What the twitchers saw – delving into 16 years of bird census data

Viveca McGhie, Tina Hsu, and Jennifer O'Meara
Sydney Olympic Park Authority

Sydney Olympic Park Authority, in partnership with the Cumberland Bird Observers' Club, has conducted an annual Spring Bird Census across Sydney Olympic Park since 2004 using a standardised approach. The long-term dataset generated by this program provides an important tool for identifying trends and changes in bird populations, to inform and test habitat management against conservation goals. The 2019 census represents the 16th annual snapshot of birds across the Park generated by these surveys. Generally, bird abundance and richness across the Park in 2019 was consistent with data from recent years. Long-term trends include significant increases in urban adapted species, particularly the Noisy Miner, in parallel with long-term declines in small passerines such as honeyeaters and finches. State-wide climatic events have had a strong influence on abundance of bird groups such as waterbirds and vagrant and migratory species recorded at the Park from year to year. The Spring Bird Census dataset is due to the generosity of volunteers who have freely provided their birdwatching expertise to help inform the environmental management of Sydney Olympic Park.

Introduction

The Parklands of Sydney Olympic Park cover 430 hectares and are a mosaic of freshwater wetlands, estuarine wetlands, constructed landscapes, historic landscapes and remnant bushland. The Park supports three Endangered Ecological Communities and many threatened species listed under the NSW *Biodiversity Conservation Act* 2016.

Nearly half (304 hectares) of the Park is zoned under NSW planning legislation for environmental conservation and management. The site has been recognised from the early 1990's as having high ecological values at a local, regional, national and international level and has been managed by the Sydney Olympic Park Authority (the Authority) since 2000 to protect and enhance those values (Major 2004).

The Authority maintains and enhances habitat areas to

- protect threatened species, groups and communities;
- sustain and increase biodiversity at the community level, and;
- foster resilience for long term conservation against numerous and ongoing threats.

To achieve the Authority's commitment to best practice environmental management, adaptive management of habitats is guided by an ecological monitoring program that allows the performance of management activities to be assessed against proposed outcomes, refined and reassessed. This environmental management system enables the Authority to deliver informed management decisions, to direct limited resources to the management actions that are most likely to be effective and to measure improvement of ecological outcomes in relation to corporate and legislative environmental objectives.

Birds are a highly visual part of biodiversity, they are easy to see and identify, are comparatively well-studied, and are able to respond quickly to environmental change. This makes them useful indicators of environmental health (Mekonen 2017). Bird populations are known to be dynamic and may fluctuate over seasons or years, so long-term monitoring is needed to allow for meaningful interpretation of trends (State of Australia's Birds 2015). The two main purposes of long-term monitoring of birds as part of an adaptive management framework are:

1) to identify changes in populations that indicate a need for management intervention, and;
2) to measure the success of any intervention.

The Spring Bird Census and citizen science

Due to the size of the Park and the diversity of habitat types present, an intense sampling effort was required to achieve a robust snapshot of bird populations. The ability of citizen science programs to engage large numbers of volunteers provided the opportunity to gather information at the scale required that would otherwise be impossible for individual researchers or the Authority to achieve due to limitations of time and resources (Koboria *et al.* 2016). For this reason, volunteers have been involved in ecological monitoring programs at Sydney Olympic Park since 1995, providing the foundation for long-term assessment of trends in species diversity and abundance.

In 2004, the Authority entered into a partnership with the Cumberland Bird Observers' Club (CBOC) under a memorandum of understanding for their

members to participate in the 'Spring Bird Census'. CBOC has been a birdwatching club since 1979 and offered a source of field experience, practical skills and scientific knowledge.
The Spring Bird Census is now the fundamental source of data for monitoring performance indicators for birds such as species richness, abundance and breeding occurrence at both precinct and Parkland scales, and answers the following fundamental questions:

- General population trends - how does total species richness and abundance change over time?
- Is the number of introduced species increasing?
- Is the population of Noisy Miners increasing with time?
- Is the population of Pied Currawongs, Australian Ravens and other large urban-adapted birds increasing?
- What are the trends in different bird groups over time?

These questions relate directly to how the bird populations respond to a maturing Parkland and direct management of their habitats. Other questions were posed in 2004 that are now resolved or answered by other modules within the ecological monitoring program.

CBOC members have become champions of the Census and exhibit a collective passion and commitment towards the program with many members having participated every year. This strong and enduring partnership has been at the heart of the success of this 16-year program. Thanks to their dedication, the Census now has 16 years of repeated data that allows analysis of changes in the population size and distribution of the majority of species present.

Volunteers from CBOC are also recruited when required for other ecological monitoring programs or community events.

Survey methodology

Each year between September and November, surveys of 46 quadrats amounting to approximately 126 hectares are undertaken by approximately forty to forty-five volunteers from CBOC between 6am and 9am (Figure 3) concurrently each week for eight weeks. The quadrats are representative of all habitat types and varying mixed-use zones in the Park from the highly urbanised town centre to remnant bushland.

All quadrats are surveyed for 20 minutes. During each survey, all birds seen or heard were recorded on survey datasheets or on the BirdLife Australia Birdata app, along with observations on habitat and behaviour, breeding activity and species interaction.

The resulting data was then examined for bird richness and abundance across the Park, as well as by precinct, and by group, and compared to previous years. At a quadrat level, a regression analysis using R^2 value was undertaken to investigate if any trends were evident in bird richness and abundance.

Key management issues such as the influence of the Noisy Miner were investigated through changes in abundance and distribution. Trends for each species and for major bird groups were also examined across the whole Park. A table of bird groups and species belonging to each group can be seen in Appendix 2.

Box 1

Citizen science programs help to achieve broader environmental and social outcomes

Citizen science involves the collection of data by volunteers as part of scientific inquiry (Silvertown 2009). In addition to the contribution of data collection for the Spring Bird Census, CBOC volunteers also participate in other surveys in the Authority's bird monitoring program and make valuable contributions by reporting incidental sightings. These interactions serve to build stronger relationships, increasing shared learning and motivation through collective capital (Newman *et al.* 2012).

Volunteers that regularly participate in scientific research via citizen science programs benefit from increased scientific knowledge and associated skills, as well as increased appreciation and positive attitudes toward science and environmental stewardship (Brossard *et al.* 2005; Bell *et al.* 2008; Bonney *et al.* 2009; Silvertown 2009; Dickinson and Bonney 2012). CBOC members' understanding, connection with and appreciation for biodiversity at Sydney Olympic Park have resulted in participants actively participating in advocacy for the Park. Volunteers promote Park values to their personal networks and contribute to education and engagement at events at the Park.

Tony Dymond has been volunteering at Sydney Olympic Park for 17 years. As president of the Cumberland Bird Observers' Club in 2004, he was instrumental in constructing the first Census and has been a staunch supporter ever since. During an interview in May 2020, Tony indicated that the reason he became a volunteer was to help ensure that the rehabilitation works of the Parklands did not go to waste; *'to make sure it stays pristine'.*

"*People are gobsmacked by the wildlife at Sydney Olympic Park. There are very few, if any, big cities in the world where you have this sort of habitat within 30minutes of the CBD,*" said Tony.

Tony believes "*One of the key benefits of volunteering at Sydney Olympic Park is the knowledge that data is then used to maintain the quality of all the wetlands, woodlands, grasslands and parklands. Volunteers feel they are making a major contribution to preserve the area - our contributions to the Park are valued.*"

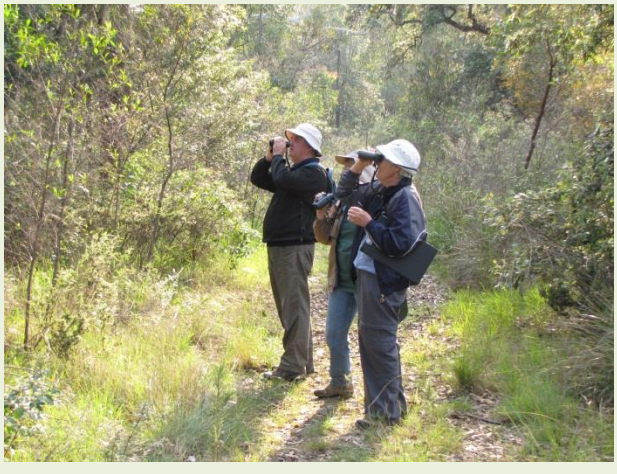


Figure 1 Volunteers surveying birds during the Spring Bird Census at Sydney Olympic Park

Figure 2 Regular presentations of survey results assist in building volunteers' understanding of monitoring program aims, their contributions to Park management and empowerment.

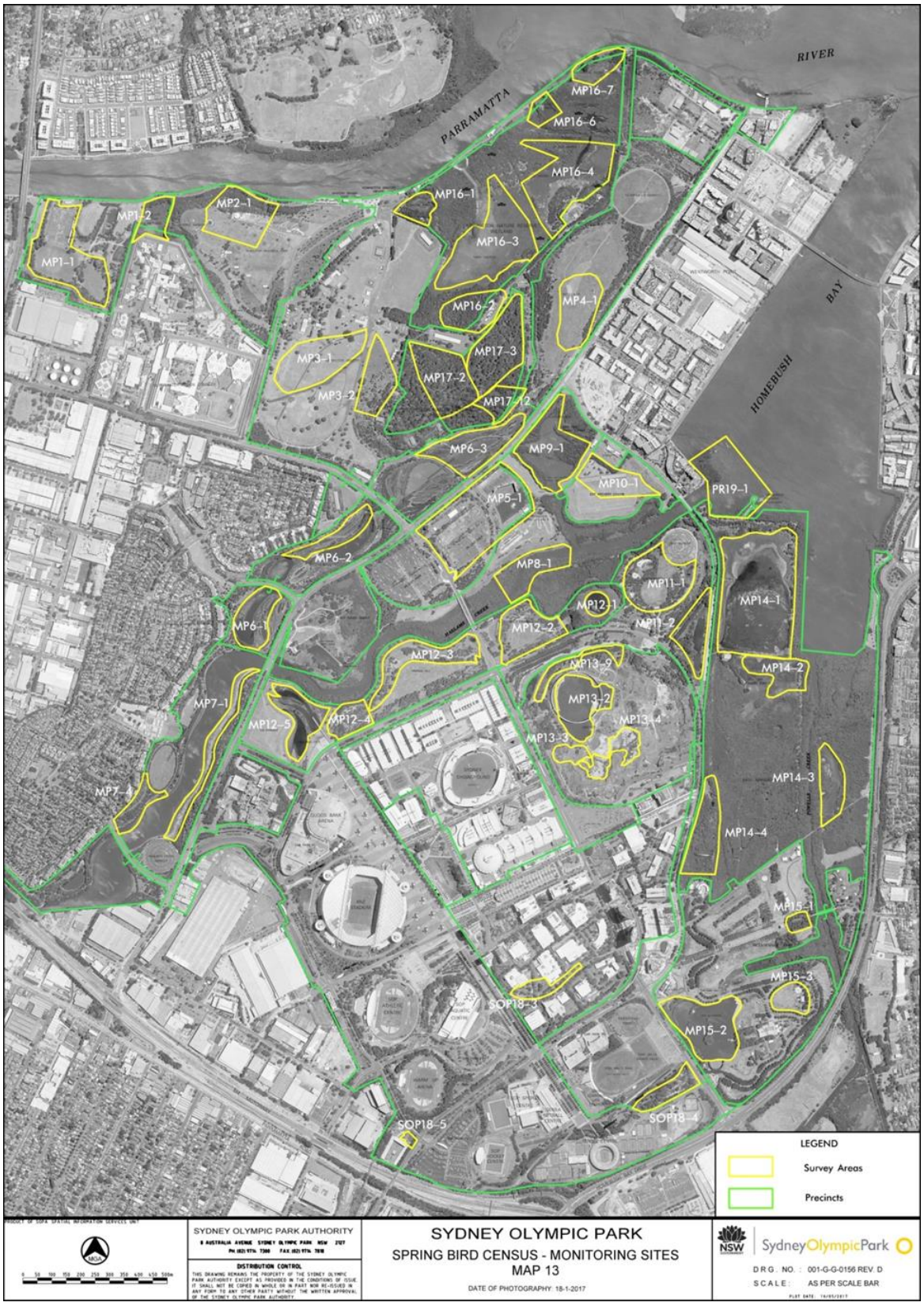


Figure 3 Spring Bird Census monitoring sites at Sydney Olympic Park

Results

1. Volunteer contribution

In 2019 volunteers contributed 3,824 records of 109 bird species composed of 102 native species and 7 introduced species, for a total of 21,193 birds. Over the 16 years of the survey a total of approximately 13,078 hours have been contributed and 70,625 records entered into the database.

2. General population trends

2.1 Species richness

The 2019 Spring Bird Census captured 82% of bird species seen between July 2018 and June 2019 (109 of 133 species) indicating a high capture rate of avian biodiversity across the site. The Census recorded cryptic residents such as the Australian Spotted Crake, species at the edge of their range like Mangrove Gerygone and many migratory species including those protected by international agreements such as the Red-necked Stint (last recorded in 2014); and notable species such as the Tree Martin (last recorded in 2007).

Over 16 years of the Census, a cumulative total of 189 bird species has been recorded, which is approximately 83% of all bird species recorded since 2000 (189 of 229 species). Species richness has remained similar throughout the survey period (Figure 4). Species not detected by the Census are rare, vagrant visitors and nocturnal species some of which are surveyed through separate targeted surveys. Examples from the 2019 period are nocturnal species such as the Barn Owl and Southern Boobook, many seasonal migrants and nomadic species, including the first sighting of the Fuscous Honeyeater and a return of the Swift Parrot (last recorded 1998).

At the quadrat level, quadrats with a combination of large wetlands and associated terrestrial plantings are the most diverse and have the highest avian abundance. This habitat mix supports a mix of both waterbirds and terrestrial species and reflects the large contribution of waterbirds to overall abundance and diversity in the Park.

Quadrats with lower species richness tended to be urban sites with limited vegetation cover.

2.2 Abundance

With a total count of 21,193 birds, bird abundance in 2019 was comparable to recent years except a below-average year in 2016 (Figure 5). Native bird abundance was also comparable to previous years and higher than the long-term (2004-2018) average.

2.3 Abundance of introduced species

Introduced species recorded in the 2019 census included Common Myna, Common Starling, Red-whiskered Bulbul, Rock Dove, Spotted Dove, and farm ducks. Abundance of introduced species has decreased from a cumulative high of 1,520 birds in 2005 to 322 birds in 2019, a further decrease from a record low of 386 birds in 2018. The trend of decline began in 2013, and abundance in 2019 was markedly lower than the long term average of 998 birds (Figure 6). The House Sparrow has not been recorded during a Census since 2011 and Nutmeg Mannikin since 2017. European Goldfinch was not recorded in 2019.

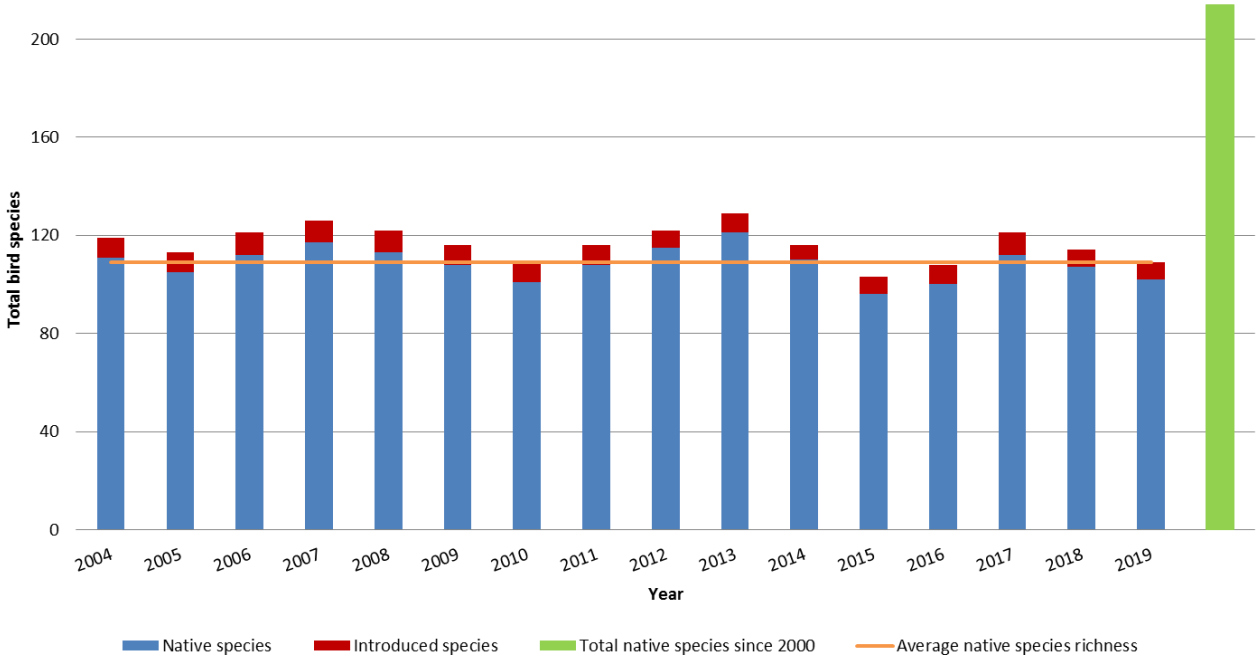


Figure 4 Native and introduced species richness recorded during the Spring Bird Census at Sydney Olympic Park from 2004 to 2019. Average native species richness from the Spring Bird Census 2004-2018 and total native species richness from all surveys since 2000 are provided for comparison.

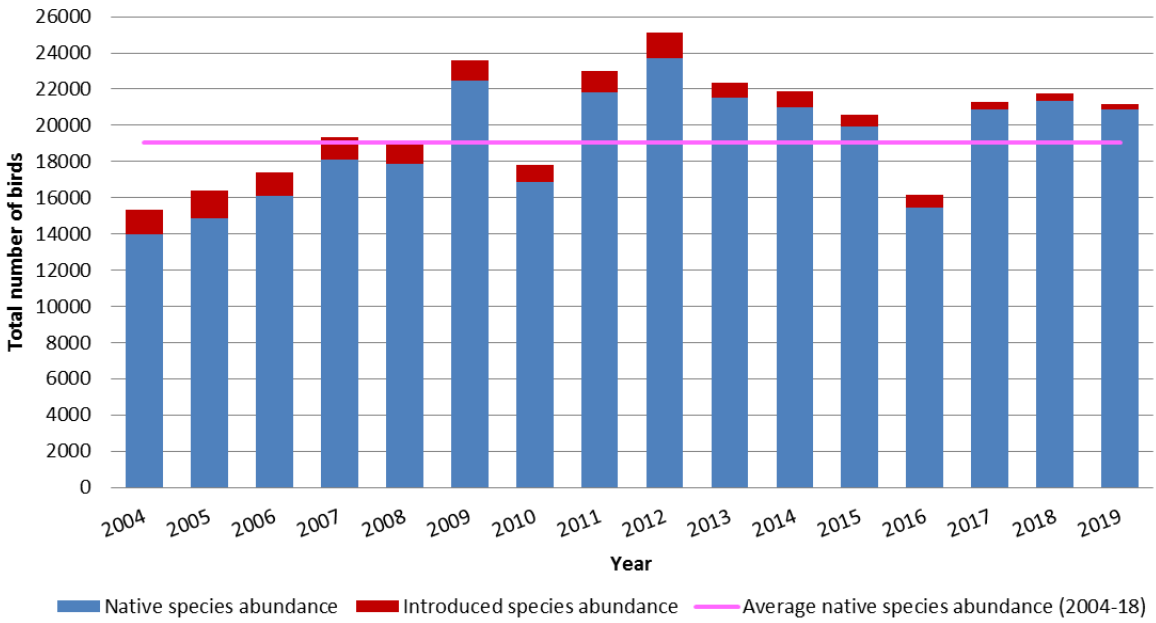


Figure 5 Abundance of native and introduced birds recorded during the Spring Bird Census at Sydney Olympic Park from 2004 to 2019. Average native species abundance from the Spring Bird Census 2004-2018 provided for comparison.

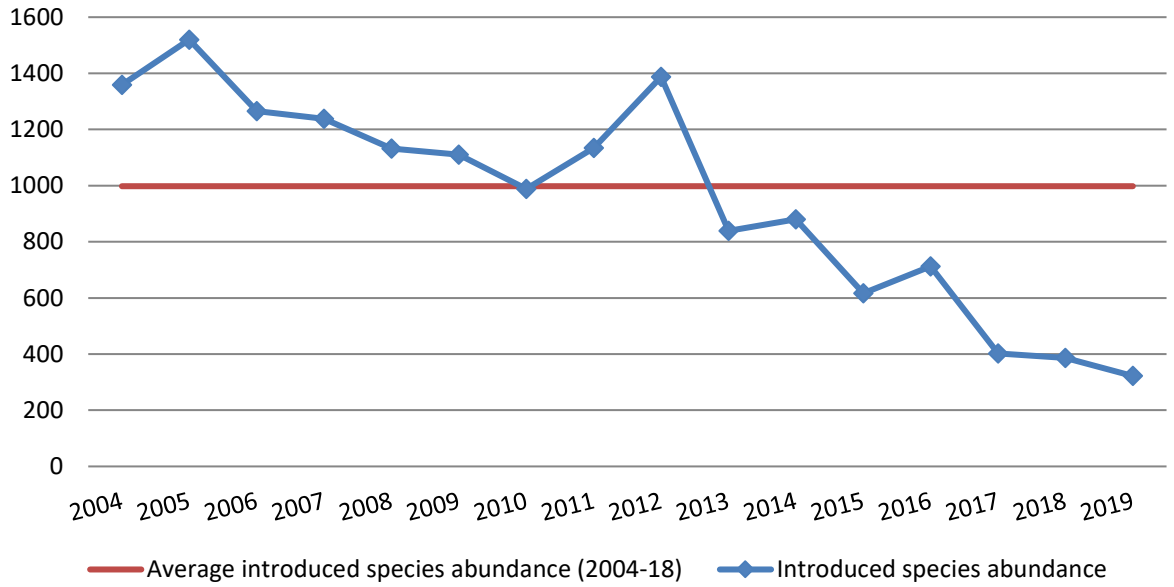


Figure 6 Introduced species cumulative abundance and long term average during the Spring Bird Census at Sydney Olympic Park from 2004 to 2019

2.4 Long-term comparisons

A regression analysis using R^2 was examined to quantify the magnitude of change in quadrats for species richness and average abundance over time (Appendix 1). For this data set, these parameters were considered to be increasing if R^2 was greater than 0.3, decreasing if less than -0.3. Quadrats with R^2 values between -0.3 and 0.3 were ranked as stable. Quadrats were then sorted into:

1. management types; Parklands (generally high presentation standards across turf, gardens and simplistic bushland comprised of trees and a grassy understory) or Natural Areas (generally managed for their environmental values);
2. vegetation type/structure. Examples include saltmarsh, freshwater, estuarine or bushland;
3. whether quadrats were terrestrial or wetland.

The results are shown in Appendix 1 and summarised in Table 1.

Table 1 Changes in bird species richness and abundance by quadrat (2004-19)

Richness:	Increasing: 4 (8%)
	Decreasing: 10 (22%)
	Stable: 32 (70%) consisting of 3 quadrats at 0, 10 increasing and 19 decreasing
Average abundance	Increasing: 5 (11%)
	Decreasing: 3 (7%)
	Stable: 38 (82%) with 1 quadrat at 0, 19 increasing and 18 decreasing

Richness increased considerably in 8% of all quadrats and decreased in 22% of quadrats. The majority of quadrats in the stable category (59%) showed a small decline over the 16 years of the survey. Abundance increased considerably across 11% of quadrats but decreased in 7% of quadrats. There was close to an even divide between quadrats classified as stable that increased in average abundance versus those that decreased in average abundance.

Terrestrial quadrats were more likely to show a decreasing trend in richness than wetland habitats (8 quadrats cf. 2 quadrats); the decline was not restricted to simplistic or planted bushland or turf with scattered trees, as three of four remnant bushland quadrats decreased in richness. Freshwater wetland quadrats in Narawang Wetland declined in richness, while estuarine wetlands and saltmarsh habitats appear to be relatively stable. While some of the quadrats that had decreased in richness also decreased in abundance, there was no clear pattern associated with habitat type, with declines observed in one quadrat each in remnant bushland, estuarine wetland and turf with scattered trees. Increases in average abundance were observed in freshwater wetland, estuarine wetland, saltmarsh, and planted bushland.

The large wetlands of Lake Belvedere and the Waterbird Refuge have been known throughout the Census as hotspots of diversity, consistently ranking highly for both richness and abundance. In this study, both quadrats are shown to have the greatest increases in abundance and richness (Figures 7 and 8). In Figure 8, the Waterbird Refuge abundance visually reflects state-wide climactic patterns with waterbird numbers decreasing rapidly in 2010 and 2016; periods of above average rainfall in western New South Wales (BOM).

An example of increasing abundance in a terrestrial quadrat (planted bushland) can be seen in the Brickpit, an old quarry with a reputation as a refuge for small woodland birds (Figure 9). The vegetation adjacent to the service track is part of a 14 year staged program to remove invasive species such as *Lantana camara.* The shrub layer of this quadrat was primarily Lantana and as it was gradually removed and replaced by native shrubs and ground covers, bird

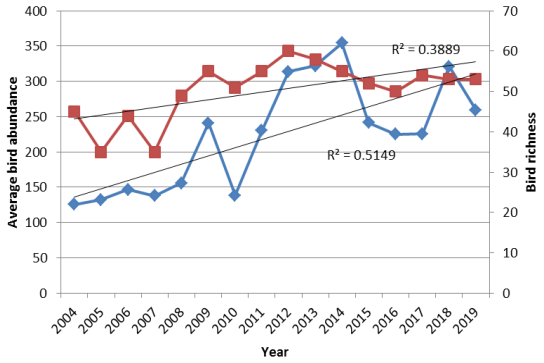


Figure 7 Bird species richness (red) and average abundance (blue) for Lake Belvedere during the Spring Bird Census 2004-2019.

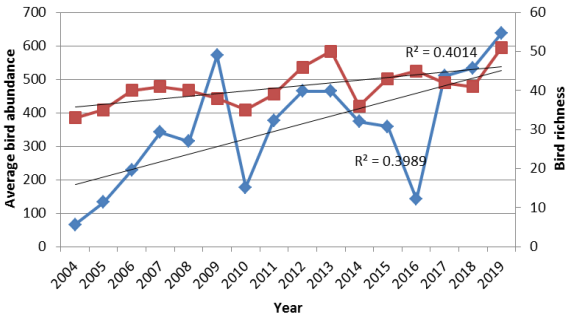


Figure 8 Bird species richness (red) and average abundance (blue) for the Waterbird Refuge during the Spring Bird Census 2004-2019.

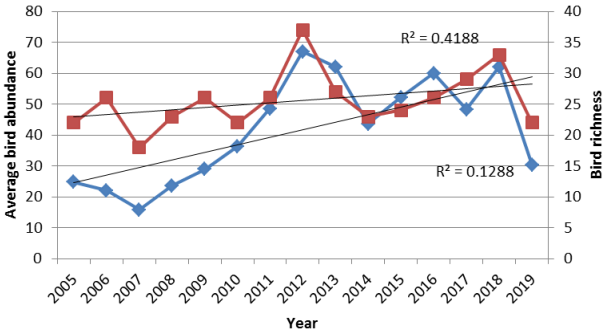


Figure 9 Bird species richness (red) and average bird abundance (blue) for the Brickpit service track quadrat 2005-2019.

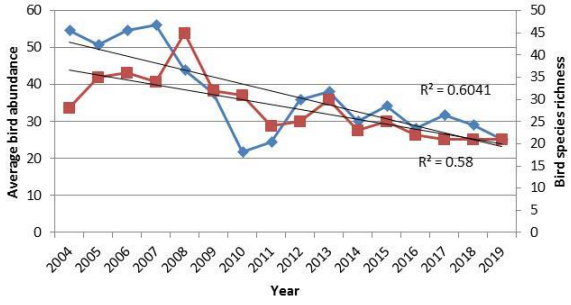


Figure 10 Bird species richness (red) and average bird abundance (blue) for Archery Park during the Spring Bird Census 2004-2019.

richness and abundance has performed positively. Works in this quadrat began in 2009 and was completed in 2015. Figure 9 also shows a trend seen in many terrestrial quadrats for 2019 – a significant decline in both richness and abundance.

Significant decline in bird species richness and abundance was observed in Archery Park, a turf dominated site with few trees (Figure 10). Of the five quadrats dominated by turf (Appendix 1), two were identified with considerably reduced richness and one with the highest loss in abundance.

2.5 Impact of Noisy Miners on species richness and abundance

To further investigate the relationship between declining richness and stable abundance in terrestrial quadrats, the impact of the Noisy Miner was examined.

The Noisy Miner is a honeyeater with a reputation for shifting bird diversity through their 'aggressive despotic behaviour' (MacNally *et al.* 2012). Thomson *et al.* (2015) found that the presence of Noisy Miners in a vegetation patch can reduce the richness and abundance of smaller birds (less than 63g) by 50% through aggressive exclusion (also Clarke and Oldland (2007), Maron and Kennedy (2007) and McNally *et al.* (2012)).

Average Noisy Miner abundance between 2004 and 2019 is shown to be steadily increasing (Figure 11). In 2019, this species made up more than 30% of total bird abundance in a quarter of all quadrats (11 of 46 quadrats or 24%). The quadrats with the highest percentage of Noisy Miners as a proportion of total abundance are located in the highly simplistic landscapes of the Town Centre and are associated with decreasing richness and abundance presented at Table 1. This is closely followed by quadrats in simplistic planted bushlands of Kronos Hill and Haslams Creek Flats and Bicentennial Park Forest Grids where they make up 54% total abundance. The vegetation of these quadrats consists of a eucalypt canopy over a grassy understory.

The terrestrial quadrats of Kronos Hill (Q2, Q3 and Q4) recorded the Noisy Miner at 34% of total abundance. Since 2016, these quadrats have been the focus of a staged planting program to create frog and woodland bird habitat. Closely

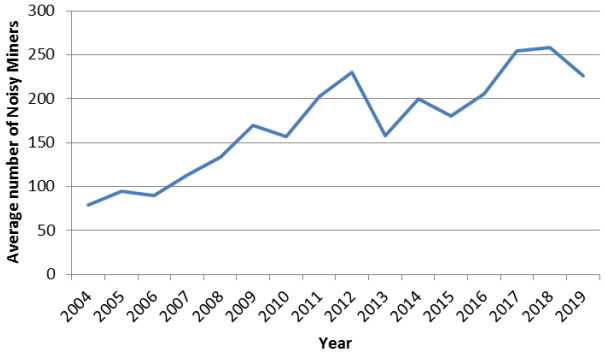


Figure 11 Average abundance per survey of Noisy Miners from Spring Bird Census 2004 to 2019

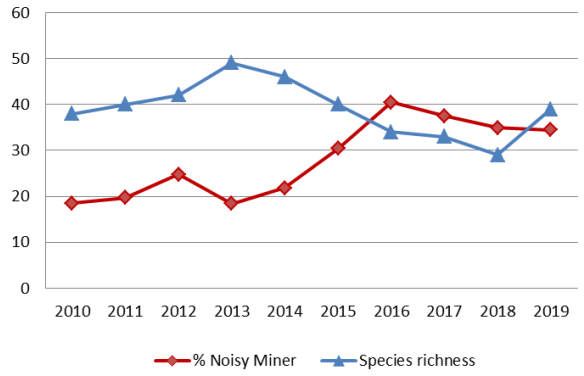


Figure 12 shows species richness declining over the long term from a peak of 49 species in 2013 to 29 in 2018 (then increasing to 39 in 2019), as Noisy Miner abundance increased from just below 20% in 2013 to 34% in 2019.

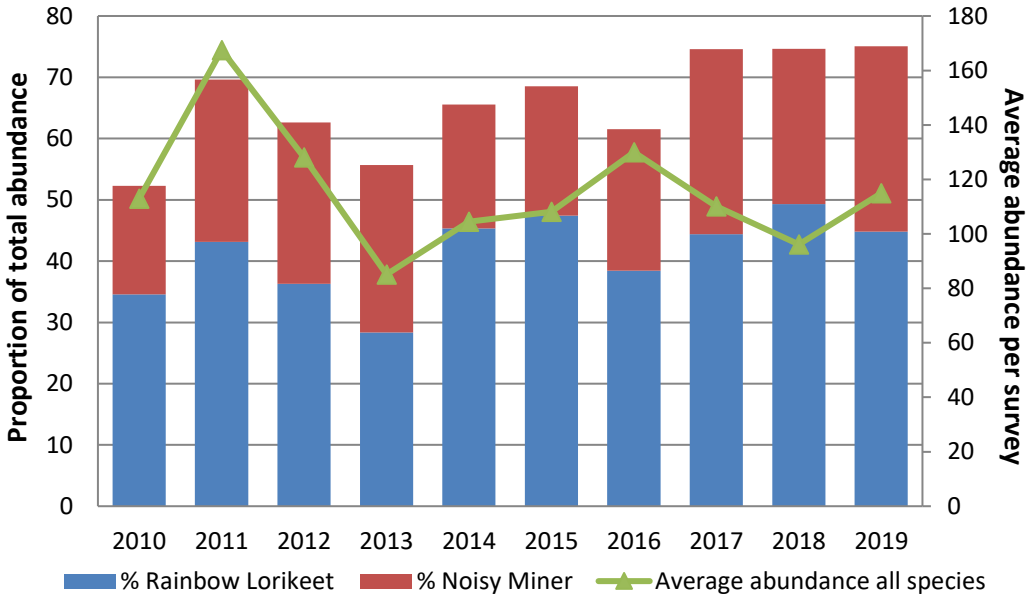


Figure 13 Average abundance per survey and percentage of Rainbow Lorikeet and Noisy Miner in Newington Nature Reserve forest from 2010 to 2019

planted stands of eucalypt trees have been thinned and replaced with shrubs including Acacia spp., Hakea spp., *Indigofera australis, Kunzea ambigua* and *Pomaderris spp.*, and ground covers such as *Dianella cearulea, Austrostipa spp., Microlaena stipoides, Themada australis*, and *Einadia spp.* Replanted areas now comprise approximately 50% of the quadrat. This program of habitat enhancement is staged and still immature. Data from future Census surveys will shed light on how long it takes for habitat restoration to achieve its objective of supporting a diverse bird population.

A similar pattern of dominance by a few species is emerging in remnant bushland of Newington Nature Reserve forest (the Forest). Across a 13-hectare patch, species richness has decreased over time from a peak of 37 species in 2013 to 20 species in 2019, a decline of 46%. While some woodland bird species continue to be recorded on a regular basis, including the Superb Fairy-wren, Red-rumped Parrot, Spotted Pardalote and White-browed Scrubwren, other woodland bird species that were once recorded annually appear to have disappeared from the Forest in recent years. The White-plumed Honeyeater, for example, was recorded annually from 2010 to 2015; the Red-browed Finch from 2012 to 2016, and the Tawny Frogmouth from 2010 to 2017. The Forest has also provided habitat to woodland birds that are seasonal migrants/nomadic or infrequent visitors, including the Crested Shrike-tit, Rufous Fantail, Golden Whistler, Leaden Flycatcher and Varied Triller. However, in the last two years, only larger woodland birds such as the Australian King Parrot, Crimson Rosella, Eastern Rosella and Olive-backed Oriole were recorded (except the regularly recorded woodland bird species mentioned above).

The decline in species richness has not been mirrored by a decline in abundance, which has been relatively stable since 2014 (Figure 13). The two

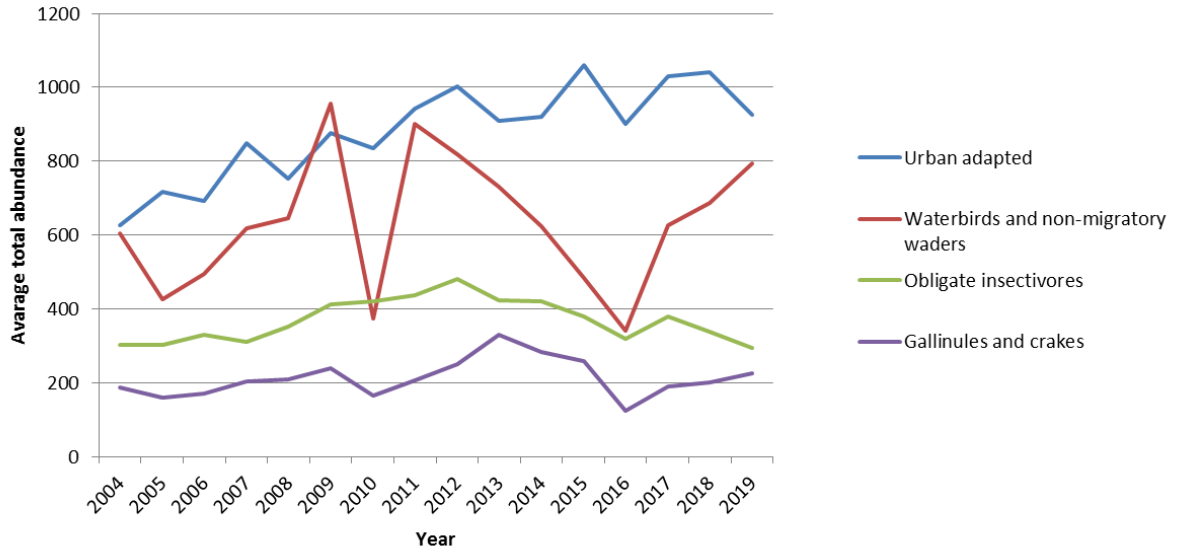
most abundant species in the precinct, the Noisy Miner and Rainbow Lorikeet, have gradually increased in abundance over time, so that they now comprise over 70% of total bird abundance in the precinct.

3. Bird group representation

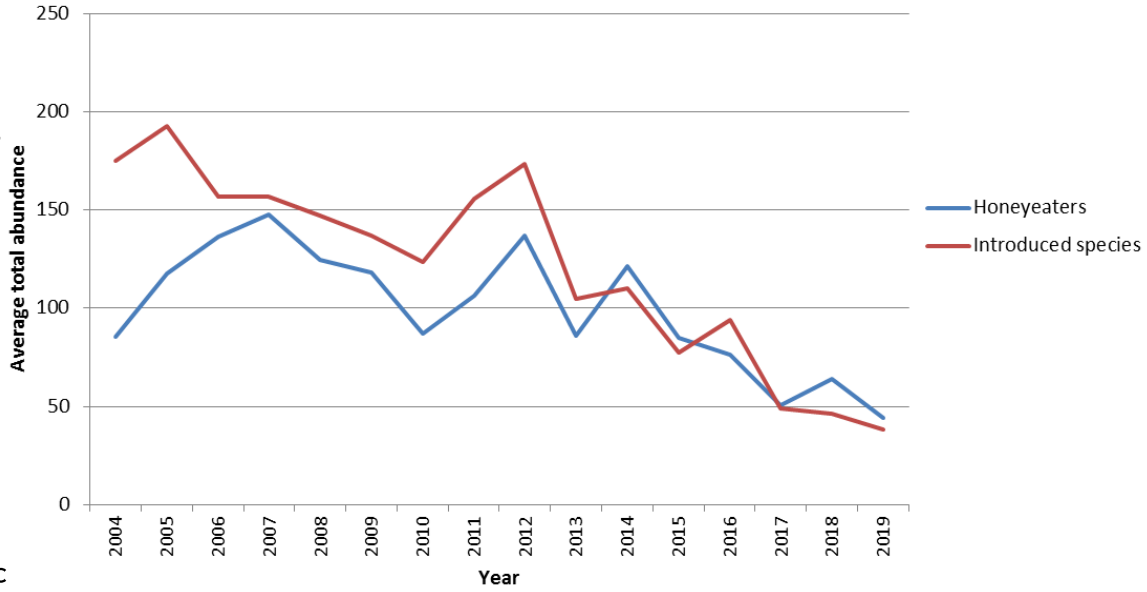
Figures 14a to c examine trends in average abundance for bird groups using data from Spring Bird Census 2004-2019 (for bird groups see Appendix 2). Since 2004, the abundance of different bird groups has changed:

- The Urban-adapted group have been the dominant bird group since the Census began in 2004, and exhibit an increasing trend over the long term. Even though abundance decreased in 2019 compared to the two previous years, it is still the most abundant bird group, and has been the most abundant bird group in all years except 2010 (Figure 14a).
- Waterbirds and non-migratory waders have been recovering in abundance since a low in 2016. The sharp decrease in 2016 was most likely in response to state-wide climatic events (Figure 14a), which resulted in birds moving to wetlands in western NSW after rains. The increased abundance in 2019 may be related to drought and bushfires across the eastern states pushing waterbirds to take refuge in reliable wetlands.
- The obligate insectivores group is ranked third in abundance as in previous years. Their numbers have been declining from 2012 (Figure 14a).
- Gallinules and Crakes is the 4th most abundant group; it exhibits a similar but less dramatic pattern of fluctuation to the waterbirds and non-migratory waders group. Their numbers declined from 2013 to a low in 2016, but have been increasing since (Figure 14a). These variations are driven by Eurasian Coots who follow a similar behavioural response to state-wide rainfall as species in the waterbird group.
- Introduced species are decreasing steadily, and have done so since 2007 except for a peak in 2012; abundance in 2019 is approximately 20% of peak abundance recorded in 2005 (Figure 14b).
- Honeyeater abundance fluctuated over time with peaks in 2007, 2012 and 2015, but has been on a downward trajectory since 2015. Abundance in 2019 is approximately 30% of the peak abundance recorded in 2007 (Figure 14b).
- Parrot abundance showed a small increase, however, it is approximately 40% of the numbers recorded in 2004 (Figure 14c).
- Finch abundance continues to decline after a peak from 2012 to 2013; present abundance is approximately 20% of abundance at the peak in 2012. Only the Red-browed Finch was present in 2019; the Double-barred Finch and Zebra Finch were last recorded in 2017 (Figure 14c).
- Raptor abundance began declining after 2015; abundance in 2019 continues to be low (Figure 14c).

14a



14b



14c

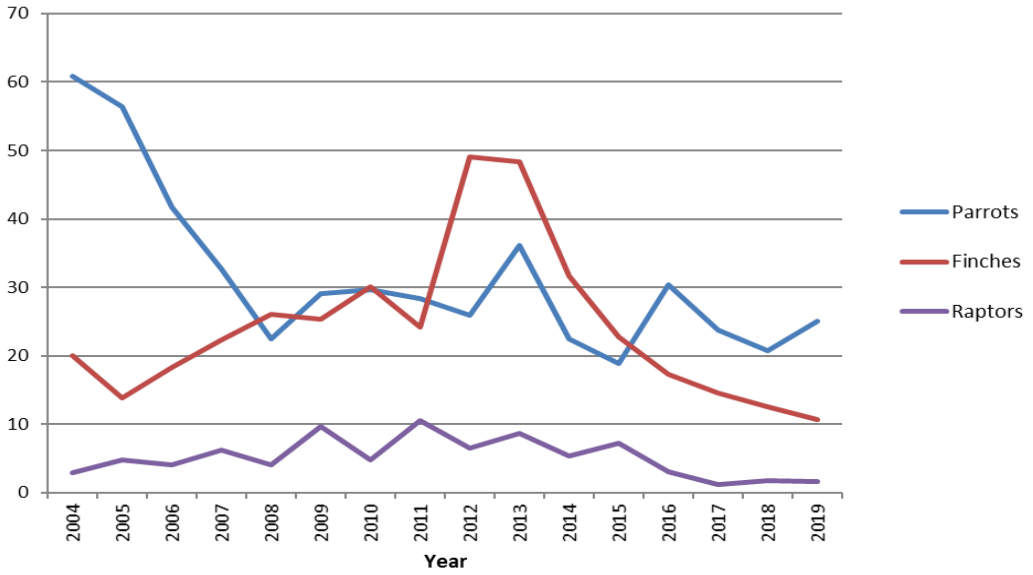


Figure 14 a-c. Average abundance of various bird groups during the Spring Bird Census at Sydney Olympic Park from 2004 to 2019

Discussion

Adaptive management is a fundamental process to achieve best practice environmental management; environmental monitoring is a central principle of this approach. The Spring Bird Census is one module in a large monitoring program enabling the Authority to manage habitat for endangered and protected species, including those of regional significance.

The Census allows temporal changes in the abundance of key bird species to be assessed as the habitats of Sydney Olympic Park mature. The Census remains a highly effective tool, consistently recording just over 80% of all bird species seen since the Census began in 2004.

Quadrats comprised of wetland and terrestrial elements consistently had the highest avian species richness and abundance. Large permanent wetlands show increases in bird abundance during times of drought and decreases during periods of high rainfall in western New South Wales. This is likely to be in response to species seeking refuge from drought illustrating the importance of the Park to state-wide bird movements. The last three years show the wetlands increasing in abundance of birds as the inland drought continued.

The story for terrestrial bird groups is very different. The Brickpit Service Track quadrat saw a sharp drop in species richness in 2019 (dropping by 10), particularly in woodland bird species that make seasonal or nomadic movements. These birds are likely to have been impacted by the warm and dry conditions prevalent over the last three seasons. This would no doubt have caused mortality of small woodland birds, and affected the movement of survivors. The State of Australian Birds (2015) also found a declining trend in East Coast Dry Sclerophyll Woodland/Forest Associated species with highly significant decreases for species such as fairy-wrens and finches.

Interestingly, introduced species continue to decline in species richness. Abundance in 2019 is only one-fifth of the abundance in 2005; although this is positive as introduced species compete with native species for resources (e.g. Common Mynas and Starlings are known to take over nest boxes).

While overall species richness and abundance appear stable, the story at the quadrat level is different. About 22% of quadrats have declined considerably in species richness. A further 59% of quadrats are currently ranked as stable but show slow declining trends. In contrast, only 7% of quadrats declined in abundance; of those ranked as stable, 47% show a slow decreasing trend. This suggests the quadrats are now dominated by large numbers of a few species. It is particularly concerning as this pattern of decline occurred across all habitat types, including precincts of high ecological value - the Brickpit, Narawang Wetland, Newington Nature Reserve wetland and forest. Climatic factors no doubt played a role; however, Noisy Miners and their aggressive territorial behaviour would have contributed as well.

Noisy Miner has consistently been the most abundant species in recent years and the most widely distributed. Noisy Miner made up more than a third of all bird abundance in a quarter of quadrats; with abundance exceeding 50% in five quadrats. As Noisy Miner abundance climbed, species richness declined.

Analysis by bird group illustrates the gradual decline in all groups except the waterbird group and the urban adapted group. The reasons for these declines need to be investigated in detail and

possible means of reversing the decline identified. The reality may be that some solutions are beyond the capacity of Park management. Elements such as Park design, vegetation structure, plant selection and water availability can be manipulated but large-scale processes such as changing climactic patterns or landscape scale habitat loss cannot.

Future conservation of birds at Sydney Olympic Park will depend on addressing resilience in the many habitat types present. Steps may include accelerating revegetation and restoration efforts, consideration of active intervention to mitigate threats presented by introduced and native species alike, and recognition and increased protection of ecologically sensitive areas from further anthropogenic disturbances.

Spring Bird Census and Park management

Each year, the results of the Spring Bird Census are compared to previous surveys and an annual report created. This report includes management recommendations in response to changes observed in bird richness and abundance.

Following are some examples of how the Census stimulated new habitat enhancement programs or ecological infrastructure and tested habitat management against conservation goals:

1. **The installation of artificial roost habitat in the Waterbird Refuge.** This large estuarine waterbody hosts the greater part of a regionally significant population of Black-winged Stilts (Major 2004). Breeding by the stilts was noted in the surveys from 2004 to 2006 but successful recruitment was rare and breeding activity had contracted from three sites to one – the Waterbird Refuge. A dirt island 10 metres from the bank was installed in 2007 and five car tyre islands were installed in 2010. In 2010, the Census report recommended further artificial roost/nest sites be installed based on the success of the initial island. Two floating islands 70 metres from shore were added in 2012. A targeted survey was established and supplemented by the Census with both contributing important information to evaluate the success of these installations. Monitoring showed that the floating islands were the preferred roost and nest site for Stilts, probably due to their location further away from disturbance, with 18 other species also utilising them.
2. **Woodland bird habitat modification project.** From 2004, the Census was identifying changes to small woodland bird populations with some increasing but many decreasing. This was in parallel with increasing abundance of Noisy Miners and other large urban adapted birds. The Census data was used to identify where woodland bird hotspots existed and where potential corridors could be enhanced. Since 2006, a habitat modification program has been in place to improve the quality of Park habitat and management of site-specific factors to address woodland bird conservation. Monitoring is on-going as these changes to habitats mature. Initial monitoring is positive with strong correlations being found between increasing shrub density and small woodland bird diversity and abundance in a relatively short time (four years) (Saunders 2019).
3. **The Brickpit staged weed removal project.** In the Brickpit, two Census quadrats contained *Lantana camara*, an invasive weed species. This placed them in an excellent position to test the success of a staged weed removal

program. Over a period of 11 years, the Lantana was slowly removed and replaced with native shrubs and groundcovers. Census monitoring showed small bird density remained high throughout the process with surveys recording good abundance and an increasing diversity of species.

4. **Tidal flushing of the Waterbird Refuge.** The Census was used to assist in evaluating the success of the introduction of tidal flushing to the Waterbird Refuge in 2007. Increases in the target group of protected migratory shorebirds such as the Bar-Tailed Godwit were reported within one year in 2008. The 2009 Census report notes that abundance of Black-winged Stilts rose sharply from an average of 68 birds to over 150 post-restoration. The Census is used annually to check performance of this important wetland with the Refuge performing consistently as one of the most abundant waterbird sites at the Park.
5. **Red-rumped Parrot nest boxes.** In 2008, the Census identified a decline in Red-rumped Parrots. In response, the Authority conducted a study on hollow usage over 2011 and 2012, finding intense competition for hollows and constant displacement of the smaller Red-rumped Parrot by the larger Rainbow Lorikeets. In 2012, a successful nest box program designed specifically for the Red-rumped Parrot has led to the adoption of multiple boxes by the species. Placement of boxes was guided by Census data that identified their feeding grounds.
6. **Recognition of Sydney Olympic Park's role as a refuge and stepping stone.** The Park functions as a refuge for migratory and vagrant species that either remain for a period of time or use the Park as a stepping stone to other parts of the region/state or country. The Census data illustrates this ebb and flow of both terrestrial and wetland passage migrants over the years. Park management aims to maintain resilient habitats that provide for both resident and migratory species through provision of a wide range of habitat types, diverse plantings and vegetation structure to offer a range of food and shelter resources.

Citizen science

Citizen science has long been used to collect reliable environmental data, with federal and local governments, non-governmental organisations (NGOs), research institutes, museums, and conservation organisations relying on volunteer-compiled datasets to inform their resource management and conservation strategies (Silvertown 2009; Miller-Rushing *et al.* 2012; McKinley *et al.* 2015).

At Sydney Olympic Park, management has benefited from partnering with ecological community groups such as CBOC, with long-term partnerships now also in place with the Frog and Tadpole Study Group for auditory frog monitoring and with the Australian Herpetology Society for reptile surveys.

By engaging volunteers, the Authority has access to regular replicated estimates of the population size of important faunal groups over multiple quadrats across precincts, Park-wide and over time. This has contributed significantly to providing data to support conservation and management at Sydney Olympic Park, enabling analysis of the richness, distribution and abundance of species across spatial and temporal scales.

Acknowledgments

The Spring Bird Census is made possible through the contribution of volunteer

hours from members of the Cumberland Bird Observers' Club. This contribution has enabled vast amounts of data to be collected, providing the foundation for long-term assessment of trends in species diversity and abundance at Sydney Olympic Park.

Our thanks go to the dedicated volunteers who have contributed to the Spring Bird Census over the past 16 years, with particular thanks to Judy Harrington for coordinating the Census for many years.

The dedication, time, and skill of our volunteers is critical to our bird monitoring programs.

A large part of this report is based on the 2019 Spring Bird Census Report written by Dr Tina Hsu.

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Appendix 1

Regression analysis values (R^2) for species richness and total average bird abundance in all quadrats from the 2004-2019 Spring Bird Census. Quadrats were considered to be increasing if $R^2 > 0.3$, decreasing if $R^2 < -0.3$. Notable increases/decreases are highlighted.

Management type	Description	Quadrat	Richness (R^2)	Av Abundance (R^2)
Natural area	Simplistic bushland	Kronos Hill - Q2	0	0.0798
		Kronos Hill - Q3	-0.5035	0.0304
		Kronos Hill - Q4	-0.5119	-0.1631
	Freshwater wetland	Narawang Wetland - Q1	-0.1097	0.0144
		Narawang Wetland - Q2	-0.4269	-0.1319
		Narawang Wetland - Q3	-0.4046	-0.0153
		Eastern Pond - Q1	0	-0.154
		Northern Water Feature - Q5	-0.0005	0.5409
		Wharf Pond - Q1	0.0251	0.0926
		Brickpit reservoir - Q2	-0.0003	0.1607
		Brickpit natural wetlands - Q4	-0.0009	0.0371
		Lake Belvedere - Q3	0.3889	0.5419
	Estuarine wetland	Nuwi Wetland - Q1	-0.1245	-0.5951
		Haslams Reach - Q1	-0.0477	-0.2972
		Waterbird Refuge - Q1	0.4014	0.3
		Billabong - Q3	-0.0255	0.0009
		Bennelong Pond - Q4	0.0876	0.2053
		Main Lagoon - Q3	-0.0535	-0.0109
		Parramatta River - Q1	0.001	-0.2604
	Saltmarsh	33 Marsh - Q4	-0.0385	0.0014
		Flushing Channel 1 - Q6	0.2214	0.2471
		Saltmarsh Nursery - Q7	0.005	0.2565
		Badu Saltmarsh - Q2	0.0171	0.3011
		Haslams Creek Flats - Q1	-0.019	0.125
	Remnant bushland	Newington Nature Reserve forest - Q12	-0.3155	-0.4586
		Newington Nature Reserve forest - Q2	-0.4718	-0.2409
		Newington Nature Reserve forest - Q3	-0.3135	-0.2538
		Swamp Oak Floodplain Forest - Q2	-0.1296	-0.0655
	Planted bushland	Newington Armory - Q2	0.0098	-0.0028
		Woo-la-ra Q1	-0.0387	-0.1222
		Wentworth Common - Q2	-0.472	-0.0001
		Brickpit mezzanine - Q3	-0.2923	-0.1379
		Brickpit entry track - Q9	0.1288	0.4188
Parklands	Turf with scattered trees	Wilson Park-Q1	-0.5453	-0.0106
		Wilson Park -Q2	-0.0068	-0.0102
		Newington Armory - Q1	0.0033	0
		Archery Park - Q1	-0.58	-0.6041
		Village Green - Q2	0	0.2025
	Planted bushland	Blaxland Riverside Park - Q1	0.3212	0.04
		Haslams Creek Flats - Q4	-0.0343	0.0063
		Wentworth Common - Q1	0.0312	0.1519
		Forest grid - Q1	-0.0966	-0.0002
		Boundary Creek - Q4	0.3451	0.0672
Urban	Street trees	Figtree Drive - Q3	-0.2132	0.0475
		Parklands Junction – Q1	-0.0446	0.2677
		Park Management Centre - Q5	-0.1152	-0.1032

Appendix 2

Bird species groups recorded during the 2004-2019 Spring Bird Census at Sydney Olympic Park; only bird species represented in more than 6 of the possible 16 years were included in the analysis.

Waterbirds and non-migratory waders			
Australasian Grebe	Cattle Egret	Grey Teal	Nankeen Night Heron
Australian Pelican	Chestnut Teal	Hardhead	Pacific Black Duck
Australian Wood Duck	Darter	Hoary-headed Grebe	Pied Cormorant
Black Swan	Glossy Ibis	Intermediate Egret	Royal Spoonbill
Black-fronted Dotterel	Great Egret	Little Black Cormorant	Striated Heron
Black-winged Stilt	Great Cormorant	Little Pied Cormorant	White-faced Heron

Gallinules and Crakes			
Dusky Moorhen	Purple Swamphen		
Buff-banded Rail	Eurasian Coot		

Obligate insectivores			
Eastern Shrike-tit	Spotted Pardalote	White-winged Triller	Leaden Flycatcher
Golden Whistler	Superb Fairy-wren	Yellow Thornbill	Little Grassbird
Grey Fantail	Yellow-rumped Thornbill	Australian Reed-Warbler	Welcome Swallow
Mangrove Gerygone	White-browed Scrubwren	Australian Pipit	Fairy Martin
Dollarbird	Tawny Grassbird	Black-faced Monarch	White-fronted Chat
Rufous Whistler	White-throated Gerygone	Golden-headed Cisticola	Tawny Frogmouth

Urban adapted			
Silver Gull	Sulphur-crested Cockatoo	Black-faced Cuckoo-Shrike	Pied Currawong
Australian White Ibis	Rainbow Lorikeet	Grey Butcherbird	Magpie-lark
Galah	Laughing Kookaburra	Australian Magpie	Crested Pigeon
Little Corella	Noisy Miner	Australian Raven	Willie Wagtail

Honey-eaters			
Brown Honeyeater	New Holland Honeyeater	White-plumed Honeyeater	
Little Wattlebird	Red Wattlebird	Yellow-faced Honeyeater	

Raptors			
Australian Hobby	Brown Goshawk	Nankeen Kestrel	White-bellied Sea-Eagle
Black-shouldered Kite	Collared Sparrowhawk	Peregrine Falcon	

Finches			
Double-barred Finch	Zebra Finch	Red-browed Finch	

Parrots			
Australian King-Parrot	Crimson Rosella	Eastern Rosella	Red-rumped Parrot

Cuckoos			
Channel-billed Cuckoo	Fan-tailed Cuckoo	Horsfield's Bronze-Cuckoo	Pacific Koel

Introduced species			
Common Myna	European Goldfinch	Mallard	Red-whiskered Bulbul
Common Starling	House Sparrow	Nutmeg Mannikin	Rock Dove
Spotted Turtle-dove			