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Biodiversity values on selected Kimberley islands, Australia

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The avifauna of larger islands along the Kimberley coast, Western Australia

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ABSTRACT – Bird observations were collected opportunistically on 24 islands along the remote Kimberley coast of Western Australia between 2007 and 2010. We present a summary of our observations, along with bird data collated from other sources, to provide baseline inventories for these islands. A total of 157 species were recorded during our survey. The inclusion of other records increased the total number of bird species known from these islands to 179, with species richness for individual islands ranging from 22 to 95 taxa. We found that, in general, more bird species were observed on larger islands. Island attributes most closely correlated with observed bird assemblages included the extent of rugged habitat, the number of habitats and temperature in the warmest month of the year. No bird species or subspecies are confined to the Kimberley islands. Only one threatened bird species, the northern subspecies of the Masked Owl (*Tyto novaehollandiae kimberli*), is known to occur on the islands we sampled. Further surveys are required to better document the avifauna of these and other Kimberley islands and to improve our understanding of the biogeographical patterns of Kimberley island birds.

KEYWORDS: birds, Kimberley coast, inventory, species richness, island attributes

INTRODUCTION

The study of insular birds has been fundamental in the development of theories of evolution (Darwin 1859) and island biogeography (Simberloff and Wilson 1969; Diamond and Mayr 1976). Birds are a readily observed (and heard) part of the vertebrate fauna and usually display considerable species richness and abundance often making their study more amenable than other vertebrate groups. However, birds are also much more mobile, so barriers to movement, such as inter-island distances, are less significant for most species (except for a few taxa such as fairy wrens) in determining island avifaunas. Distinct island forms are less likely to develop; except where islands are isolated or existing bird taxa have limited dispersal capabilities (Diamond 1975). Islands may also support more species than their habitat diversity would suggest, as birds can utilize an island's resources and then move to other islands or to the mainland. Other species, such as migratory or nomadic waders, may also visit islands to use small areas of habitat such as fringing mangroves and associated mudflats.

The study of island avifaunas has been extensive around the world. In Australia, there have been a number of studies documenting insular bird faunas ranging from species lists (e.g. Robinson and Smyth 1976; Abbott 1979, 1982; Lane 1982) to more complex analyses of the causal factors underlying the presence and distribution of birds on islands (Draffan et al. 1983; Woinarski et al. 2001). The work of Draffan et al. (1983), examining birds occurring on the islands in the Torres Strait, and Woinarski et al. (2001) on the Wessel and English Company Islands off the Arnhem Land coast, provide particularly useful datasets for comparison with the patterns we observed in the avifauna of the Kimberley islands.

The Kimberley region is situated within the Timorian zoogeographic sub-region (Heatwole 1987). Its avifauna shows greater affinity to that of other areas of northern Australia (the 'Top End' of the Northern Territory (NT) and North Queensland), than to the remainder of Western Australia (Johnstone and Storr 1998). These regions share similar seasonal tropical climates and are dominated by vast areas of savannah woodlands. Despite the separation of north-west Kimberley rainforests from similarly wet areas of the NT by more arid country around the Joseph Bonaparte Gulf, there has been surprisingly little geographic differentiation of bird taxa between them (Johnstone and Storr 1998). In contrast, birds that occur in drier habitats have shown

considerable divergence between Arnhem Land (NT) and the Kimberley with the evolution of a number of distinct subspecies (Johnstone and Storr 1998).

The mangroves that fringe the Kimberley coast and islands are home to one of the world's richest mangrove bird faunas; up to 20 species are confined or predominantly confined to these habitats (Johnstone 1990). Kimberley shorebirds (oystercatchers, plovers, sandpipers and others) include some resident species, but many species are migrants that arrive each year to utilize the extensive mudflats of the Kimberley and so escape the north Asian winter (Johnstone 1990).

Draffan et al. (1983) documented bird records for 80 continental and oceanic islands in the Torres Strait. For 34 islands, they had sufficient data to model the biogeographical associations of the birds in relation to environmental variables. They found that bird species richness was more closely related to the area of forest or woodland on an island rather than its actual area or any other measure of ecological diversity they examined. Almost half of the bird species seen in the Torres Strait were migratory; with several using the islands as resting places during migration (Draffan et al. 1983).

The avifauna of the Wessel and English Company Islands situated off the Arnhem Land coast of the NT was examined by Woinarski et al. (2001) using quadrat counts and island searches. They recorded 171 species across the 62 islands sampled. A strong relationship existed between the number of species present on an island and its area. The terrestrial bird composition of these islands showed patterns related to their area and degree of isolation. The abundance of some widespread species was found to be relatively higher on smaller islands (Woinarski et al. 2001).

Along the north-western coast of Australia bordering the Kimberley mainland, there is estimated to be around 2630 islands (Conservation Commission of Western Australia 2010). Uncertainty as to the actual number is complicated by the fractured rocky coastline, huge tidal ranges, shifting mud banks and extensive intervening mangrove stands that may join and isolate islands from the mainland or other islands. Most are continental islands, separated from the mainland by sea level rises commencing around 10,000–12,000 years ago with current sea levels attained around 6000 years ago (Nix and Kalma 1972; Thom and Chappell 1975; Burbidge and McKenzie 1978). There are a smaller number of oceanic islands formed from deposited sand, mud and coral rubble but these tend to be situated well offshore. These oceanic islands are very important as roost and nesting sites for birds, especially pelagic and inshore seabirds (Storr 1980; Johnstone and Storr 1998; Kirkwood and O'Connor 2010).

The avifauna of the Kimberley region was extensively described by Storr (1980), but there has been considerable additional work since the publication of that volume. Johnstone (1990) published a detailed account of mangrove birds along the Western Australian coastline including the Kimberley and its islands. While there has been no specific treatment of the birds of the Kimberley islands, especially terrestrial species (i.e. non-marine or wetland taxa), there are relevant data on the distribution of bird species on Kimberley islands in a number of publications such as Smith et al. (1978) and Johnstone and Storr (1998, 2004).

The collection of bird data on the Kimberley islands described here was undertaken as part of a broader biodiversity survey to document the fauna and flora of the largest islands and to assess their conservation value as natural refuges for species susceptible to threatening processes operating on the mainland (see Gibson and McKenzie 2012). The survey provided an opportunity to sample the avifauna on many of the larger islands to better understand the biogeography of Kimberley island birds in relation to a suite of environmental variables and to identify populations of taxa threatened on the mainland such as some granivorous birds including pigeons and finches (Franklin 1999; Carwardine et al. 2011).

METHODS

SURVEY AREA

The islands along the Kimberley coast span a considerable latitudinal (14° to 16°40'S) and longitudinal (approximately 123° to 128°E) range. Only 145 are larger than 100 ha in area and just 20 larger than 1000 ha (Conservation Commission of Western Australia 2010). The islands are primarily underlain by three major sandstone strata (Warton, King Leopold and Pentecost units) and two volcanic units (Carson Volcanics and Hart Dolerite). The sandstones tend to give rise to rugged and dissected terrain featuring fractured blocks and extensive cliff lines. The two volcanic rocks tend to weather to produce richer dark soils on undulating hills. There are limited areas of Tertiary laterite. Around the coastline and margins of islands are extensive deposits of Quaternary beach sands and grey saline mud in bays (Gibson and McKenzie 2012).

Vegetation on the islands and its relationship to geological surfaces and landforms is outlined in detail by Gibson and McKenzie (2012). In brief, the major vegetation communities on the islands were: tropical savannas of *Eucalytpus* and *Cormybia* spp. with a grassy understorey of hummock or

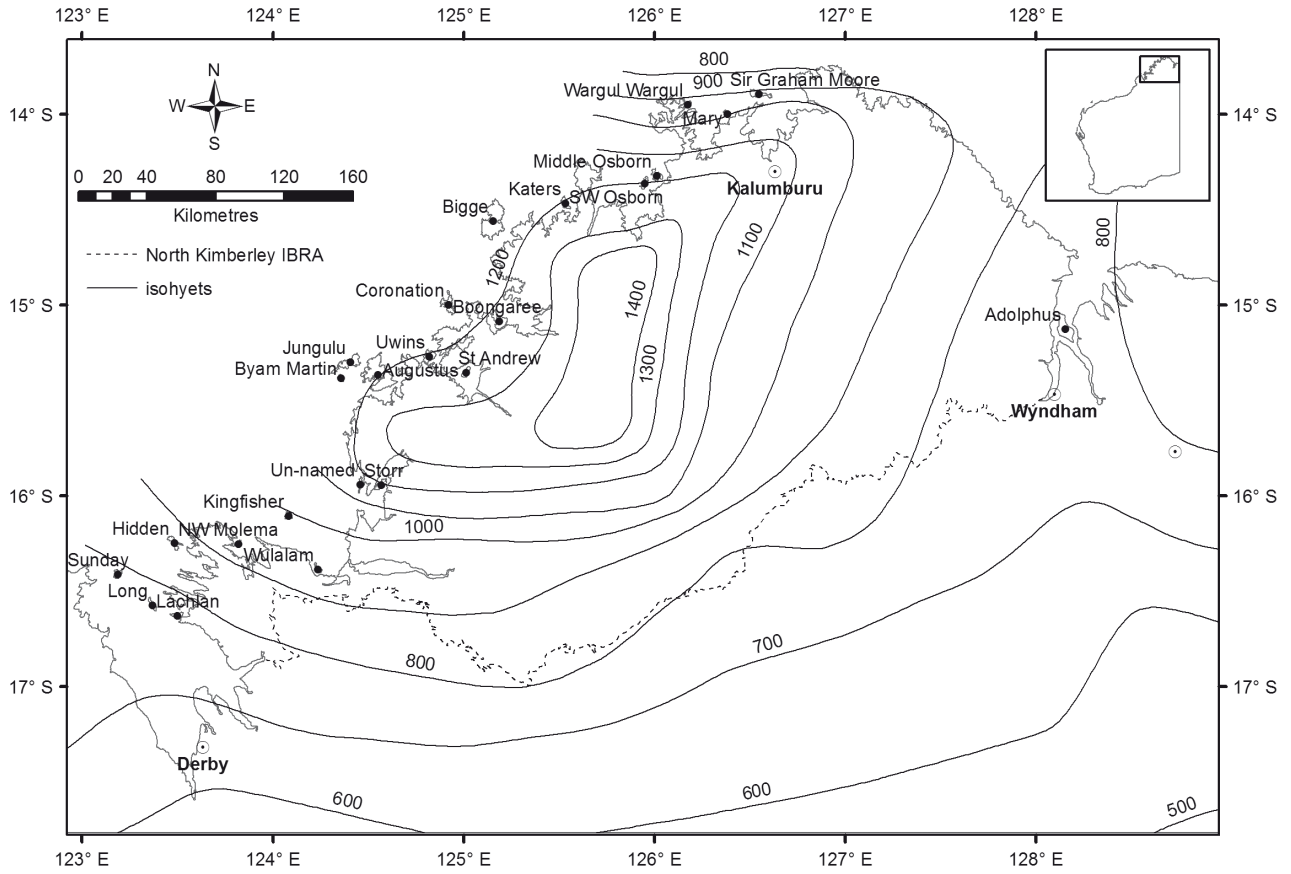

FIGURE 1 The location of sampled islands along the Kimberley coast with an inset map showing the position of the study area within Western Australia.

tussock grasses; hummock grasslands of *Triodia* spp. typically on rocky surfaces; tall shrublands of *Acacia* spp. on sand sheets; mangroves of mixed species composition; monsoon rainforest along drainage lines and in scree; riparian *Melaleuca*, *Lophostemon* and *Pandanus* woodlands; and *Spinifex* tussock grassland on foredunes (Gibson and McKenzie 2012). Monsoon rainforest generally occur as small patches growing in fire-protected sites and on pockets of richer soil, with the most diverse and extensive patches occurring in the highest rainfall area of the north-western Kimberley (McKenzie et al. 1991).

STUDY SITE SELECTION

A subset of the larger islands were selected for the multi-taxa survey, based on the rationale that relatively large islands were more likely to display greater species diversity, have greater substrate, topographic and vegetation variation, and have a greater capacity to withstand the impacts of disturbances such as fire. In addition, some islands were chosen to sample gradients in rainfall, distance from the mainland and other islands, and proximity to river mouths (see Gibson and McKenzie 2012). Koolan Island was excluded as it is well studied due to environmental assessments associated with existing iron ore extraction projects. Cockatoo Island has a long term and currently active iron ore mine and active exploration was underway on Bathurst and Irvine Islands. Due to logistical and safety issues, none of these islands were surveyed. Islands that were joined to the mainland at low tide or by mudflats, reef or mangrove communities were also rejected since their position may have permitted the passage of terrestrial species (Gibson and McKenzie 2012). Byam Martin Island was sampled after it was found that the nearby and larger Champagny Island had been almost totally burnt by a recent wildfire.

Table 1 lists the 24 islands surveyed, their area and other salient features. Figure 1 shows their distribution along the coastline in relation to mean annual rainfall gradients. All surveyed islands were either Unallocated Crown Land or gazetted Aboriginal Reserves and all islands are currently under native title claim (Gibson and McKenzie 2012).

TABLE 1 Location of the 24 Kimberley islands sampled during the survey and values of the island attributes used to examine bird assemblage associations.

Notes: Latitude and longitude calculated for the mid-point of the island. Island 'Area' extends down to high water mark. 'Number of habitats' refers to how many of nine identified habitat types occur on the island (scree, massive boulder faces and cliffs, alluvial flats, volcanic slopes, rainforest, mangrove, beach sand, sandplain and riparian). 'Boulder' relates to the extent of rock outcrops and the size of scree. Generally the more rugged, the more sites are protected from fire (0 = flat, outcrops mantled by soil; 1 = rounded, soil-mantled hill slopes and plateaux; 2 = shallow joints, wide ledges and moderate scree development; 3 = massive scree, deep joints and scarp country).

Island	Latitude (°S)	Longitude (°E)	Area (ha)	Shortest distance to mainland (km)	Mean annual rainfall (mm)	Maximum temperature of the warmest period (°C)	Number of habitats on the island	Boulder	Maximum elevation (m)
Adolphus	15.1120	128.1483	4134	1.96	827	37.6	4	2	244
Augustus	15.3614	124.5516	18,929	1.79	1170	34.2	6	3	181
Bigge	14.5553	125.1560	17,108	2.97	1103	34.6	8	3	138
Boongaree	15.0776	125.1871	4164	0.14	1138	35.3	6	3	235
Byam Martin	15.3792	124.3577	816	13.28	1144	33.6	5	3	69
Coronation	14.9927	124.9221	3791	6.07	1141	34.8	7	2	153
Hidden	16.2431	123.4824	1871	1.48	839	33.2	3	3	127
Jungulu	15.2959	124.4068	4803	18.91	1148	33.9	5	3	95
Katers	14.4637	125.5336	1713	1.40	1069	35.0	6	3	101
Kingfisher	16.1073	124.0752	300	15.47	943	34.0	4	1	82
Lachlan	16.6247	123.4984	1150	0.17	787	33.9	5	2	93
Long	16.5697	123.3690	1125	9.36	768	34.0	4	2	65
Mary	13.9923	126.3831	847	0.68	968	34.5	5	0	11
Middle Osborn	14.3182	126.0131	2378	2.34	1051	34.5	6	2	240
NW Molema	16.2488	123.8208	592	1.06	881	33.4	3	2	154
St Andrew	15.3522	125.0139	1465	2.23	1127	35.7	5	2	284
Sir Graham Moore	13.8896	126.5494	2812	2.84	979	34.4	7	1	61
SW Osborn	14.3582	125.9508	1340	3.07	1041	34.8	6	3	134
Storr	15.9413	124.5659	1883	0.26	1007	35.4	6	3	165
Sunday	16.4059	123.1869	1186	8.06	778	33.2	3	2	59
Un-named	15.9367	124.4590	897	0.69	1000	35.2	6	2	83
Uwins	15.2662	124.8202	3219	0.23	1155	34.8	5	3	134
Wargul Wargul	13.9442	126.1758	626	0.25	946	33.7	6	1	87
Wulalam	16.3711	124.2290	415	0.86	901	35.3	4	1	77

SURVEY TECHNIQUES

Sampling of the islands took place between July 2007 and June 2010. Four 'dry' season trips (in the period May to August each year) and three 'wet' season trips (February 2008, January/February 2009, February 2010) were undertaken. The primary focus of the survey was to sample biotic groups that had declined markedly on the mainland (terrestrial mammals) and those most susceptible to current disruptive influences, including the arrival in the north Kimberley of the introduced cane toad. Logistical constraints precluded detailed systematic sampling of island bird communities. Consequently, birds were recorded on an opportunistic basis.

The dry season surveys were carried out by three teams each consisting of two vertebrate zoologists, a botanist, a land snail expert and typically two Aboriginal Traditional Owners (see Gibson and McKenzie 2012). Each team had at least one experienced ornithologist; however, bird sightings were collated from all team members. Islands were accessed by helicopter and a campsite selected on the basis of its access to as many habitats (combinations of substrate and vegetation types) as possible. Most islands were only sampled from one camp, but seven of the largest islands (Augustus, Bigge, Sir Graham Moore, Middle Osborn, Coronation, Darcy and Adolphus) were sampled by us at two sites to allow better coverage of their environmental variation. Teams remained at each campsite for six days, after which, each team was picked up by helicopter and moved to another campsite where sampling commenced again.

Wet season surveys were much shorter in duration, using a chartered vessel and/or a helicopter to visit the islands (see Gibson and McKenzie 2012). Individual islands were visited for around one day and a night during these surveys.

Birds were recorded opportunistically while placing or checking ground-vertebrate traps, during flora sampling, searching for land snails or on exploratory trips away from the campsite. Many bird species were also observed at campsites during rest periods. Team members carried binoculars to enable close examination of features to aid bird identification. Each evening, bird sightings were discussed by the team, checked against field guides and collated to build up a list for each island. These data took the form of presence records; there was no attempt to record abundance of taxa, nor were rigorous searches undertaken to locate nests or other indications of breeding activity. Similarly, our limited temporal sampling meant that we were unable to obtain data on whether species were resident, nomadic or migratory. The Kimberley islands are part of a major flyway for Northern Hemisphere shorebirds and to a lesser extent, Palaearctic land birds. Many of these species overwinter in the Kimberley and northern Australia while others disperse widely through mainland Australia (Johnstone and Storr 1998).

On a few occasions, birds (especially quail) were captured in traps set for mammals or reptiles or dead individuals were found and photos taken for later checking with field guides. The taxonomy we have used follows that of the most recent Western Australian Museum checklist (Johnstone 2009).

In addition to the bird sighting data we recorded during the surveys, we searched the literature to locate other published records and also obtained unpublished notes from visits to the islands by ornithologists (see Table 2 for a listing of these resources). Some islands had been visited on several occasions and birds recorded; while other islands had been rarely visited and had no available bird lists.

DATA ANALYSIS

We selected a number of environmental attributes that have been shown to influence composition of bird assemblages on islands to run in the analyses (e.g. Woinarski et al. 2001). These included island size, distance to the mainland, average annual rainfall, maximum temperature of the warmest period and maximum elevation of an island (Table 1). We also included a habitat descriptor called 'Boulder' which represents the abundance of scree on each island (this constitutes a refuge habitat). It was a derived character based on subjective assessment on a scale of 0–3 of the extent of rock outcrops and the size of scree (Table 1). Since cliffs and scree cause fires to reticulate or limits their spread, their existence provides some protection for fire-susceptible vegetation types such as monsoon rainforest. Islands ranked '0' for 'Boulder' were flat with no outcrops through to '3' which had massive scree, deep joints and scarps. A further habitat descriptor 'rainforest' representing the extent of monsoon rainforest on each island (0–3; none to substantial patches on islands) was considered. Additionally, a subjective assessment of the number of habitats on an island was included and refers to how many of nine identified habitat types occur on the island (i.e. scree, massive boulder faces and cliffs, alluvial flats, volcanic slopes, rainforest, mangrove, beach sand, sandplain and riparian).

We defined island size as the area of land mass (ha) that was unlikely to be inundated and this was determined from digitised 1:100,000 topographic maps. Maximum elevation (m) was also extracted from the 1:100,000 topographic maps. Distance to the mainland (km) was estimated using Google Earth™ imagery. Rainfall and temperature values were derived using the BIOCLIM module of ANUCLIM (Houlder et al. 2000). All environmental variables were tested pairwise for correlations using Pearson correlation coefficient. One of any

TABLE 2 Published and unpublished data used to supplement bird species lists collected for 24 Kimberley islands. Further details can be found in the Reference list.

Source	Years	Islands	Data form/Reference
R. Söderberg	1910–13	Sunday	Söderberg (1918); WA Museum library
L. Smith, R. Johnstone and J. Dell	1971–73	Augustus, Bigge, Boongaree, Byam Martin, Coronation, Jungulu, Katers, Kingfisher, Mary, Middle Osborn, St Andrew, South West Osborn, Sir Graham Moore, Uwins	Smith et al. (1978)
R. Johnstone and A.H. Burbidge	1987–89	Augustus, Bigge, Boongaree, Middle Osborn, St Andrew, South West Osborn, Storr	Johnstone and Burbidge (1991)
K. Coates	1987–2009	Bigge, Coronation, St Andrew, Storr, Sunday, Wargul Wargul (Woku Woku)	Unpublished notes
G. Storr	1980	Augustus, Bigge, Boongaree, Byam Martin, Coronation, Jungulu, Katers, Kingfisher, Middle Osborn, South West Osborn, Sir Graham Moore, St Andrew, Uwins	Storr (1980)
N. McKenzie	1982	Hidden, Lachlan, Long, Sunday	Unpublished notes from Buccaneer Archipelago survey
R. Johnstone	1990 review	Augustus, Bigge, Boongaree, Byam Martin, Coronation, Hidden, Katers, Kingfisher, Sir Graham Moore, South West Osborn, Sunday, Uwins	Johnstone (1990)
R. Johnstone and G. Storr	1998 review	Numerous islands	Johnstone and Storr (1998) Handbook of Western Australian Birds Volume 1
A.H. Burbidge	2003	Adolphus, Bigge	Unpublished notes
R. Johnstone and G. Storr	2004	Numerous islands	Johnstone and Storr (2004) Handbook of Western Australian Birds Volume 2
M. Bamford	2006	Bigge	Unpublished notes
D. Pearson	2011	Adolphus	Unpublished notes

pair was rejected from the final dataset where this value was equal to or exceeded 0.8. A strong inter-correlation between rainforest and rainfall was revealed (P = 0.8); the latter was retained in the analysis as rainfall was considered more informative.

For the analysis, 13 marine species and seven mangrove specialists were removed from the data matrix (these species are indicated in Appendix 1). The marine species are those that are almost entirely present over the open sea and so were not readily seen by island-bound observers. These species did not utilize the terrestrial portion of the islands (e.g. terns, frigatebirds). Mangrove specialist birds were removed from the analysis as on several islands (Augustus, Darcy, Hidden, Katers, Kingfisher, NW Molema, Storr and Wargul Wargul) survey campsites were not located near mangroves so sampling was not possible.

A multivariate statistical approach was used to examine bird assemblage structure between island pairs and to assess the contribution of the environmental variables to the observed patterns. A similarity matrix for the 24 sampled islands was prepared using the resemblance routine in PRIMER v6 (Clarke and Gorley 2006). The default Bray-Curtis distance coefficient was used which when applied to occurrence data, as was the case here, is equivalent to the Sorensen coefficient. This coefficient provides double weight to double presence since the presence of a species is more informative than its absence (Legendre and Legendre 1998). The resultant association matrix was clustered using the unweighted pair-group method with arithmetic

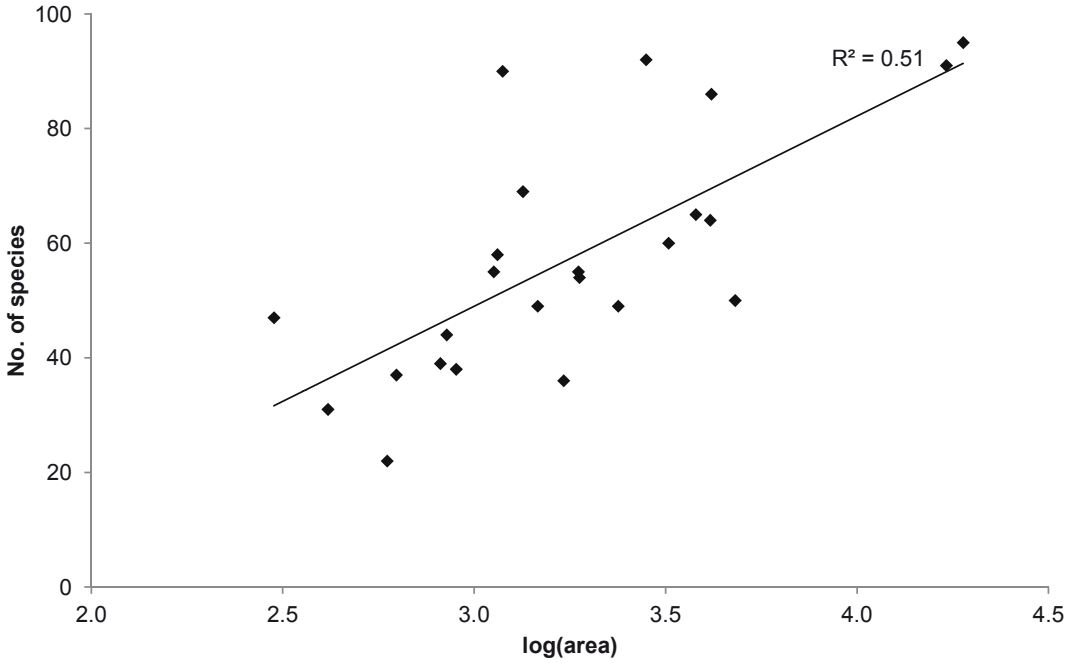

FIGURE 2 Number of bird species recorded on each island in relation to island area for 24 sampled Kimberley islands.

mean (UPGMA) to produce a dendrogram.

Since it is often difficult to interpret bio-geographical relationships from a dendrogram (Fattorini 2010), the defined clusters were overlain on a non-metric multi-dimensional scaling ordination (nMDS), while preserving relative distance relationships between all points. This nMDS ordination plot was used to examine trends in similarity between islands with all existing bird data. An arbitrary cut point of 60% similarity was used as it provided what appeared to be reasonable number of clusters to enable meaningful interpretation.

Permutated species accumulation curves were produced in PRIMER using the islands as samples. The Chao 2 and Jacknife 1 species richness estimators were used as they are considered to give a meaningful view of species richness where only occurrence data are available (Magurran 2004).

The relationship between environmental variables and the island bird association matrix was investigated using the BEST function in PRIMER. The BEST routine searches for individual and combinations of variables that produce the highest Spearman rank correlation with a sample-based association or resemblance matrix. These data were normalised prior to analysis and the default settings of a maximum of five trial variables and the 10 best results was chosen in the BIOENV function. Statistical significance was tested using 99 trials in the permutation test.

The degree of spatial structure in the bird composition was examined using the Mantel test. A Euclidian distance matrix was calculated for geographical distance based on the coordinates of the mid-points of the islands. The significance of the relationship between this matrix and the species association matrix were examined over 999 permutations. Partial mantel tests were used to examine the relationship between species similarity and each of the environmental attributes identified above, while holding the geographic distance matrix constant. All Mantel tests were performed using the program PASSaGE 2.0.11.6 (Rosenberg and Anderson 2011).

RESULTS

ISLAND BIRD INVENTORY

We recorded a total of 157 species of birds on the 24 islands we sampled. The number of species on individual islands ranged from 22 (Hidden and NW Molema) to 60 (Sir Graham Moore). When data collected during our survey were combined with records from the literature or unpublished lists (as outlined in Table 2), a total of 179 bird species are now known from the islands we sampled (Appendix 1). Using this expanded dataset, the number of bird species on individual islands ranged from 22 (NW Molema) to 95 (Augustus). No species or sub-species of birds are known to be restricted to any Kimberley island, although populations of nationally and internationally recognised species of concern are present on some islands. The relationship between the number of bird species recorded on each island and its area is shown in Figure 2.

Species accumulation data (Figure 3) indicates

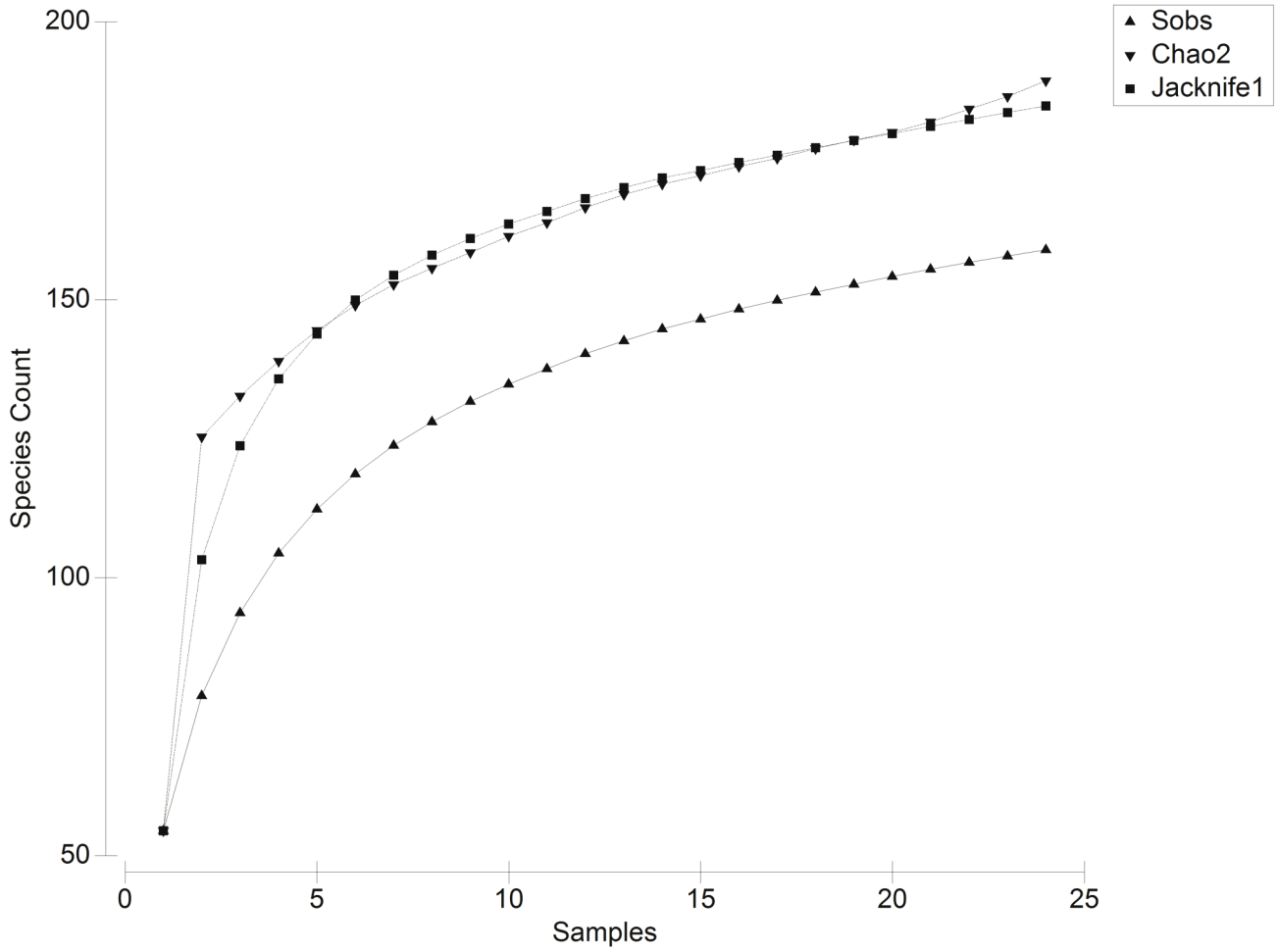

FIGURE 3 Species accumulation plots of species observed (Sobs). Chao 2 and first order Jacknife estimators for the 24 islands are also shown.

that at the conclusion of this work, and with the incorporation of all available occurrence records for each island, further search effort and/or an increase in the number of islands sampled would result in additional species being recorded. The Chao2 and Jacknife 1 estimators were in close agreement indicating that between 85% and 87%, respectively, of the collective island avifauna had been identified.

BIRD ASSEMBLAGES

The Leaden Flycatcher, Brown Honeyeater and Bar-shouldered Dove were ubiquitous, occurring on all 24 islands surveyed. The Pheasant Coucal, Black-faced Cuckoo-shrike and Rainbow Bee-eater were recorded on 23 islands, while the Brahminy Kite was recorded on 22 islands. Forty-eight species occurred on at least half of the islands surveyed. In contrast, 31 bird species were recorded on just one island; typically larger islands or those with a longer history of observations (e.g. Sunday Island). Consequently, the bird lists for these islands tended to also include rare species or vagrants. These single records included ducks, terns, waders, pigeons, cuckoos and finches.

The nMDS ordination plot of the combined data for terrestrial birds (this survey, unpublished observation and literature records) identified nine clusters when cut at the 60% similarity point (2D stress = 0.2; Figure 4). The largest cluster contained nine islands, while four islands did not cluster with any other. Some of the islands which clustered together were widely separated geographically; while others in close proximity and with similar climatic conditions and geology were clustered separately. This complicated the consideration of the underlying environmental parameters (such as rainfall) that might explain the relative island assemblages.

The main cluster of nine islands lay off the central north-western coast of the Kimberley, the most mesic section of the coastline. These islands had relatively speciose terrestrial bird faunas

which were indicative of the types of habitat on the islands. Each had all or most of 26 widespread species (present on >15 islands) with generalised habitat requirements (e.g. Brown Honeyeater, Bar-shouldered Dove, Black-faced Cuckoo-shrike, Mistletoebird, Leaden Flycatcher, Northern Fantail, Red-winged Parrot and Rufous Whistler). In addition, they had a diverse suite of monsoon rainforest or riparian species (e.g. Rose-crowned Fruit-Dove, Pied Imperial Pigeon, Emerald Dove, Rainbow Pitta, Spangled Drongo, Yellow Oriole, Shining Flycatcher and Orange-footed Scrubfowl [Johnstone and Burbidge 1991]). These islands also had good representations of eucalypt woodland species (e.g. White-bellied Cuckoo-shrike, Red-tailed Black Cockatoo, Sulphur-crested Cockatoo, Blue-winged Kookaburra and White-winged Triller), rugged sandstone species (e.g. White-quilled Rock Pigeon, Sandstone Shrike-thrush and Little Woodswallow), predominantly but not-exclusively mangrove species (e.g. Mangrove Golden Whistler and Red-headed Honeyeater), and a few waders (e.g. Eastern Curlew). Interestingly, two islands within the geographic spread of this group of islands formed a separate cluster. Katers and Wargul Wargul islands formed a cluster on account of their depauperate species lists, with the absence of several near-ubiquitous species, and an absence of almost all rainforest/riparian species.

The second largest cluster of islands consisted of three islands in the Buccaneer Archipelago (Hidden, Lachlan and Long) and included Uwins Island, an island geographically located among distant islands in the largest cluster. The bird fauna of these four islands were delineated from other clusters by having a suite of species that occur in drier woodlands or grasslands (e.g. Common Bronzewing, Variegated Fairy-wren, and Little Corella).

Kingfisher, Sunday and Sir Graham Moore Islands surprisingly clustered together. Sunday and Sir Graham Moore both had diverse terrestrial bird lists (90 and 92 species, respectively) presumably on account of their diverse habitats and good

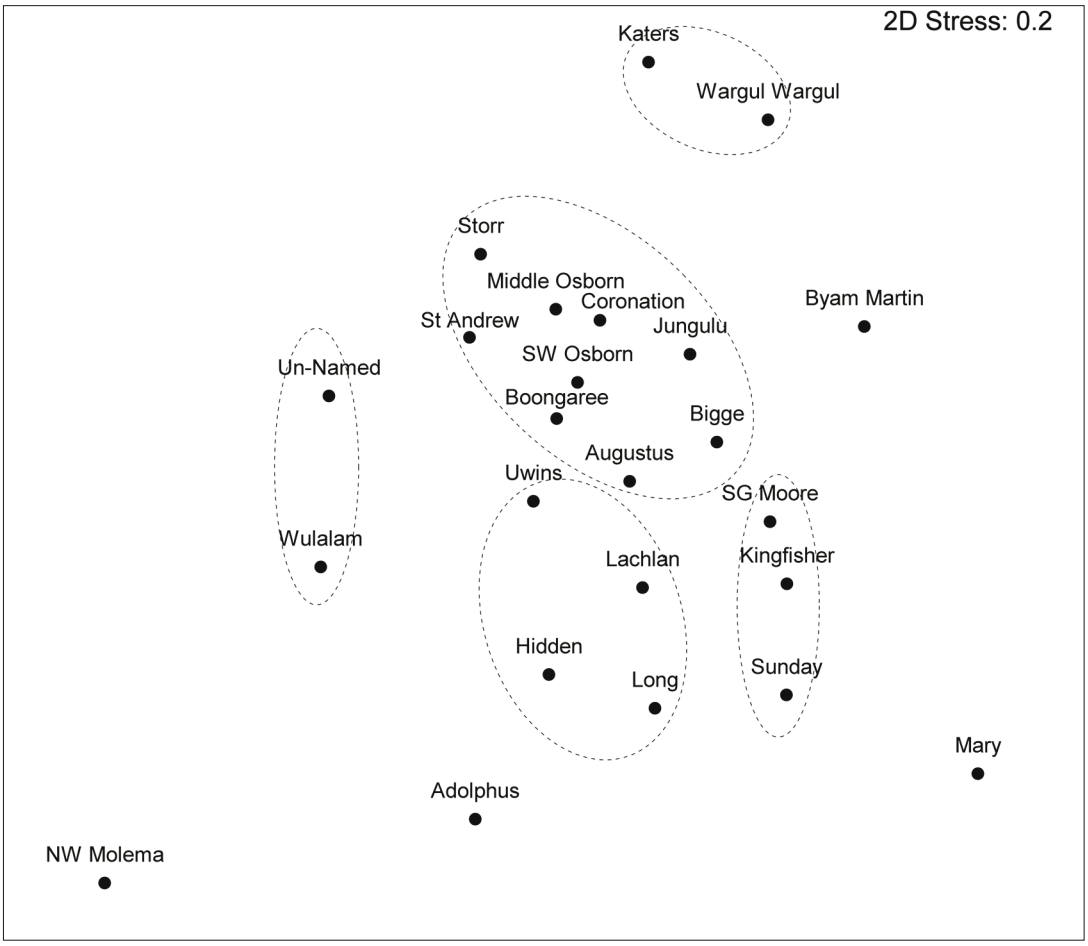

FIGURE 4 nMDS ordination of collated bird observations from the Kimberley island survey for 24 islands using the Bray-Curtis similarity coefficient (2D stress level = 0.203). Mangrove specialists and marine species were excluded (see Appendix 1).

historical data, but they also lie at the extreme ends of the north-western Kimberley coastline. In contrast, Kingfisher Island only had a recorded terrestrial avifauna of 47 species. The similarity in their avifauna assemblages is related to their shared array of shorebirds including Grey-tailed Tattler, Whimbrel and Eastern Curlew and a number of mesic forest species that can occur in monsoon rainforest or mangroves such as the Shining Flycatcher and Rose-crowned Fruit-Dove, but also some woodland birds such as Brown Quail and Grey Shrike-thrush.

Un-named and Wulalam Islands were clustered together due to their restricted bird lists (38 and 31 species, respectively), their absence of some near-ubiquitous species (e.g. Brahminy Kite and White-bellied Sea Eagle), as well as missing many widespread shorebirds such as the Beach Stone-curlew, Sooty Oystercatcher, Whimbrel and Striated Heron.

The remaining four islands did not cluster with any others. NW Molema had the smallest species list of any of the surveyed islands (22 species) with several of the most widespread species missing and an almost total absence of woodland taxa. Adolphus Island had an extensive bird list of 64 terrestrial species which includes the widespread species, good representations of dry woodland taxa, but was missing the rainforest species reflecting its position on the drier far-eastern part of the Kimberley coast. Byam Martin Island had moderate terrestrial bird species richness with a good representation of shorebirds and almost all of the widespread species, but it was missing many of the monsoon rainforest taxa as well as a mixed array of woodland species. Finally, Mary Island had an unusual assemblage of 44 species. It included a scattering of the widespread species, many woodland species, a diverse range of shorebirds, but no rainforest taxa (with the exception of the highly mobile Pied Imperial Pigeon).

ISLAND ATTRIBUTES AND ASSEMBLAGE PATTERNS

The BEST analysis identified that the strongest correlation between island attributes and the composition of bird assemblages (P = 0.468) included a combination of 'Boulder' ('ruggedness' or complexity of rocky habitat), the number of different habitats present on an island and the maximum temperature in the warmest period of the year.

Our examination of the spatial structure of the bird assemblages indicated that species similarity between islands decreased significantly with geographical distance (Mantel r = -0.239, P <0.05). When we corrected for the effect of geographical distance, the correlation of species similarity with 'Boulder' remained significant (Mantel r = -0.205, P <0.05).

DISCUSSION

SAMPLING ADEQUACY

The sampling of birds on the 24 Kimberley islands reported here clearly had limitations regarding the quantity and quality of data that could be collected. This means there are important caveats on the potential interpretation of our results. Birds were recorded on an opportunistic basis, largely while carrying out other biological survey work, and bird observations were not necessarily collected during prime activity times (i.e. in the early morning and late afternoon). Many different observers were involved of varying ornithological ability, although to minimise erroneous records, there was rigorous checking of identifications each day by the most experienced ornithologist in each team. Some generalised habitat information and notes on abundance were recorded but this was not done in a systematic way. In addition, the lack of island vegetation maps limited any analysis of the habitat preferences of bird species.

Campsites were placed on islands to facilitate sampling of as many habitats as possible, but also to allow landings by helicopter. Consequently, some of these campsites were situated considerable distances from the island's coast and so on some islands it was not possible to record birds in mangrove communities. Most of the islands were very rugged with extensive areas of broken sandstone escarpment, scree slopes, tall grasslands or thick scrub which limited exploration and hence the recording of birds. Generally, only the margins of mangrove swamps and mudflats could be searched for birds; more detailed sampling of these environments would require a small boat so the seaward edge could be examined and mangroves could be penetrated when inundated. Many small and cryptic mangrove species which are known from the Kimberley coastline (Johnstone 1990) were either not or rarely recorded during this survey strongly suggesting this habitat was under-sampled. Consequently, bird species only known to occur in mangroves along the Kimberley coast were removed from the community analysis.

Islands were sampled primarily in the dry winter months and only briefly in the wet season, so it is likely we have missed summer migrants which move into the Kimberley in the wet season (e.g. Koel, Dollarbird and a range of waders). Sampling across islands was neither uniform nor proportional to their area or the number of habitats present. The largest islands were sampled from two

campsites (for 10–12 days), but for most, sampling was conducted within a 3 km radius of a single campsite.

Despite these constraints, our survey did collect detailed bird species lists for a number of the largest islands. Comparatively long periods were spent on individual islands in contrast to some other studies of insular bird faunas (e.g. Woinarski et al. 2001) as our teams camped on islands and visited a small number of islands during each survey period. Birds were recorded by a number of observers during surveys, so lists are likely to be more comprehensive than if it was the work of one individual. In addition, we combined our data with other published (especially work done by WA Museum staff) and unpublished sources to provide detailed island inventories. While we were able to intensively sample birds on a few islands, we were unable to examine bird assemblages on a wide range of different island sizes such as described by Woinarski et al. (2001), and this limited our ability to explore aspects of island biogeography.

An examination of the adequacy of surveys of individual islands based on a species accumulation curve of actual observations versus estimators of potential species richness suggested that the surveys were successful in detecting a large proportion of terrestrial species that were expected to be present (Figure 3). We believe that we under-sampled mangrove taxa, summer migrants and cryptic species (e.g. quail) on account of the lack of time spent in mangroves, the timing of our surveys and the opportunistic nature of our sampling.

SPECIES RICHNESS

The avifauna of the Kimberley islands is comparatively rich with 179 species now known from the 24 islands visited during the survey. Wetland species were generally rarely observed, as there are few sites where permanent fresh water suitable for wetland species is present, with the exception of Sir Graham Moore Island. A survey of Arnhem Land islands recorded a comparably rich avifauna with 171 bird species detected on 62 islands (Woinarski et al. 2001); however, they generally sampled smaller islands and many were considerable distances from the mainland compared to Kimberley islands. Draffan et al. (1983) noted many more taxa (243 species) on Torres Strait islands, but their list includes large numbers of seabirds and waders. In addition, these islands are along a major flightway of migratory species from Asia to Australia and many of these species use the islands as staging posts in their journey. Their survey involved a long period of sampling and the close proximity of some islands to Papua New Guinea supplemented their list (Draffan et al. 1983). The Kimberley islands are also on a major flyway, not only for Palaearctic birds, but also for Australian land birds moving between the Australian mainland and the Lesser Sunda Islands (R. Johnstone, pers. comm.). Many of these species undertake their migrations in summer months, so given our surveys were conducted primarily in the dry season, we were unlikely to observe these taxa.

Avian species richness on individual Kimberley islands we sampled ranged from 22 to 95 species. Koolan Island (not sampled by us) in the south-western portion of our study area has the most speciose recorded bird fauna among the Kimberley islands with 116 species (McKenzie et al. 1995). The size of its bird list is largely due to detailed recording of birds on a monthly basis over a 10-year period and it includes many seabirds and vagrants, with 22 species only observed on one occasion during that period (McKenzie et al. 1995).

Woinarski et al. (2001) reported that species richness on Arnhem Land islands was related more closely to island size than isolation, topographic relief or any of the other variables that they measured. However, they noted that on islands of comparable size, species richness varied depending on the types of habitats present with denser vegetation harbouring more species (Woinarski et al. 2001). In contrast, island area explained less of the variation in avian species richness on Torres Strait islands than the areas of particular habitats (Draffan et al. 1983). While the presence of mangroves and grassland made no difference to island species richness, they found that bird species richness increased with the extent of forest and woodland habitats available. In contrast to the Kimberley coast, Torres Strait islands are comparatively depauperate in mangrove specialist birds (R. Johnstone, pers. comm.).

SPECIES ASSEMBLAGES AND ISLAND ATTRIBUTES

Our examination of the bird assemblages on the islands we sampled showed that most of the islands fell into two large clusters and then a number of small clusters (each with one to three islands). The largest cluster of islands were those that occur in the wettest part of the Kimberley coastline and consisted of islands with rugged topography including extensive rocky habitats, but also pockets of monsoon rainforest and woodlands. Suites of species associated with those habitats, especially taxa that utilise monsoon rainforest, were well-represented on these islands. While the patches of rainforest are typically small on North Kimberley islands (McKenzie et al. 1991), the proximity of islands to one another and the mainland still allows nomadic frugivores such as the Pied Imperial Pigeon and Rose-crowned Fruit-Dove to forage in these small pockets. Islands in the drier south and north had a smaller number of these species,

TABLE 3 Endemic and near-endemic Kimberley birds (based on Johnstone and Storr 1998, 2004 and including current survey).

Common Name	Scientific Name	Known Kimberley island populations	Comments
Rainbow Pitta	*Pitta iris johnstoneiana* Schodde and Mason, 1999	Augustus, Boongaree, Byam Martin, Coronation, Fenton, Jungulu, Middle Osborn, Naturalist, St Andrew, St Patrick, South West Osborn, Storr	Nominate subsp. in Top End NT
Black Grasswren	*Amytornis housei* Milligan, 1902	None known	
Kimberley White-lined Honeyeater	*Meliphaga albilineata fordiana* Schodde, 1989	Bigge, Boongaree, Carlia, South West Osborn, Storr, Wollaston	Another subsp. in NT
Lemon-breasted Flycatcher	*Microeca flavigaster flavigaster* Gould, 1843	None known	
Kimberley Flycatcher	*Microeca flavigaster tormenti* Mathews, 1916	Adolphus, Augustus, Bigge, Boongaree, Hidden, St Andrew	
Grey Butcherbird	*Cracticus torquatus latens* Ford, 1979	Augustus, Storr, Uwins	
Chestnut-backed Button-quail	*Turnix castanota magnifica* Mathews, 1912	None known	
Partridge Pigeon	*Geophaps smithii blaauwi* Mathews, 1912	None known	Eastern form *G. s. smithii* apparently extinct (last record 1904)
White-quilled Rock Pigeon	*Petrophassa albipennis albipennis* Gould, 1841	Boongaree, Hidden, Lachlan, South West Osborn, Uwins, Wollaston	Also in far west of NT

and some, such as Adolphus and the Buccaneer Archipelago islands of Hidden, Lachlan and Long, had a number of species more characteristic of drier woodlands (e.g. Common Bronzewing, Striated Pardalote, White-breasted Woodswallow and Little Corella).

Those species that occurred on all or most of the islands sampled were taxa with broad habitat preferences and large geographic distributions and in general terms, are typically disproportionately represented on islands (Graves and Gotelli 1983). Terrestrial taxa such as the Brown Honeyeater and the Bar-shouldered Dove are near-ubiquitous on northern Australian tropical islands (Woinarski et al. 2001). These species have generalised dietary requirements and foraging strategies. Taxa are unlikely to persist on islands if their preferred resources are patchily distributed or only seasonally abundant (MacArthur et al. 1972). Furthermore, larger species that require sizeable territories are less likely to persist on islands (Faaborg 1979).

CONSERVATION CONSIDERATIONS

No bird species are known to have become extinct on Kimberley islands since European settlement. However, detailed observations of the avifauna are in their infancy, commencing in earnest in the 1970s with the first biological surveys of the region. There are no bird species endemic to the Kimberley islands. Of those species that are Kimberley endemics or near endemics (if their ranges extend slightly into the NT), only very few are known to occur on islands (see Table 3).

Only one threatened bird species is known to occur on Kimberley islands. The northern subspecies of the Masked Owl (*Tyto novaehollandiae kimberli*) is listed as 'Vulnerable' under the EPBC Act (1999). A number of taxa are identified as being of particular conservation significance. The Burdekin Duck and the Peregrine Falcon are listed as 'Specially Protected Fauna' under the provisions of the WA Wildlife Conservation Act (1950). A few Kimberley island bird species are listed under the Department of Environment and Conservation's (DEC) Priority Fauna list (DEC 2010): Masked Owl (Kimberley subspecies; 'P1' – 'taxa with few, poorly known populations on threatened lands'); Black Bittern ('P3' – 'taxa with several, poorly known populations, some on conservation lands'; and Chestnut-backed Button-quail ('P4' – 'taxa in need of monitoring'). There is little information available on the threats to these species, but changed fire regimes which lead to the loss of habitat or to an increased dominance of *Sorghum* spp. have been suggested as the major potential threat for a number of species (Garnett and Crowley 2000).

There are currently few other threatening processes on these islands that have disrupted island faunas elsewhere in the world, such as anthropogenic habitat destruction or the introduction of feral cats and exotic rats (Courchamp et al. 2003; Jones et al. 2008; Le Corre 2008). Cyclones may cause extensive damage to vegetation by defoliation and bringing down of trees and erosion of coastlines with damage to mangrove communities. Few islands have suffered extensive human disturbance of habitats. Koolan and Cockatoo Islands (not sampled in our survey) are currently being mined for iron ore. Several were occupied for military purposes during the Second World War; Sir Graham Moore was used briefly in the 1920s for agriculture; and a few islands have Aboriginal outstations that are occasionally inhabited. Oil spills are possible from accidents associated with increasing ship traffic along the Kimberley coast.

Non-native rats (*Rattus rattus* and *R. exulans*) are known to have occurred on five Kimberley islands. They have been eradicated from three islands in the Lacepede group but remain extant on Adele Island despite two attempts at extermination (K. Morris, pers. comm.). They may still be extant on Sunday Island (two specimens in June 1982, N. McKenzie, pers. comm.). Feral cats are not known from any Kimberley islands and while dingoes were historically taken by Aboriginal people to some islands, there are no confirmed extant island populations (N. McKenzie, pers. comm.).

The Cane Toad (*Rhinella marinus*) was introduced to eastern Australia in 1935 and has spread across northern Australia. It is in the process of invading the Kimberley region at rates of 30–50 km/yr (Phillips et al. 2010). Toads are already on the mainland adjacent to Adolphus Island and could conceivably raft onto this island during wet season floods. They have already established on the major islands in the vast freshwater Lake Argyle further east. At their current rate of spread, cane toads could potentially reach the mainland coast adjacent to most (if not all) of the Kimberley islands in the next two decades. While it appears toxic ingestion of cane toads is not a significant threat to any of the bird species so far examined (Shine 2010), there are many species whose response has not been studied.

The introduction of weeds onto the islands is also a potential threat to the quality of the habitats for birds. For instance, Stinking Passionfruit (*Passiflora foetida*) is a widespread invasive vine that scrambles over and chokes native vegetation, especially in rainforest patches. It is spread by humans and birds and establishes vigorously in disturbed areas and after fire (Carwardine et al. 2011).

Despite the current lack of exotic species on the Kimberley islands, this should not be seen as a justification for complacency. While islands make

up only 3% of the earth's land area, extinction rates are exponentially higher with 95% of recent bird extinctions worldwide occurring on islands (Island Conservation 2007). Woinarski et al. (2011) documented how feral cats and toads were able to colonise islands of the Sir Edward Pellew group in the Gulf of Carpentaria (NT) with consequent serious risks to the wildlife on these biologically valuable islands. There is increasing human activity along the Kimberley coastline beyond existing pearling and iron ore extraction industries. Tourists, fishermen and mineral exploration companies are regularly landing on islands. While some quarantine protocols are in place on islands with iron ore mines (e.g. Ecologia Environmental and Aztec Resources 2006), there are no widely available protocols to guide visitors along the Kimberley coast on reducing the risk of introductions of both exotic animals and plants to islands. Education, compliance and enforcement are required to minimise the risk of exotic pests reaching islands (Burbidge 2010). Monitoring is needed so that should an exotic introduction occur, it can be detected early and a rapid management response put in place to check its spread and provide an opportunity for extermination.

Visits to the islands by Indonesian fishing boats also raises the possibility of the introduction of a range of exotic avian diseases such as avian influenza and Newcastle disease. These diseases could also be spread by migrating birds (DAFF 2007a, b). Some monitoring of nesting seabirds and migratory waders is conducted as part of the North Australian Quarantine Strategy (Wallner 2006).

Inappropriate fire regimes on the Kimberley islands appear to constitute the greatest current threat to the avifauna at a landscape level. Current regimes on islands vary markedly, largely dependent on the extent and type of human visitation. Lightning-ignited (natural) fires tend to occur in the early wet season, but areas burnt may be limited by rain associated with thunderstorms or constrained by areas of rugged or wet habitats. There has been no study of the frequency of such events on Kimberley islands (*c.f.* Kimberley mainland; Vigilante et al. 2004). Human-ignited fires lit on islands during the dry season may burn large areas or even across entire islands, which is likely to severely impact on less mobile species (such as fairy wrens) and those with requirements for thick vegetation strata. The role of fire in determining the uneasy boundary of rainforest and savannah in northern Australia is now appreciated (Clayton-Greene and Beard 1985; McKenzie et al. 1991; Russell-Smith and Stanton 2002). Given the importance of rainforest patches to the avifauna of Kimberley islands and in turn their susceptibility to fire, sensitive fire management of the Kimberley islands is essential.

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APPENDIX 1 Matrix of bird species versus surveyed islands (*marine or **mangrove specialists excluded from the analysis).

Common Name	Scientific Name	Adolphus	Augustus	Bigge	Boongaree	Byam Martin	Coronation	Jungulu	Hidden	Katers	Kingfisher	Lachlan	Long	Mary	Middle Osborn	NW Molema	Sir Graham Moore	St Andrew	Storr	Sunday	SW Osborn	Un-named	Uwins	Wargul Wargul	Wulalam	No. of islands
Arctic Warbler	*Phylloscopus borealis*																			+						1
Australian Hobby	*Falco longipennis*		+	+																						2
Australian Kestrel	*Falco cenchroides*	+											+				+			+						4
Australian Magpie	*Cracticus tibicen*																		+							1
Australian Owlet-nightjar	*Aegotheles cristatus*	+	+						+				+			+				+						6
Australian Pelican	*Pelecanus conspicillatus*						+										+			+						3
Australian Pipit	*Anthus australis*	+																								1
Australian White Ibis	*Threskiornis molucca*				+							+	+	+						+						5
Azure Kingfisher	*Alcedo azurea*		+		+								+						+							4
Banded Honeyeater	*Cissomela pectoralis*				+												+			+						3
Bar-breasted Honeyeater	*Ramsayornis fasciatus*	+	+		+							+	+				+						+			7
Barking Owl	*Ninox connivens*	+			+	+													+							4
Barn Owl	*Tyto alba*	+			+																					2
Barn Swallow	*Hirundo rustica*			+																						1
Bar-shouldered Dove	*Geopelia humeralis*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	24
Bar-tailed Godwit	*Limosa lapponica*				+												+			+						3
Beach Stone-curlew	*Esacus neglectus*		+	+		+	+	+	+		+	+	+	+	+		+			+	+		+	+		16
Black Bittern	*Ixobrychus flavicollis*		+	+										+												3
Black Kite	*Milvus migrans*		+					+						+			+									4
Black-breasted Buzzard	*Hamirostra melanosternon*	+	+	+	+			+		+		+														7
Black-chinned Honeyeater	*Melithreptus gularis*		+														+									2
Black-eared Cuckoo	*Chrysococcyx osculans*						+																			1
Black-faced Cuckoo-shrike	*Coracina novaehollandiae*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	23
Black-faced Woodswallow	*Artamus cinereus*	+			+																+					3
Black-necked Stork	*Ephippiorhynchus asiaticus*			+			+				+			+			+			+						6
Black-shouldered Kite	*Elanus caeruleus*																			+						1
Blue-winged Kookaburra	*Dacelo leachii*	+	+	+	+						+				+		+	+			+	+	+			11
Boobook Owl	*Ninox novaeseelandiae*	+	+	+	+		+	+			+	+	+		+		+	+	+		+	+			+	16
Brahminy Kite	*Haliastur indus*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+		22
Bridled Tern	*Sterna anaethetus**																			+						1
Broad-billed Flycatcher	*Myiagra ruficollis*		+		+		+		+				+				+	+	+	+	+	+			+	12
Brolga	*Grus rubicunda*		+	+				+						+			+			+						6
Brown Falcon	*Falco berigora*	+	+	+	+		+				+				+				+							8
Brown Goshawk	*Accipiter fasciatus didimus*	+	+	+	+	+	+				+				+		+	+		+	+					12
Brown Honeyeater	*Lichmera indistincta*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	24
Brown Quail	*Coturnix ypsilophora*	+								+	+	+	+	+	+		+			+						9
Brush Cuckoo	*Cacomantis variolosus*			+							+	+			+							+				5
Budgerigar	*Melopsittacus undulatus*												+													1
Bush Stone-curlew	*Burhinus grallarius*			+													+			+						3
Caspian Tern	*Sterna caspia**				+			+				+					+									4
Chestnut Rail	*Eulabeornis castaneoventris***			+	+												+				+					4
Chestnut-breasted Mannikin	*Lonchura castaneothorax*				+		+													+	+					4
Cicadabird	*Coracina tenuirostris*			+																						1
Collared Kingfisher	*Todiramphus chloris*			+	+		+			+	+	+		+						+		+	+	+		11
Collared Sparrowhawk	*Accipiter cirrocephalus*		+		+			+			+	+	+		+					+	+					9

Common Name	Scientific Name	Adolphus	Augustus	Bigge	Boongaree	Byam Martin	Coronation	Jungulu	Hidden	Katers	Kingfisher	Lachlan	Long	Mary	Middle Osborn	NW Molema	Sir Graham Moore	St Andrew	Storr	Sunday	SW Osborn	Un-named	Uwins	Wargul Wargul	Wulalam	No. of islands
Common Bronzewing	*Phaps chalcoptera*		+	+		+		+	+			+	+							+			+			9
Common Greenshank	*Tringa nebularia**		+	+																						2
Common Koel	*Eudynamys scolopacea*				+					+											+					3
Common Noddy	*Anous stolidus**																			+						1
Common Sandpiper	*Tringa hypoleucos*																+			+	+					3
Crested Tern	*Sterna bergii**	+		+			+					+								+						5
Crimson Finch	*Neochmia phaeton*													+												1
Darter	*Anhinga melanogaster*			+													+									2
Diamond Dove	*Geopelia cuneata*		+				+		+				+													4
Double-barred Finch	*Taeniopygia bichenovii*	+	+		+		+		+			+	+		+			+	+	+	+	+	+	+	+	15
Dusky Gerygone	*Gerygone tenebrosa***																			+						1
Eastern Curlew	*Numenius madagascariensis*										+						+			+						3
Eastern Reef Heron	*Ardea sacra*	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+			+	+	+		+		19
Emerald Dove	*Chalcophaps indica*		+	+	+		+	+		+		+	+		+			+	+	+	+			+		14
Fairy Martin	*Hirundo ariel*		+	+		+		+						+						+						6
Figbird	*Sphecotheres viridis*																				+					1
Fork-tailed Swift	*Apus pacificus*			+																						1
Golden-headed Cisticola	*Cisticola exilis*		+	+	+							+			+		+		+			+	+	+	10
Great Bowerbird	*Ptilonorhynchus nuchalis*	+	+	+	+		+	+	+	+		+	+		+	+	+	+	+	+	+	+	+		+	20
Great Egret	*Ardea alba*							+					+							+						3
Great-billed Heron	*Ardea sumatrana*				+			+						+			+	+		+			+			7
Greater Sand Plover	*Charadrius leschenaultii*						+										+									2
Green-backed Gerygone	*Gerygone chloronota*		+	+	+	+	+						+		+		+	+	+		+		+			12
Grey Butcherbird	*Cracticus torquatus*		+													+			+				+			4
Grey Plover	*Pluvialis squatarola*			+													+									2
Grey Shrike-thrush	*Colluricincla harmonica brunnea*		+	+			+				+						+		+					+		7
Grey-crowned Babbler	*Pomatostomus temporalis*		+																							1
Grey-fronted Honeyeater	*Lichenostomus plumulus*													+			+									2
Grey-tailed Tattler	*Tringa brevipes*		+	+					+	+	+						+			+				+		8
Gull-billed Tern	*Sterna nilotica**										+															1
Kimberley Flycatcher	*Microeca flavigaster tormenti***		+	+	+				+									+								5
Kimberley White-lined Honeyeater	*Meliphaga albilineata fordiana*			+	+														+		+					4
Large-billed Gerygone	*Gerygone magnirostris***				+								+				+	+			+		+			6
Leaden Flycatcher	*Myiagra rubecula*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	24
Lesser Crested Tern	*Sterna bengalensis**												+				+			+						3
Lesser Frigatebird	*Fregata ariel**			+					+			+					+			+						5
Little Bronze Cuckoo	*Chrysococcyx minutillus*																			+			+			2
Little Button-quail	*Turnix velox*						+										+					+				3
Little Corella	*Cacatua sanguinea*		+						+		+	+	+	+	+			+	+	+					+	11
Little Eagle	*Aquila morphnoides*	+							+			+	+				+			+						6
Little Friarbird	*Philemon citreogularis*		+	+		+	+	+	+	+	+	+			+		+			+	+					13
Little Pied Cormorant	*Phalacrocorax melanoleucos**		+																	+						2
Little Shrike-thrush	*Colluricincla megarhyncha*		+		+												+	+	+		+					6
Little Tern	*Sterna sinensis**							+												+						2
Little Woodswallow	*Artamus minor*	+	+	+	+		+		+	+		+	+		+	+				+	+	+	+		+	16

Common Name	Scientific Name	Adolphus	Augustus	Bigge	Boongaree	Byam Martin	Coronation	Jungulu	Hidden	Katers	Kingfisher	Lachlan	Long	Mary	Middle Osborn	NW Molema	Sir Graham Moore	St Andrew	Storr	Sunday	SW Osborn	Un-named	Uwins	Wargul Wargul	Wulalam	No. of islands
Magpie Goose	*Anseranas semipalmata*											+														1
Magpie-lark	*Grallina cyanoleuca*	+	+	+	+		+	+													+					7
Mangrove Gerygone	*Gerygone levigaster***	+												+						+				+		4
Mangrove Golden Whistler	*Pachycephala melanura*	+	+	+	+		+			+	+	+	+	+			+	+	+	+	+		+		+	17
Mangrove Grey Fantail	*Rhipidura phasiana*										+						+			+		+			+	5
Mangrove Robin	*Eopsaltria pulverulenta***	+	+										+				+			+				+		6
Masked Owl	*Tyto novaehollandiae*		+																							1
Mistletoebird	*Dicaeum hirundinaceum*	+	+	+	+	+	+	+	+	+	+	+	+		+		+	+	+	+	+	+	+		+	21
Northern Fantail	*Rhipidura rufiventris*	+	+	+	+	+	+	+	+		+	+	+	+	+		+	+	+	+	+	+	+	+		21
Northern Rosella	*Platycercus venustus*		+		+		+		+							+						+	+		7
Olive-backed Oriole	*Oriolus sagittatus*	+	+	+	+	+	+	+									+	+	+		+		+			12
Orange-footed Scrubfowl	*Megapodius reinwardt*		+	+	+		+			+					+			+	+		+					9
Osprey	*Pandion haliaetus*		+	+	+	+	+	+	+	+	+	+	+		+		+		+	+	+	+	+	+	+	20
Pacific Golden Plover	*Pluvialis fulva*												+				+									2
Pallid Cuckoo	*Cuculus pallidus*					+																				1
Peaceful Dove	*Geopelia striata placida*	+	+	+	+		+	+	+	+		+	+	+	+		+	+	+	+	+		+	+	+	20
Peregrine Falcon	*Falco peregrinus*																				+					1
Pheasant Coucal	*Centropus phasianinus*	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	23
Pied Butcherbird	*Cracticus nigrogularis*	+	+	+	+			+	+		+			+		+	+	+			+		+		+	14
Pied Cormorant	*Phalacrocorax varius**			+													+							+		3
Pied Imperial Pigeon	*Ducula bicolor*		+	+	+	+	+	+					+	+	+	+	+	+	+		+		+	+	+	17
Pied Oystercatcher	*Haematopus longirostris*			+			+			+		+			+		+			+				+		8
Pink-eared Duck	*Malacorhynchus membranaceus*													+												1
Radjah Shelduck	*Tadorna radjah rufitergum*											+														1
Rainbow Bee-eater	*Merops ornatus*	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	23
Rainbow Lorikeet	*Trichoglossus haematodus*		+	+	+			+			+			+			+						+			8
Rainbow Pitta	*Pitta iris johnstoneiana*		+		+	+	+	+						+				+	+		+					9
Red-backed Button-quail	*Turnix maculosa*			+																+						2
Red-backed Fairy-wren	*Malurus melanocephalus*				+																					1
Red-backed Kingfisher	*Todiramphus pyrrhopygius*	+																								1
Red-capped Plover	*Charadrius ruficapillus*					+	+							+			+			+				+		6
Red-chested Button-quail	*Turnix pyrrhothorax*	+																								1
Red-headed Honeyeater	*Myzomela erythrocephala*		+	+	+		+				+		+	+	+		+	+		+		+	+			13
Red-necked Stint	*Calidris ruficollis*			+			+										+									3
Red-tailed Black Cockatoo	*Calyptorhynchus macrorhynchus*	+	+	+	+	+	+			+				+	+		+	+			+	+	+		+	15
Red-winged Parrot	*Aprosmictus erythropterus*	+	+	+	+		+	+	+		+	+		+	+	+	+	+	+		+	+	+		+	19
Restless Flycatcher	*Myiagra inquieta nana*	+	+	+	+		+				+							+						+		8
Roseate Tern	*Sterna dougallii**		+	+													+			+						4
Rose-crowned Fruit-Dove	*Ptilinopus regina*		+	+	+	+	+	+		+	+				+		+	+	+	+	+		+			15
Rufous Night Heron	*Nycticorax caledonicus*	+	+	+		+														+						5
Rufous Owl	*Ninox rufa*																		+							1
Rufous Whistler	*Pachycephala rufiventris*	+	+		+	+	+	+	+	+		+	+	+		+	+		+	+	+		+	+	+	19
Rufous-throated Honeyeater	*Conopophila rufogularis*				+		+					+						+			+		+			6
Sacred Kingfisher	*Todiramphus sanctus*	+	+	+	+	+	+	+	+		+	+	+		+		+	+		+	+	+	+	+	+	20
Sandstone Shrike-thrush	*Colluricincla woodwardi*			+	+				+												+	+				5
Shining Flycatcher	*Myiagra alecto*		+	+	+		+		+		+		+		+		+	+	+	+	+	+	+	+	+	17

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Silver Gull	*Larus novaehollandiae*	+	+	+	+				+								+			+						7
Silver-crowned Friarbird	*Philemon argenticeps*	+	+	+	+		+	+	+	+	+	+			+	+	+	+	+	+	+	+	+	+	+	21
Singing Honeyeater	*Lichenostomus virescens*	+		+												+	+									4
Sooty Oystercatcher	*Haematopus fuliginosus*		+	+		+	+		+	+	+	+	+	+			+			+	+			+		14
Spangled Drongo	*Dicrurus bracteatus*		+	+	+	+	+	+		+					+		+	+	+		+	+		+		14
Spinifex Pigeon	*Geophaps plumifera*	+																								1
Spotted Harrier	*Circus assimilis*	+	+																	+						3
Spotted Nightjar	*Eurostopodus argus*		+	+		+	+		+			+	+				+		+	+	+		+	+	+	14
Square-tailed Kite	*Hamirostra isura*				+												+									2
Striated Heron	*Butorides striatus*			+	+	+		+	+		+	+	+	+			+			+	+		+			13
Striated Pardalote	*Pardalotus striatus uropygialis*		+		+			+	+		+						+		+				+	+		9
Sulphur-crested Cockatoo	*Cacatua galerita*		+	+	+									+			+	+	+		+	+				9
Tawny Frogmouth	*Podargus strigoides*	+	+						+					+				+									5
Tawny Grassbird	*Megalurus timoriensis*								+				+				+									3
Terek Sandpiper	*Tringa cinerea*													+												1
Torresian Crow	*Corvus orru*	+	+	+									+	+			+	+	+	+		+				10
Tree Martin	*Hirundo nigricans*	+	+	+		+		+	+	+	+	+					+			+	+		+			13
Varied Lorikeet	*Trichoglossus versicolor*	+	+	+	+															+	+					6
Varied Sittella	*Daphoenositta chrysoptera leucoptera*	+																								1
Varied Triller	*Lalage leucomela*		+	+	+		+	+		+					+		+	+	+		+	+	+	+		14
Variegated Fairy-wren	*Malurus lamberti*		+		+				+			+	+						+				+	+		8
Wedge-tailed Eagle	*Aquila audax*	+	+	+	+					+										+			+			7
Weebill	*Smicrornis brevirostris*	+																							+	2
Whimbrel	*Numenius phaeopus*	+	+	+	+	+			+		+	+	+				+			+	+					12
Whistling Kite	*Haliastur sphenurus*	+	+	+	+	+					+	+					+			+		+	+			11
White-bellied Cuckoo-shrike	*Coracina papuensis hypoleuca*	+	+	+	+		+	+	+						+		+	+	+		+	+	+		+	15
White-bellied Sea Eagle	*Haliaeetus leucogaster*	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+		+	+	+		+	+		20
White-breasted Whistler	*Pachycephala lanioides***								+											+						2
White-breasted Woodswallow	*Artamus leucorynchus*	+	+	+					+		+		+	+			+			+		+	+			11
White-faced Heron	*Ardea novaehollandiae*		+	+				+	+			+		+			+			+						8
White-gaped Honeyeater	*Lichenostomus unicolor*		+	+	+				+	+		+		+	+			+	+		+		+	+		13
White-quilled Rock Pigeon	*Petrophassa albipennis*				+				+			+									+		+			5
White-throated Honeyeater	*Melithreptus albogularis*	+	+		+		+	+	+			+				+	+	+	+	+	+		+		+	15
White-winged Triller	*Lalage tricolor*	+	+		+	+	+		+									+					+		+	9
Willie Wagtail	*Rhipidura leucophrys*	+	+	+	+	+	+	+	+		+	+	+		+	+			+	+	+	+	+		+	19
Wilson's Storm Petrel	*Oceanites oceanicus**			+																+						2
Wood Fantail	*Rhipidura dryas*				+		+	+		+					+		+		+		+					8
Wood Sandpiper	*Tringa glareola*																			+						1
Yellow Oriole	*Oriolus flavocinctus*		+	+	+		+	+		+		+	+	+				+	+	+	+		+	+		15
Yellow White-eye	*Zosterops luteus*		+	+	+	+	+		+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	21
Yellow-throated Miner	*Manorina flavigula*	+							+							+							+			4
Yellow-tinted Honeyeater	*Lichenostomus flavescens*														+				+				+			3
Zebra Finch	*Taeniopygia guttata*																			+						1
No. of species		64	95	91	86	39	65	50	55	36	47	58	55	44	49	22	92	49	54	90	69	38	60	37	31	