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Terrestrial birds of the southern Carnarvon Basin, Western Australia: contemporary patterns of occurrence

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Abstract – We recorded 126 bird species at 63 sites in the northern Geraldton Sandplains and southern Carnarvon Regions, Western Australia. Classification of sites on the basis of the bird species present revealed the presence of five main groups of sites, each with at least two recognisable sub-groups. Classification of bird species on the basis of the sites at which they occurred, revealed the presence of four main species groups, with some structuring within these.

INTRODUCTION

Knowledge of biodiversity and biogeographic patterning is necessary for long term planning of rangeland management. Even for well-known groups such as birds, such information is lacking for much of the Australian arid zone, and this situation has led to a number of authors (e.g., Foran *et al.*, 1990; Landsberg *et al.*, 1997) recommending that conservation values be identified and measures taken to ensure that these values are protected and not significantly impacted upon. Surveys of range condition have been carried out over large areas of the pastoral zone in Western Australia in recent years (e.g., Payne *et al.*, 1992; Pringle, 1991). However, such surveys have not included animal taxa except in an incidental way, leaving a major gap in our knowledge of bird diversity and biogeographic patterning in most pastoral regions of Western Australia.

In the southern Carnarvon and northern Geraldton Sandplains Regions (Thackway and Cresswell, 1995) the bird fauna is reasonably well known in terms of the inventory of species known to occur in the area. The occurrence and geographic distribution of the species present has been summarised by Storr (1985) for the Shark Bay region and by Storr (1990) for the Gascoyne Region (encompassing the present study area plus a considerable area to the east). Further detail for the species occurring in the present study area is included in Johnstone *et al.* (2000).

Little is known, however, about community structure or composition in Australian arid land bird faunas. Schodde (1982) discussed the origins of the bird fauna and described environmental factors influencing the biology and distribution of birds in the Australian arid zone, thus providing a framework for subsequent field studies. In Western Australia, species assemblage data have been published for various sites including 30 on the Nullarbor (Burbidge *et al.*, 1987) and numerous sites in the Eastern Goldfields (e.g. Dell and How, 1988, 1992; McKenzie *et al.*, 1992; Burbidge *et al.*, 1995). Examples from other parts of arid Australia are few, but include the study by Robinson *et al.* (1988) from the Gawler Ranges, South Australia. Various other authors (e.g., Gibson and Cole, 1988) have described avian faunas on a land unit basis (i.e. without site specific assemblage data) as part of general biological survey work. Landsberg *et al.* (1997) described variation in avian communities in the vicinity of water points in various parts of the arid zone. Cody (1994) described regional variation in mulga bird communities and Recher and Davis (1997) described the foraging behaviour of birds in a mulga community in central Australia. In a broader perspective, Wiens (1991) compared and contrasted shrub-desert avifaunas in Australia and North America, with one of the conclusions being that an understanding of the composition and dynamics of local assemblages requires a broad-scale perspective.

In this paper we document the bird species assemblages at 63 sites in a 75 000 km^2 study area on the arid central west coast of Australia, and describe how the composition of these assemblages varies across the study area.

METHODS

The study area approximated to the southern part of the Carnarvon Basin (Playford *et al.*, 1975) and

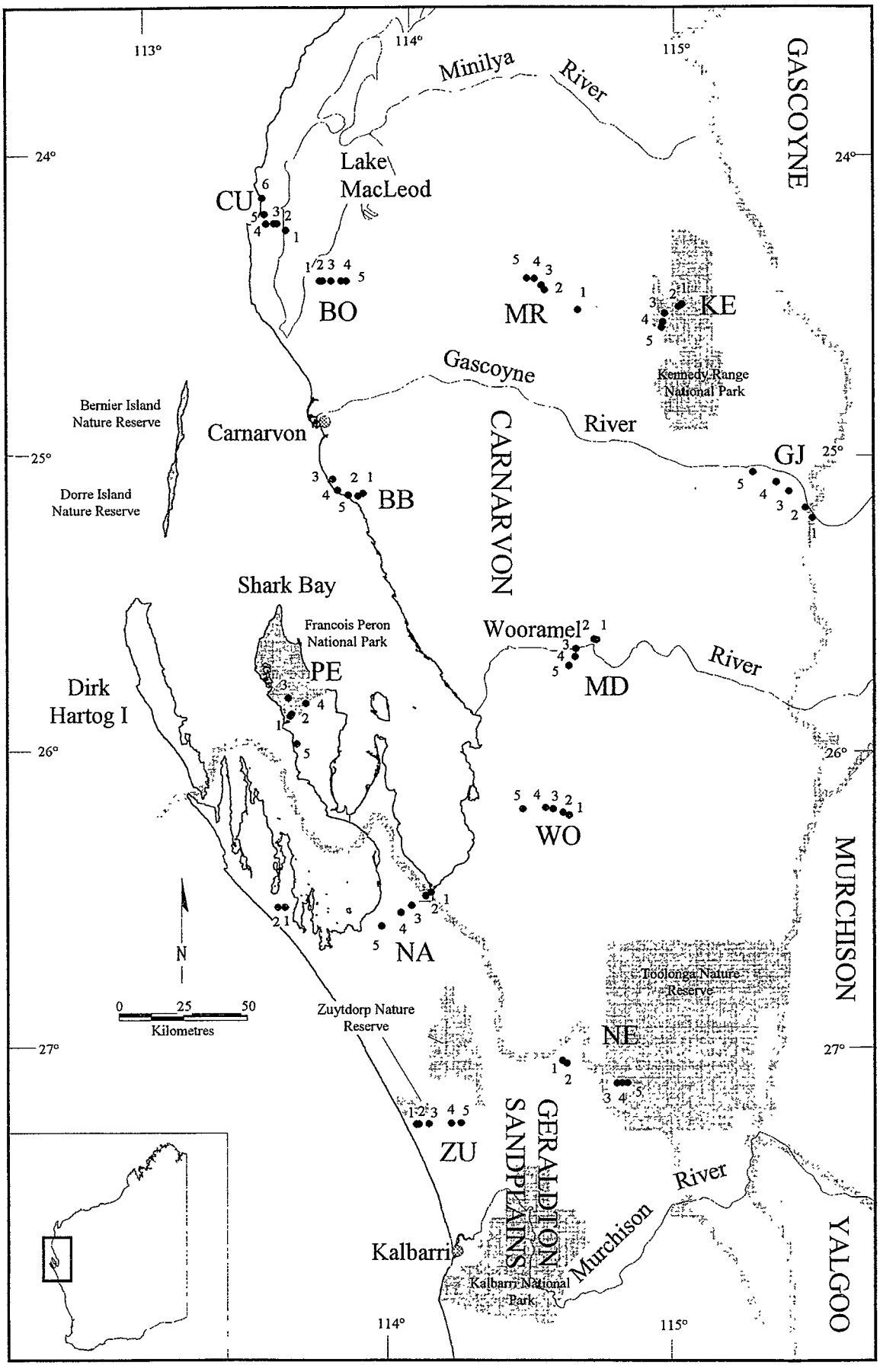

Figure 1 Sample sites in the southern Carnarvon Basin; the study area covered the southern Carnarvon and northern Geraldton Sandplains Regions of Thackway and Cresswell (1995). Also shown are existing and proposed conservation reserves.

included the southern two-thirds of the Carnarvon and the far northern part of the Geraldton Sandplains Regions (Thackway and Cresswell, 1995). Quadrats (sample sites; Figure 1 and Appendix A) were selected as described in Burbidge *et al.* (2000). The physical environment is described in Wyrwoll *et al.* (2000).

Birds were recorded at 63 unbounded quadrats, each about 16 ha, during spring (26 September to 19 October 1994) and autumn (8 May to 3 June 1995). Quadrats EL1 and EL2 were sampled in May and August 1995. The two EL quadrats were sampled for three days in each sampling period, while the other 61 quadrats were searched for five to six days in each sampling period. The objective of sampling was to determine species presence/absence at each quadrat, by searching each quadrat exhaustively in each of spring and autumn. No attempt was made to estimate species abundance, as reliable abundance measures require about an order of magnitude more effort to acquire and, in any case, are subject to significant stochastic variation (e.g., Ives and Klopfer, 1997).

Pattern analyses were carried out using the computer package PATN (Belbin, 1989, 1991a). A cluster analysis technique was used to detect similarities between sites. Sites were classified in terms of bird species presence or absence using the Czekanowski association measure, followed by hierarchical agglomerative fusion classification (flexible UPGMA, beta = -0.1). This procedure is appropriate for ecological presence-absence data and is robust to variations in species abundance patterns and hence sampling efficiencies (Faith *et al.*, 1987; Belbin, 1991a). The association matrix was also subjected to an ordination procedure to provide a second method of clustering sites. Sites close together in the ordination space will be similar in species composition. Ordination was carried out using the procedure SSH (semi-strong hybrid multi-dimensional scaling) (Belbin, 1991b), which is robust to species richness effects. This was followed by principal axis rotation in order to maximise the variance on each axis. In order to facilitate interpretation of the observed patterns, bird species were also classified in terms of the sites at which they occurred. This was done using the two-step association measure of Belbin (1980) as this measure is robust for use in situations such as the present one where sites vary greatly in their levels of species richness (Austin and Belbin, 1982). A two-way table was constructed from the classifications of sites and birds, in order to facilitate interpretation of both classifications.

Certain species were recorded at only a single site (referred to herein as singletons). These species tended to be rare or under-sampled, sometimes cryptic, species that may be overlooked during brief sampling sessions. There was no obvious pattern of occurrence of these species in the data set and they appeared to contribute little to estimation of similarity between sites or interpretation of pattern in the data, so they were excluded from further analyses.

As many non-passerines occur at low densities or are highly mobile, they have a lower probability of being detected on a given quadrat at a given point in time. This may lead to inadequate sampling of certain groups. The analyses were therefore also run after removal of those non-passerine groups that were thought to be inadequately sampled, i.e. galliforme birds, button-quails, aquatic or semi-aquatic non-passerines, and nocturnal and diurnal raptors (listed in Appendix 2).

The patterns revealed by these analyses were interpreted in terms of climatic and physical attributes of the quadrats, together with a knowledge of the range and general habitat preferences of the bird species recorded. The climatic attributes of each quadrat were estimated using ANUCLIM (McMahon *et al.* 1995) (see Appendix F for actual values). Soil and geomorphic attributes are detailed in Wyrwoll *et al.* (2000) and Appendix D of this volume. Significant inter-correlations between quantitative attributes were identified using Rank Correlation (Kendall's tau), and are listed in Appendix I.

Bird species nomenclature follows Johnstone (2000).

RESULTS

A total of 126 bird species (75 passerines, 51 non-passerines) were recorded at the 63 sites. Of these, 20 species occurred at a single site (Appendix 1). Thirteen species were recorded at more than 40 sites (Table 1); one (Emu) was recorded at most sites (61) and two (Singing Honeyeater and Crested Bellbird) were recorded at more than 80% of sites (Table 1).

Site Classification (all birds)

Classification of the 63 sites on the basis of all bird species (106 taxa after removal of singletons) revealed the presence of five groups of sites. This classification was then re-run without galliforme birds, button-quails, aquatic or semi-aquatic non-passerines, and nocturnal and diurnal raptors. This left 86 taxa including the Emu, pigeons, parrots, kingfishers and allies, cuckoos and passerines. The resultant site classification was virtually unaltered. The Hubert-Arabie modification of Rand's statistic (Hubert and Arabie, 1985; Rand, 1971) was 1.00 at the 5 group level, 0.96 at the 11 group level (with 98% of sites on the diagonal of the comparison matrix), dropping to 0.71 at the 12 group level (49% of sites on the diagonal) and then rising for higher numbers of groups. This suggests that the excluded species contributed very little to the site

Table 1 Frequency of occurrence of the most commonly encountered bird species on the 63 sites sampled in the southern Carnarvon Basin.

Species		No. of sites	Percent
Emu	*Dromaius novaehollandiae*	61	97
Singing Honeyeater	*Lichenostomus virescens*	56	89
Crested Bellbird	*Oreoica gutturalis*	54	86
White-browed Babbler	*Pomatostomus superciliosus*	48	76
Variegated Fairy-wren	*Malurus lamberti*	46	73
Spiny-cheeked Honeyeater	*Acanthagenys rufogularis*	45	71
Little Crow	*Corvus bennetti*	44	70
Crested Pigeon	*Ocyphaps lophotes*	44	70
Zebra Finch	*Taeniopygia guttata*	44	70
Redthroat	*Pyrrholaemus brunneus*	44	70
Australian Kestrel	*Falco cenchroides*	43	68
Willie Wagtail	*Rhipidura leucophrys*	41	65
Western Wedgebill	*Psophodes occidentalis*	41	65
Grey Shrike-thrush	*Colluricincla harmonica*	38	60

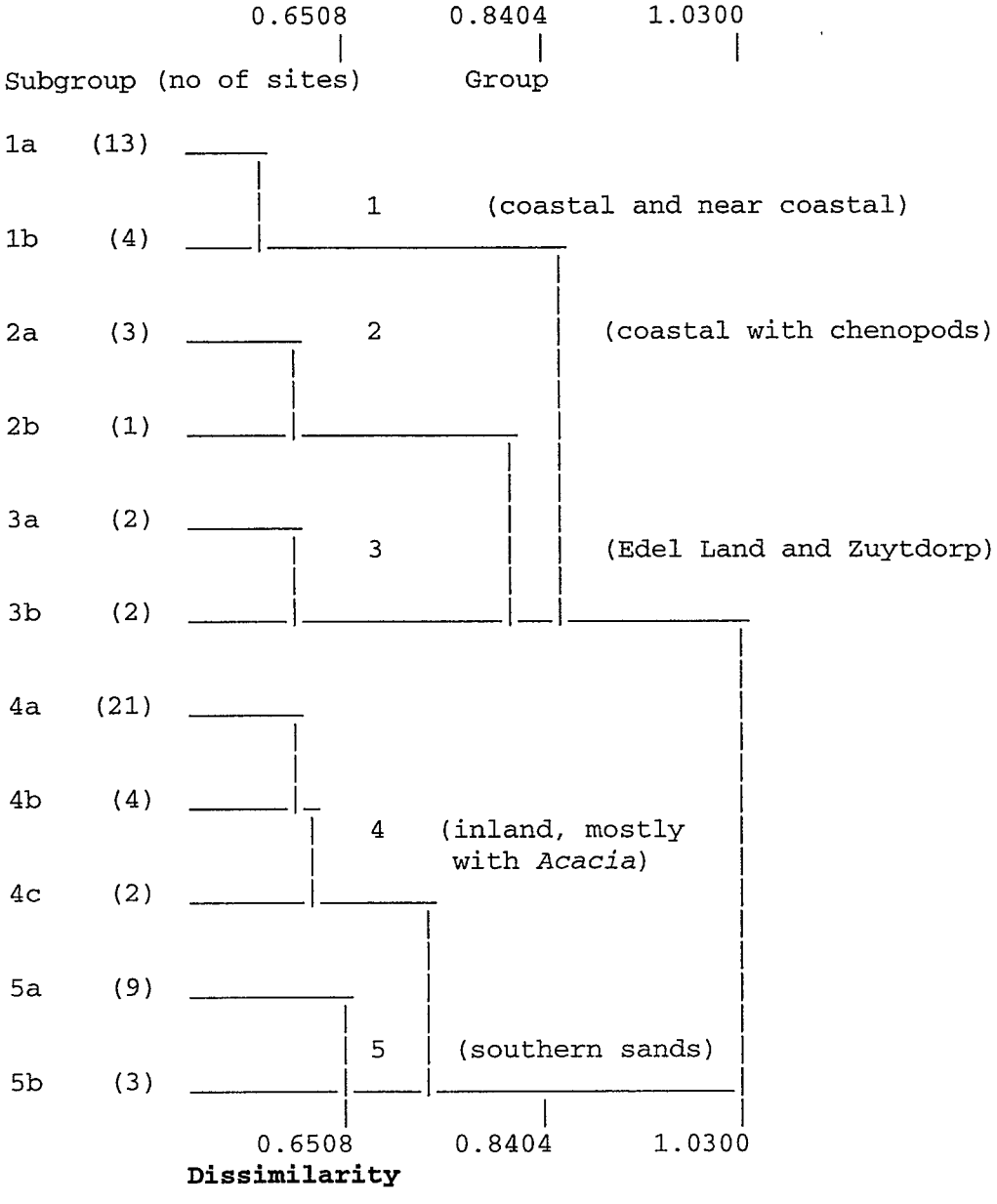

Figure 2 Classification of 63 sites in the southern Carnarvon Basin based on presence of bird species (singletons and some non-passerine species excluded; see text for explanation).

Table 2 Summary of classification of sites in terms of bird species (passerines and non-passerines) recorded at each site sampled in the Carnarvon Basin (see text for details).

Group	Number of sites	Common species		Frequency
1	17	White-winged Fairy-wren	*Malurus leucopterus*	0.94
		Rufous Field-wren	*Calamanthus campestris*	0.94
2	3	Emu	*Dromaius novaehollandiae*	1.00
		White-winged Fairy-wren	*Malurus leucopterus*	1.00
		Australian Pipit	*Anthus australis*	1.00
3	4	Emu	*Dromaius novaehollandiae*	1.00
		Rufous Field-wren	*Calamanthus campestris*	1.00
		White-winged Fairy-wren	*Malurus leucopterus*	1.00
4	27	Spiny-cheeked Honeyeater	*Acanthagenys rufogularis*	0.96
		Crested Bellbird	*Oreoica gutturalis*	0.96
		Chestnut-rumped Thornbill	*Acanthiza uropygialis*	0.96
		Emu	*Dromaius novaehollandiae*	0.93
		Redthroat	*Pyrrholaemus brunneus*	0.89
		Red-capped Robin	*Petroica goodenovii*	0.85
		Zebra Finch	*Taeniopygia guttata*	0.85
		Singing Honeyeater	*Lichenostomus virescens*	0.85
5	12	Common Bronzewing	*Phaps chalcoptera*	1.00
		Grey Shrike-thrush	*Colluricincla harmonica*	1.00
		Broad-tailed Thornbill	*Acanthiza apicalis*	1.00
		White-browed Babbler	*Pomatostomus superciliosus*	1.00
		Emu	*Dromaius novaehollandiae*	1.00
		Singing Honeyeater	*Lichenostomus virescens*	1.00

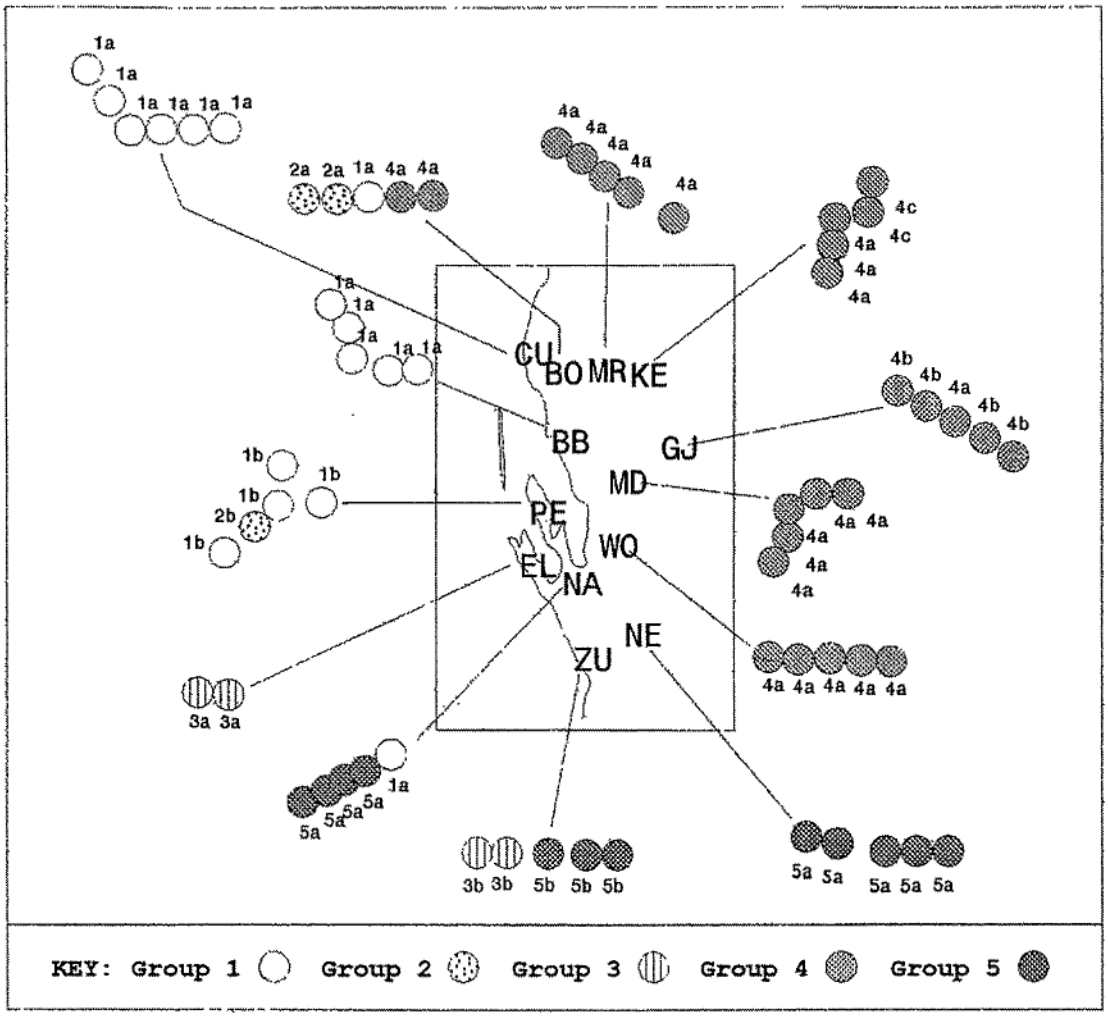

Figure 3 Distribution of site groups in the southern Carnarvon Basin from the classification of sites based on presence of bird species (singletons and some non-passerine species excluded; see text for explanation).

Figure 4 Two way table of passerine and selected non-passerine bird species recorded at 63 sites in the southern Carnarvon Basin (singletons excluded). See text for explanation of groups excluded.

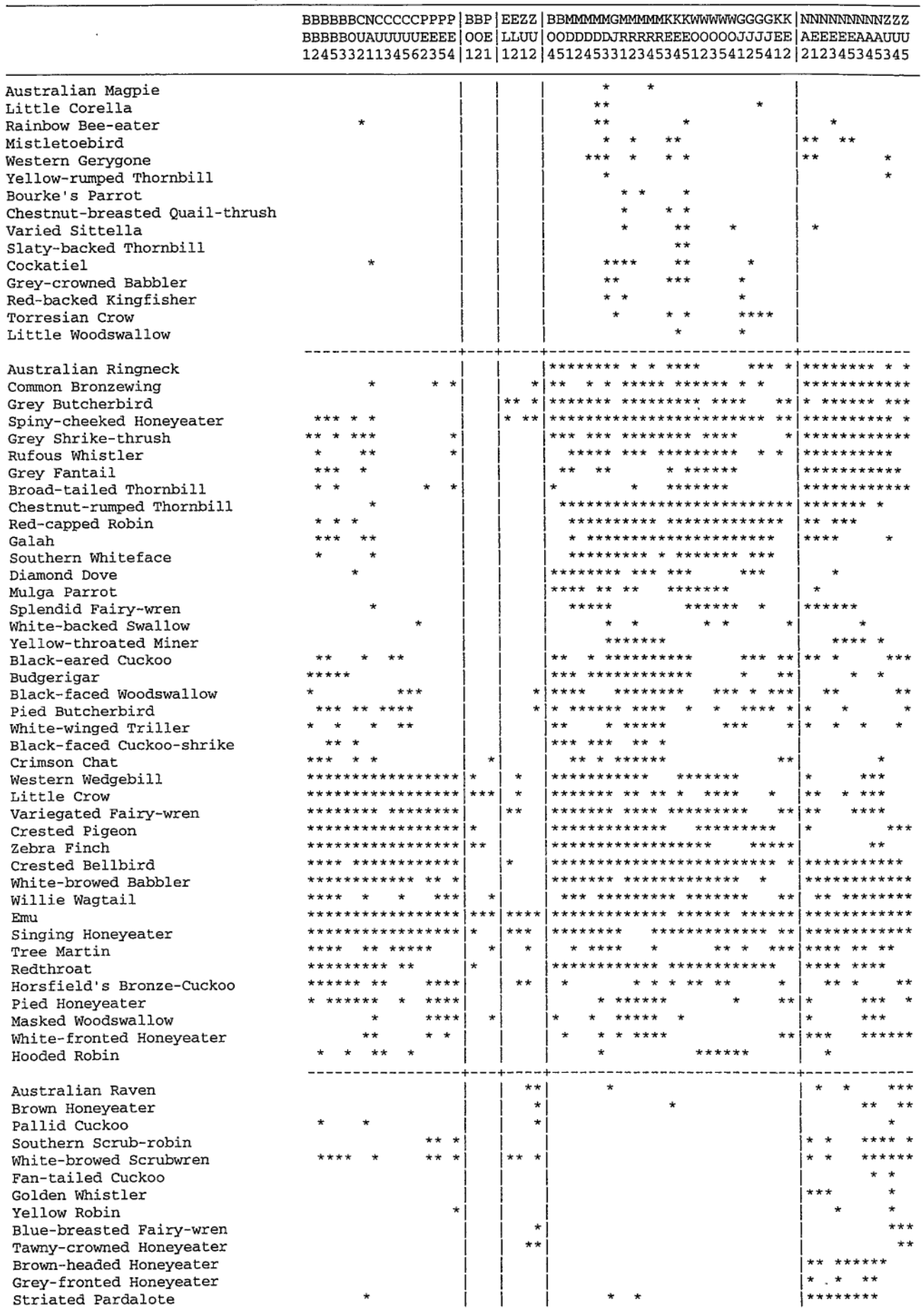

Figure 4 (cont.)

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                          BBBBBBCNCCCCCPPPP|BBP|EEZZ|BBMMMMMGMMMMKKKWWWWWGGGGKK|NNNNNNNNNZZZ
                          BBBBBOUAUUUUUEEEE|OOE|LLUU|OODDDDDJRRRRREEEOOOOOJJJEE|AEEEEEAAAUUU
                          12453321134562354|121|1212|45124533123453451235412541 2|212345345345
Weebill                                    |   |    |      *      *       *     |********
Red-tailed Black-Cockatoo                  |   |    |                     * *   |  * ***
Chestnut Quail-thrush                    * |   |    |                 ***       |    * **
Black Honeyeater                           |   |    |                       *   | *
Rufous-crowned Emu-wren                    |   |    |                       **  |
-------------------------------------------+---+----+---------------------------+-----------
Brown Songlark                *            |  *|    |                           |
Australian Pipit              ****** **** * |***|  * |  **                 * *   |        *
White-winged Fairy-wren       **************|***|****|  *      ****       ** **** |      * *
Rufous Fieldwren              ***** **********|   |****|                           |        **
Welcome Swallow                    * **** * |  *|**  |                           |        ***
Grey-breasted White-eye       ***** *   *   |   |**  |                           |        *
Orange Chat                     **         |  *|    |                           |
Samphire Thornbill              **         |   |    |                           |
Yellow White-eye               ****        |   |    |                           |
White-fronted Chat             * *         |  *|    |                           |
Laughing Turtle-Dove                 *  *   |   |    |                           |
Thick-billed Grasswren               ****   |   |    |                 *         |
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classification, presumably because they were not abundant or widely distributed. The resultant classification, based on the selected bird species, is shown in Figures 2, 3 and 4, and a summary of the Groups and the most frequently occurring species is presented in Table 2.

The classification structure was tightly correlated with temperature and precipitation variables. However, it should be noted that many of the climatic and substrate variables are inter-correlated (see Appendix I to this volume). Temperature appeared to be the major influence on the early divisions in the dendrogram, with diurnal temperature range being particularly important (Kruskall-Wallis ANOVA 37.24, $P<0.001$ at two group level; Figure 5). Precipitation effects became prominent at the five group level (Kruskall-Wallis ANOVA 48.02, $P<0.001$; Figure 6, Table 3).

Group 1 consisted of 17 coastal and near coastal sites. Within this group, there was a fairly distinct north-south split, with four of the five Peron sites (all shrublands) clustered together as a sub-group distinct from the remainder of the group (almost entirely from Bush Bay and Cuvier). (The remaining Peron site was a saline playa (birrida) with samphire vegetation, and fell into Group 2). Group 2 consisted of three near coastal sites with chenopod shrubs: subgroup 2a consisted of a samphire community and an *Atriplex* dominated shrubland near the shores of Lake MacLeod and sub-group 2b consisted of a birrida on Peron Peninsula. Group 3 (four sites) included two low coastal heaths on sand over limestone at Edel Land (sub-group 3a) and two low heathlands on sand/limestone (one with emergent *Banksia*) near the coast at Zuytdorp (sub-group 3b). Group 4 contained 27 inland sites on

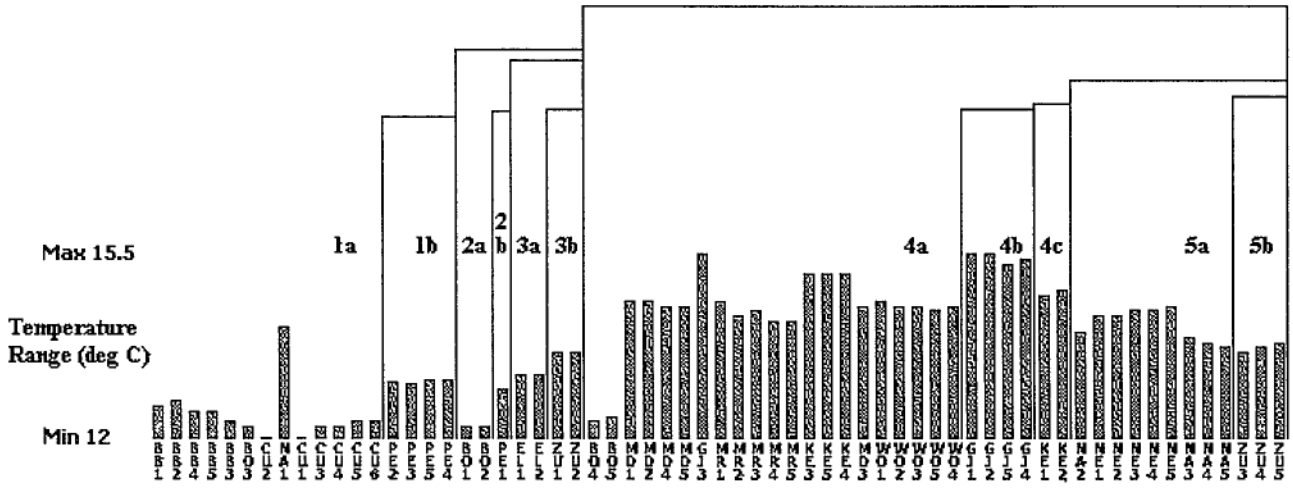

Figure 5 Diurnal temperature range at each site. Sites are ordered according to the classification in terms of bird species composition (presence or absence), and the dendrogram superimposed on the histogram of environmental values. Site groups are shown on the dendrogram and site labels are shown vertically under the histogram.

Table 3 Significant differences (determined by Kruskal-Wallis anova) between site groups in terms of various environmental parameters measured or estimated for each site, for the five groups based on a classification of sites in terms of presence of selected bird species. Parameters listed are those that showed statistical significance (* = 0.01<P<0.05; ** = 0.001<P<0.01; *** = P<0.001). (Note that, even with five groups, there are small samples, as there were only three sites in Group 2).

Variable (5 group)	Kruskall-Wallis value
Precipitation in coldest quarter	51.15***
Precipitation in wettest quarter	50.24***
Precipitation in wettest period	50.03***
Temperature in warmest quarter	49.60***
Seasonality of precipitation	48.02***
Distance to coast	43.62***
Max temp warmest period	43.35***
Temperature diurnal range	43.32***
Longitude	42.23***
Min temp coolest period	41.46***
Annual precipitation	41.18***
Annual temperature	41.12***
Temperature annual range	40.13***
Temperature in coldest quarter	39.15***
Temperature in wettest quarter	36.97***
Latitude	36.12***
K (HCO_3)	34.50***
Isotherms	33.95***
Altitude	33.60***
Precipitation in warmest quarter	32.93***
pH ($CaCl_2$)	32.10***
Exchangeable K	31.40***
Total carbon	31.11***
pH (H_2O)	29.35***
$CaCO_3$	29.19***
P (HCO_3)	26.46***
No. tree and shrub strata	26.08***
Total P	22.89***
Electrical conductivity	22.61***
Total N	20.81***
Temperature in driest quarter	20.29***
Exchangeable Mg	19.28***
Exchangeable Ca	17.37**
% silt	15.94**
Total no. plant strata	15.53**
Temperature seasonality	15.28**
Exchangeable Na	13.18*
Cation exchange capacity	10.19*

various substrates and mostly dominated by *Acacia* species. Sub-group 4a contained all the sites at Mardathuna, Meedo and Woodleigh, together with one of the Gascoyne Junction sites (the sandiest one), three of the Kennedy Range sites (the slope sites) and the three more inland of the Boolathana sites. Sub-group 4b contained the remaining four Gascoyne Junction sites and sub-group 4c contained the remaining two Kennedy Range sites (the two on the sandy surface of the plateau). The fifth group consisted of 12 sites on sands in the south of the study area; these sites all show affinities with the south-west of the state. Sub-group 5a contained all the Nerren Nerren sites and all but one (the samphire flat) of the Nanga sites, while sub-group 5b contained the three Zuytdorp sites without shallow limestone.

Results of ordination of the 63 sites were consistent with the classification of sites in that the five groups recognised in the classification all separated in a three-dimensional ordination plot. The stress measure for this ordination was 0.16.

Site Classification (passerine birds only)

Classification of sites on the basis of passerine bird species alone (67 taxa after removal of singletons) resulted in a dendrogram in which four groups could be distinguished. Within each of these groups it was possible to distinguish two or three subgroups.

The first group consisted of 19 northern and central coastal or near coastal sites. These sites had slightly higher average rainfall (mean 249 mm) than groups 2 and 3, with rainfall being mostly in winter. Diurnal temperature range was relatively low (12.7). The two Edel Land sites separated within this group and four sites from Peron Peninsular separated as another subgroup. (The fifth Peron site was a birrida, and classified in the second group).

Group two consisted of three sites, each dominated by chenopods: a samphire site and a saltbush site on the eastern side of Lake MacLeod and the birrida site (dominated by samphires) from Peron Peninsula. Sites in this group have low diurnal temperature range and relatively high annual rainfall (mean 245 mm). The Lake MacLeod sites separated from the birrida site as a subgroup.

The third group was the largest, with 36 sites. This group included all the inland sites. These sites had the highest range of diurnal temperatures and the lowest annual rainfall (mean 226 mm). Rainfall was as frequent in late summer as in winter, with this being more noticeable in the north-eastern sites. Three recognisable subgroups included (1) four of the Gascoyne Junction sites, (2) all Nerren Nerren sites, most of the Nanga sites and one site from Meedo (the riverbank site) (i.e. sites with higher rainfall/water availability) and (3) the remainder of the inland sites, including all the Woodleigh, Mardathuna and Kennedy Range sites.

The fourth group comprised all five Zuytdorp sites from the extreme south west of the study area. These sites have the highest rainfall (mean 324 mm) and rainfall here has a distinct pattern of occurrence in winter. The two heath sites closer to the coast separated out from the other three sites (tall shrublands) to form two separate subgroups.

As with analyses incorporating non-passerines and passerines, the classification structure was correlated with temperature and precipitation

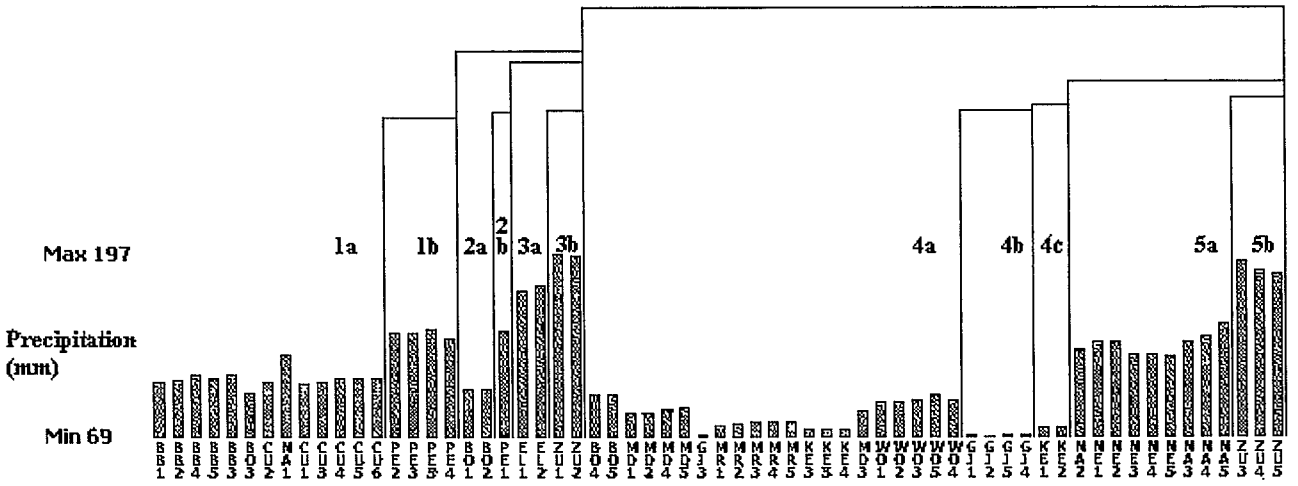

Figure 6 Precipitation in the coldest quarter at each site. Sites are ordered according to the classification in terms of bird species composition (presence or absence), and the dendrogram superimposed on the histogram of environmental values. Site groups are shown on the dendrogram and site labels are shown vertically under the histogram.

variables. At the two group level, annual temperature (Kruskall-Wallis ANOVA 13.7, P=0.0002) and temperature in the warmest quarter (Kruskall-Wallis ANOVA 13.7, P=0.0002) appear to have a major effect. At the four group level, temperature variables are still the most important: maximum temperature warmest period (Kruskall-Wallis ANOVA 40.8, P<0.0001) and temperature diurnal range (Kruskall-Wallis ANOVA 40.6, P<0.0001) showed the tightest correlations (Table 4).

Species Classification

Four major groups were discernible when species were classified according to their co-occurrence at sites where they were recorded (Figure 7). Some structure was also evident within each of these four groups, but sampling at extra sites would be required to properly elucidate the finer patterns of occurrence. The first dichotomy in the dendrogram was between species with inland or ubiquitous distributions within this data set (two groups) and species with mainly coastal or south-western occurrences (the remaining two groups). The 15 species in the first group occurred primarily at inland sites, with one sub-group occurring on sandier surfaces and extending into south-western woodlands, and the other sub-group being more common on inland sites with rocky substrates. The 41 species in the second group were ubiquitous species showing high levels of similarity in their occurrences. Within this group were two weakly separated sub-groups. One contained species such as the Emu and Singing Honeyeater that were mostly truly ubiquitous, while the other contained species including the Australian Ringneck, Mulga Parrot and Yellow-throated Miner that tended to avoid the low coastal shrublands or were less frequently encountered in such areas. The third group included 18 species with south-western affinities, but also occurring coastally and sporadically inland, particularly in proximity to riverine areas. The fourth group consisted of 12 species occupying sites with low vegetation, usually heath, and primarily coastal.

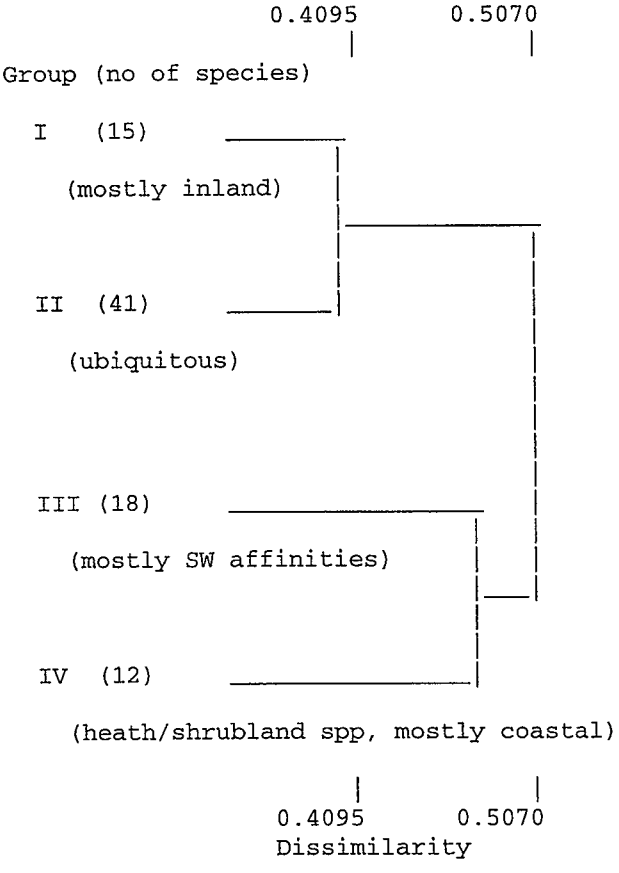

Figure 7 Classification of bird species (excluding singletons and some non-passerines; see text for explanation) on the basis of sites of occurrence in the southern Carnarvon Basin.

Table 4 Significant differences (determined by Kruskal-Wallis anova) between passerine site groups in terms of various environmental parameters measured or estimated for each site. Parameters listed are those that showed statistical significance (* = 0.01<P<0.05; ** = 0.001<P<0.01; *** = P<0.001). (Note that, even with four groups, there are small samples, as there were only three sites in Group 2).

Variable	Kruskal-Wallis value (Passerine 4 group)
Longitude	42.2***
Maximum temperature warmest period	40.8***
Temperature diurnal range	40.6***
Temperature annual range	39.1***
Precipitation seasonality	35.0***
pH ($CaCl_2$)	34.7***
$CaCO_3$	34.7***
pH (H_2O)	32.5***
Altitude	32.5***
Precipitation wettest period	30.1***
Precipitation wettest quarter	30.1***
Precipitation wettest period	30.1***
Precipitation coldest quarter	28.2***
Electrical conductivity	27.2***
Temperature warmest quarter	26.5***
Minimum temperature coolest period	25.9***
Precipitation annual	24.1***
P (HCO_3)	23.0***
Total N	21.1***
Temperature coldest quarter	19.8***
Exchangeable Ca	18.3***
Total C	17.2***
Latitude	17.0***
Temperature wettest quarter	16.3**
Total P	16.1**
Temperature driest quarter	15.7**
Temperature annual	15.4**
Exchangeable Na	13.8**
Precipitation warmest quarter	13.0**
K (HCO_3)	12.8**
Exchangeable K	11.4**
No. of tree and shrub strata	11.4*
Cation exchange capacity	9.5*
% Silt	8.3*

DISCUSSION

Broad Scale Biogeographic Patterns

Removal of the non-passerine groups thought to be under-sampled (galliform birds, button-quails, aquatic and semi-aquatic non-passerines and nocturnal and diurnal raptors) made no difference to the site classification. This could be because they were rare in the study area or were under-sampled (for reasons such as being inconspicuous in the case of nocturnal species, or having large home ranges (e.g., some raptors) and therefore being difficult to detect reliably in a short survey). Removal of species responding to the same factors as the remaining species would also have minimal effect on the classification. Removal of singletons and all non-passerines reduced the data set to 67 species, with all but one (Western Gerygone) being species that breed in the study area. While resulting in a site classification that was easier to interpret, removal of all non-passerines also resulted in noticeable differences in the classification. This suggests that these taxa made a significant contribution to the site classification, and any analysis based on passerines alone would be incomplete.

At the broadest scale of resolution, biogeographic patterns in the avifauna of the study area appear to be determined primarily by climatic factors. Of the parameters available for analysis, temperature, particularly diurnal temperature range, appears to have an over-riding effect on broad scale patterns of distribution. Superimposed on this, but operating at a finer scale, precipitation also has a major influence. This is consistent with Schodde's (1982) thesis that climate has been the major biogeographic influence in the Australian arid zone, both contemporaneously and in an evolutionary perspective.

Substrate and vegetation characteristics primarily operate at a more local scale. Consequently, at a broad scale, there are no sharp biogeographic boundaries evident in bird species distributions across the bulk of the study area, except in near-coastal areas. In our data set, the greatest differences are between sites east and west of Lake MacLeod, the base of the Shark Bay peninsulas and the heath/scrub boundary at Zuytdorp. Among the sites east of this line, the major differences are between the south-western sites dominated by eucalypts and plant genera with south-western affinities (e.g., *Banksia*) and inland sites (usually dominated by *Acacia*, but sometimes also by Eremian genera such as *Eremophila* or hummock grasses, with or without *Acacia*). This is also the northern range limit for a number of species with south-western affinities, such as Brown-headed Honeyeater (*Melithreptus brevirostris*), and the usual southern limit for a number of species with arid zone affinities, such as the Diamond Dove (*Geopelia cuneata*).

Populations of a number of bird species isolated in the North West Cape area (north of our study area, but still within the Carnarvon Basin) show considerable geographic variation, some to subspecific level. These include the Spinifex Pigeon (*Geophaps plumifera*), Grey Shrike-thrush (*Colluricincla harmonica kolichisi*) (Ford, 1987), Grey-headed Honeyeater (*Lichenostomus keartlandi*), Brown Honeyeater (*Lichmera indistincta*), Spinifexbird (*Eremiornis carteri*), Rufous-crowned Emu-wren (*Stipiturus ruficeps*), Striated Grasswren (*Amytornis striatus*) and Spotted Bowerbird (*Chlamydera guttata carteri*) (Frith and Frith, 1997). Within our study area, the Shark Bay area (and islands) contain a

number of geographic isolates that are distinct subspecies: the black and white nominate race *Malurus l. leucopterus* of the White-winged Fairy-wren is confined to Dirk Hartog Island, a subspecies of the Variegated Fairy-wren (*Malurus lamberti bernieri*) is confined to Bernier Island and a subspecies of the Southern Emu-wren (*Stipiturus malachurus hartogi*) is confined to Dirk Hartog Island (Storr, 1985, 1990). The mangrove vegetation of the Lake MacLeod and Carnarvon region also contains a number of isolated populations sometimes recognised as distinct subspecies, including Dusky Gerygone (*Gerygone tenebrosa christophori*) and White-breasted Whistler (*Pachycephala lanioides carnarvoni*). Noteworthy also are the isolated populations on the riverine systems; for example the Gascoyne supports populations of the Black-tailed Treecreeper (*Climacteris melanura*) and a subspecies of the Black-faced Cuckoo-shrike, *Coracina novaehollandiae subpallida*, is found on the Minilya, Gascoyne and Wooramel Rivers.

At the coarse level of discrimination provided by the five groups of sites identified on the basis of classification of sites according to bird species presence and the four groups identified on the basis of passerine bird species presence, all site groups are represented in the current conservation reserve system (compare Figures 1 and 3). However, each of these groups is somewhat heterogeneous, and examination of the various sub-groups recognised (see Results) and reference to Figure 1 shows that some of these are not represented in the conservation reserve system. Sampling of more sites would have enabled better discrimination between species assemblages and increased resolution in any biogeographic analyses. Nevertheless, several northern coastal and sub-coastal sub-groups (1a, 2a and 3a from the analysis including non-passerines) and inland riverine systems represented by the Gascoyne Junction sites are not represented in the conservation reserve system. There is also heterogeneity evident in sub-group 4a (inland sites). Although reasonably closely related, in terms of bird species presence, to sites in the Kennedy Range National Park, sites on inland river systems, plains and dunefields (other than the distinctive ones on the Kennedy Range) are not represented in the conservation reserve system. This is an area in which off-reserve conservation can have a positive effect for management of conservation values. Potential impacts (see e.g., Landsberg *et al.* 1997; Johnstone *et al.*, 2000) can be reduced through fencing waterholes and other management actions as described by, for example, Foran *et al.* (1990).

Birds of Acacia Woodlands

Cody (1994) surveyed mulga sites across the arid zone of Australia and, based on the frequency of encountering bird species at each of his 20 sites, classified the species observed into "core" species, "peripheral" species and "casual" species. The lists of species from the six sites with mulga (or structurally similar *Acacia* species) that we observed show a high proportion of Cody's 18 core species (44–83%, mean 65%) and a moderate proportion of his 28 peripheral species (32–54%, mean 40%). Interestingly, we recorded a mean of 33 species (SD = 5.1; range 27 to 41) (excluding raptors, nocturnal species, etc.) at these quadrats, whereas Cody (1994) recorded a mean of 23 species at five Western Australian mulga quadrats and Recher and Davis (1997) found a mean of 30 species (SD = 9.6, range 19–41) at five central Australian sites. These differences could be because (1) Cody (1994) and Recher and Davis (1997) sampled only at one time of year (spring-summer; late winter, respectively) while we sampled twice (autumn and spring), (2) we sampled a similar area at each site to Recher and Davis but a larger area than Cody, and for more time, or (3) most sites used by Cody and all by Recher and Davis were further inland than ours. Also, Cody (1994) and Recher and Davis (1997) were asking different questions from us, and this

Table 5 Identity and incidence of the core bird species of bird assemblages in *Acacia* dominated shrublands and woodlands of the Carnarvon study area. See text for explanation (Incidence is J = (number of sites at which species observed/number of sites in sample), as defined by Cody 1994).

Species	Incidence
Spiny-cheeked Honeyeater	1.00
Crested Bellbird	1.00
Chestnut-rumped Thornbill	0.95
White-browed Babbler	0.95
Redthroat	0.95
Grey Butcherbird	0.90
Variegated Fairy-wren	0.90
Emu	0.90
Western Wedgebill	0.86
Crested Pigeon	0.86
Galah	0.86
Grey Shrike-thrush	0.86
Zebra Finch	0.86
Red-capped Robin	0.86
Singing Honeyeater	0.86
Willie Wagtail	0.86
Rufous Whistler	0.81
Southern Whiteface	0.81
Little Crow	0.76
Mulga Parrot	0.71
Common Bronzewing	0.71
Budgerigar	0.71
Black-faced Woodswallow	0.71
Australian Ringneck	0.67
Diamond Dove	0.67
Pied Butcherbird	0.62
Black-faced Cuckoo-shrike	0.62
Australian Kestrel	0.57

needs to be borne in mind in any comparison. Nevertheless, all three studies were examining bird communities, and so broad comparisons should be possible at least at the level of community composition (i.e. species presence/absence).

From this perspective, one can ask the question of whether a mulga bird community exists as an identifiable entity. Our data suggest that, while sites sampled by us and dominated by mulga (in the broad sense) all classify in Group IVa, within that group these sites are interspersed among sites dominated by other *Acacia* species, such as *A. grasbyi*, *A. ramulosa* and *A. victoriae* which are structurally unlike mulga, although they are still large shrubs or small trees. Our data do suggest that, at least in our study area, there is a recognisable community of birds that inhabit *Acacia* woodlands and tall shrublands, and these communities consist of species from our species groups I and II. Using Cody's (1994) criteria on our data, there are 28 core species occurring in these 21 sites (Table 5).

All Cody's core species were seen at one or more of our *Acacia* dominated sites, but five of them do not classify as core species in our data set. Ten species classified by us as core species were not regarded by Cody as such. Some of these differences are quite marked; for example Cody considered the Emu to be a casual species, whereas we found it at all six of our mulga sites and at 19 out of 21 *Acacia* dominated woodlands. However, this particular species was probably under-sampled in Cody's methodology [because of shorter sampling time and smaller plot size (especially compared with the area likely to be used by such a large bird on a daily basis)]. Overall, the major differences between the two data sets are most likely to be due to (1) geographic variation in *Acacia* woodland communities and (2) the broader range of *Acacia* woodlands and tall shrublands investigated in the present study. Another reason to further pursue this question is that Cody (1994) (and Recher and Davis, 1997) interpreted 'mulga' as a single species of *Acacia* (*A. aneura*) and mulga vegetation to be a single habitat type distinct from other possible habitat types. We suggest this view should be reconsidered on several grounds. First, 'mulga' is actually a number of more or less closely related species (with varying degrees of ecological differentiation) previously regarded as *A. aneura* (Randell, 1992) and structurally they merge into other, less closely related species of *Acacia*. Second, Specht (1970) considered that the various mulga communities occurred in at least two of the broad structural classes of vegetation that he recognised. Furthermore, he noted considerable floristic and structural variation in the understorey of these communities [varying from virtually no understorey to either bunch grasses or chenopodiaceous or sclerophyllous shrubs (e.g., *Senna*, *Eremophila*)]. One would expect that such levels of floristic and structural variation would exert a strong influence on the composition of the bird species assemblage present. Third, our data suggest that birds do not discriminate strongly between 'mulga' and other *Acacia* woodlands that are structurally similar. This is shown by the dispersion of mulga sites among other *Acacia* dominated sites in classifications of sites in our study area and of *Acacia* dominated sites in the Western Australian eastern goldfields, although the Recher and Davis (1997) sites cluster as a discrete group when included in such an analysis (Burbidge *et al.*, 1995; A.H. Burbidge, unpublished). On the other hand, bird communities may differ between *Acacia* sites that are structurally different and/or occur on different substrates. For example, bird communities in mulga woodlands on flat sandy sites differ from those in mixed *Acacia* woodlands on rocky hills near Alice Springs (H. Recher, personal communication).

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Appendix 1

Species encountered at only one of the 63 quadrats sampled in the survey of the southern Carnarvon Basin.

Common name	Scientific name	Quadrat
Stubble Quail	*Coturnix pectoralis*	CU6
Australian Pelican	*Pelecanus conspicillatus*	BB5
White-faced Heron	*Ardea novaehollandiae*	MD3
Square-tailed Kite	*Hamirostra isura*	NE2
White-bellied Sea-Eagle	*Haliaeetus leucogaster*	CU6
Grey Falcon	*Falco hypoleucos*	BO4
Red-necked Stint	*Calidris ruficollis*	PE1
Banded Lapwing	*Vanellus tricolor*	BB2
Domestic Pigeon	*Columba livia*	CU6
Spinifex Pigeon	*Geophaps plumifera*	GJ1
Blue-winged Kookaburra	*Dacelo leachii*	MD3
Sacred Kingfisher	*Todiramphus sanctus*	MD3
Red-browed Pardalote	*Pardalotus rubricatus*	MD3
Red Wattlebird	*Anthochaera carunculata*	ZU3
White-plumed Honeyeater	*Lichenostomus penicillatus*	MD3
Magpie-lark	*Grallina cyanoleuca*	MD3
Ground Cuckoo-shrike	*Coracina maxima*	KE3
Grey Currawong	*Strepera versicolor*	ZU3
Painted Finch	*Emblema pictum*	KE1
Fairy Martin	*Hirundo ariel*	GJ1

Appendix 2

Species excluded from the analyses (except species recorded at only one site, which are listed in Appendix 1). (See text for explanation).

Common name	Scientific name	BB1	BB2	BB3	BB4	BB5	BO1	BO2	BO3	BO4	BO5	CU1	CU2	CU3	CU4	CU5	CU6	EL1	EL2	GJ1	GJ2	GJ3	GJ4	GJ5	KE1	KE2	KE3	KE4	KE5	MD1	MD2	MD3	MD4	MD5	MR1	MR2	MR3	MR4	MR5	NA1	NA2	NA3	NA4	NA5	NE1	NE3	NE4	NE5	PE1	PE2	PE4	PE5	WO1	WO2	WO3	WO4	ZU1	ZU2	ZU3	ZU4	ZU5
Malleefowl	*Leipoa ocellata*																																									*	*																*		
Black-shouldered Kite	*Elanus caeruleus*			*												*	*																				*		*				*																		
Letter-winged Kite	*Elanus scriptus*								*					*	*		*																																									*			
Black-breasted Buzzard	*Hamirostra melanosternon*																							*								*	*			*																									
Whistling Kite	*Haliastur sphenurus*		*																		*			*					*			*				*	*		*																						
Spotted Harrier	*Circus assimilis*						*					*														*	*									*	*		*											*							*	*			
Brown Goshawk	*Accipiter fasciatus*																																								*					*															
Collared Sparrowhawk	*Accipiter cirrhocephalus*		*			*																					*				*	*																											*		
Wedge-tailed Eagle	*Aquila audax*	*							*		*	*				*	*			*	*		*	*		*	*	*		*			*			*				*	*				*											*		*			*
Little Eagle	*Aquila morphnoides*																																			*	*	*				*	*																		
Brown Falcon	*Falco berigora*			*			*	*	*												*	*	*		*	*			*	*			*	*	*	*	*		*	*	*	*											*	*					*	*	
Australian Hobby	*Falco longipennis*	*				*			*																*											*																									
Australian Kestrel	*Falco cenchroides*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*		*	*	*	*	*		*		*	*	*		*		*	*		*			*		*	*					*	*	*				*	*	*	*	*	*
Australian Bustard	*Ardeotis australis*	*		*	*		*			*			*		*		*						*		*	*					*				*	*		*	*	*																					
Little Button-quail	*Turnix velox*	*		*		*		*		*					*										*	*									*	*	*	*											*												
Red-capped Plover	*Charadrius ruficapillus*					*																																											*												
Boobook Owl	*Ninox novaeseelandiae*																										*		*			*																													
Tawny Frogmouth	*Podargus strigoides*									*	*	*								*															*										*	*		*										*			
Spotted Nightjar	*Eurostopodus argus*																			*		*				*	*	*	*										*																						
Australian Owlet-nightjar	*Aegotheles cristatus*																			*		*					*	*	*			*				*			*		*				*	*	*	*							*						