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**Supplementary material**

**Supplementary Material**  
**DYNAMIC SPECIES CO-OCCURRENCE NETWORKS REQUIRE DYNAMIC**  
**BIODIVERSITY SURROGATES**

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## **Appendix 1. Species co-occurrence matrices and derived networks**

### **1.1 Additional survey method details**

We investigated species co-occurrence in two ecosystems in south-eastern Australia with different histories of land management and different bird species assemblages. Both case studies are expected to undergo change in community composition and potentially species co-occurrence after disturbances of fire (Booderee National Park) or revegetation (Southwest Slopes). We monitor birds using repeated 5-minute point count surveys. In both case studies, all point counts are completed within four hours of dawn and we do not undertake surveys on windy or rainy days. Surveys are completed in early November, which is the peak breeding season in both study areas, by experienced ornithologists from the Australian National University and the Canberra Ornithologists Group.

In the Southwest Slopes, a permanent 200-m transect (i.e. a 'site') with three survey points (0m, 100m, and 200m) running through a woodland patch is surveyed. The choice of transect length was influenced by The first 3 out of 6 point counts are conducted by one observer on the same day, and the last 3 point counts are conducted by a different observer on a second day (within 4 days of the initial count). Surveying over two separate days results in six repeated point counts per season, which are pooled to provide a single season estimate of each bird species' occurrence in each site.

In the heathland of Booderee National Park, a permanent 100-m long transect (a 'site') includes two survey points (at 20m and 80m). Surveys conducted by different observers over two separate days results in four repeated point counts per season, which are pooled to again provide a single season estimate of each bird species' occurrence in each site. The choice of transect length was influenced by the substantial heterogeneity of vegetation cover in the Park, with major changes often occurring over a short distance. Transect lengths in excess of 100 m would result in many transects spanning two vegetation types.

Our protocol of repeat surveys by multiple observers on different days follows standards that are widely reported in the ecology literature (de Lima et al. 2013, Driscoll and Lindenmayer 2010). Pooling all species observed during repeated counts by multiple observers has been shown to reliably detect species within our study communities (Lindenmayer et al. 2009b) due to: (a) high levels of replication of field sites; (b) pre-survey screening to ensure that only experienced ornithologists participate; (c) repeat sampling of field sites by a different observer on a different day to reduce impacts of observer heterogeneity and 'day' effects; (d) precluding surveys during poor weather or long after dawn, also to limit 'day' effects (Lindenmayer et al. 2009b).

The lists of species detected throughout all years in each case study are provided in Tables S1 and S2.

**Table S1.** List of all bird species detected in the Southwest Slopes plantings case study.

| Key to Fig S2 | Common name               | Species names                      | Number of times detected | Detection rate (% of all surveys) | NSW threat status | Commonwealth threat status |
|---------------|---------------------------|------------------------------------|--------------------------|-----------------------------------|-------------------|----------------------------|
|               | Apostlebird               | <i>Struthidea cinerea</i>          | 3                        | 0.42                              |                   |                            |
|               | Australasian Grebe        | <i>Tachybaptus novaehollandiae</i> | 16                       | 2.26                              |                   |                            |
| AP            | Australasian Pipit        | <i>Anthus novaeseelandiae</i>      | 74                       | 10.45                             |                   |                            |
|               | Australasian Shoveler     | <i>Anas rhynchos</i>               | 1                        | 0.14                              |                   |                            |
|               | Australian Hobby          | <i>Falco longipennis</i>           | 1                        | 0.14                              |                   |                            |
|               | Australian King-Parrot    | <i>Alisterus scapularis</i>        | 2                        | 0.28                              |                   |                            |
| AM            | Australian Magpie         | <i>Cracticus tibicen</i>           | 502                      | 70.90                             |                   |                            |
|               | Australian Pelican        | <i>Pelecanus conspicillatus</i>    | 1                        | 0.14                              |                   |                            |
| AR            | Australian Raven          | <i>Corvus coronoides</i>           | 86                       | 12.15                             |                   |                            |
|               | Australian Reed-Warbler   | <i>Acrocephalus stentoreus</i>     | 14                       | 1.98                              |                   |                            |
|               | Australian Shelduck       | <i>Tadorna tadornoides</i>         | 1                        | 0.14                              |                   |                            |
|               | Australian White Ibis     | <i>Threskiornis molucca</i>        | 1                        | 0.14                              |                   |                            |
| AWD           | Australian Wood Duck      | <i>Chenonetta jubata</i>           | 28                       | 3.95                              |                   |                            |
|               | Banded Lapwing            | <i>Vanellus tricolor</i>           | 1                        | 0.14                              |                   |                            |
|               | Black-chinned Honeyeater  | <i>Melithreptus gularis</i>        | 9                        | 1.27                              | Vulnerable        | Declining                  |
| BFCS          | Black-faced Cuckoo-shrike | <i>Coracina novaehollandiae</i>    | 116                      | 16.38                             |                   | Declining                  |
|               | Black-faced Woodswallow   | <i>Artamus cinereus</i>            | 2                        | 0.28                              |                   |                            |
|               | Black-fronted Dotterel    | <i>Elsemyornis melanops</i>        | 2                        | 0.28                              |                   |                            |
|               | Black-shouldered Kite     | <i>Elanus axillaris</i>            | 6                        | 0.85                              |                   |                            |
|               | Black-tailed Native-hen   | <i>Tribonyx ventralis</i>          | 1                        | 0.14                              |                   |                            |
|               | Black-winged Stilt        | <i>Himantopus himantopus</i>       | 1                        | 0.14                              |                   |                            |
|               | Blue Bonnet               | <i>Northiella haematogaster</i>    | 1                        | 0.14                              |                   |                            |
| BFH           | Blue-faced Honeyeater     | <i>Entomyzon cyanotis</i>          | 30                       | 4.24                              |                   | Declining                  |
|               | Brown Falcon              | <i>Falco berigora</i>              | 17                       | 2.40                              |                   |                            |
|               | Brown Goshawk             | <i>Accipiter fasciatus</i>         | 9                        | 1.27                              |                   | Declining                  |
|               | Brown Quail               | <i>Coturnix ypsilophora</i>        | 3                        | 0.42                              |                   |                            |
| BS            | Brown Songlark            | <i>Cincloramphus cruralis</i>      | 77                       | 10.88                             |                   |                            |
|               | Brown Thornbill           | <i>Acanthiza pusilla</i>           | 13                       | 1.84                              |                   |                            |
|               | Brown Treecreeper         | <i>Climacteris picumnus</i>        | 16                       | 2.26                              | Vulnerable (ACT)  | Declining                  |
| BHH           | Brown-headed Honeyeater   | <i>Melithreptus brevirostris</i>   | 31                       | 4.38                              |                   |                            |
| BRT           | Buff-rumped Thornbill     | <i>Acanthiza reguloides</i>        | 44                       | 6.21                              |                   | Declining                  |

|     |                           |                                     |     |       |            |                      |
|-----|---------------------------|-------------------------------------|-----|-------|------------|----------------------|
|     | Chestnut-rumped Thornbill | <i>Acanthiza uropygialis</i>        | 2   | 0.28  |            | Declining            |
|     | Cockatiel                 | <i>Nymphicus hollandicus</i>        | 15  | 2.12  |            |                      |
|     | Collared Sparrowhawk      | <i>Accipiter cirrocephalus</i>      | 3   | 0.42  |            |                      |
| CBI | Common Blackbird          | <i>Turdus merula</i>                | 50  | 7.06  |            | Invasive             |
| CBr | Common Bronzewing         | <i>Phaps chalcoptera</i>            | 71  | 10.03 |            |                      |
| CS  | Common Starling           | <i>Sturnus vulgaris</i>             | 191 | 26.98 |            | Invasive             |
|     | Crescent Honeyeater       | <i>Phylidonyris pyrrhopterus</i>    | 1   | 0.14  |            |                      |
| CP  | Crested Pigeon            | <i>Ocyphaps lophotes</i>            | 288 | 40.68 |            |                      |
| CST | Crested Shrike-tit        | <i>Falcunculus frontatus</i>        | 70  | 9.89  |            |                      |
|     | Crimson Chat              | <i>Epthianura tricolor</i>          | 5   | 0.71  |            |                      |
| CR  | Crimson Rosella           | <i>Platycercus elegans</i>          | 73  | 10.31 |            |                      |
|     | Diamond Dove              | <i>Geopelia cuneata</i>             | 1   | 0.14  |            |                      |
| DF  | Diamond Firetail          | <i>Stagonopleura guttata</i>        | 44  | 6.21  | Vulnerable | Declining            |
|     | Dollarbird                | <i>Eurystomus orientalis</i>        | 4   | 0.56  |            | Declining            |
|     | Double-barred Finch       | <i>Taeniopygia bichenovii</i>       | 5   | 0.71  |            |                      |
|     | Dusky Woodswallow         | <i>Artamus cyanopterus</i>          | 16  | 2.26  |            | Migratory, declining |
|     | Eastern Great Egret       | <i>Ardea alba</i>                   | 1   | 0.14  |            |                      |
| ER  | Eastern Rosella           | <i>Platycercus eximius</i>          | 389 | 54.94 |            |                      |
|     | Eastern Spinebill         | <i>Acanthorhynchus tenuirostris</i> | 1   | 0.14  |            |                      |
|     | Eastern Yellow Robin      | <i>Eopsaltria australis</i>         | 11  | 1.55  |            |                      |
| EGf | European Goldfinch        | <i>Carduelis carduelis</i>          | 14  | 1.98  |            | Invasive             |
|     | Fairy Martin              | <i>Petrochelidon ariel</i>          | 8   | 1.13  |            | Migratory, declining |
|     | Fan-tailed Cuckoo         | <i>Cacomantis flabelliformis</i>    | 1   | 0.14  |            |                      |
| FR  | Flame Robin               | <i>Petroica phoenicea</i>           | 98  | 13.84 | Vulnerable | Declining            |
|     | Fuscous Honeyeater        | <i>Lichenostomus fuscus</i>         | 14  | 1.98  |            |                      |
| Ga  | Galah                     | <i>Eolophus roseicapillus</i>       | 166 | 23.45 |            |                      |
|     | Gang-gang Cockatoo        | <i>Callocephalon fimbriatum</i>     | 2   | 0.28  | Vulnerable | Declining            |
| GW  | Golden Whistler           | <i>Pachycephala pectoralis</i>      | 31  | 4.38  |            |                      |
|     | Golden-headed Cisticola   | <i>Cisticola exilis</i>             | 2   | 0.28  |            |                      |
|     | Grey Butcherbird          | <i>Cracticus torquatus</i>          | 22  | 3.11  |            |                      |
|     | Grey Currawong            | <i>Strepera versicolor</i>          | 2   | 0.28  |            |                      |
| GF  | Grey Fantail              | <i>Rhipidura albiscapa</i>          | 137 | 19.35 |            |                      |
| GST | Grey Shrike-thrush        | <i>Colluricincla harmonica</i>      | 308 | 43.50 |            |                      |
|     | Grey Teal                 | <i>Anas gracilis</i>                | 6   | 0.85  |            |                      |

|     |                           |                                |     |       |            |                      |
|-----|---------------------------|--------------------------------|-----|-------|------------|----------------------|
|     | Grey-crowned Babbler      | <i>Pomatostomus temporalis</i> | 11  | 1.55  | Vulnerable | Declining            |
|     | Hardhead                  | <i>Aythya australis</i>        | 4   | 0.56  |            |                      |
|     | Hooded Robin              | <i>Melanodryas cucullata</i>   | 4   | 0.56  | Vulnerable | Declining            |
| HBC | Horsfield's Bronze-Cuckoo | <i>Chalcites basalis</i>       | 21  | 2.97  |            |                      |
|     | Horsfield's Bushlark      | <i>Mirafra javanica</i>        | 7   | 0.99  |            |                      |
| HS  | House Sparrow             | <i>Passer domesticus</i>       | 41  | 5.79  |            | Invasive             |
|     | Jacky Winter              | <i>Microeca fascinans</i>      | 18  | 2.54  |            | Declining            |
| LK  | Laughing Kookaburra       | <i>Dacelo novaeguineae</i>     | 42  | 5.93  |            |                      |
|     | Leaden Flycatcher         | <i>Myiagra rubecula</i>        | 4   | 0.56  |            | Migratory, declining |
|     | Little Corella            | <i>Cacatua sanguinea</i>       | 15  | 2.12  |            |                      |
|     | Little Eagle              | <i>Hieraetus morphnoides</i>   | 2   | 0.28  | Vulnerable | Declining            |
| LF  | Little Friarbird          | <i>Philemon citreogularis</i>  | 36  | 5.08  |            |                      |
|     | Little Lorikeet           | <i>Glossopsitta pusilla</i>    | 4   | 0.56  | Vulnerable | Declining            |
|     | Little Pied Cormorant     | <i>Microcarbo melanoleucos</i> | 1   | 0.14  |            |                      |
| LR  | Little Raven              | <i>Corvus mellori</i>          | 30  | 4.24  |            |                      |
| ML  | Magpie-lark               | <i>Grallina cyanoleuca</i>     | 198 | 27.97 |            |                      |
|     | Masked Lapwing            | <i>Vanellus miles</i>          | 7   | 0.99  |            |                      |
| MWs | Masked Woodswallow        | <i>Artamus personatus</i>      | 18  | 2.54  |            |                      |
|     | Mistletoebird             | <i>Dicaeum hirundinaceum</i>   | 15  | 2.12  |            | Declining            |
|     | Nankeen Kestrel           | <i>Falco cenchroides</i>       | 11  | 1.55  |            |                      |
| NF  | Noisy Friarbird           | <i>Philemon corniculatus</i>   | 41  | 5.79  |            |                      |
| NM  | Noisy Miner               | <i>Manorina melanocephala</i>  | 181 | 25.56 |            |                      |
|     | Olive-backed Oriole       | <i>Oriolus sagittatus</i>      | 6   | 0.85  |            |                      |
|     | Pacific Black Duck        | <i>Anas superciliosa</i>       | 11  | 1.55  |            |                      |
|     | Painted Button-quail      | <i>Turnix varius</i>           | 5   | 0.71  |            | Declining            |
| PD  | Peaceful Dove             | <i>Geopelia striata</i>        | 44  | 6.21  |            |                      |
|     | Peregrine Falcon          | <i>Falco peregrinus</i>        | 1   | 0.14  |            |                      |
|     | Pied Butcherbird          | <i>Cracticus nigrogularis</i>  | 19  | 2.68  |            |                      |
|     | Pied Cormorant            | <i>Phalacrocorax varius</i>    | 2   | 0.28  |            |                      |
| PC  | Pied Currawong            | <i>Strepera graculina</i>      | 24  | 3.39  |            |                      |
|     | Rainbow Bee-eater         | <i>Merops ornatus</i>          | 16  | 2.26  |            |                      |
| RWa | Red Wattlebird            | <i>Anthochaera carunculata</i> | 297 | 41.95 |            |                      |
|     | Red-browed Finch          | <i>Neochmia temporalis</i>     | 23  | 3.25  |            |                      |
| RCR | Red-capped Robin          | <i>Petroica goodenovii</i>     | 74  | 10.45 |            | Declining            |
|     | Red-kneed Dotterel        | <i>Erythronyctes cinctus</i>   | 1   | 0.14  |            |                      |

|     |                             |                                   |     |       |            |                      |
|-----|-----------------------------|-----------------------------------|-----|-------|------------|----------------------|
| RRP | Red-rumped Parrot           | <i>Psephotus haematonotus</i>     | 330 | 46.61 |            |                      |
| RF  | Restless Flycatcher         | <i>Myiagra inquieta</i>           | 32  | 4.52  |            | Migratory, declining |
| RS  | Rufous Songlark             | <i>Cincloramphus mathewsi</i>     | 202 | 28.53 |            |                      |
| RWh | Rufous Whistler             | <i>Pachycephala rufiventris</i>   | 168 | 23.73 |            | Declining            |
|     | Sacred Kingfisher           | <i>Todiramphus sanctus</i>        | 11  | 1.55  |            |                      |
|     | Satin Flycatcher            | <i>Myiagra cyanoleuca</i>         | 1   | 0.14  |            | Migratory, declining |
| SR  | Scarlet Robin               | <i>Petroica boodang</i>           | 25  | 3.53  | Vulnerable | Declining            |
|     | Shining Bronze-Cuckoo       | <i>Chalcites lucidus</i>          | 4   | 0.56  |            |                      |
| Si  | Silvereye                   | <i>Zosterops lateralis</i>        | 34  | 4.80  |            |                      |
|     | Southern Boobook            | <i>Ninox novaeseelandiae</i>      | 11  | 1.55  |            |                      |
|     | Southern Whiteface          | <i>Aphelocephala leucopsis</i>    | 25  | 3.53  |            | Declining            |
| SW  | Speckled Warbler            | <i>Chthonicola sagittata</i>      | 32  | 4.52  | Vulnerable | Declining            |
|     | Spotted Harrier             | <i>Circus assimilis</i>           | 2   | 0.28  | Vulnerable | Declining            |
|     | Spotted Pardalote           | <i>Pardalotus punctatus</i>       | 16  | 2.26  |            | Declining            |
|     | Straw-necked Ibis           | <i>Threskiornis spinicollis</i>   | 8   | 1.13  |            |                      |
| StP | Striated Pardalote          | <i>Pardalotus striatus</i>        | 282 | 39.83 |            | Declining            |
|     | Striated Thornbill          | <i>Acanthiza lineata</i>          | 27  | 3.81  |            |                      |
| SQ  | Stubble Quail               | <i>Coturnix pectoralis</i>        | 31  | 4.38  |            |                      |
| SCC | Sulphur-crested Cockatoo    | <i>Cacatua galerita</i>           | 31  | 4.38  |            |                      |
| SFW | Superb Fairy-wren           | <i>Malurus cyaneus</i>            | 444 | 62.71 |            |                      |
| SuP | Superb Parrot               | <i>Polytelis swainsonii</i>       | 30  | 4.24  | Vulnerable | Vulnerable           |
|     | Swamp Harrier               | <i>Circus approximans</i>         | 1   | 0.14  |            |                      |
|     | Swift Parrot                | <i>Lathamus discolor</i>          | 1   | 0.14  | Endangered | Endangered           |
|     | Tree Martin                 | <i>Petrochelidon nigricans</i>    | 17  | 2.40  |            | Declining            |
|     | Varied Sittella             | <i>Daphoenositta chrysoptera</i>  | 3   | 0.42  | Vulnerable | Declining            |
|     | Wedge-tailed Eagle          | <i>Aquila audax</i>               | 1   | 0.14  |            |                      |
| We  | Weebill                     | <i>Smicronis brevirostris</i>     | 135 | 19.07 |            | Declining            |
| WS  | Welcome Swallow             | <i>Hirundo neoxena</i>            | 91  | 12.85 |            |                      |
| WG  | Western Gerygone            | <i>Gerygone fusca</i>             | 39  | 5.51  |            |                      |
|     | White-bellied Cuckoo-shrike | <i>Coracina papuensis</i>         | 3   | 0.42  |            |                      |
|     | White-browed Babbler        | <i>Pomatostomus superciliosus</i> | 25  | 3.53  |            | Declining            |
|     | White-browed Scrubwren      | <i>Sericornis frontalis</i>       | 18  | 2.54  |            |                      |
| WBW | White-browed Woodswallow    | <i>Artamus superciliosus</i>      | 75  | 10.59 |            | Declining            |

|     |                              |                                  |     |       |            |           |
|-----|------------------------------|----------------------------------|-----|-------|------------|-----------|
|     | White-faced Heron            | <i>Egretta novaehollandiae</i>   | 9   | 1.27  |            |           |
|     | White-fronted Chat           | <i>Epthianura albifrons</i>      | 13  | 1.84  | Vulnerable | Declining |
|     | White-naped Honeyeater       | <i>Melithreptus lunatus</i>      | 7   | 0.99  |            |           |
|     | White-necked Heron           | <i>Ardea pacifica</i>            | 5   | 0.71  |            |           |
| WPH | White-plumed Honeyeater      | <i>Lichenostomus pencillatus</i> | 545 | 76.98 |            |           |
|     | White-throated Gerygone      | <i>Gerygone albogularis</i>      | 11  | 1.55  |            | Declining |
|     | White-throated Treecreeper   | <i>Cormobates leucophaea</i>     | 7   | 0.99  |            |           |
| WWC | White-winged Chough          | <i>Corcorax melanorhamphos</i>   | 130 | 18.36 |            |           |
| WWT | White-winged Triller         | <i>Lalage sueurii</i>            | 56  | 7.91  |            |           |
| WW  | Willie Wagtail               | <i>Rhipidura leucophrys</i>      | 533 | 75.28 |            |           |
| YT  | Yellow Thornbill             | <i>Acanthiza nana</i>            | 147 | 20.76 |            | Declining |
|     | Yellow-billed Spoonbill      | <i>Platalea flavipes</i>         | 1   | 0.14  |            |           |
| YFH | Yellow-faced Honeyeater      | <i>Lichenostomus chrysops</i>    | 24  | 3.39  |            | Declining |
| YRT | Yellow-rumped Thornbill      | <i>Acanthiza chrysorrhoa</i>     | 269 | 37.99 |            | Declining |
|     | Yellow-tailed Black-Cockatoo | <i>Calyptorhynchus funereus</i>  | 2   | 0.28  |            |           |
|     | Yellow-tufted Honeyeater     | <i>Lichenostomus melanops</i>    | 9   | 1.27  |            |           |
|     | Zebra Finch                  | <i>Taeniopygia guttata</i>       | 4   | 0.56  |            |           |



**Table S2.** List of all bird species detected in the Booderee National Park heathland case study.

| Key to Fig S4 | Species                   | Species names                       | Number of detections | Detection rate (% of all surveys) | NSW threat status | Commonwealth threat status |
|---------------|---------------------------|-------------------------------------|----------------------|-----------------------------------|-------------------|----------------------------|
|               | Australasian Pipit        | <i>Anthus novaeseelandiae</i>       | 4                    | 1.54                              |                   |                            |
|               | Australian King-Parrot    | <i>Alisterus scapularis</i>         | 7                    | 2.69                              |                   |                            |
|               | Australian Magpie         | <i>Cracticus tibicen</i>            | 10                   | 3.85                              |                   |                            |
| AR            | Australian Raven          | <i>Corvus coronoides</i>            | 62                   | 23.85                             |                   |                            |
|               | Bar-shouldered Dove       | <i>Geopelia humeralis</i>           | 2                    | 0.77                              |                   |                            |
|               | Bassian Thrush            | <i>Zoothera lunulata</i>            | 2                    | 0.77                              |                   |                            |
|               | Beautiful Firetail        | <i>Stagonopleura bella</i>          | 5                    | 1.92                              |                   |                            |
|               | Black-faced Cuckoo-shrike | <i>Coracina novaehollandiae</i>     | 17                   | 6.54                              |                   |                            |
|               | Black-faced Monarch       | <i>Monarcha melanopsis</i>          | 1                    | 0.38                              |                   |                            |
|               | Black-shouldered Kite     | <i>Elanus axillaris</i>             | 1                    | 0.38                              |                   |                            |
|               | Blue-faced Honeyeater     | <i>Entomyzon cyanotis</i>           | 1                    | 0.38                              |                   |                            |
|               | Brown Cuckoo-dove         | <i>Macropygia amboinensis</i>       | 1                    | 0.38                              |                   |                            |
|               | Brown Gerygone            | <i>Gerygone mouki</i>               | 3                    | 1.15                              |                   |                            |
|               | Brown Goshawk             | <i>Accipiter fasciatus</i>          | 2                    | 0.77                              |                   | Declining                  |
|               | Brown Quail               | <i>Coturnix ypsilophora</i>         | 3                    | 1.15                              |                   |                            |
| BT            | Brown Thornbill           | <i>Acanthiza pusilla</i>            | 108                  | 41.54                             |                   |                            |
|               | Brown-headed Honeyeater   | <i>Melithreptus brevirostris</i>    | 12                   | 4.62                              |                   |                            |
|               | Brush Bronzewing          | <i>Phaps elegans</i>                | 16                   | 6.15                              |                   |                            |
|               | Brush Cuckoo              | <i>Cacomantis variolosus</i>        | 1                    | 0.38                              |                   |                            |
|               | Chestnut-rumped Heathwren | <i>Calamanthus pyrrhopygia</i>      | 5                    | 1.92                              |                   | Declining                  |
|               | Common Blackbird          | <i>Turdus merula</i>                | 1                    | 0.38                              |                   | Invasive                   |
|               | Common Bronzewing         | <i>Phaps chalcoptera</i>            | 8                    | 3.08                              |                   |                            |
|               | Crescent Honeyeater       | <i>Phylidonyris pyrrhopterus</i>    | 3                    | 1.15                              |                   |                            |
|               | Crested Pigeon            | <i>Ocyphaps lophotes</i>            | 2                    | 0.77                              |                   |                            |
| CR            | Crimson Rosella           | <i>Platycercus elegans</i>          | 103                  | 39.62                             |                   |                            |
| EB            | Eastern Bristlebird       | <i>Dasyornis brachypterus</i>       | 228                  | 87.69                             | Endangered        | Endangered                 |
| ES            | Eastern Spinebill         | <i>Acanthorhynchus tenuirostris</i> | 162                  | 62.31                             |                   |                            |
|               | Eastern Whipbird          | <i>Psophodes olivaceus</i>          | 187                  | 71.92                             |                   |                            |
| EYR           | Eastern Yellow Robin      | <i>Eopsaltria australis</i>         | 70                   | 26.92                             |                   |                            |
| FTC           | Fan-tailed Cuckoo         | <i>Cacomantis flabelliformis</i>    | 131                  | 50.38                             |                   |                            |
|               | Gang-gang Cockatoo        | <i>Callocephalon</i>                | 18                   | 6.92                              | Vulnerable        | Declining                  |

|     |                           |                                     |     |       |            |                      |
|-----|---------------------------|-------------------------------------|-----|-------|------------|----------------------|
|     |                           | <i>fimbriatum</i>                   |     |       |            |                      |
|     | Glossy Black-Cockatoo     | <i>Calyptorhynchus lathamii</i>     | 1   | 0.38  | Vulnerable | Declining            |
| GW  | Golden Whistler           | <i>Pachycephala pectoralis</i>      | 55  | 21.15 |            |                      |
|     | Golden-headed Cisticola   | <i>Cisticola exilis</i>             | 1   | 0.38  |            |                      |
|     | Grey Butcherbird          | <i>Cracticus torquatus</i>          | 15  | 5.77  |            |                      |
| GF  | Grey Fantail              | <i>Rhipidura albiscapa</i>          | 158 | 60.77 |            |                      |
|     | Grey Goshawk              | <i>Accipiter novaehollandiae</i>    | 1   | 0.38  |            |                      |
| GST | Grey Shrike-thrush        | <i>Colluricincla harmonica</i>      | 101 | 38.85 |            |                      |
|     | Ground Parrot             | <i>Pezoporus wallicus</i>           | 9   | 3.46  | Vulnerable | Declining            |
| HBC | Horsfield's Bronze-Cuckoo | <i>Chalcites basalis</i>            | 52  | 20.00 |            |                      |
| LK  | Laughing Kookaburra       | <i>Dacelo novaeguineae</i>          | 42  | 16.15 |            |                      |
|     | Leaden Flycatcher         | <i>Myiagra rubecula</i>             | 1   | 0.38  |            | Migratory, declining |
|     | Lewin's Honeyeater        | <i>Meliphaga lewinii</i>            | 26  | 10.00 |            |                      |
|     | Little Lorikeet           | <i>Glossopsitta pusilla</i>         | 1   | 0.38  | Vulnerable | Declining            |
| LW  | Little Wattlebird         | <i>Anthochaera chrysoptera</i>      | 152 | 58.46 |            |                      |
|     | Magpie-lark               | <i>Grallina cyanoleuca</i>          | 3   | 1.15  |            |                      |
|     | Masked Lapwing            | <i>Vanellus miles</i>               | 2   | 0.77  |            |                      |
|     | Musk Lorikeet             | <i>Glossopsitta concinna</i>        | 2   | 0.77  |            |                      |
| NHH | New Holland Honeyeater    | <i>Phylidonyris novaehollandiae</i> | 215 | 82.69 |            |                      |
| NF  | Noisy Friarbird           | <i>Philemon corniculatus</i>        | 58  | 22.31 |            |                      |
| OBO | Olive-backed Oriole       | <i>Oriolus sagittatus</i>           | 40  | 15.38 |            |                      |
|     | Pheasant Coucal           | <i>Centropus phasianinus</i>        | 4   | 1.54  |            |                      |
| PC  | Pied Currawong            | <i>Strepera graculina</i>           | 42  | 16.15 |            |                      |
| RL  | Rainbow Lorikeet          | <i>Trichoglossus haematodus</i>     | 41  | 15.77 |            |                      |
| RWa | Red Wattlebird            | <i>Anthochaera carunculata</i>      | 74  | 28.46 |            |                      |
|     | Red-browed Finch          | <i>Neochmia temporalis</i>          | 11  | 4.23  |            |                      |
|     | Rose Robin                | <i>Petroica rosea</i>               | 1   | 0.38  |            | Declining            |
| RWh | Rufous Whistler           | <i>Pachycephala rufiventris</i>     | 103 | 39.62 |            | Declining            |
|     | Sacred Kingfisher         | <i>Todiramphus sanctus</i>          | 2   | 0.77  |            |                      |
|     | Satin Bowerbird           | <i>Ptilonorhynchus violaceus</i>    | 13  | 5.00  |            |                      |
|     | Scarlet Honeyeater        | <i>Myzomela sanguinolenta</i>       | 4   | 1.54  |            |                      |

|     |                              |                                  |     |       |                      |
|-----|------------------------------|----------------------------------|-----|-------|----------------------|
| SBC | Shining Bronze-Cuckoo        | <i>Chalcites lucidus</i>         | 96  | 36.92 |                      |
| Si  | Silvereye                    | <i>Zosterops lateralis</i>       | 98  | 37.69 |                      |
|     | Southern Boobook             | <i>Ninox novaeseelandiae</i>     | 1   | 0.38  |                      |
| SEW | Southern Emu-wren            | <i>Stipiturus malachurus</i>     | 76  | 29.23 |                      |
|     | Spectacled Monarch           | <i>Symposiarchus trivirgatus</i> | 1   | 0.38  |                      |
|     | Spotted Dove                 | <i>Streptopelia chinensis</i>    | 1   | 0.38  | Invasive             |
| SpP | Spotted Pardalote            | <i>Pardalotus punctatus</i>      | 56  | 21.54 | Declining            |
|     | Striated Thornbill           | <i>Acanthiza lineata</i>         | 9   | 3.46  |                      |
|     | Stubble Quail                | <i>Coturnix pectoralis</i>       | 2   | 0.77  |                      |
|     | Sulphur-crested Cockatoo     | <i>Cacatua galerita</i>          | 2   | 0.77  |                      |
| SFW | Superb Fairy-wren            | <i>Malurus cyaneus</i>           | 46  | 17.69 |                      |
|     | Swamp Harrier                | <i>Circus approximans</i>        | 9   | 3.46  |                      |
|     | Tawny-crowned Honeyeater     | <i>Glyciphila melanops</i>       | 28  | 10.77 | Declining            |
|     | Tree Martin                  | <i>Petrochelidon nigricans</i>   | 2   | 0.77  | Migratory, declining |
| VFW | Variiegated Fairy-wren       | <i>Malurus lamberti</i>          | 128 | 49.23 |                      |
|     | Weebill                      | <i>Smicronis brevirostris</i>    | 1   | 0.38  | Declining            |
|     | Welcome Swallow              | <i>Hirundo neoxena</i>           | 28  | 10.77 |                      |
|     | Whistling Kite               | <i>Haliastur sphenurus</i>       | 3   | 1.15  |                      |
|     | White-bellied Sea-Eagle      | <i>Haliaeetus leucogaster</i>    | 4   | 1.54  | Declining            |
|     | White-browed Scrubwren       | <i>Sericornis frontalis</i>      | 124 | 47.69 |                      |
|     | White-cheeked Honeyeater     | <i>Phylidonyris niger</i>        | 30  | 11.54 |                      |
|     | White-eared Honeyeater       | <i>Lichenostomus leucotis</i>    | 1   | 0.38  |                      |
|     | White-naped Honeyeater       | <i>Melithreptus lunatus</i>      | 7   | 2.69  |                      |
|     | White-throated Gerygone      | <i>Gerygone albogularis</i>      | 1   | 0.38  | Declining            |
|     | White-throated Nightjar      | <i>Eurostopodus mystacalis</i>   | 1   | 0.38  | Declining            |
| WTT | White-throated Treecreeper   | <i>Cormobates leucophaea</i>     | 58  | 22.31 |                      |
|     | Wonga Pigeon                 | <i>Leucosarcia picata</i>        | 4   | 1.54  | Declining            |
| YFH | Yellow-faced Honeyeater      | <i>Lichenostomus chrysops</i>    | 103 | 39.62 |                      |
|     | Yellow-tailed Black-Cockatoo | <i>Calyptorhynchus funereus</i>  | 16  | 6.15  |                      |

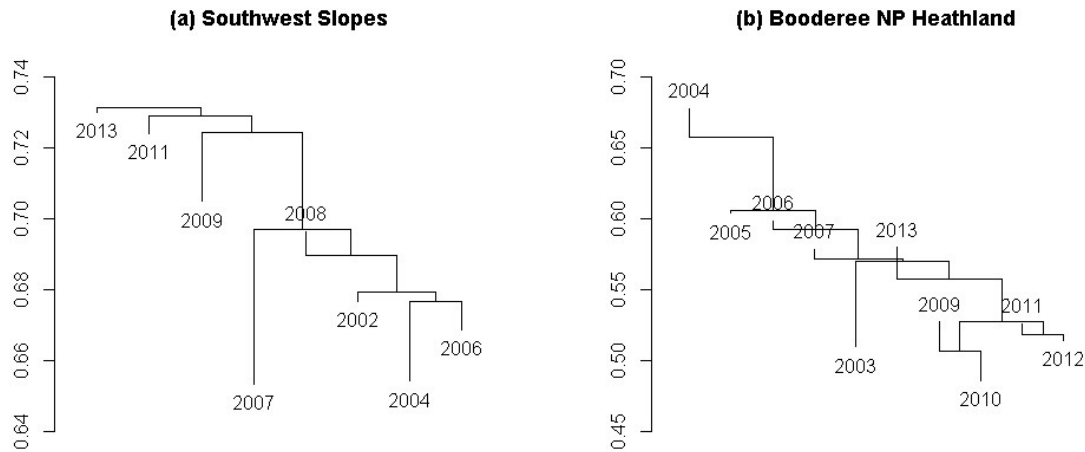
## 1.2 Community composition

In the Southwest Slopes, there are 38 bird species classified as threatened at the State or Commonwealth level or known to be declining (Table S1). The most commonly detected species here are the White-plumed Honeyeater (a nectarivore), the Willie Wagtail (an insectivore) and the Australian Magpie (an omnivore), all detected in more than 70% of all surveys. Six species have been detected only once in the Southwest Slopes. In the heathland of Booderee National Park (NP) there are 18 bird species classified as threatened or known to be declining (Table S2), including the nationally Endangered Eastern Bristlebird *Dasyornis brachypterus* (Lindenmayer et al. 2009a). This species is also the most commonly detected (>80% out of 260 surveys), followed by the New Holland Honeyeater and Eastern Whipbird (both detected in >70% of surveys). In this case study 19 species have been detected only once.

We carried out multivariate analyses evaluating whether community 'subsets' from each case study representing different time periods post-disturbance differed in composition. We asked:

- (a) Are there significant differences in the composition of communities between the two most extreme successional scenarios - the "first half" subset (1-5 years post-disturbance, scenario 2b) and the "last half" subset (6-11 years post-disturbance, scenario 3)?
- (b) Are there significant differences in the composition of communities between years?
- (c) Are there significant differences in the composition of the Southwest Slopes bird communities in winter and spring?

We used Multi-Response Permutation Procedures (MRPP) in R (using the vegan package) to test whether the composition of communities subsetted under these three analyses were significantly different. We found significant differences ( $P < 0.05$ ) in the composition of the communities between the first half and second half of the monitoring record, and between all years, in both case studies (Figure S1). We also found a significant difference in the composition of spring and winter bird communities in the Southwest Slopes.



**Figure S1.** Dendrograms of the result matrix of MRPP for (a) Southwest Slopes and (b) Booderee NP heathland case studies, based on the within-group and between group dissimilarities.

### 1.3 Network metrics

The species with the highest odds ratio over all time with any other species (i.e. strongest co-occurrence) are the Black-fronted Dotterel ( $s_{ij}=0.98$ , with the Black-tailed Native-hen, Black-winged Stilt and Red-kneed Dotterel) and the Golden-headed Cisticola (with the Australian Shoveler, Australian Shelduck and Banded Lapwing,  $s_{ij}=0.99$ ). The species with the highest network strength are the Australian King-Parrot (average  $s_{ij} = 0.88$ ), Crimson Chat (average  $s_{ij} = 0.88$ ), and Little Lorikeet (average  $s_{ij} = 0.87$ ). The species with the highest degree (i.e. most positive co-occurrences) is the White-plumed Honeyeater (104 links), followed by the Red-rumped Parrot (100 links; Figure S2).

In the heathland of Booderee National Park the species with the highest odds ratio over all time with any other species (i.e. strongest single co-occurrence link) are the Scarlet Honeyeater ( $s_{ij}=0.99$ , with the Leaden Flycatcher) and Australian King-Parrot ( $s_{ij}=0.99$ , with the Leaden Flycatcher). The species with the highest network strength are the Bassian Thrush (average  $s_{ij} = 0.88$ ) and the Spotted Dove (average  $s_{ij} = 0.88$ ). The species with the highest degree (i.e. most positive co-occurrences) is the Grey Fantail (67 links), followed by the Little Wattlebird (63 links; Figure S4).

Reducing the temporal spread of data in the Southwest Slopes changes representations of species associations and associated network structure. Visualisation of these relationships through network analyses shows differences between seasons (Figure S3a and b, Table S3) and depending on how many years of data have been collected. The winter species associations are much less correlated with the associations derived from all data than the spring, and spring and winter species associations are even less correlated (Table 1 in main text). Bray-Curtis dissimilarity indices show that many of the optimal solutions (achieving 70% surrogacy power under each scenario) have very little overlap (average

dissimilarity 87%; Table S3). The spring dataset solution has the most overlap with the all-data (i.e. 11-year) solution (Bray-Curtis index = 0.43). All scenarios appear to have been adequately sampled to detect at least 80% of the species present (Figure S6, Table S3). The species with the highest gain in degree between the 1-5yr and 6-11yr monitoring scenarios is the Pacific Black Duck, and the species with the highest loss of degree is the Black-chinned Honeyeater (Table S5).

In the Booderee NP heathland, visualisation of co-occurrence relationships through network analyses shows differences depending on how many years of data have been collected (Figure S5). Bray-Curtis dissimilarity indices again reveal very little overlap in the species selected in the optimal surrogate set for achieving 70% of the surrogacy power of the whole network under each data reduction scenario (average dissimilarity 80%; Table S4). The two solutions with the highest overlap (and lowest dissimilarity) in the Booderee NP heathland are the 7-year (2003-2009) and 9-year (2003-2011) monitoring datasets (Bray-Curtis index = 0.43). As in the Southwest Slopes, several solutions have no overlap between optimal surrogate sets (no common species selected), including the 1-5yr and 6-11yr scenarios. All scenarios were adequately sampled to detect at least 90% of all species likely to be present in the Booderee NP heathland (Figure S7). The species with the highest gain in degree between the 1-5yr and 6-11yr monitoring scenarios are the Australasian Pipit and White-naped Honeyeater, and the species with the highest loss of degree are the Pied Currawong and Gang-gang Cockatoo (Table S6).

#### **1.4 Details of network analysis methodology and supporting data**

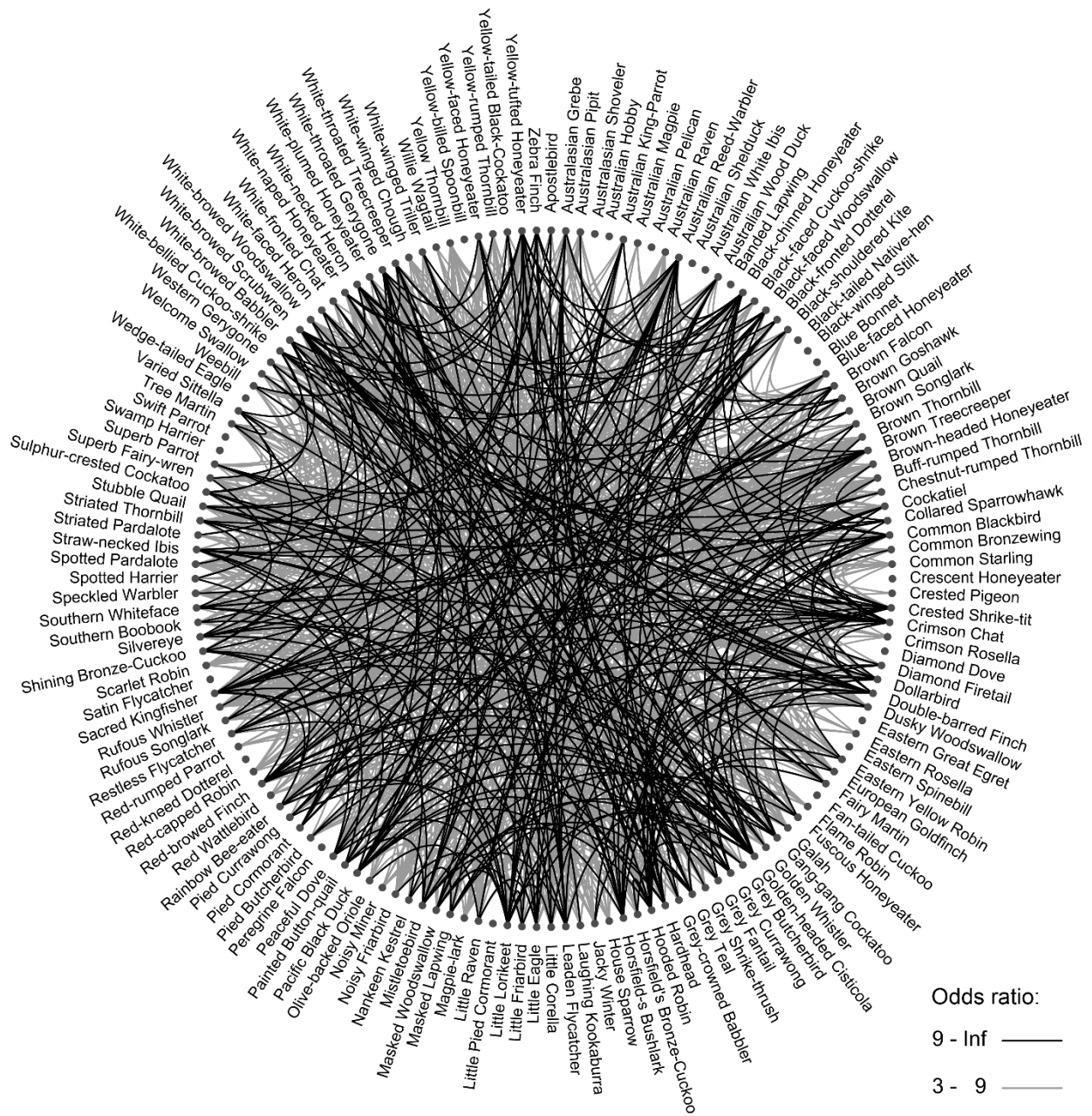
Matrices supporting all data analyses can be found as text files using the following link from the Dryad Digital Repository:

<http://dx.doi.org/10.5061/dryad.5c4d6>

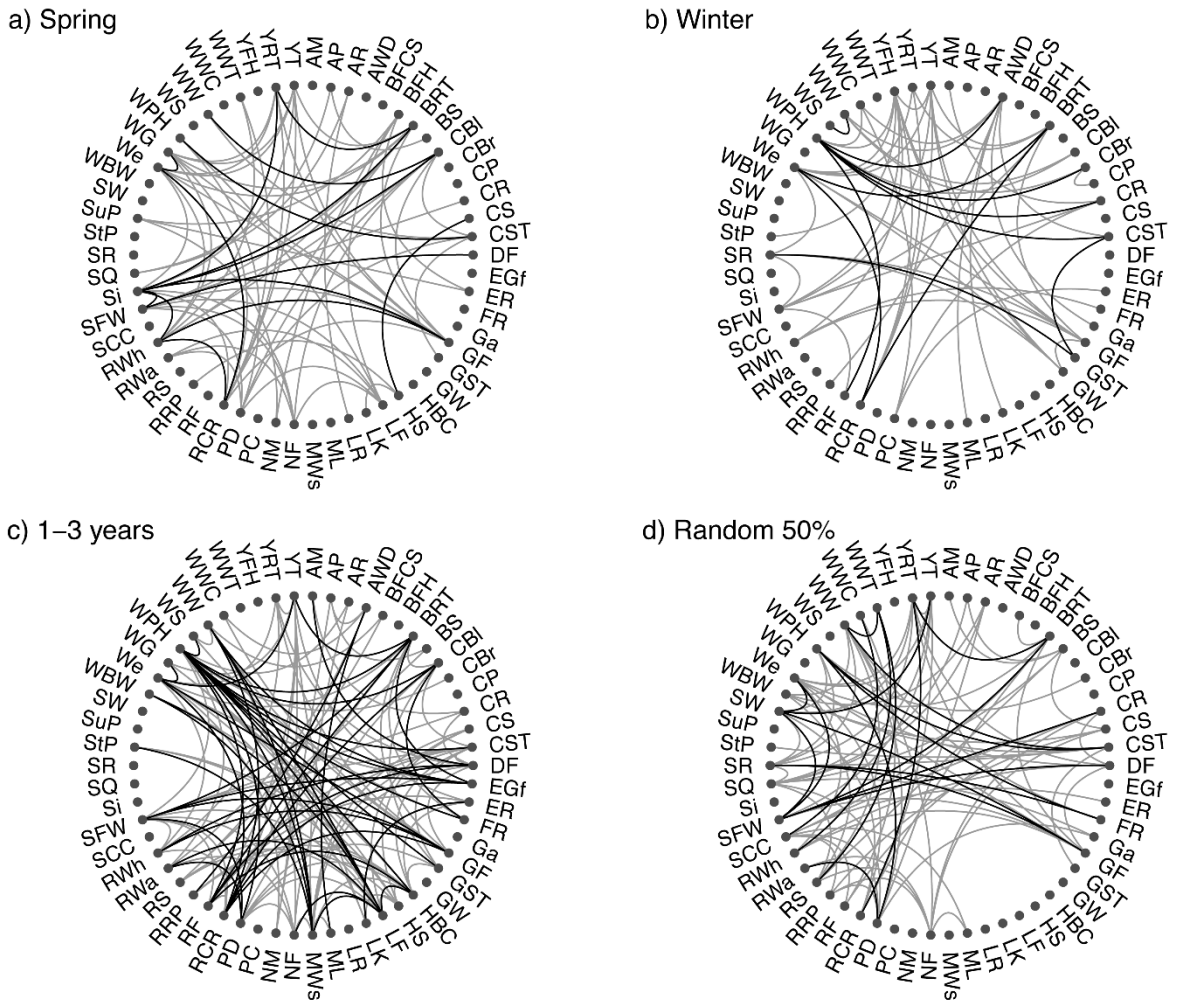
When calculating odds ratios to derive surrogacy networks, we used the default setting of contingency tables (`or.contingency()`), but with no rarity cutoff (i.e. no species excluded from analysis, including species that occurred only once in the dataset). Note that an odds ratio of  $<1$  would correspond with  $r_{ij}$  values of  $<0.5$ , i.e. more likely to indicate absence than presence (Lane et al. 2014). For this study, we ignored any information provided by negative associations between species (giving values of  $s_{ij} < 0.5$ , when the presence of one species is positively associated with the absence of another).

A tutorial for using the R `sppairs` library (Westgate and Lane 2015) to derive odds ratios representing species associations is available here:

<http://martinwestgate.com/software/sppairs/tutorial/>



**Figure S2.** Species co-occurrence network in the Southwest Slopes plantings derived from all 11 years of monitoring. Showing odds ratio threshold of >3 for strong positive effects (light grey) and >9 for very strong effects (black).

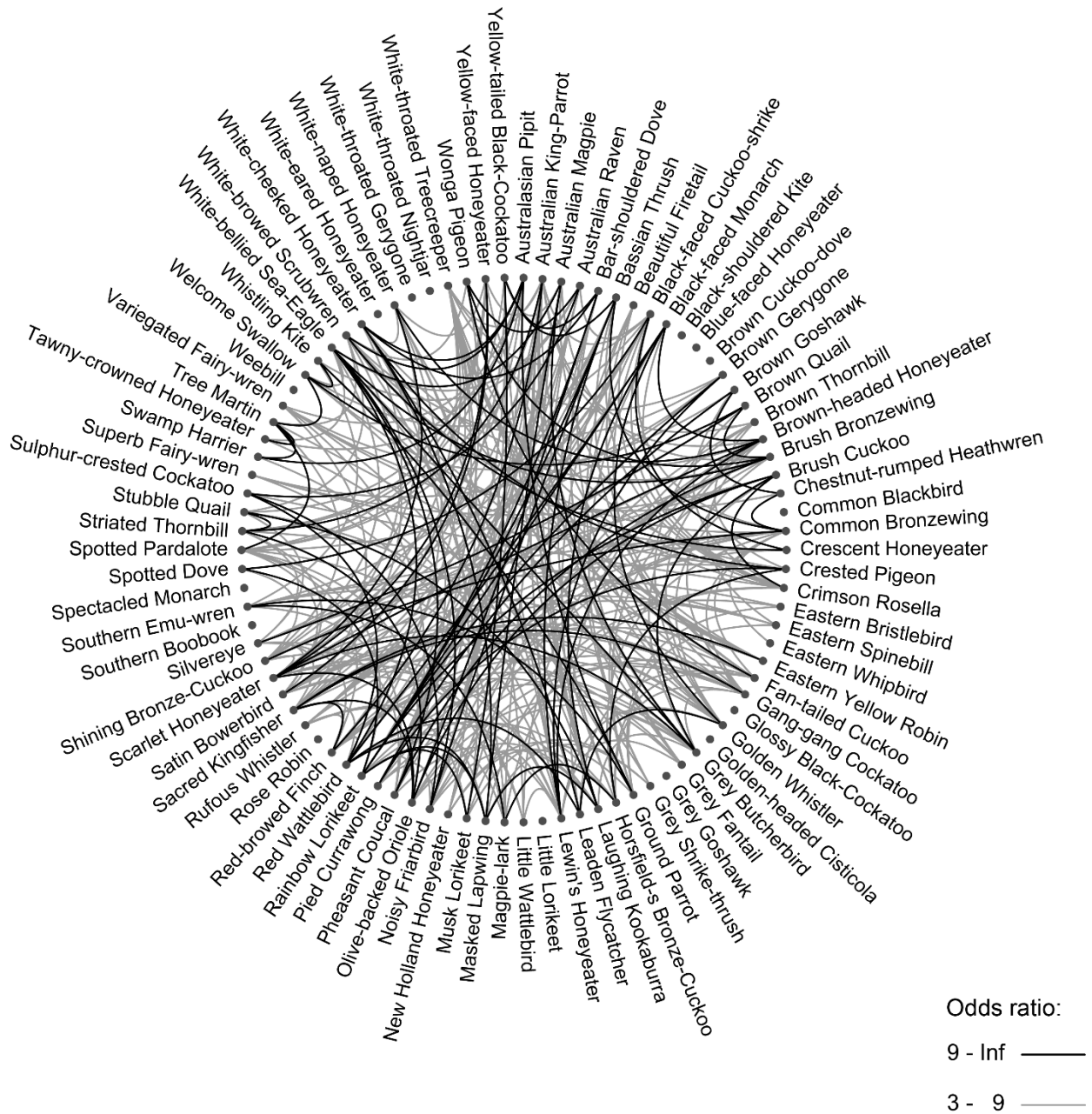


**Figure S3.** Species co-occurrence networks in the Southwest Slopes plantings derived from only (a) spring, (b) winter, (c) 1-3 years of surveys and (d) taking a random half of all surveys. Showing odds ratio threshold of >3 for strong positive effects (light grey) and >9 for very strong effects (black).

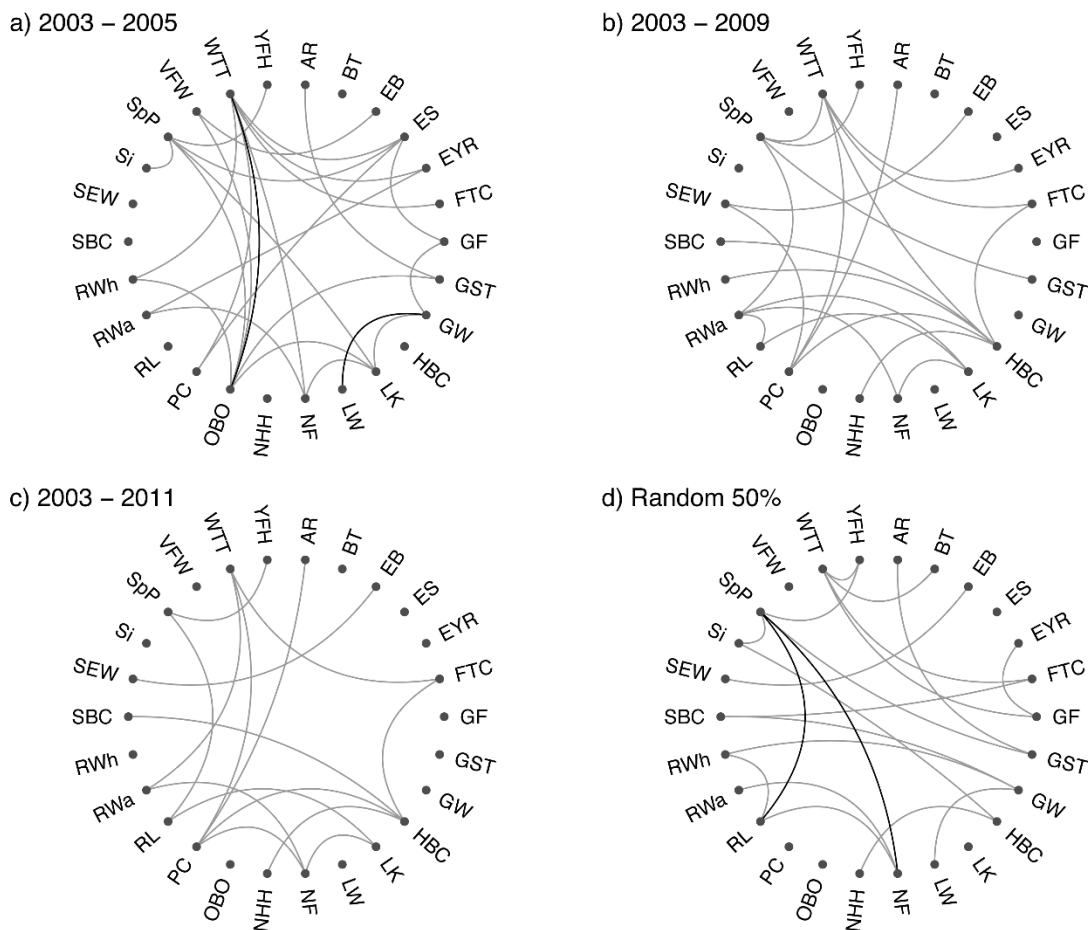
| Key to labels: | Species                   | Acronym | Species                   | Acronym | Species                  | Acronym |
|----------------|---------------------------|---------|---------------------------|---------|--------------------------|---------|
|                | Australasian Pipit        | AP      | Golden Whistler           | GW      | Scarlet Robin            | SR      |
|                | Australian Magpie         | AM      | Grey Fantail              | GF      | Silvereeye               | Si      |
|                | Australian Raven          | AR      | Grey Shrike-thrush        | GST     | Speckled Warbler         | SW      |
|                | Australian Wood Duck      | AWD     | Horsfield's Bronze-Cuckoo | HBC     | Striated Pardalote       | StP     |
|                | Black-faced Cuckoo-shrike | BFCS    | House Sparrow             | HS      | Stubble Quail            | SQ      |
|                | Blue-faced Honeyeater     | BFH     | Laughing Kookaburra       | LK      | Sulphur-crested Cockatoo | SCC     |
|                | Brown-headed Honeyeater   | BHH     | Little Friarbird          | LF      | Superb Fairy-wren        | SFW     |
|                | Brown Songlark            | BS      | Little Raven              | LR      | Superb Parrot            | SuP     |
|                | Buff-rumped Thornbill     | BRT     | Magpie-lark               | ML      | Weebill                  | We      |
|                | Common Blackbird          | CBI     | Masked Woodswallow        | MWs     | Welcome Swallow          | WS      |
|                | Common Bronzewing         | CBr     | Noisy Friarbird           | NF      | Western Gerygone         | WG      |
|                | Common Starling           | CS      | Noisy Miner               | NM      | White-browed Woodswallow | WBW     |
|                | Crested Pigeon            | CP      | Peaceful Dove             | PD      | White-plumed Honeyeater  | WPH     |
|                | Crested Shrike-tit        | CST     | Pied Currawong            | PC      | White-winged Chough      | WWC     |
|                | Crimson Rosella           | CR      | Red-capped Robin          | RCR     | White-winged Triller     | WWT     |
|                | Diamond Firetail          | DF      | Red-rumped Parrot         | RRP     | Willie Wagtail           | WW      |



|                    |     |                     |     |                         |     |
|--------------------|-----|---------------------|-----|-------------------------|-----|
| Eastern Rosella    | ER  | Red Wattlebird      | RWa | Yellow-faced Honeyeater | YFH |
| European Goldfinch | EGf | Restless Flycatcher | RF  | Yellow-rumped Thornbill | YRT |
| Flame Robin        | FR  | Rufous Songlark     | RS  | Yellow Thornbill        | YT  |
| Galah              | Ga  | Rufous Whistler     | RWh |                         |     |



**Figure S4.** Species co-occurrence network in the Booderee NP heathland derived from all 11 years of monitoring. Showing odds ratio threshold of >3 for strong positive effects (light grey) and >9 for very strong effects (black).

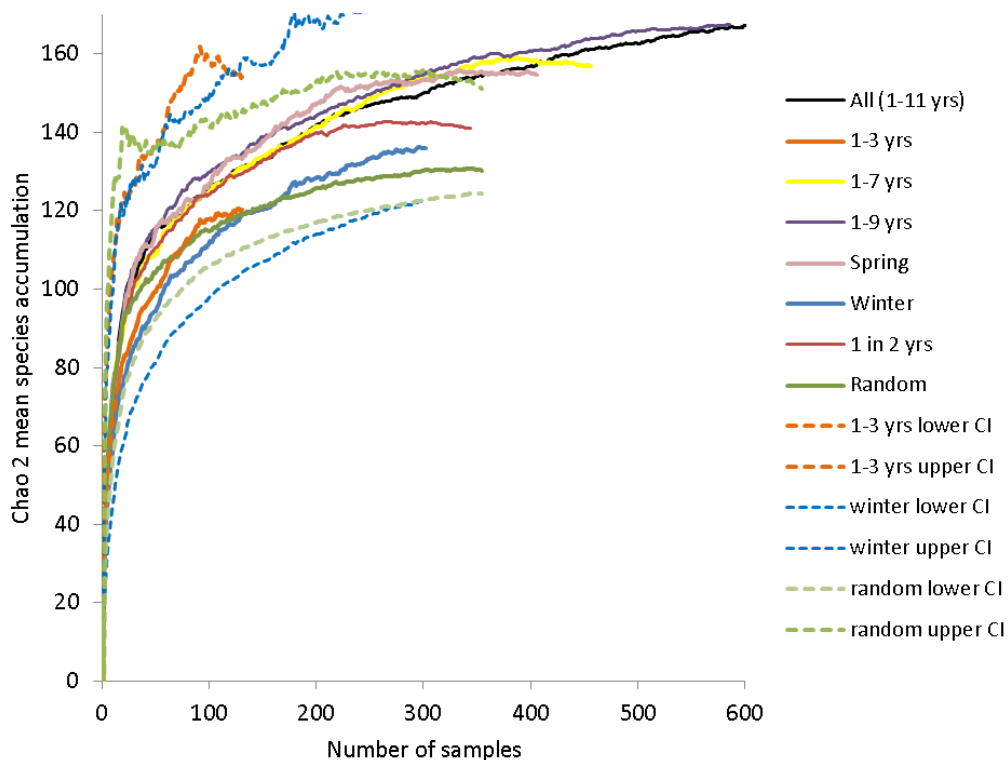


**Figure S5.** Species co-occurrence networks in the Booderee NP heathland derived from (a) 1-3 consecutive years (2003 to 2005), (b) 1-7 consecutive years (2003 to 2009), (c) 1-9 consecutive years (2003 to 2011) of bird monitoring, or (d) taking a random half of all surveys. Showing odds ratio threshold of >3 for strong positive effects.

| Key to labels | Species                   | Acronym | Species                    | Acronym |
|---------------|---------------------------|---------|----------------------------|---------|
|               | Australian Raven          | AR      | Noisy Friarbird            | NF      |
|               | Brown Thornbill           | BT      | Olive-backed Oriole        | OBO     |
|               | Crimson Rosella           | CR      | Pied Currawong             | PC      |
|               | Eastern Bristlebird       | EB      | Rainbow Lorikeet           | RL      |
|               | Eastern Spinebill         | ES      | Red Wattlebird             | RWa     |
|               | Eastern Yellow Robin      | EYR     | Rufous Whistler            | RWh     |
|               | Fan-tailed Cuckoo         | FTC     | Shining Bronze-Cuckoo      | SBC     |
|               | Golden Whistler           | GW      | Silvereye                  | Si      |
|               | Grey Fantail              | GF      | Southern Emu-wren          | SEW     |
|               | Grey Shrike-thrush        | GST     | Spotted Pardalote          | SpP     |
|               | Horsfield's Bronze-Cuckoo | HBC     | Superb Fairy-wren          | SFW     |
|               | Laughing Kookaburra       | LK      | Variegated Fairy-wren      | VFW     |
|               | Little Wattlebird         | LW      | White-throated Treecreeper | WTT     |
|               | New Holland Honeyeater    | NHH     | Yellow-faced Honeyeater    | YFH     |

**Table S3.** Results of Bray-Curtis dissimilarity indices for optimal surrogate solutions achieving 70% surrogacy power in the Southwest Slopes, comparing different scenarios of reductions in the temporal cover of data. Higher numbers indicate more dissimilarity between optimal solutions.

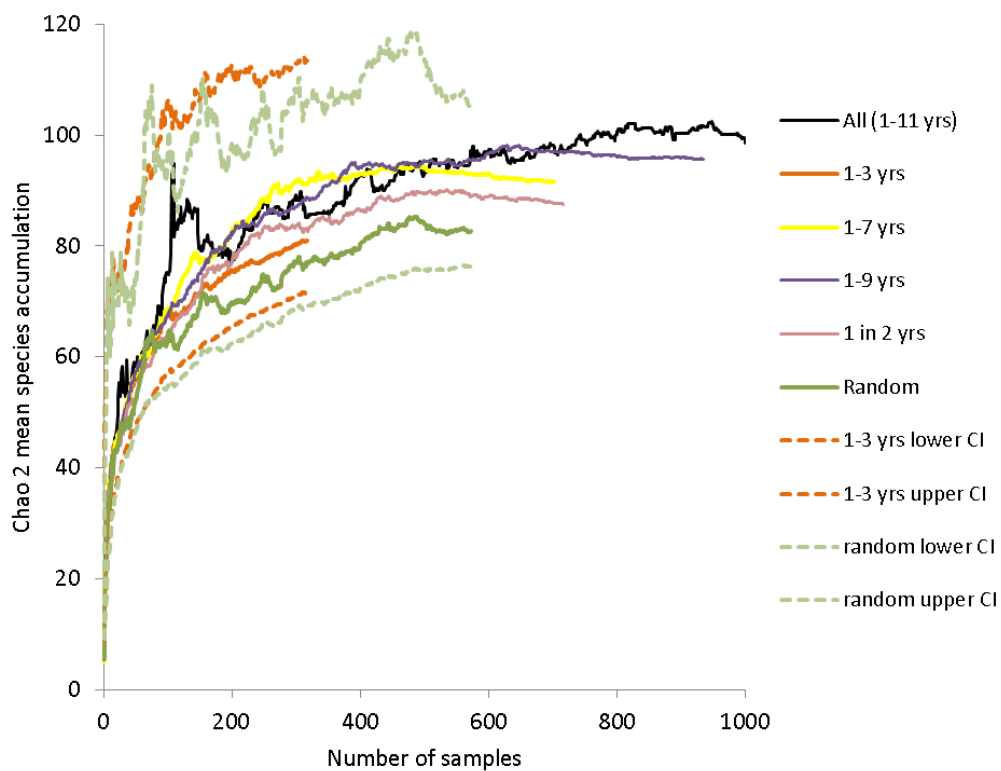
|                   | All  | 1–3<br>yrs | 1–5<br>yrs | 1–7<br>yrs | 1–9<br>yrs | 6–11<br>yrs | Spring | Winter | 1 in 2<br>yrs |
|-------------------|------|------------|------------|------------|------------|-------------|--------|--------|---------------|
| <b>1–3 yrs</b>    | 1.00 |            |            |            |            |             |        |        |               |
| <b>1–5 yrs</b>    | 0.83 | 0.71       |            |            |            |             |        |        |               |
| <b>1–7 yrs</b>    | 0.71 | 1.00       | 0.85       |            |            |             |        |        |               |
| <b>1–9 yrs</b>    | 0.67 | 1.00       | 0.83       | 0.43       |            |             |        |        |               |
| <b>6–11 yrs</b>   | 0.75 | 0.88       | 1.00       | 1.00       | 1.00       |             |        |        |               |
| <b>Spring</b>     | 0.43 | 0.88       | 0.85       | 0.50       | 0.71       | 0.78        |        |        |               |
| <b>Winter</b>     | 1.00 | 0.82       | 0.68       | 1.00       | 1.00       | 0.87        | 1.00   |        |               |
| <b>1 in 2 yrs</b> | 1.00 | 1.00       | 1.00       | 0.86       | 1.00       | 1.00        | 0.86   | 1.00   |               |
| <b>Random</b>     | 1.00 | 1.00       | 0.89       | 1.00       | 1.00       | 0.86        | 1.00   | 0.89   | 0.79          |



**Figure S6.** Species accumulation curves for datasets of reduced temporal coverage in the Southwest Slopes (calculated from Chao 2 estimator In EstimateS).

**Table S4.** Results of Bray-Curtis dissimilarity indices for optimal surrogate solutions achieving 70% surrogacy power in the Booderee NP heathland, comparing different scenarios of reductions in the temporal cover of data. Higher numbers indicate more dissimilarity between optimal solutions.

|            | All  | 1-3<br>yrs | 1-5<br>yrs | 1-7<br>yrs | 1-9<br>yrs | 6-11<br>yrs | 1 in 2<br>yrs |
|------------|------|------------|------------|------------|------------|-------------|---------------|
| 1-3 yrs    | 1.00 |            |            |            |            |             |               |
| 1-5 yrs    | 1.00 | 0.76       |            |            |            |             |               |
| 1-7 yrs    | 0.75 | 0.73       | 0.64       |            |            |             |               |
| 1-9 yrs    | 0.43 | 0.86       | 1.00       | 0.78       |            |             |               |
| 6-11 yrs   | 0.69 | 1.00       | 1.00       | 0.87       | 0.71       |             |               |
| 1 in 2 yrs | 0.80 | 0.65       | 0.69       | 0.67       | 0.64       | 0.65        |               |
| Random     | 1.00 | 0.88       | 0.85       | 0.83       | 1.00       | 0.88        | 0.71          |



**Figure S7.** Species accumulation curves for datasets of reduced temporal coverage in the Booderee NP heathland (calculated from Chao 2 estimator In EstimateS).

**Table S5.** Network metric results for the co-occurrence network of 150 species in the Southwest Slopes. Showing changes in species degree and strength between co-occurrence networks representing 1-5yrs, 6-11yrs, and 1-11yrs post-disturbance.

| Species                   | Degree   |         |          |                               | Strength |         |          |                               |
|---------------------------|----------|---------|----------|-------------------------------|----------|---------|----------|-------------------------------|
|                           | All data | 1-5 yrs | 6-11 yrs | Difference btw 1-5 & 6-11 yrs | All data | 1-5 yrs | 6-11 yrs | Difference btw 1-5 & 6-11 yrs |
| Apostlebird               | 11       | 1       | 9        | 8                             | 0.78     | 0.50    | 0.75     | 0.25                          |
| Australasian Grebe        | 51       | 13      | 48       | 35                            | 0.76     | 0.84    | 0.76     | -0.08                         |
| Australasian Pipit        | 57       | 35      | 50       | 15                            | 0.65     | 0.68    | 0.67     | -0.01                         |
| Australasian Shoveler     | 1        | 1       | 1        | 0                             | 0.50     | 0.50    | 0.50     | 0.00                          |
| Australian Hobby          | 1        | 1       | 1        | 0                             | 0.50     | 0.50    | 0.50     | 0.00                          |
| Australian King-Parrot    | 15       | 1       | 15       | 14                            | 0.88     | 0.50    | 0.88     | 0.38                          |
| Australian Magpie         | 93       | 80      | 79       | -1                            | 0.55     | 0.55    | 0.55     | 0.00                          |
| Australian Pelican        | 1        | 1       | 1        | 0                             | 0.50     | 0.50    | 0.50     | 0.00                          |
| Australian Raven          | 76       | 56      | 67       | 11                            | 0.64     | 0.65    | 0.65     | 0.00                          |
| Australian Reed-Warbler   | 59       | 33      | 42       | 9                             | 0.78     | 0.83    | 0.82     | -0.02                         |
| Australian Shelduck       | 1        | 1       | 1        | 0                             | 0.50     | 0.50    | 0.50     | 0.00                          |
| Australian White Ibis     | 1        | 1       | 1        | 0                             | 0.50     | 0.50    | 0.50     | 0.00                          |
| Australian Wood Duck      | 63       | 47      | 51       | 4                             | 0.71     | 0.72    | 0.73     | 0.01                          |
| Banded Lapwing            | 1        | 1       | 1        | 0                             | 0.50     | 0.50    | 0.50     | 0.00                          |
| Black-chinned Honeyeater  | 57       | 49      | 1        | -48                           | 0.78     | 0.78    | 0.50     | -0.28                         |
| Black-faced Cuckoo-shrike | 91       | 66      | 78       | 12                            | 0.65     | 0.67    | 0.65     | -0.03                         |
| Black-faced Woodswallow   | 18       | 1       | 18       | 17                            | 0.87     | 0.50    | 0.86     | 0.36                          |
| Black-fronted Dotterel    | 20       | 1       | 20       | 19                            | 0.86     | 0.50    | 0.87     | 0.37                          |
| Black-shouldered Kite     | 27       | 1       | 27       | 26                            | 0.76     | 0.50    | 0.75     | 0.25                          |
| Black-tailed Native-hen   | 1        | 1       | 1        | 0                             | 0.50     | 0.50    | 0.50     | 0.00                          |
| Black-winged Stilt        | 1        | 1       | 1        | 0                             | 0.50     | 0.50    | 0.50     | 0.00                          |
| Blue Bonnet               | 1        | 1       | 1        | 0                             | 0.50     | 0.50    | 0.50     | 0.00                          |
| Blue-faced Honeyeater     | 61       | 58      | 42       | -16                           | 0.69     | 0.73    | 0.69     | -0.04                         |
| Brown Falcon              | 50       | 18      | 48       | 30                            | 0.71     | 0.78    | 0.72     | -0.06                         |
| Brown Goshawk             | 38       | 27      | 24       | -3                            | 0.73     | 0.77    | 0.78     | 0.02                          |
| Brown Quail               | 13       | 1       | 13       | 12                            | 0.77     | 0.50    | 0.75     | 0.25                          |
| Brown Songlark            | 56       | 32      | 51       | 19                            | 0.65     | 0.66    | 0.68     | 0.02                          |
| Brown Thornbill           | 50       | 27      | 44       | 17                            | 0.72     | 0.77    | 0.76     | -0.01                         |
| Brown Treecreeper         | 68       | 50      | 46       | -4                            | 0.77     | 0.80    | 0.80     | -0.01                         |
| Brown-headed Honeyeater   | 50       | 31      | 49       | 18                            | 0.72     | 0.78    | 0.71     | -0.08                         |
| Buff-rumped Thornbill     | 57       | 58      | 42       | -16                           | 0.69     | 0.72    | 0.73     | 0.00                          |
| Chestnut-rumped Thornbill | 14       | 1       | 1        | 0                             | 0.81     | 0.50    | 0.50     | 0.00                          |
| Cockatiel                 | 48       | 1       | 42       | 41                            | 0.75     | 0.50    | 0.76     | 0.26                          |
| Collared Sparrowhawk      | 19       | 1       | 11       | 10                            | 0.81     | 0.50    | 0.84     | 0.34                          |
| Common Blackbird          | 72       | 68      | 43       | -25                           | 0.69     | 0.72    | 0.71     | -0.01                         |
| Common Bronzewing         | 61       | 51      | 48       | -3                            | 0.64     | 0.65    | 0.68     | 0.03                          |
| Common Starling           | 89       | 64      | 77       | 13                            | 0.63     | 0.61    | 0.65     | 0.04                          |
| Crescent Honeyeater       | 1        | 1       | 1        | 0                             | 0.50     | 0.50    | 0.50     | 0.00                          |
| Crested Pigeon            | 81       | 70      | 64       | -6                            | 0.58     | 0.57    | 0.61     | 0.04                          |
| Crested Shrike-tit        | 80       | 80      | 68       | -12                           | 0.69     | 0.70    | 0.69     | -0.01                         |

|                           |    |    |    |     |      |      |      |       |
|---------------------------|----|----|----|-----|------|------|------|-------|
| Crimson Chat              | 28 | 1  | 27 | 26  | 0.88 | 0.50 | 0.89 | 0.39  |
| Crimson Rosella           | 71 | 58 | 59 | 1   | 0.66 | 0.70 | 0.66 | -0.05 |
| Diamond Dove              | 1  | 1  | 1  | 0   | 0.50 | 0.50 | 0.50 | 0.00  |
| Diamond Firetail          | 59 | 48 | 46 | -2  | 0.65 | 0.71 | 0.67 | -0.04 |
| Dollarbird                | 33 | 1  | 19 | 18  | 0.81 | 0.50 | 0.84 | 0.34  |
| Double-barred Finch       | 38 | 1  | 38 | 37  | 0.82 | 0.50 | 0.82 | 0.32  |
| Dusky Woodswallow         | 57 | 50 | 27 | -23 | 0.74 | 0.74 | 0.82 | 0.08  |
| Eastern Great Egret       | 1  | 1  | 1  | 0   | 0.50 | 0.50 | 0.50 | 0.00  |
| Eastern Rosella           | 80 | 83 | 62 | -21 | 0.57 | 0.57 | 0.58 | 0.01  |
| Eastern Spinebill         | 1  | 1  | 1  | 0   | 0.50 | 0.50 | 0.50 | 0.00  |
| Eastern Yellow Robin      | 43 | 35 | 30 | -5  | 0.76 | 0.76 | 0.82 | 0.05  |
| European Goldfinch        | 43 | 32 | 25 | -7  | 0.71 | 0.73 | 0.81 | 0.09  |
| Fairy Martin              | 40 | 22 | 33 | 11  | 0.76 | 0.78 | 0.79 | 0.01  |
| Fan-tailed Cuckoo         | 1  | 1  | 1  | 0   | 0.50 | 0.50 | 0.50 | 0.00  |
| Flame Robin               | 57 | 43 | 48 | 5   | 0.64 | 0.65 | 0.66 | 0.01  |
| Fuscous Honeyeater        | 45 | 17 | 41 | 24  | 0.74 | 0.75 | 0.77 | 0.02  |
| Galah                     | 82 | 79 | 67 | -12 | 0.63 | 0.62 | 0.64 | 0.02  |
| Gang-gang Cockatoo        | 22 | 21 | 1  | -20 | 0.82 | 0.83 | 0.50 | -0.33 |
| Golden Whistler           | 53 | 33 | 44 | 11  | 0.71 | 0.75 | 0.74 | -0.01 |
| Golden-headed Cisticola   | 34 | 1  | 1  | 0   | 0.87 | 0.50 | 0.50 | 0.00  |
| Grey Butcherbird          | 51 | 38 | 35 | -3  | 0.69 | 0.80 | 0.73 | -0.07 |
| Grey Currawong            | 20 | 1  | 1  | 0   | 0.82 | 0.50 | 0.50 | 0.00  |
| Grey Fantail              | 71 | 67 | 58 | -9  | 0.67 | 0.72 | 0.66 | -0.06 |
| Grey Shrike-thrush        | 84 | 72 | 76 | 4   | 0.59 | 0.60 | 0.59 | -0.01 |
| Grey Teal                 | 37 | 19 | 27 | 8   | 0.84 | 0.80 | 0.86 | 0.06  |
| Grey-crowned Babbler      | 28 | 13 | 30 | 17  | 0.73 | 0.83 | 0.71 | -0.12 |
| Hardhead                  | 25 | 1  | 25 | 24  | 0.82 | 0.50 | 0.82 | 0.32  |
| Hooded Robin              | 39 | 38 | 1  | -37 | 0.84 | 0.85 | 0.50 | -0.35 |
| Horsfield's Bronze-Cuckoo | 56 | 43 | 42 | -1  | 0.70 | 0.78 | 0.70 | -0.09 |
| Horsfield's Bushlark      | 35 | 1  | 29 | 28  | 0.77 | 0.50 | 0.80 | 0.30  |
| House Sparrow             | 65 | 61 | 38 | -23 | 0.67 | 0.67 | 0.73 | 0.06  |
| Jacky Winter              | 52 | 43 | 38 | -5  | 0.70 | 0.75 | 0.73 | -0.03 |
| Laughing Kookaburra       | 63 | 44 | 54 | 10  | 0.64 | 0.68 | 0.67 | -0.01 |
| Leaden Flycatcher         | 36 | 1  | 18 | 17  | 0.80 | 0.50 | 0.81 | 0.31  |
| Little Corella            | 59 | 37 | 47 | 10  | 0.74 | 0.81 | 0.75 | -0.06 |
| Little Eagle              | 17 | 1  | 1  | 0   | 0.84 | 0.50 | 0.50 | 0.00  |
| Little Friarbird          | 81 | 65 | 52 | -13 | 0.72 | 0.76 | 0.74 | -0.03 |
| Little Lorikeet           | 39 | 1  | 28 | 27  | 0.87 | 0.50 | 0.86 | 0.36  |
| Little Pied Cormorant     | 1  | 1  | 1  | 0   | 0.50 | 0.50 | 0.50 | 0.00  |
| Little Raven              | 53 | 12 | 57 | 45  | 0.70 | 0.77 | 0.67 | -0.09 |
| Magpie-lark               | 98 | 89 | 69 | -20 | 0.62 | 0.63 | 0.64 | 0.01  |
| Masked Lapwing            | 28 | 22 | 14 | -8  | 0.83 | 0.80 | 0.88 | 0.09  |
| Masked Woodswallow        | 58 | 36 | 36 | 0   | 0.71 | 0.75 | 0.81 | 0.05  |
| Mistletoebird             | 65 | 31 | 49 | 18  | 0.73 | 0.79 | 0.75 | -0.03 |
| Nankeen Kestrel           | 33 | 19 | 29 | 10  | 0.70 | 0.78 | 0.73 | -0.05 |
| Noisy Friarbird           | 62 | 65 | 33 | -32 | 0.68 | 0.69 | 0.70 | 0.00  |
| Noisy Miner               | 57 | 51 | 47 | -4  | 0.63 | 0.63 | 0.65 | 0.02  |
| Olive-backed Oriole       | 22 | 1  | 22 | 21  | 0.73 | 0.50 | 0.73 | 0.23  |

|                             |     |    |    |     |      |      |      |       |
|-----------------------------|-----|----|----|-----|------|------|------|-------|
| Pacific Black Duck          | 48  | 1  | 48 | 47  | 0.79 | 0.50 | 0.78 | 0.28  |
| Painted Button-quail        | 24  | 1  | 22 | 21  | 0.79 | 0.50 | 0.80 | 0.30  |
| Peaceful Dove               | 86  | 70 | 64 | -6  | 0.69 | 0.73 | 0.74 | 0.01  |
| Peregrine Falcon            | 1   | 1  | 1  | 0   | 0.50 | 0.50 | 0.50 | 0.00  |
| Pied Butcherbird            | 58  | 33 | 54 | 21  | 0.68 | 0.72 | 0.71 | -0.01 |
| Pied Cormorant              | 15  | 1  | 15 | 14  | 0.82 | 0.50 | 0.83 | 0.33  |
| Pied Currawong              | 41  | 28 | 42 | 14  | 0.70 | 0.72 | 0.69 | -0.03 |
| Rainbow Bee-eater           | 55  | 44 | 33 | -11 | 0.76 | 0.76 | 0.80 | 0.03  |
| Red Wattlebird              | 90  | 74 | 71 | -3  | 0.58 | 0.63 | 0.58 | -0.05 |
| Red-browed Finch            | 66  | 53 | 48 | -5  | 0.74 | 0.76 | 0.77 | 0.01  |
| Red-capped Robin            | 60  | 49 | 56 | 7   | 0.65 | 0.72 | 0.66 | -0.06 |
| Red-kneed Dotterel          | 1   | 1  | 1  | 0   | 0.50 | 0.50 | 0.50 | 0.00  |
| Red-rumped Parrot           | 100 | 85 | 80 | -5  | 0.58 | 0.59 | 0.59 | 0.00  |
| Restless Flycatcher         | 71  | 58 | 47 | -11 | 0.70 | 0.72 | 0.72 | 0.00  |
| Rufous Songlark             | 86  | 67 | 80 | 13  | 0.62 | 0.65 | 0.63 | -0.02 |
| Rufous Whistler             | 95  | 83 | 69 | -14 | 0.64 | 0.68 | 0.65 | -0.03 |
| Sacred Kingfisher           | 47  | 22 | 40 | 18  | 0.82 | 0.84 | 0.81 | -0.03 |
| Satin Flycatcher            | 1   | 1  | 1  | 0   | 0.50 | 0.50 | 0.50 | 0.00  |
| Scarlet Robin               | 42  | 18 | 38 | 20  | 0.72 | 0.79 | 0.73 | -0.06 |
| Shining Bronze-Cuckoo       | 21  | 1  | 20 | 19  | 0.80 | 0.50 | 0.80 | 0.30  |
| Silvereye                   | 64  | 45 | 53 | 8   | 0.72 | 0.83 | 0.71 | -0.12 |
| Southern Boobook            | 43  | 36 | 23 | -13 | 0.72 | 0.75 | 0.80 | 0.04  |
| Southern Whiteface          | 63  | 43 | 39 | -4  | 0.69 | 0.72 | 0.77 | 0.06  |
| Speckled Warbler            | 52  | 46 | 44 | -2  | 0.71 | 0.74 | 0.73 | -0.01 |
| Spotted Harrier             | 10  | 1  | 10 | 9   | 0.80 | 0.50 | 0.82 | 0.32  |
| Spotted Pardalote           | 50  | 17 | 42 | 25  | 0.73 | 0.83 | 0.74 | -0.09 |
| Straw-necked Ibis           | 40  | 1  | 42 | 41  | 0.76 | 0.50 | 0.74 | 0.24  |
| Striated Pardalote          | 98  | 77 | 81 | 4   | 0.59 | 0.62 | 0.58 | -0.04 |
| Striated Thornbill          | 54  | 39 | 44 | 5   | 0.73 | 0.78 | 0.74 | -0.04 |
| Stubble Quail               | 65  | 26 | 54 | 28  | 0.69 | 0.82 | 0.68 | -0.14 |
| Sulphur-crested Cockatoo    | 67  | 56 | 52 | -4  | 0.71 | 0.76 | 0.69 | -0.08 |
| Superb Fairy-wren           | 96  | 84 | 86 | 2   | 0.57 | 0.59 | 0.57 | -0.02 |
| Superb Parrot               | 55  | 35 | 40 | 5   | 0.72 | 0.80 | 0.72 | -0.08 |
| Swamp Harrier               | 1   | 1  | 1  | 0   | 0.50 | 0.50 | 0.50 | 0.00  |
| Swift Parrot                | 1   | 1  | 1  | 0   | 0.50 | 0.50 | 0.50 | 0.00  |
| Tree Martin                 | 40  | 18 | 33 | 15  | 0.68 | 0.79 | 0.69 | -0.10 |
| Varied Sittella             | 24  | 18 | 1  | -17 | 0.79 | 0.84 | 0.50 | -0.34 |
| Wedge-tailed Eagle          | 1   | 1  | 1  | 0   | 0.50 | 0.50 | 0.50 | 0.00  |
| Weebill                     | 52  | 50 | 50 | 0   | 0.66 | 0.72 | 0.66 | -0.06 |
| Welcome Swallow             | 83  | 58 | 71 | 13  | 0.67 | 0.64 | 0.71 | 0.06  |
| Western Gerygone            | 64  | 53 | 52 | -1  | 0.69 | 0.74 | 0.71 | -0.03 |
| White-bellied Cuckoo-shrike | 25  | 25 | 1  | -24 | 0.78 | 0.77 | 0.50 | -0.27 |
| White-browed Babbler        | 52  | 25 | 47 | 22  | 0.71 | 0.74 | 0.74 | 0.00  |
| White-browed Scrubwren      | 57  | 42 | 47 | 5   | 0.77 | 0.77 | 0.79 | 0.02  |
| White-browed Woodswallow    | 76  | 50 | 69 | 19  | 0.67 | 0.71 | 0.67 | -0.04 |
| White-faced Heron           | 34  | 28 | 15 | -13 | 0.76 | 0.86 | 0.78 | -0.08 |
| White-fronted Chat          | 34  | 27 | 24 | -3  | 0.73 | 0.71 | 0.82 | 0.11  |
| White-naped Honeyeater      | 39  | 1  | 39 | 38  | 0.78 | 0.50 | 0.78 | 0.28  |



|                              |     |    |    |    |      |      |      |       |
|------------------------------|-----|----|----|----|------|------|------|-------|
| White-necked Heron           | 41  | 1  | 27 | 26 | 0.80 | 0.50 | 0.77 | 0.27  |
| White-plumed Honeyeater      | 104 | 88 | 96 | 8  | 0.55 | 0.53 | 0.56 | 0.03  |
| White-throated Gerygone      | 38  | 1  | 36 | 35 | 0.77 | 0.50 | 0.76 | 0.26  |
| White-throated Treecreeper   | 50  | 1  | 31 | 30 | 0.75 | 0.50 | 0.80 | 0.30  |
| White-winged Chough          | 89  | 65 | 81 | 16 | 0.62 | 0.66 | 0.62 | -0.04 |
| White-winged Triller         | 72  | 54 | 64 | 10 | 0.67 | 0.74 | 0.66 | -0.08 |
| Willie Wagtail               | 97  | 90 | 89 | -1 | 0.55 | 0.54 | 0.55 | 0.01  |
| Yellow Thornbill             | 51  | 50 | 48 | -2 | 0.65 | 0.70 | 0.65 | -0.05 |
| Yellow-billed Spoonbill      | 1   | 1  | 1  | 0  | 0.50 | 0.50 | 0.50 | 0.00  |
| Yellow-faced Honeyeater      | 53  | 33 | 46 | 13 | 0.73 | 0.81 | 0.74 | -0.06 |
| Yellow-rumped Thornbill      | 52  | 46 | 53 | 7  | 0.60 | 0.63 | 0.60 | -0.02 |
| Yellow-tailed Black-Cockatoo | 13  | 1  | 1  | 0  | 0.81 | 0.50 | 0.50 | 0.00  |
| Yellow-tufted Honeyeater     | 53  | 29 | 37 | 8  | 0.78 | 0.82 | 0.82 | 0.01  |
| Zebra Finch                  | 29  | 1  | 30 | 29 | 0.76 | 0.50 | 0.75 | 0.25  |

**Table S6.** Network metric results for the co-occurrence network of 90 species in the Booderee NP heathland. Showing changes in species degree and strength between co-occurrence networks representing 1-5yrs, 6-11yrs, and 1-11yrs post-disturbance.

| Species                   | Degree   |         |          |                               | Strength |         |          |                               |
|---------------------------|----------|---------|----------|-------------------------------|----------|---------|----------|-------------------------------|
|                           | All data | 1-5 yrs | 6-11 yrs | Difference btw 1-5 & 6-11 yrs | All data | 1-5 yrs | 6-11 yrs | Difference btw 1-5 & 6-11 yrs |
| Australasian Pipit        | 15       | 1       | 14       | 13                            | 0.81     | 0.50    | 0.81     | 0.31                          |
| Australian King-Parrot    | 31       | 24      | 21       | -3                            | 0.76     | 0.76    | 0.83     | 0.08                          |
| Australian Magpie         | 20       | 17      | 1        | -16                           | 0.80     | 0.79    | 0.50     | -0.29                         |
| Australian Raven          | 43       | 41      | 28       | -13                           | 0.66     | 0.65    | 0.68     | 0.03                          |
| Bar-shouldered Dove       | 11       | 1       | 11       | 10                            | 0.83     | 0.50    | 0.81     | 0.31                          |
| Bassian Thrush            | 12       | 13      | 1        | -12                           | 0.88     | 0.85    | 0.50     | -0.35                         |
| Beautiful Firetail        | 10       | 13      | 8        | -5                            | 0.71     | 0.76    | 0.69     | -0.08                         |
| Black-faced Cuckoo-shrike | 25       | 19      | 22       | 3                             | 0.74     | 0.72    | 0.78     | 0.06                          |
| Black-faced Monarch       | 11       | 11      | 1        | -10                           | 0.86     | 0.87    | 0.50     | -0.37                         |
| Black-shouldered Kite     | 1        | 1       | 1        | 0                             | 0.50     | 0.50    | 0.50     | 0.00                          |
| Blue-faced Honeyeater     | 1        | 1       | 1        | 0                             | 0.50     | 0.50    | 0.50     | 0.00                          |
| Brown Cuckoo-dove         | 36       | 27      | 28       | 1                             | 0.76     | 0.74    | 0.78     | 0.04                          |
| Brown Gerygone            | 1        | 1       | 1        | 0                             | 0.50     | 0.50    | 0.50     | 0.00                          |
| Brown Goshawk             | 15       | 15      | 1        | -14                           | 0.77     | 0.77    | 0.50     | -0.27                         |
| Brown Quail               | 7        | 8       | 1        | -7                            | 0.86     | 0.82    | 0.50     | -0.32                         |
| Brown Thornbill           | 11       | 1       | 9        | 8                             | 0.76     | 0.50    | 0.80     | 0.30                          |
| Brown-headed Honeyeater   | 39       | 32      | 33       | 1                             | 0.65     | 0.65    | 0.65     | 0.00                          |
| Brush Bronzewing          | 31       | 21      | 27       | 6                             | 0.73     | 0.71    | 0.77     | 0.06                          |
| Brush Cuckoo              | 13       | 13      | 1        | -12                           | 0.77     | 0.78    | 0.50     | -0.28                         |
| Chestnut-rumped Heathwren | 15       | 9       | 9        | 0                             | 0.69     | 0.74    | 0.83     | 0.08                          |
| Common Blackbird          | 1        | 1       | 1        | 0                             | 0.50     | 0.50    | 0.50     | 0.00                          |
| Common Bronzewing         | 27       | 23      | 9        | -14                           | 0.76     | 0.78    | 0.79     | 0.00                          |
| Crescent Honeyeater       | 10       | 10      | 1        | -9                            | 0.80     | 0.79    | 0.50     | -0.29                         |
| Crested Pigeon            | 10       | 1       | 1        | 0                             | 0.83     | 0.50    | 0.50     | 0.00                          |
| Crimson Rosella           | 49       | 51      | 34       | -17                           | 0.66     | 0.63    | 0.67     | 0.04                          |
| Eastern Bristlebird       | 54       | 45      | 40       | -5                            | 0.58     | 0.58    | 0.58     | 0.00                          |
| Eastern Spinebill         | 58       | 47      | 49       | 2                             | 0.62     | 0.67    | 0.59     | -0.07                         |
| Eastern Whipbird          | 60       | 50      | 53       | 3                             | 0.59     | 0.59    | 0.59     | 0.00                          |
| Eastern Yellow Robin      | 43       | 38      | 34       | -4                            | 0.68     | 0.69    | 0.68     | -0.01                         |
| Fan-tailed Cuckoo         | 45       | 41      | 42       | 1                             | 0.64     | 0.66    | 0.63     | -0.02                         |
| Gang-gang Cockatoo        | 33       | 35      | 7        | -28                           | 0.71     | 0.71    | 0.77     | 0.06                          |
| Glossy Black-Cockatoo     | 1        | 1       | 1        | 0                             | 0.50     | 0.50    | 0.50     | 0.00                          |
| Golden Whistler           | 1        | 1       | 1        | 0                             | 0.50     | 0.50    | 0.50     | 0.00                          |
| Golden-headed Cisticola   | 45       | 31      | 38       | 7                             | 0.67     | 0.69    | 0.69     | 0.01                          |
| Grey Butcherbird          | 31       | 31      | 9        | -22                           | 0.75     | 0.75    | 0.80     | 0.05                          |
| Grey Fantail              | 67       | 57      | 45       | -12                           | 0.62     | 0.64    | 0.62     | -0.01                         |
| Grey Goshawk              | 1        | 1       | 1        | 0                             | 0.50     | 0.50    | 0.50     | 0.00                          |
| Grey Shrike-thrush        | 51       | 49      | 37       | -12                           | 0.65     | 0.66    | 0.68     | 0.02                          |
| Ground Parrot             | 21       | 7       | 17       | 10                            | 0.74     | 0.78    | 0.79     | 0.00                          |
| Horsfield's Bronze-Cuckoo | 40       | 31      | 39       | 8                             | 0.67     | 0.68    | 0.67     | -0.01                         |

|                            |    |    |    |     |      |      |      |       |
|----------------------------|----|----|----|-----|------|------|------|-------|
| Laughing Kookaburra        | 43 | 45 | 24 | -21 | 0.72 | 0.69 | 0.75 | 0.06  |
| Leaden Flycatcher          | 9  | 1  | 9  | 8   | 0.83 | 0.50 | 0.80 | 0.30  |
| Lewin's Honeyeater         | 38 | 27 | 32 | 5   | 0.74 | 0.77 | 0.75 | -0.02 |
| Little Lorikeet            | 1  | 1  | 1  | 0   | 0.50 | 0.50 | 0.50 | 0.00  |
| Little Wattlebird          | 63 | 57 | 43 | -14 | 0.63 | 0.65 | 0.61 | -0.03 |
| Magpie-lark                | 15 | 11 | 1  | -10 | 0.74 | 0.86 | 0.50 | -0.36 |
| Masked Lapwing             | 11 | 12 | 1  | -11 | 0.85 | 0.82 | 0.50 | -0.32 |
| Musk Lorikeet              | 11 | 1  | 11 | 10  | 0.80 | 0.50 | 0.79 | 0.29  |
| New Holland Honeyeater     | 46 | 44 | 45 | 1   | 0.58 | 0.60 | 0.54 | -0.06 |
| Noisy Friarbird            | 44 | 39 | 32 | -7  | 0.68 | 0.67 | 0.70 | 0.03  |
| Olive-backed Oriole        | 36 | 32 | 30 | -2  | 0.72 | 0.72 | 0.73 | 0.01  |
| Pheasant Coucal            | 12 | 1  | 12 | 11  | 0.78 | 0.50 | 0.76 | 0.26  |
| Pied Currawong             | 41 | 44 | 20 | -24 | 0.70 | 0.68 | 0.75 | 0.06  |
| Rainbow Lorikeet           | 44 | 42 | 32 | -10 | 0.71 | 0.69 | 0.70 | 0.01  |
| Red Wattlebird             | 25 | 17 | 21 | 4   | 0.72 | 0.80 | 0.75 | -0.05 |
| Red-browed Finch           | 47 | 42 | 36 | -6  | 0.69 | 0.68 | 0.69 | 0.01  |
| Rose Robin                 | 1  | 1  | 1  | 0   | 0.50 | 0.50 | 0.50 | 0.00  |
| Rufous Whistler            | 51 | 45 | 43 | -2  | 0.67 | 0.66 | 0.67 | 0.00  |
| Sacred Kingfisher          | 18 | 18 | 1  | -17 | 0.83 | 0.84 | 0.50 | -0.34 |
| Satin Bowerbird            | 29 | 32 | 13 | -19 | 0.71 | 0.70 | 0.71 | 0.01  |
| Scarlet Honeyeater         | 22 | 10 | 20 | 10  | 0.82 | 0.87 | 0.78 | -0.09 |
| Shining Bronze-Cuckoo      | 50 | 43 | 45 | 2   | 0.67 | 0.67 | 0.66 | -0.01 |
| Silvereye                  | 45 | 41 | 35 | -6  | 0.66 | 0.68 | 0.63 | -0.05 |
| Southern Boobook           | 1  | 1  | 1  | 0   | 0.50 | 0.50 | 0.50 | 0.00  |
| Southern Emu-wren          | 43 | 42 | 28 | -14 | 0.67 | 0.70 | 0.69 | -0.01 |
| Spectacled Morch           | 1  | 1  | 1  | 0   | 0.50 | 0.50 | 0.50 | 0.00  |
| Spotted Dove               | 5  | 5  | 1  | -4  | 0.88 | 0.91 | 0.50 | -0.41 |
| Spotted Pardalote          | 38 | 36 | 30 | -6  | 0.70 | 0.72 | 0.69 | -0.03 |
| Striated Thornbill         | 23 | 13 | 16 | 3   | 0.72 | 0.81 | 0.78 | -0.03 |
| Stubble Quail              | 10 | 10 | 1  | -9  | 0.81 | 0.82 | 0.50 | -0.32 |
| Sulphur-crested Cockatoo   | 6  | 7  | 1  | -6  | 0.84 | 0.77 | 0.50 | -0.27 |
| Superb Fairy-wren          | 18 | 19 | 13 | -6  | 0.69 | 0.71 | 0.60 | -0.11 |
| Swamp Harrier              | 10 | 8  | 9  | 1   | 0.71 | 0.71 | 0.70 | 0.00  |
| Tawny-crowned Honeyeater   | 23 | 22 | 20 | -2  | 0.68 | 0.68 | 0.66 | -0.03 |
| Tree Martin                | 10 | 1  | 1  | 0   | 0.86 | 0.50 | 0.50 | 0.00  |
| Variiegated Fairy-wren     | 39 | 35 | 35 | 0   | 0.67 | 0.64 | 0.63 | 0.00  |
| Weebill                    | 1  | 1  | 1  | 0   | 0.50 | 0.50 | 0.50 | 0.00  |
| Welcome Swallow            | 23 | 15 | 23 | 8   | 0.68 | 0.72 | 0.67 | -0.05 |
| Whistling Kite             | 10 | 4  | 1  | -3  | 0.76 | 0.78 | 0.50 | -0.28 |
| White-bellied Sea-Eagle    | 15 | 13 | 8  | -5  | 0.84 | 0.85 | 0.84 | -0.01 |
| White-browed Scrubwren     | 55 | 45 | 40 | -5  | 0.64 | 0.66 | 0.63 | -0.03 |
| White-cheeked Honeyeater   | 27 | 25 | 21 | -4  | 0.73 | 0.80 | 0.70 | -0.10 |
| White-eared Honeyeater     | 1  | 1  | 1  | 0   | 0.50 | 0.50 | 0.50 | 0.00  |
| White-ped Honeyeater       | 24 | 1  | 23 | 22  | 0.77 | 0.50 | 0.76 | 0.26  |
| White-throated Gerygone    | 1  | 1  | 1  | 0   | 0.50 | 0.50 | 0.50 | 0.00  |
| White-throated Nightjar    | 1  | 1  | 1  | 0   | 0.50 | 0.50 | 0.50 | 0.00  |
| White-throated Treecreeper | 43 | 44 | 34 | -10 | 0.71 | 0.72 | 0.71 | -0.01 |
| Wonga Pigeon               | 11 | 1  | 11 | 10  | 0.79 | 0.50 | 0.79 | 0.29  |

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|                              |    |    |    |    |      |      |      |      |
|------------------------------|----|----|----|----|------|------|------|------|
| Yellow-faced Honeyeater      | 43 | 38 | 36 | -2 | 0.68 | 0.66 | 0.68 | 0.02 |
| Yellow-tailed Black-Cockatoo | 35 | 29 | 20 | -9 | 0.71 | 0.72 | 0.74 | 0.02 |

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## Appendix 2. Optimisation details

### 2.1. Code

The optimisation code in CPLEX (run through Matlab), and sample input files for finding the optimal surrogates for the 'all-data' matrix in the Booderee NP heathland, are available here (or from authors):

<https://www.dropbox.com/sh/3um2ak5prwvqsgt/AADalk2aHp1RcSdegK7QwhR4a?dl=0>

To run the code, the following files are required in the same folder:

1. CPLEX optimisation code ("version2.mod")
2. Code to loop through scenarios and budgets to call CPLEX from Matlab ("solve\_all.m")
3. Input files (one per cmax budget per scenario; ".dat")
4. Output file (one for all budgets, with a new sheet name for each data reduction scenario, and separate columns within each worksheet representing different budgets; ".csv").

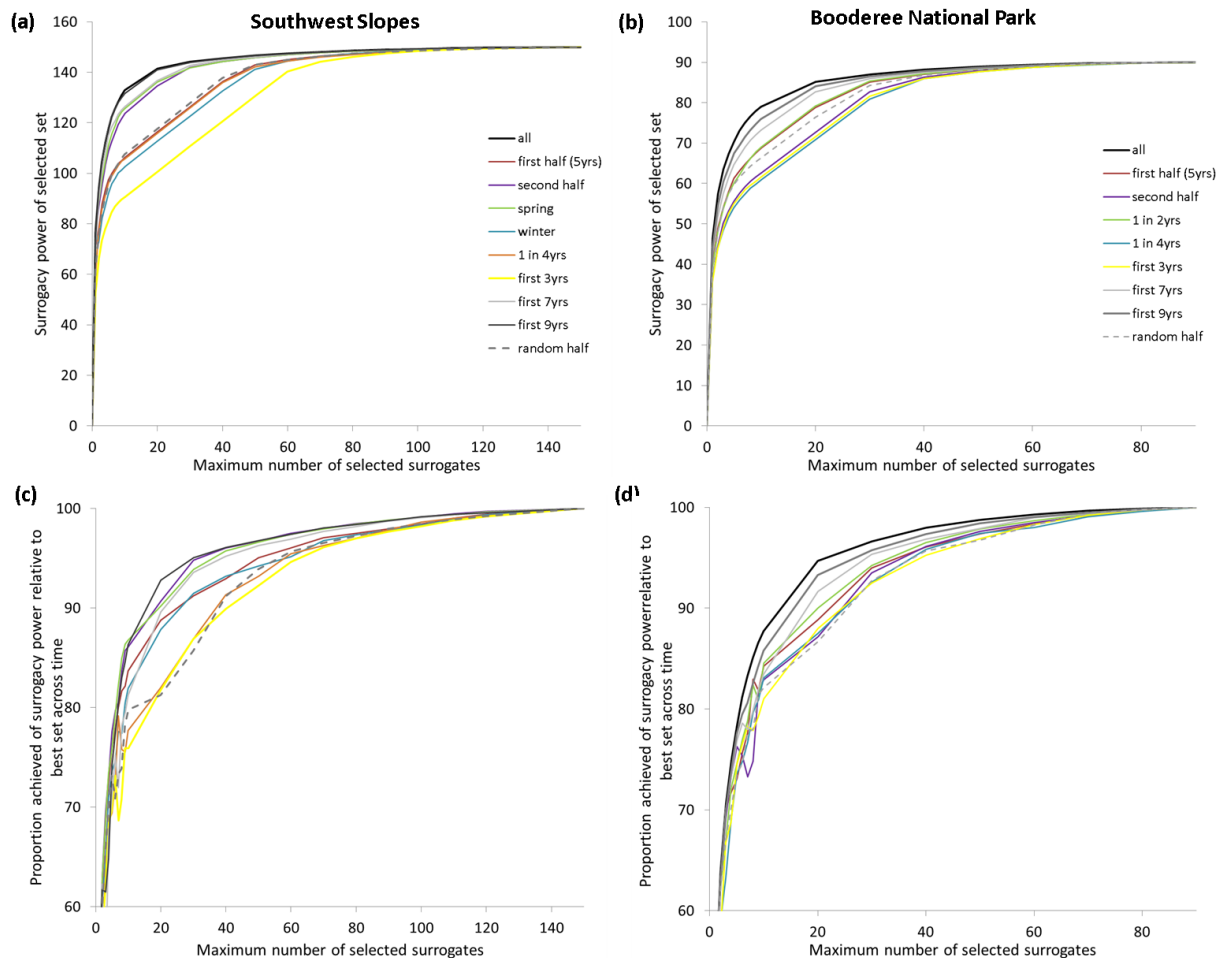
For further details of the integer linear programming method and applications to fields other than conservation and evaluation, refer to Dujardin et al. (2015) and Williams (1990).

### 2.2. Sensitivity analyses

We first ran analyses to explore how many surrogate species might be required to learn only about the species detected in a given monitoring scenario (Figure S8a, b). Monitoring scenarios with fewer data (reduced temporal representativeness due to shorter time-frames of monitoring, e.g. first 3 years, 5 years) always required more surrogates to represent species occurrences during that time frame than monitoring scenarios with 7 or more years of continuous monitoring (grey lines, Figure S8a, b).

We then ran sensitivity analyses to explore the relative surrogacy power of the optimal surrogate set selected under different scenarios of collecting monitoring data compared with the surrogacy power of the surrogate 'budget' (Figure S8c, d). Using fewer surveys to inform optimal surrogates resulted in more surrogates required to achieve the same surrogacy power as the all-data scenario. For example, in the Southwest Slopes, at least 11 surrogates were needed to achieve 80% surrogacy power across all time if only 7 years of monitoring were used to inform optimal surrogate choices, increasing to more than 20 surrogates needed to achieve 80% surrogacy power if only 3 years of monitoring were used.

Ignoring the first half of the data in the Booderee NP heathland to wait for a response lag made a much greater difference if those surrogates were meant to represent species over all of the 11 years than the same scenario in the Southwest Slopes dataset. In the Southwest Slopes, surveying in spring led to the selection of surrogates closer to the surrogacy power over all years than surveying in winter, or compared with surveying in both seasons but reducing the frequency to monitoring every other year (Figure S8c). In the Booderee NP heathland, reducing the frequency by monitoring every other year achieved a similar surrogacy power to monitoring over the first half of the total time frame (Figure S8d).



**Figure S8.** Performance (in terms of surrogacy power of the association network at that time) of different monitoring strategies for finding optimal surrogates at different ‘budgets’ of numbers of surrogate species selected for (a) monitoring in the Southwest Slopes plantings, or (b) monitoring in Booderee National Park heathland. Also showing proportion of the surrogacy power of the best set across all monitoring time achieved by using temporally reduced monitoring datasets for (c) surrogates in the Southwest Slopes, and (d) surrogates in the Booderee National Park heathland.

### 2.3. Null model analysis

We performed a final sensitivity analysis to explore the effect of using an arbitrary cut-off of an odds ratio of 3 to represent strong co-occurrences (which, due to its non-statistical nature, could result in the chance of random or non-significant interactions being included in the surrogacy matrix for optimisation). The empirical Bayes approach of Gotelli and Ulrich (2010) calculates multiple fixed/fixed null models of the network, which take into account both the commonness and rarity of different species and the differences among sites in suitability. The associations within these models are calculated for different co-occurrence scores (C-scores) to derive expected numbers of associations for each score bin, then the observed co-occurrences are compared with those expected under random distributions to determine how many associations were non-random with respect to aggregation (i.e. positive co-occurrence, indicated by a low C-score) or segregation (i.e. negative co-occurrence, indicated by a high C-score). This approach is known to be a more conservative way of estimating co-occurrences (von Gagern et al. 2015). Our sensitivity analyses therefore compared the outcomes of using one co-occurrence matrix approach sensitive to Type I errors (false positives; the odds ratio method with arbitrary cut-offs of Lane et al. 2014), with another approach sensitive to Type II errors (false negatives; the C-score null model approach of Gotelli and Ulrich 2010).

We took the empirical binary presence-absence matrix of the first 1-3 years of bird occurrences in the Booderee National Park heathland case study (scenario 2a) and used EcoSimR version 0.1.0 (Gotelli et al. 2015) to test for non-random co-occurrence, by calculating C-scores (Stone and Roberts 1990), which evaluate the tendency of species not to co-occur; using the default settings. We then tested for non-random associations between pairs of species using the PAIRS program (Ulrich 2008). A total of 1000 random matrices were obtained to generate C-scores using the fixed row and fixed column constraints algorithm (Gotelli and Ulrich 2010). Significant species under-dispersion or over-dispersion (at the 5% probability level) is indicated by Z-transformed scores (observed C-score - expected C-score) above 1.96 or below -1.96 (Ulrich and Zalewski 2006).

We then reran our surrogacy optimisation for this new statistical association matrix. The results of these optimisations were compared with the optimisation results based on our original odds ratio matrices from the corresponding scenario, to determine how sensitive our odds ratio results were to including random species pairs. We reran the above analyses for the presence-absence matrix of the first 1-3 years (scenario 2a), and 1-5 years (scenario 2b) of bird occurrences to determine if the best set of surrogates changed over time when an alternative co-occurrence measure was used.

In the Booderee NP heathland, using a conservative null model analysis (Gotelli and Ulrich 2010) to eliminate non-random associations supports the results of our less conservative odds ratio threshold approach that indicates that species are more segregated and aggregated than expected by chance. For the 1 to 3 year dataset (scenario 2a), null model analysis suggests there are 50 more positive species co-

occurrences than expected by chance (aggregation), and 28 more negative species co-occurrences than expected by chance (segregation). This compares with 604 positive species co-occurrence relationships derived from our odds ratio method alone. For the 1 to 5 year dataset (scenario 2b), null model analysis indicates there are 80 more positive species co-occurrences and 42 more negative species co-occurrences than expected by chance (compared with 877 positive species co-occurrence relationships derived from the odds ratio method alone). Using only the statistically non-random associations in the surrogacy optimisation results in different sets of top surrogates compared with using the odds ratio results without testing for significance of the relationship between each species pair (Figure S9). For the 1 to 3 year dataset (scenario 2a) and an objective of achieving surrogacy power across 70% of species, four surrogates (Australian Magpie, Australian Raven, Sacred Kingfisher, Southern Emu-wren) out of eleven are robust to the co-occurrence method used – the other 7 selected surrogates in each set are unique to the set depending on which matrix was used (only odds ratios, or only non-random associations; Figure S9). Similar results are found when comparing the sets selected using the 1 to 5 year dataset and either odds ratios with an arbitrary cut-off (Figure S9a) or statistically non-random associations only (Figure S9b), with one shared species between the methods, and the rest of the set unique.

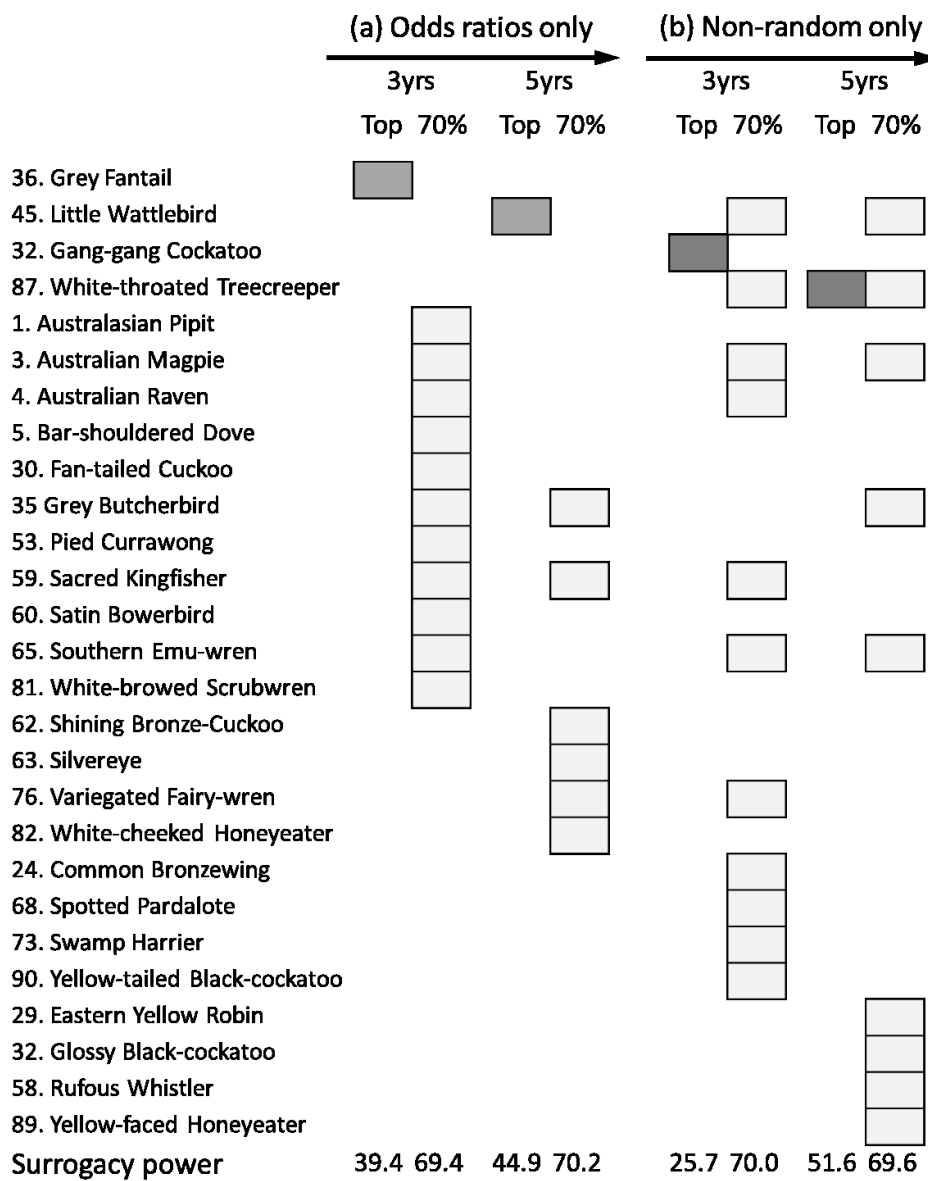
Bray-Curtis dissimilarity indices show that the optimal solutions (achieving 70% surrogacy power under each scenario) within and between scenarios have little overlap (average dissimilarity 72%). Within scenarios (and between co-occurrence methods), the dissimilarity in optimal surrogate sets is 64% (scenario 2a) and 87% (scenario 2b). Encouragingly, the selected surrogates change between scenarios of temporal coverage of data regardless of the co-occurrence measure used (Figure S9). Under the conservative co-occurrence method of Gotelli and Ulrich (2010), we find 38% overlap in the surrogate sets representing 1 to 3 years and 1 to 5 years post-fire (Bray-Curtis index = 0.62), compared with 24% overlap dissimilarity under our odds ratio threshold approach (Bray-Curtis index = 0.76). Our findings therefore appear to be robust to the method used to derive species co-occurrence matrices.

Because the optimal surrogates are sensitive to the co-occurrence matrix used, we suggest that careful thought is needed about whether researchers or managers are more willing to accept Type I or Type II errors in their monitoring and management surrogate selection. More research is required to determine whether sensitivity to co-occurrence metrics for selecting surrogates is unique to dynamic networks of species co-occurrence, or if it remains true in more stable environmental contexts.

The change over time in optimal surrogates selected using the conservative null model approach (under scenarios of 1 to 3 years versus 1 to 5 years after fire) is similar to the change in the optimal set of surrogates selected using our original odds ratio approach (Figure S9). This provides further support to our conclusions that, regardless of *how* we measure co-occurrence, the best set of surrogates is



dependent on the successional state of the system in dynamic environments. Surrogate sets need to be dynamic to ensure that community succession in successional landscapes is detected.



**Figure S9.** Composition of best surrogate sets for datasets of 1 to 3 years and 1 to 5 years coverage in the Booderee National Park heathland, with species co-occurrence matrices calculated using either (a) our odds ratio approach excluding all ‘weak’ positive co-occurrences under an arbitrary threshold of 3 (Lane et al. 2014), or (b) a C-score approach that excludes all random positive co-occurrences (Gotelli and Ulrich 2010). Showing the best single surrogate (dark grey boxes) and the best complementary set of surrogates achieving 70% surrogacy power (light grey boxes).

## Appendix 3. Details of network subsets

### 3.1. Details of expected communities under different network subsets

We construct a set of monitoring scenarios that subset the network dataset in ways that reflect different decisions about when to select surrogates during a monitoring program, and consequently are likely to represent different ecological and successional communities (see Table S7).

**Table S7.** Details of each monitoring scenario in terms of the ecological community that the data are intended to represent.

| Scenario  | Definition of community | Details of survey data subsetting in case studies  | Possible cause of change in species co-occurrence networks due to sampling effort (compared with network derived from combining data from all years) | Possible cause of change in species co-occurrence networks due to ecological change (compared with network derived from combining data from all years) |
|---|-------------------------|--|--|--|
| 1. Monitor all sites and all years                  | All time                | Use all available survey data (11 years)   | NA   | NA   |
| 2. Short-term monitoring directly after disturbance | Early successional      | Use data only from the first (a) 3, (b) 5, (c) 7, or (d) 9 years after disturbance       | Continuous sampling but too few data to detect non-random associations or rare species, or might miss late-successional associations                 | Community change over time (between-year) due to succession over short time-frames   |
| 3. Wait for response lag                            | Late successional       | Use data only from the second half of survey years (survey 6-11 years after disturbance) | Continuous sampling but too few data to detect early-successional associations   | Community change over time (between-year) due to succession over longer time-frames  |
| 4. Survey only in one season: (a) spring            | Breeding                | Use data only collected in spring; only for Southwest Slopes                             | Sampling missing intra-seasonal variation  | Alternative community states (within-year) due to resources fluctuating with seasons and immigration of breeding birds                                 |
| 4. Survey only in one season:                       | Non-breeding            | Use data only collected in winter;   | Sampling missing intra-seasonal  | Alternative community states   |

|                                   |          |   |   |  |
|-----------------------------------|----------|---|---|--|
| (b) winter                        |          | only for Southwest Slopes   | variation   | (within-year) due to resources fluctuating with seasons and emigration of breeding birds                             |
| 5. Reduce frequency               | All time | Survey only once every two years  | Sampling too infrequent   | Cyclical community states (between-year) due to resources fluctuating regularly with years (this is highly unlikely) |
| 6. Reduce temporal cover randomly | All time | Randomly select half of all surveys (Southwest Slopes: 354 surveys; Booderee NP heathland: 130 surveys) | Random sampling results in inability to detect non-random associations, intra-seasonal variation and rare species | Community co-occurrence patterns are truly random (this is highly unlikely)  |

### 3.2. Costs of monitoring strategies for deriving different network subsets

Our study assumes equal costs of surveys for each species. This is acceptable for the bird survey datasets we used as all data for each study came from the same survey technique and methodology (standardised point counts for birds). Costs that vary between species can also be incorporated in the optimisation. Because all surveys in our study were of equal duration, the total survey effort for a given monitoring strategy is simply equal to the number of surveys in the dataset (Tables S8 and S9). We did not include travel costs as the sites were relatively close together, but in other cases travel time might need to be incorporated as well.

**Table S8.** Survey effort for ten scenarios of data collection in the Southwest Slopes bird monitoring dataset.

| <b>Surrogate matrix</b> | <b>Strategy</b>  | <b>No. of surveys</b> | <b>No. of trips (i.e. years of data)</b> | <b>Number of surveys * trips</b> | <b>Number of species detected</b> |
|-------------------------|------------------|-----------------------|--|----------------------------------|-----------------------------------|
| 1                       | 1 – 11 yrs (all) | 708                   | 12                                       | 8496                             | 150                               |
| 2                       | 1 – 5 yrs        | 261                   | 5  | 1305                             | 118                               |
| 3                       | 6 – 11 yrs       | 447                   | 7  | 3129                             | 140                               |
| 4                       | spring           | 406                   | 7  | 2842                             | 141                               |
| 5                       | winter           | 302                   | 5  | 1510                             | 115                               |
| 6                       | 1 in 2 yrs       | 497                   | 6  | 2982                             | 132                               |
| 7                       | 1 – 3 yrs        | 131                   | 3  | 393                              | 101                               |
| 8                       | 1 – 7 yrs        | 456                   | 8  | 3648                             | 140                               |
| 9                       | 1 – 9 yrs        | 586                   | 10                                       | 5860                             | 148                               |
| 10                      | random half      | 354                   | 12                                       | 4248                             | 122                               |

**Table S9.** Survey effort for eight scenarios of data collection in the Booderee National Park bird monitoring dataset.

| <b>Surrogate matrix</b> | <b>Strategy</b>  | <b>No. of surveys</b> | <b>No. of trips (i.e. years of data)</b> | <b>Number of surveys * trips</b> | <b>Number of species detected</b> |
|-------------------------|------------------|-----------------------|--|----------------------------------|-----------------------------------|
| 1                       | 1 – 11 yrs (all) | 260                   | 10                                       | 2600                             | 90                                |
| 2                       | 1 – 5 yrs        | 130                   | 5  | 650                              | 75                                |
| 3                       | 6 – 11 yrs       | 130                   | 5  | 650                              | 66                                |
| 4                       | 1 in 2 yrs       | 156                   | 5  | 936                              | 78                                |
| 5                       | 1 – 3 yrs        | 78                    | 3  | 234                              | 68                                |
| 6                       | 1 – 7 yrs        | 182                   | 6  | 1092                             | 83                                |
| 7                       | 1 – 9 yrs        | 234                   | 8  | 1872                             | 87                                |
| 8                       | random half      | 130                   | 10                                       | 1300                             | 74                                |

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