007, Maron and Kennedy 2007, MacNally *et al.* 2012 and Thomson *et al.* 2015). MacNally *et al.* (2012) found that densities of Noisy Miner greater than 0.8 birds per hectare had a negative correlation with the abundance of smaller birds.

The extensive plantings of eucalyptus species and casuarinas between 1998 and 2000 gradually evolved from a dense shrub layer to a developing canopy as the trees matured (Appendix 1; Figures 1a and 1b). In 2005, the Authority commissioned a study examining the relationship between bird diversity and vegetation. The bird survey component of the study collected information on the abundance, diversity and distribution of bird species and the vegetation analysis component collected important data on habitat condition to relate habitat variables to bird biodiversity. This study was to be repeated every four years and provided important information about bird distribution and abundance and the habitat requirements of birds. This then became the basis for management aimed at maintaining and enhancing bird biodiversity within the Park.

The most important outcome of the first study was a prediction that the original planting design would result in a change in distribution and density of some of the bird species with declines in woodland dependent species (Saunders 2005) and increases in aggressive species such as the Noisy Miner. In 2008, woodland birds were identified in the Authority's Biodiversity Management Plan as a focal species group. The conservation actions for this group reflected the findings and recommendations of this study. In 2009 a follow-up study reported a significant relationship between Noisy Miners and small birds where the density of smaller birds decreased with increasing density of Noisy Miners. The distribution of small birds was closely related to high shrub cover rather than to tree density (Saunders 2009).

The habitat enhancement program

Woodland birds require structurally complex and diverse habitat with functional connectivity between habitat areas. The original design intent for the Park was to create a simplistic vegetation structure of mainly eucalyptus or casuarina species with grassy understory species selected for their fast growth, tolerance of poor soils and aesthetics. These landscaped habitats were then dissected by pathways and open spaces for use by the public. This study suggested that the original plantings were not likely to support large numbers of woodland birds in the long term because of their structural simplicity, small patch size and lack of connectivity. Very few of these plantings included shrub species that would have increased habitat complexity. While planted tree saplings initially supported woodland bird species by functioning as shrub habitat, they became progressively unsuitable as they matured. Additionally,

the small patch size of tree plantings, with a high edge to area ratio, favoured aggressive 'edge specialists' such as Noisy Miners and Rainbow Lorikeets that compete with and displace woodland birds.

As a result of the initial 2005 study, attention turned to improving the quality of Park habitat and management of site-specific factors to address woodland bird conservation. The Authority implemented a habitat modification program in 2006, aimed at increasing the structural diversity and complexity of key areas of the Park. The program seeks to build connectivity between key woodland bird habitats identified in the Brickpit, Narawang Wetland, Newington Nature Reserve, Kronos Hill and Woo-la-ra precincts.

Plants were sourced from local and regional provenance supported by an extensive seed collecting program from the on-site Sydney Turpentine Ironbark Forest community. The form of habitat enhancement varied depending on site characteristics and works have included:

- Enhancing the extent of remnant bushland - increasing the extent of and quality of Sydney Turpentine Ironbark Forest from 14ha to 20ha;
- Woody weed control - Since 2006, a program of long-term staged weed removal was initiated with the aim of removing the majority of dominant weeds in the Brickpit, Triangle Pond and north of the Waterbird Refuge. This program included habitat replacement with native species suitable for woodland birds. Each planting stage is required to form functional habitat before further weed removal occurs to ensure no net loss of overall habitat;
- Increasing structural complexity – the retrofitting of structural complexity under established trees:
    1. Initially the program consisted of plantings beneath the existing tree canopy but shrub growth was slow and survivorship was low;
    2. Selected areas were identified for a more active intervention program where the tree canopy was thinned to 50% or less, invasive grasses in the ground story removed and shrubs/ groundcovers retrofitted underneath. Any trees removed to reduce tree canopy cover were laid on the ground to increase coarseness within the mulch layer.

As recommended by Parsons (2007), management of small bird habitat should recognise the positive value of invasive species such as *Lantana camara*. Lantana at Sydney Olympic Park is actively restricted to current extents and new outbreaks are removed before they form habitat (greater than $1m^2$). The removal of Lantana is staged over periods of approximately four years to allow woody weeds forming good bird habitat to remain until alternative replacement habitat consisting of native species of the same density can mature.

When planting, tubestock consisting of 50% shrubs and 50% groundcovers were used, supplemented by direct seeding. The species palette included both slower growing, longer lived species and short lived species so that structure is still present as plants with different life spans mature, senesce and recruit. Acacias form a high proportion due to their cover crop role in shading and fixing nitrogen – they are quick growing, generally short lived and usually result in good recruitment. Spikey plants such as Hakeas and Bursaria are also well represented due to their prickly foliage being attractive to fairy-wrens and finches. Finches were observed to build nests in plants at least two years old. The species palette was kept as diverse as possible to offer a range of food

resources; seed, nectar or insect attracting species. Vines were also included as an important enhancement to vegetation structure, habitat values and food resources.

Plants were planted in like-species groups resulting in a matrix of species coppices allowing groundcovers to have access to sunlight and reduced competition. Ideally a good groundcover layer was encouraged to establish quickly to create a seedbank so the site can react to changes in the environment. Shrub density was generally 1-2 shrubs/m^2 but depended on the species – short lived pioneer species can be planted this densely while larger species require more space. Groundcover species were generally planted at a density of 4-6 plants/m^2, but again depended on species used.

This habitat enhancement program was applied to areas where three primary conditions could be met: the site would enhance and/or increase the area of corridors and current habitat areas used by woodland birds, there was no conflict with other threatened species habitats and complementary to other Park uses such as recreation. As at 2020, the program has covered 3.1ha across six precincts, with plans to expand those areas over the next few years. The program is staged with each section incrementally adding to woodland bird habitat each year. Maintenance of these sites is ongoing under bush regeneration contracts to ensure they meet the criteria of the Biodiversity Management Plan: >40% canopy cover located in the shrub layer (1-8m high), with an open tree canopy of less than 30% cover and the groundcover layer to be a mix of grasses/sedges, and fine and coarse mulch, including fallen branches. All sites receive maintenance weeding, supplementary planting where needed and application of grass seed to ensure vigour and diversity in both vegetation structure and age classes.

The monitoring program

There have now been four reviews of vegetation and woodland bird status at Sydney Olympic Park. This longitudinal study has evaluated change over time (from 2005 to 2019) of woodland birds and measured the success of the planting program in providing habitat for woodland bird species.

Thirty-seven 20m by 50m plots were established during the period from 2002 to 2014. As landscaping over Sydney Olympic Park has been undertaken in different stages affecting different precincts within the Park, several plots were added during this period to better sample evolving landscapes within the Park. At present only 15 of these plots are monitored as part of this study. Nine of these quadrats have been subject to some form of revegetation under the woodland bird habitat enhancement program (Appendix 2). The other plots form baseline data as they were either in natural habitat areas where no habitat modifications were considered appropriate or were duplicates of the plots monitored in the present study.

In each quadrat, both a vegetation analysis and bird survey program was completed with sampling occurring in 2005, 2009, 2014 and 2019. Many of the plots have been sampled during all four survey periods while a few have only been sampled over 2 surveys. The locations of the 15 current plots are shown in Figure 2.

Bird surveys

The fifteen quadrats were sampled for birds six times during spring and six times during autumn in 2004 and 2009 so that each quadrat was surveyed 12 times. Birds were sampled three times during spring and three times during autumn in 2014 and 2019 and so quadrats were sampled six times during the latter two survey periods. Each quadrat was surveyed for 20 minutes using an area search method. A total of 420 surveys were undertaken for a total survey effort of 140 hours.

Data collected on birds from each quadrat survey consisted of:

- numbers of each species present (birds passing over quadrats were not recorded unless actively foraging);
- position of each bird in one of the following habitat layers:
    - ground/grass layer;
    - shrub layer;
    - sub-canopy layer;
    - canopy layer;
    - air over canopy.
- the behaviour or activity of each bird as one of the following:
    - foraging (substrate [air, ground, foliage, bark, flowers, seed or fruit etc.] substrate species/ food used);
    - interacting with other birds or other animals or;
    - other non-foraging activities (perching, preening, calling or breeding).

Vegetation characteristics

Vegetation variables measured included tree height, shrub cover, tree canopy cover and the first four dominant species in each vegetation layer (canopy, shrub and groundcover). Vegetation types were separated into trees (greater than 10m), shrubs (1m to 10m) and groundcovers (less than 1 m).

Shrub index was measured at ten random points within the quadrat using a density board (Saunders 2005). The density board was viewed along the 50m edge of the quadrat to the opposite side. Visibility through the shrub layer for each 0.5 metre interval from the ground up to 2 metres above ground was scored as present at each level if vegetation obscured the view across the plot. This gave a score of 0 to 4 for each measure and then the scores were summed for all ten measures. This index ranged from 0 to 40, with zero indicating an absence of shrub cover and 40 indicating a dense cover of shrubs to 2 metres.

Tree canopy cover was estimated using the method described in Walker & Hopkins (1998). Canopy diameters and spacing between trees were measured along the mid line along the long axis of each quadrat. Measurements were made using a fibreglass measuring tape with the tree canopy cover projected onto the ground, and the means of each measure were used to estimate the tree canopy cover. A maximum of ten trees were used within each quadrat where sufficient trees were available.

Figure 2 Location of quadrats for woodland bird surveys at Sydney Olympic Park

Analysis

Twelve bird surveys were undertaken each year in 2004 and 2009, while 6 were undertaken in 2014 and 2019. Six surveys were randomly selected from the first two sampling periods so that 6 surveys were used to determine the average number of birds of each species detected per quadrat for each sampling period.

The birds were arranged into the following groups:

- aerial species foraging above the canopy of each quadrat;
- birds larger than Noisy Miners;
- Noisy Miners;
- birds smaller than Noisy Miners.

Correlations and regression analyses were done to examine relationships between vegetation structure and bird groups in the following combinations:

- tree cover vs shrub cover;
- tree cover vs small bird count;
- tree cover vs Noisy Miner count;
- tree cover vs large bird count;
- large bird count vs Noisy Miner count;
- shrub cover vs small bird count;
- shrub cover vs Noisy Miner count;
- shrub cover vs large bird count;
- small bird count vs Noisy Miner count;
- small bird count vs large bird count.

The correlations and trend lines revealed whether a relationship was not evident, positive or negative and the regression analyses determined strength of those relationships.

Results

Figure 3 shows the overall trend in tree and shrub cover across the 15 quadrats from 2005 to 2019. There was a decrease in shrub cover from 2004 to 2009 over all quadrats combined, but since then it has gradually increased but has not yet reached the same level as in 2004. Tree cover has increased from 33% to 57% during the same time period. Although trees have died or have been removed from some quadrats the remaining trees are maturing and their crowns are spreading to fill the gaps between trees with the consequence of increased tree canopy cover.

Bird richness

Seventy-one bird species were detected during 480 surveys of the 15 quadrats examined. The list of species in order from most to least common is shown in Appendix 3.

The Noisy Miner was the most common species detected followed by 4 smaller species. Smaller species make up 9 out of the 15 most common species detected during the surveys.

There has been a change over the study period in species composition; thirty-nine species were detected in 2004 and most of these were bird species were smaller than Noisy Miners. Forty-six species were detected in 2019 but these were mostly species larger than Noisy Miners. The change in species number within the three groups of birds - birds smaller than Noisy Miners, Noisy Miners and birds larger than Noisy Miners, are shown in Figure 4.

Bird abundance

There has been a gradual increase in the number of birds detected between 2004 and 2019 (Figure 5). The overall trend in average counts for small birds is a small decrease with the increase in bird count taken-up by increases in large birds and in particular Noisy Miners which have increased from an average count of 9.84

for all quadrats combined to an average count of 37.50 over the study period. Aerial species are shown, but they do not appear to be influenced by other bird groups as there is no competition between them and these other groups. Their presence does indicate good habitat below as this is often the source of insects above the canopy. There appears to be little change in the numbers of aerial species foraging over quadrats.

The patterns shown in Box 1 suggest that shrub cover and tree canopy cover influence bird species composition found within quadrats. The correlations and regression analyses tested the strength of these perceived relationships between birds and vegetation structure and are shown in Figures 8 to 17.

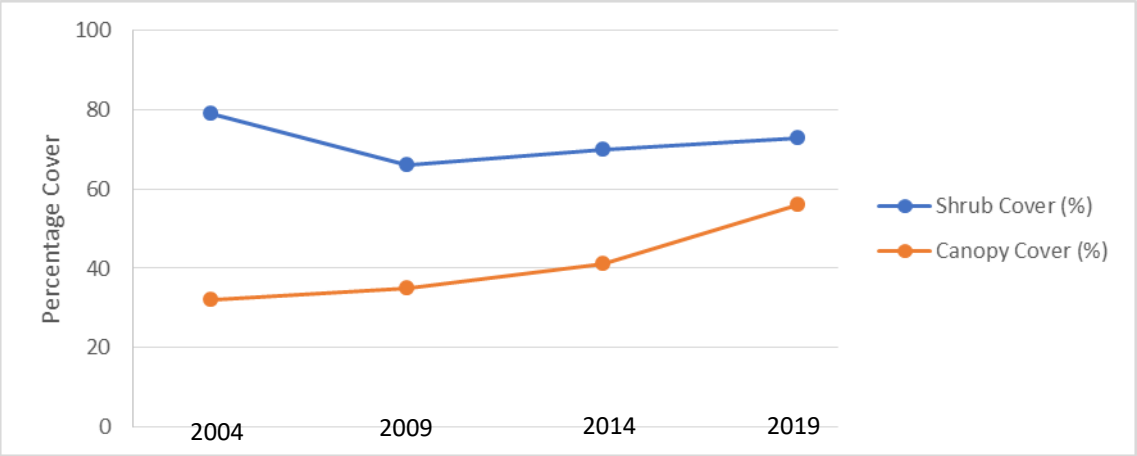

Figure 3 Average density of tree cover and shrub cover for all 15 quadrats combined within each survey period.

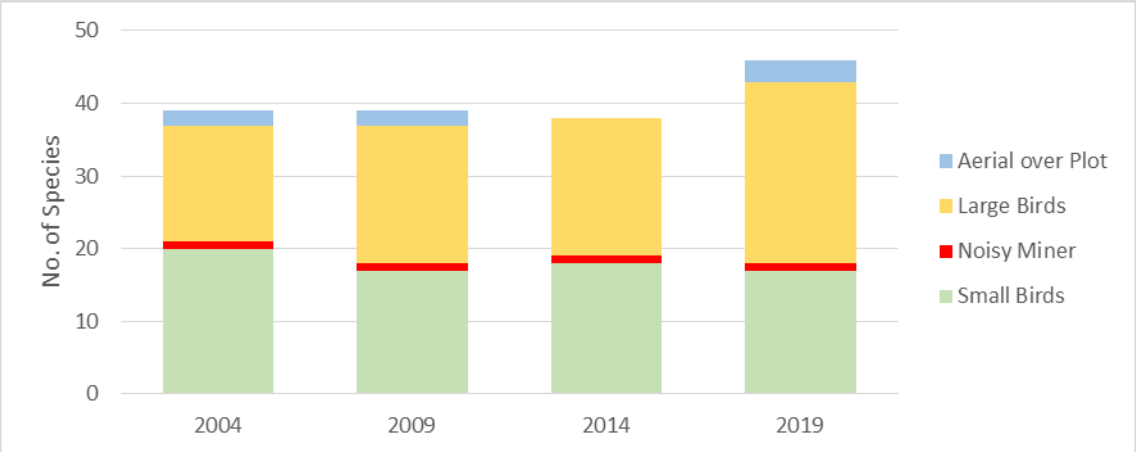

Figure 4 Number of birds in all quadrats combined within each survey period (small birds are smaller than Noisy Miners, large birds are larger than Noisy Miners and aerial birds are those that were seen foraging over the canopy of the quadrat).

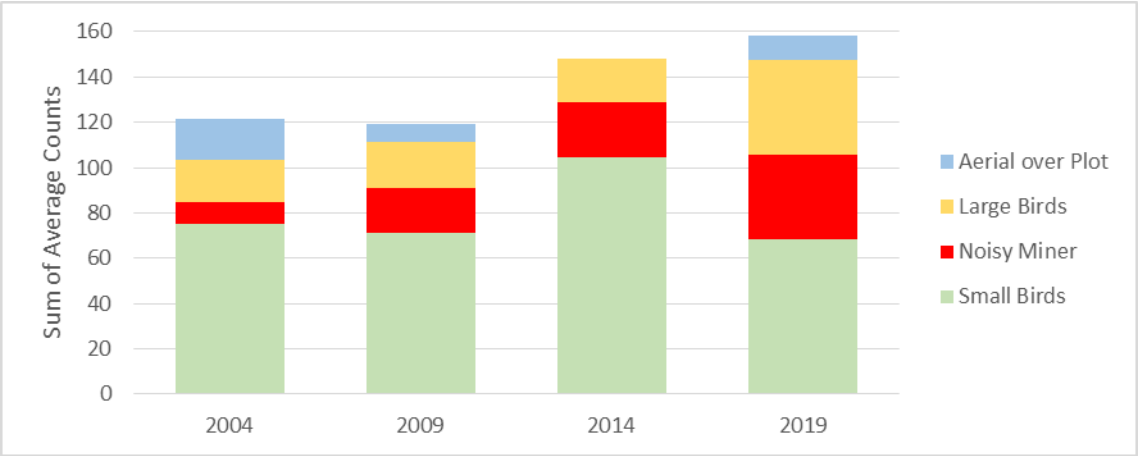

Figure 5 Sum of the average counts for birds in all quadrats combined within each survey period (small birds are smaller than Noisy Miners, large birds are larger than Noisy Miners and aerial birds are those that were seen foraging over the canopy of the quadrat).

Correlation analysis

Correlations were found between bird groups and between bird groups and vegetation structure. There was a significant negative correlation between shrub cover and tree cover (R^2 = 0.0936, P = 0.0368). Quadrats with higher tree cover generally had lower shrub cover. Small birds were strongly, positively correlated with shrub cover (R^2 = 0.2166, P = 0.0007), but strongly negatively correlated with tree cover (R^2 = 0.1183, P = 0.0145). Shrub cover accounted for 22% of the variation in counts of small birds. Small birds were very strongly negatively correlated with Noisy Miners (R^2 = 0.4509, P = 0.0001). The pattern of Noisy Miner count accounted for 45% of the variation in counts for smaller birds. Large bird numbers declined with increase in shrub cover, but the correlation was very weak (R^2 = 0.0689, P = 0.0565). Noisy Miners were strongly negatively correlated with shrub cover (R^2 = 0.1452, P = 0.0063). Tree cover was strongly positively correlated with Noisy Miners (R^2 = 0.2617, P = 0.0001) and with larger birds (R^2 = 0.2410, P = 0.0003).

Tree cover accounted for 26% of the variation in Noisy Miner counts and 24% of counts of larger birds. There was also a strong positive correlation between large birds and Noisy Miners (R^2 = 0.3994, P = 0.0001) and a strong negative correlation between small birds and large birds (R^2 = 0.1694, P = 0.0030).

Box 1 Examples of typical patterns that occur on quadrats that retain a dense canopy of eucalypts and quadrats with a high shrub cover and little to no tree cover.

Quadrat 1: Terrestrial vegetation on the edges of Narawang Wetland have a very simple structure consisting mostly of planted eucalypts. These began as a dense cover of shrubs which gradually grew into a tall layer of trees with narrow canopies - an overall increase in tree cover. As the trees changed from an immature shrub-like form to tall trees there was a loss of understorey. During that time small birds have disappeared from the quadrat while large birds and Noisy Miners have become very common. In 2015, there has been some tree thinning and planting of understorey shrubs, but at this stage they are very young and have only made a small contribution to the shrub layer.

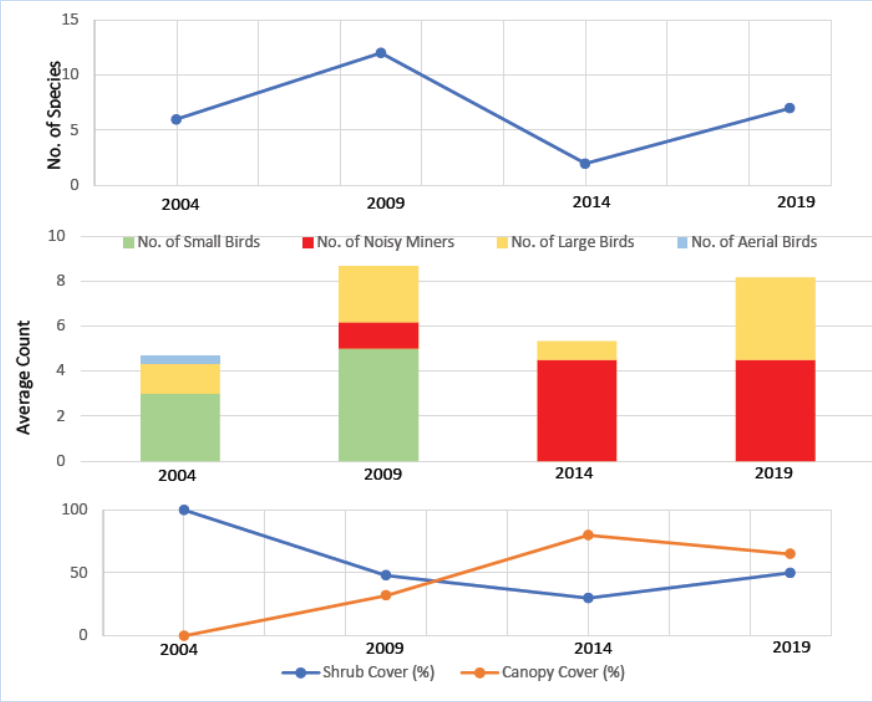

Figure 6 Changes in tree and shrub cover over the survey period along with changes in bird species count and changes in bird group composition in Narawang Wetland.

Quadrat 2: This quadrat within the Brickpit was dominated by Lantana with no canopy for the 2005 study. The site then underwent a three stage removal process from 2009 to 2015 to replace the Lantana with native shrubs. With no canopy and a good water supply, the shrubs grew very quickly and formed good habitat within 4 years. The dense shrub layer, no canopy and absence of eucalypts are likely to be the reason why small birds are found so frequently. Small bird density remained high throughout the process with the last two surveys recording good abundance and an increasing diversity of species. Noisy Miners were recorded at very low densities which is typical of the Brickpit precinct.

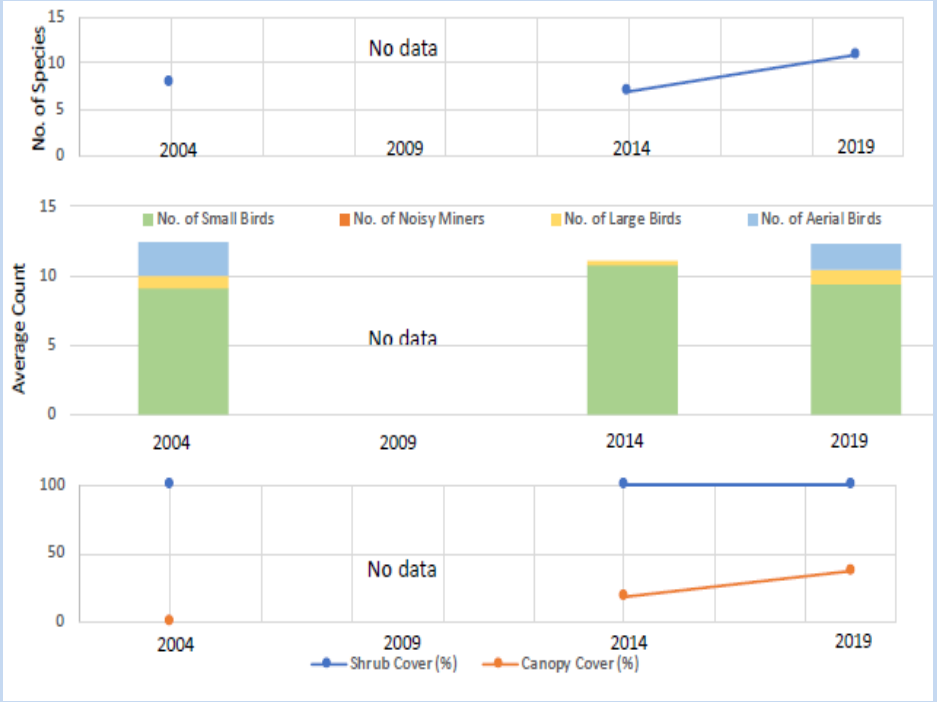

Figure 7 Changes in tree and shrub cover over the survey period along with changes in bird species count and changes in bird group composition in the Brickpit.

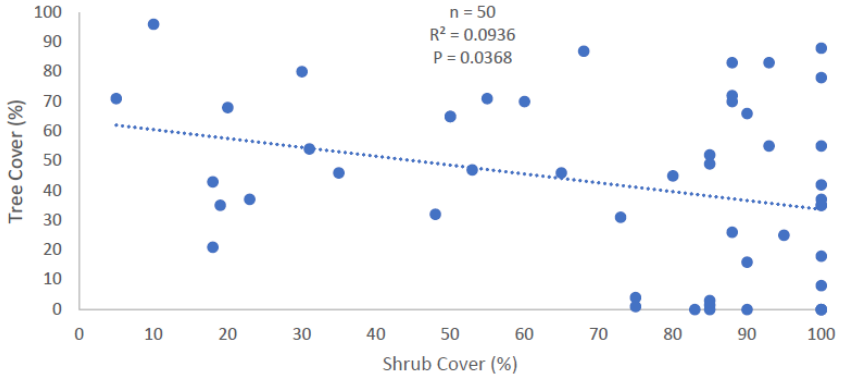

Figure 8 Correlation and regression analysis between shrub cover and tree cover for all plots and survey periods combined

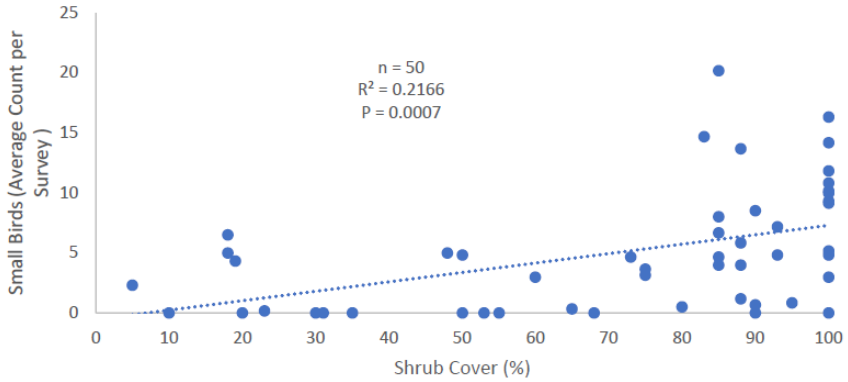

Figure 9 Correlation and regression analysis between shrub cover and average number of birds smaller than Noisy Miners for all plots and survey periods combined

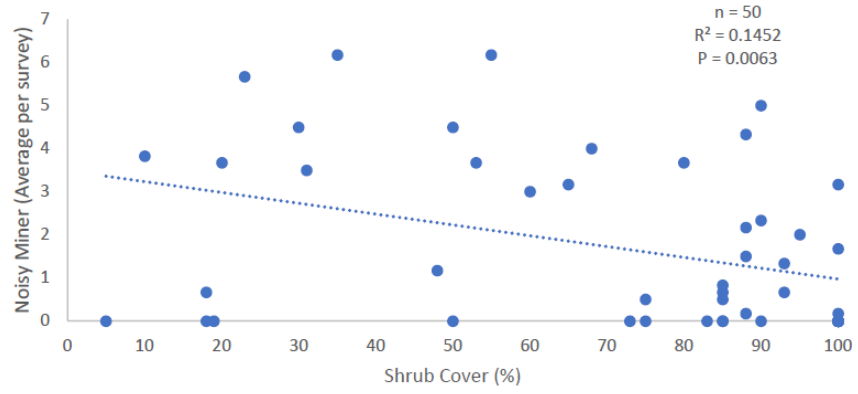

Figure 10 Correlation and regression analysis between shrub cover and average number of Noisy Miners for all plots and survey periods combined

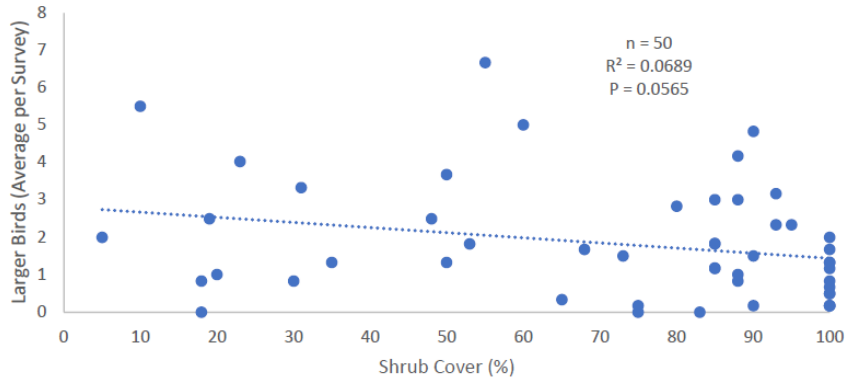

Figure 11 Correlation and regression analysis between shrub cover and average number of birds larger than Noisy Miners for all plots and survey periods combined

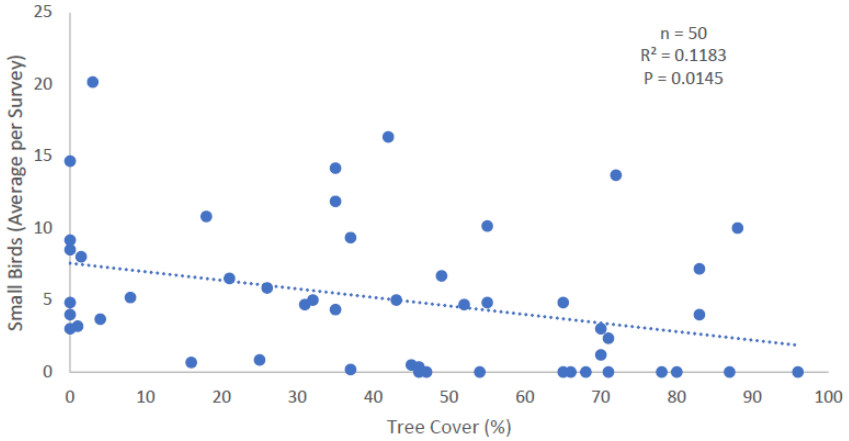

Figure 12 Correlation and regression analysis between tree cover and average number of birds smaller than Noisy Miners for all plots and survey periods combined

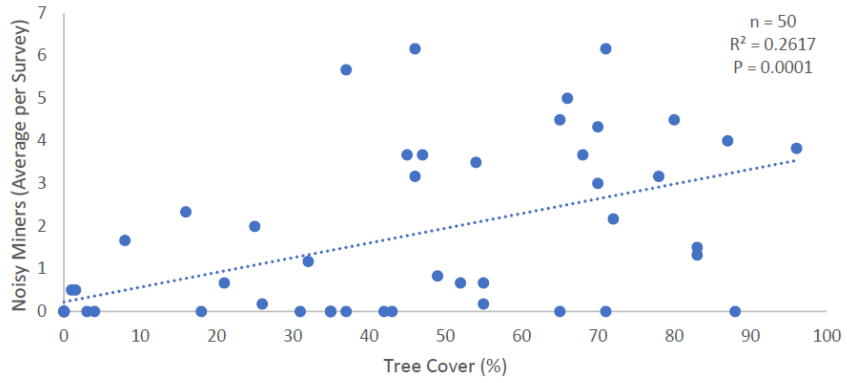

Figure 13 Correlation and regression analysis between tree cover and average number of Noisy Miners for all plots and survey periods combined

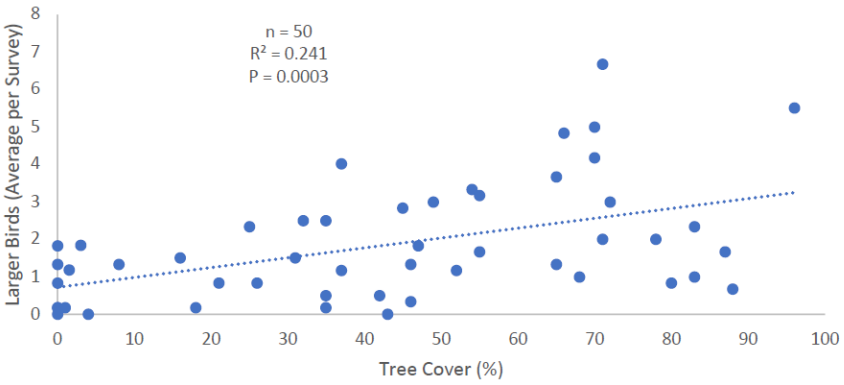

Figure 14 Correlation and regression analysis between tree cover and average number of birds larger than Noisy Miners for all plots and survey periods combined

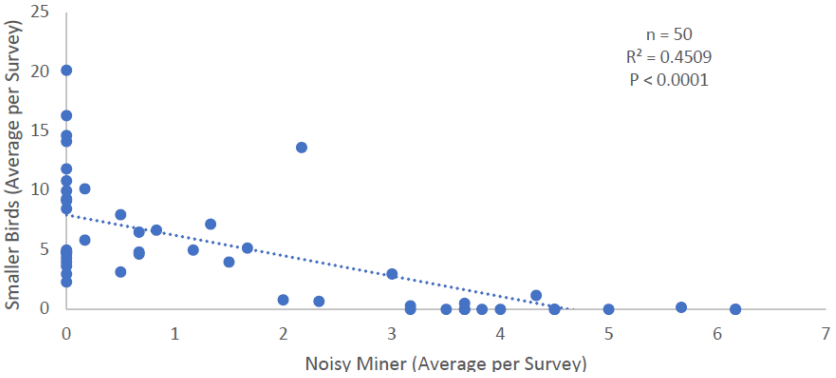

Figure 15 Correlation and regression analysis between Noisy Miners and average number of birds smaller than Noisy Miners for all plots and survey periods combined

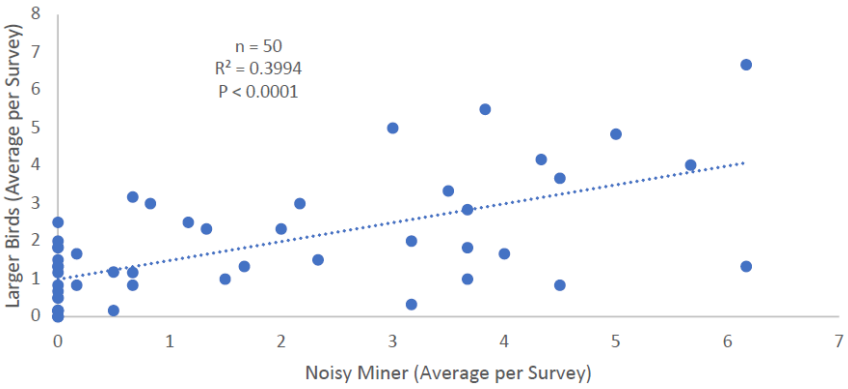

Figure 16 Correlation and regression analysis between Noisy Miners and average number of birds larger than Noisy Miners for all plots and survey periods combined

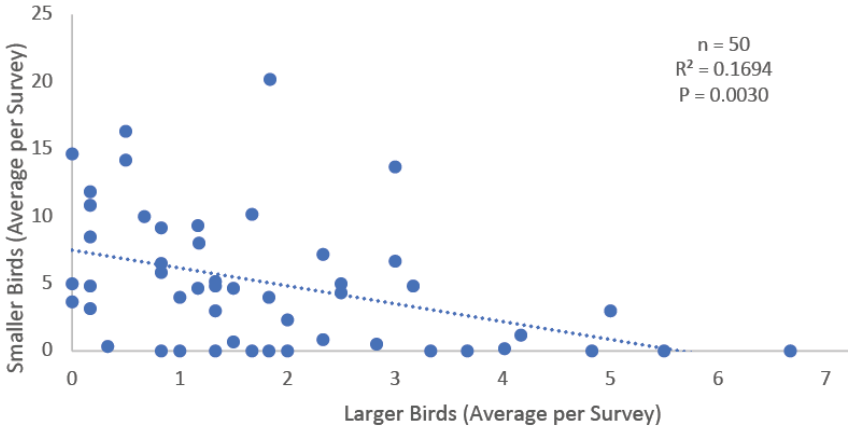

Figure 17 Correlation and regression analysis between average number of birds larger than Noisy Miners and average number of birds smaller than Noisy Miners for all plots and survey periods combined

Discussion

Summary of results

There was great variation in the vegetation structure between the 15 quadrats, however, patterns were found in the relationship between vegetation structure, as measured by shrub and tree cover, and bird community structure. Quadrats that were dominated by trees with only a sparse understorey of shrubs or were isolated and narrow were found to contain mostly Noisy Miner and larger birds. These quadrats were generally structurally very simple or were edge-affected, characteristics that favour larger birds. The more open habitat suits their foraging habits and also allows them to defend foraging and breeding territories more easily. Quadrats that had a dense shrub layer may also contain Noisy Miners and some larger birds, but they often occur at lower densities. The quadrats with a dense cover of shrubs with or without an open cover of trees generally supported a greater variety and higher density of smaller woodland bird species.

The results of this study accords with other studies (Evans *et al.* 2009, Howes *et al.* 2014, White *et al.* 2005). These studies found that increasing the shrub complexity with locally indigenous species will increase the richness and abundance of woodland birds. The positive correlation of bird species richness and abundance to shrub density and negative correlation with a simplistic eucalyptus canopy and the presence of the Noisy Miner provides evidence for adopting practices that increase shrub density and diversity.

Landscape design for woodland birds

Landscapers and park managers can change vegetation composition and structure in ways that can have profound impacts on biodiversity outcomes as much as on the aesthetics and social utility of public open spaces. The 1997 Sydney Olympic Park landscaping design master plan aimed for an aesthetic outcome based on canopy trees with a simplistic grass understory. This design contributed to a decline in woodland birds and an increase in Noisy Miners and other large bird species between 2000 and 2009. The initial planting of canopy trees was designed to provide an instant forest rather than to provide for biodiversity. Eucalypts were selected to tolerate the 'constructed' landscape produced by the significant on-site remediation necessary across the site.

The maturation of this forest resulted in change in overall vegetation structure from shrubs without trees to trees without shrubs within approximately 10 years from initial planting. An unintended consequence of this landscaping design has been reduced bird diversity over time. The loss of the shrub layer and development of a tall canopy dominated by eucalypts reduced habitat value for small woodland birds. This was exacerbated by the impact of more aggressive species such as the Noisy Miner (Thomson *et al.* 2015) that cumulatively alienated and negatively impacted on small bird populations and compositions.

Since 2006, Sydney Olympic Park Authority has implemented a habitat modification program aimed at increasing the structural diversity and complexity of key areas of the Park to support woodland birds. The program seeks to build connectivity between key woodland bird habitats identified in the Brickpit, Narawang Wetland, Newington Nature Reserve, Kronos Hill and Woo-la-ra. Areas for future works have been identified in Blaxland Riverside Park and Haslams Creek Flats that will contribute to the linking of woodland bird hotspots within the Park and to the region. The modifications have been shown by the surveys over 15 years to have had a positive influence on woodland bird population and composition.

It is expected that it will take another 5-10 years for landscape planting programs at Sydney Olympic Park to have a more significant impact on woodland bird populations, consistent with the results of a study by Barrett (2000). For this reason, the habitat modification program at Sydney Olympic Park is ongoing with maintenance of current woodland bird habitats continuing and additional areas planned.

Successful habitat enhancement at Sydney Olympic Park

This study shows that in areas of Sydney Olympic Park where dense shrubs were present and tree canopy was minimised, small bird abundance and diversity was higher. The Brickpit, a 27 hectare precinct with few eucalypts and little tree cover, had the highest proportion of small birds across the study area. The literature suggests that this is due to the lack of eucalypts, which are favoured by Noisy Miners, and the density of the shrub layer. The Brickpit is also one of the few precincts within the Park not dissected by pathways and experiences low levels of human disturbance which also may play a role in maintaining a woodland bird community.

At an individual species level, the study has revealed that habitat modification, even at the small patch scale, can have a positive impact. Edge specialists such as the Red-browed Finch and Superb Fairy-wren were advantaged by the introduction of successional stages into the vegetation structure. New plantings with vigorous groundcover growth provided new habitat niches not available in the original single aged landscape. Inclusion of shrubs with prickly leaves such as Hakeas provided nesting habitat.

Small patches of habitat were manipulated to reduce their attractiveness to Noisy Miners through canopy thinning to encourage the growth of shrubs, the preferential removal of eucalyptus species, the retention of casuarinas, or clustering of the eucalyptus canopy (maximum of 30 trees per hectare) above a very dense planting of shrubs. The shrub densities required by small woodland birds were only produced with a minimum tree canopy cover. Where maturing trees are densely planted and the tree canopy cover is high, shrub density is slow to establish

and after more than 8 years, is not attracting small birds. Ongoing monitoring is required to test whether the patterns observed at the quadrat scale are also occurring at the precinct and whole-of-Park scales.

Recommendations for designing and managing woodland bird habitat

The results of this study are relevant to design of urban parkland landscapes throughout eastern Australia and are a step towards providing knowledge of the relationship between particular bird species and restoration efforts that will enable fine-tuning of habitat design. Landscape designers and land managers can benefit from the lessons learnt at Sydney Olympic Park and can use them to refine and adapt biodiversity planning for urban green space.

The specific recommendations for landscapers and park managers include:

Design of woodland bird habitat

Planning for new sites incorporating woodland bird habitat should consider locally indigenous plant species that provide a variety of resources to woodland birds including prickly foliage for shelter and nesting, insect attracting species and grasses for granivores. The design should consider the following points:

- tree density should be < 30/ha;
- the eucalyptus component should be limited and supplemented by other genus such as Casuarina or Melaleuca;
- shrub density should be 1-2 shrubs/m2;
- groundcover density should be 4-6 plants/m2;
- coarse mulch incorporated;
- potential for future shading of groundcovers minimised by planting in bands or clumps to allow sunlight penetration.

Planning for woodland bird habitat

Woodland bird habitat can take up to four years to establish under good conditions and planning must consider funding for long-term management needs. Long-term management should consider the following points:

- weed control to prevent establishment of woody weeds that can replace woodland bird habitat. If woody weeds are established, removal should not take place until replacement habitat has been shown to support a similar diversity of woodland birds;
- follow up planting to replace unsuccessful individual plants and ensure that all habitat layers are well represented over time;
- potential thinning of all layers to ensure that shading and over competition between plants does not remove total habitat complexity and heterogeneity.

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Appendix 1 Vegetation types in woodland bird monitoring quadrats 2005-2019, Sydney Olympic Park.

2005	2009	2015	2019
			

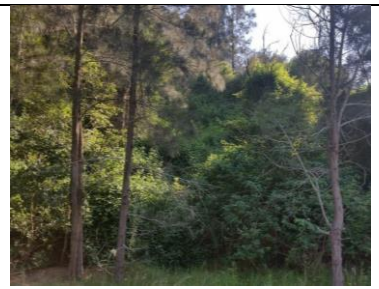
Figure 1a Unmodified landscapes (MP12-8) – Maturing trees with a canopy of eucalyptus and simple grassy understorey. No shrubs or groundcovers installed.

2005	2009	2015	2019
			

Figure 1b Modified landscape (MP12-7) – shrub planting under densely planted mature trees and kikuyu groundcover. Shrub density is slow to establish and after more than 8 years, remains scattered and thin.

2005	2009	2015	2019
No data			

Figure 1c Highly modified landscape (MP12-9) - thinning of trees and planting of a dense shrub/groundcover layer.

			
Figure 1d Natural landscape (MP17-11) located within Newington Nature Reserve	**Figure 1e** Weed dominated (MP13-7) mature canopy (*Casuarina glauca*) with an understorey of woody weeds (*Lantana camara*)	**Figure 1f** Modified Landscape (MP14-8) woody weeds have been removed and replaced with shrubs. Trees limited to perimeter of quadrat.	**Figure 1g** Modified landscape (MP13-6) woody weeds have been removed and replaced by shrubs. No tree canopy.

Appendix 2 Landscape categories, survey effort and descriptions for woodland bird quadrats, Sydney Olympic Park

Quadrat		SOPA Precinct	Previous surveys				History
			2005	2009	2015	2019	
Remnant	MP17-11	Newington Nature Reserve	X	X	X	X	Sited within Newington Nature Reserve and part of the remnant critically endangered Sydney Turpentine Ironbark Forest community. All three canopy layers in good condition.
Landscape (modified)	MP3-5	Newington Armory		X	X	X	Revegetated in 2006 as part of the extension of the Sydney Turpentine Ironbark Forest community. All three canopy layers in good condition, natural recruitment occurring.
	MP4-2	Woo-la-ra		X	X	X	Site for storing and treating soils as a result of land remediation elsewhere across the site. Restored in 2003 with a mix of shrubs and trees in a woodland matrix. Groundcover layer consists mostly of mulch.
	MP6-27	Narawang Wetland	X		X	X	Located on lands created by landfilling and remediation. Vegetation comprises solely of eucalypts planted in 1999-2000 with a mulched understorey. Tree canopy thinned and shrubs and groundcovers installed in 2015 – vegetation is still immature. Linear shape, highly edge-affected.
	MP11-6	Triangle Pond, Wentworth Common	X	X	X	X	Original edge of Homebush Bay, some dumping of clean fill in 1998. Revegetated in 2010 and 2014 to create a shrub layer which is now in good condition. Canopy trees retained throughout industrial history.
	MP12-7	Kronos Hill	X	X	X	X	Located on a remediated landfill topped with constructed soils. Originally planted with native grasses underneath a eucalypt canopy in 1996. Now dominated by trees and exotic grasses. Shrubs planted under tree canopy in 2006 and 2008 to increase structural diversity.
	MP12-9	Kronos Hill	X	X	X	X	Located on the northerly slope of a remediated landfill topped with constructed soils. In 2014, 50% of trees were removed and a mix of local and regional provenance shrubs and groundcovers installed.

	MP13-6	Brickpit		X	X	X	Located on the entry track of an old brickpit quarry. Primarily a monoculture of *Lantana camara*, one third of the quadrat was replanted in 2011 with regional provenance shrub species. No tree canopy present.
	MP13-8	Brickpit	X	X	X	X	Located on the floor of a disused brickpit quarry. Topography a result of piled demolition material. Planted with shrubs and groundcovers in 2010. Supplementary planting in 2012. No tree canopy present.
	MP14-8	Badu Mangroves	X	X	X	X	Highly modified due to historic construction of seawalls and bunds in Homebush Bay. First planted with trees and shrubs in 2008 and supplementary planted in 2012 after staged removal of woody weeds.
Landscape (unmodified)	MP2-4	Blaxland Riverside Park	X	X	X	X	Located on the slopes of a capped landfill. Vegetation primarily *Casuarina glauca* planted in 1998-99.
	MP15-10	Bicentennial Park	X	X	X	X	Located in a formal landscape derived from a capped landfill. An isolated forest patch surrounded by mown turf, vegetation is comprised of eucalypts, shrubs and grasses planted in 1993. Linear shape, highly edge-affected.
	MP12-8	Kronos Hill			X	X	Located on a remediated landfill topped with constructed soils. Originally planted with native grasses underneath a eucalypt canopy in 1996. Now dominated by trees and exotic grasses with a simplified structure.
	MP11-4	Wentworth Common	X	X	X	X	Located on remediated land capped and topped by constructed soils. Planting comprised of eucalypts and melaleucas that form a primarily canopy only structure.
Weed dominated	MP13-7	Brickpit	X	X	X	X	Located on the lower slopes of a disused brickpit quarry. Vegetation comprised of an understorey of *Lantana camara* and a canopy of *Casuarina glauca*.

Appendix 3 Bird species detected on quadrats during the 2004 to 2019 woodland birds study at Sydney Olympic Park, listed from most to least common based on average count for each species across all quadrats. Birds are grouped into colour categories: red: Noisy Miner, yellow: large Birds (>63g); light green: small birds (<63g); dark blue: aerial over quadrat.

Scientific Name	Common Name	All Surveys
Manorina melanocephala	Noisy Miner	91.39
Malurus cyaneus	Superb Fairy-wren	88.57
Zosterops lateralis	Silvereye	63.99
Neochmia temporalis	Red-browed Finch	45.46
Lichenostomus penicillatus	White-plumed Honeyeater	25.61
Hirundo neoxena	Welcome Swallow	21.45
Trichoglossus haematodus	Rainbow Lorikeet	20.04
Acanthiza nana	Yellow Thornbill	15.18
Petrochelidon ariel	Fairy Martin	14.73
Anthochaera carunculata	Red Wattlebird	14.30
Strepera graculina	Pied Currawong	12.87
Phylidonyris novaehollandiae	New Holland Honeyeater	12.12
Sericornis frontalis	White-browed Scrubwren	11.51
Pardalotus punctatus	Spotted Pardalote	10.15
Pynonotus jocosus	Red-whiskered Bulbul	9.82
Cracticus torquatus	Grey Butcherbird	7.25
Cracticus tibicen	Australian Magpie	7.23
Coracina novaehollandiae	Black-faced Cuckoo-shrike	5.49
Corvus coronoides	Australian Raven	4.74
Carduelis carduelis	European Goldfinch	4.17
Rhipidura leucophrys	Willie Wagtail	3.85
Grallina cyanoleuca	Magpie-lark	3.68
Lichenostomus chrysops	Yellow-faced Honeyeater	3.27
Pachycephala pectoralis	Golden Whistler	3.25
Rhipidura albiscapa	Grey Fantail	3.13
Porphyrio porphyrio	Purple Swamphen	2.75
Accipiter fasciatus	Brown Goshawk	2.35
Glossopsitta concinna	Musk Lorikeet	2.33
Sturnus vulgaris	Common Starling	2.22
Egretta novaehollandiae	White-faced Heron	2.18

Sturnus tristis	Common Myna	2.17
Threskiornis molucca	Australian White Ibis	1.99
Lonchura punctulata	Nutmeg Mannikin	1.95
Streptopelia chinensis	Spotted Dove	1.73
Dacelo novaeguineae	Laughing Kookaburra	1.61
Psephotus haematonotus	Red-rumped Parrot	1.35
Petroica rosea	Rose Robin	1.18
Alisterus scapularis	Australian King-Parrot	1.17
Calyptorhynchus funereus	Yellow-tailed Black-Cockatoo	0.85
Taeniopygia bichenovii	Double-barred Finch	0.84
Eolophus roseicapillus	Galah	0.83
Philemon corniculatus	Noisy Friarbird	0.83
Platycercus eximius	Eastern Rosella	0.78
Pachycephala rufiventris	Rufous Whistler	0.73
Anthochaera chrysoptera	Little Wattlebird	0.68
Hirundapus caudacutus	White-throated Needletail	0.67
Ocyphaps lophotes	Crested Pigeon	0.56
Coturnix ypsilophora	Brown Quail	0.55
Anas superciliosa	Pacific Black Duck	0.55
Platycercus elegans	Crimson Rosella	0.55
Dicaeum hirundinaceum	Mistletoebird	0.55
Falco peregrinus	Peregrine Falcon	0.51
Cacatua galerita	Sulphur-crested Cockatoo	0.50
Scythrops novaehollandiae	Channel-billed Cuckoo	0.50
Gallinago hardwickii	Latham's Snipe	0.45
Lichmera indistincta	Brown Honeyeater	0.45
Cisticola exilis	Golden-headed Cisticola	0.28
Acrocephalus australis	Australian Reed-Warbler	0.28
Chalcites basalis	Horsfield's Bronze-Cuckoo	0.23
Falcunculus frontatus	Crested Shrike-tit	0.23
Podargus strigoides	Tawny Frogmouth	0.17
Phalacrocorax varius	Pied Cormorant	0.17
Gallirallus philippensis	Buff-banded Rail	0.17
Ninox novaeseelandiae	Southern Boobook	0.17
Myzomela sanguinolenta	Scarlet Honeyeater	0.17

Sphecotheres vieilloti	Australasian Figbird	0.17
Oriolus sagittatus	Olive-backed Oriole	0.17
Dicrurus bracteatus	Spangled Drongo	0.17
Rhipidura rufifrons	Rufous Fantail	0.17
Myiagra rubecula	Leaden Flycatcher	0.17
Turdus merula	Common Blackbird	0.17