Upland savannas: the vertebrate fauna of largely unknown but significant habitat in north-eastern Queensland

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ABSTRACT

This paper reports the results of dry and wet season systematic terrestrial vertebrate fauna surveys carried out on Blackbraes, a National Park in the Einasleigh Uplands bioregion, North Queensland. It quantifies, for the first time, the biodiversity values of the highest altitude upland area in the Australian tropical savanna. Nine species, including two mammals and seven reptiles, were recorded at the limits of their known range, or in seemingly disjunct populations. Patterns of fauna assemblage in relation to underlying geology and associated habitat variables were investigated and several strong relationships emerged. Temporal patterns in the observed fauna were investigated and 20 species (15 birds, 5 reptiles) were found to be more numerous in different seasons (wet and dry). The avifauna recorded was consistent with much of Australia's tropical savanna, but the reptile and mammal assemblages were distinct, rich and unusual, with exceptionally high abundances, particularly of some arboreal mammals. Blackbraes acts as an upland refuge, but the micro-habitat refuges are unusual in that they are provided by sandy habitats rather than more typical rock refuges.

Key words: Blackbraes, vertebrate fauna, geographic isolate, upland, savanna

Introduction

Landscapes of relatively high elevation often contain relict ecosystems and biogeographically restricted and endemic species (Ashcroft 2010). Such landscapes have an increasing research currency from a conservation perspective in an era where global change is creating rapid shifts in the distribution of species (Rowe *et al.* 2010). In Australia the best example is in the Wet Tropics of north-eastern Queensland, a region not only mega-diverse and of high endemism (Williams *et al.* 2003), but with many highly restricted mountain-top species considered under threat from a changing climate (Hilbert *et al.* 2004; Shoo and Williams 2004).

In contrast to the Wet Tropics, the extensive tropical savannas that dominate northern Australia, have historically been considered featureless plains. Surveys of the fauna of Queensland shires in the 1960's and 70's focussed on Queensland's fertile coastal belt, and the biological significance and variation of the broader rangelands was dismissed as largely uniform (Kirkpatrick and Lavery 1979). Landscapes of northern Australia are 'without boundaries', that is, they are generally highly connected and shaped by subtle gradients and the fauna present is generally undifferentiated across very large areas (Woinarski *et al.* 2005). In eastern Australia, the Great Dividing Range separates the near coastal plains from the arid and semi-arid inland, and in places such as the Desert and Einasleigh Uplands, extends substantially inland to create a spine of sandstone and upland ranges to over 1000 m in some cases (the highest altitude landscapes in the Australian Tropical Savannas), often with a diverse, endemic or disjunct fauna (Kutt *et al.* 2005).

The Einasleigh Uplands bioregion stretches from tall forests abutting the Wet Tropics, through basalt plains, upland plateaux and dissected breakaways that lead into the broad Gulf Plains (Sattler and Williams 1999). The significance of these complex upland tropical woodlands in shaping bird speciation has been recognised for some time (Ford 1986; Keast 1961), and recent descriptions of endemic reptiles in the region (Amey and Couper 2009; Couper *et al.* 2010) and highly disjunct distributions (Vanderduys *et al.* 2011; Vanderduys *et al.* 2012) highlight that this region is not simply an extension of the savanna plains of northern Australia; the Einasleigh Uplands provide an exception to Woinarski *et al.*'s (2005) 'landscape without boundaries'. Apart from historical collections mainly targeting avifauna (see references in Ford 1986) there has been minimal terrestrial vertebrate survey work conducted in the Einasleigh Uplands. In the description of the values of Queensland bioregions in 1999, six previous fauna surveys are listed for the Einasleigh Uplands, compared to 24 for the Wet Tropics, despite the former covering nearly six times the area of the latter (Sattler and Williams 1999). These previous surveys were either narrowly taxon specific (e.g. bats) or localised in extent. Additionally, only 3.7% of the Einasleigh Uplands is preserved within the Queensland protected area estate compared with 29.8% for Wet Tropics (CAPAD 2006; Queensland Government 2011).

Because of their altitude, the high savannas of the Einasleigh Uplands are unique in northern Australia and contain significant fauna and landscapes that might provide buffering for local savanna species under extreme weather predicted under climate change scenarios (Shoo *et al.* 2010). Understanding the values of the entire scope and variation of the northern tropical savannas is important for effective conservation planning across this important Australian biome. This paper reports the results of vertebrate fauna surveys on Blackbraes National Park, which aimed to describe the species patterns and values of a poorly known ecosystem – upland savannas – in northern Australia.

Methods

Study area

Blackbraes National Park (19° 32' S, 144° 12' E, hereafter referred to as Blackbraes) is situated 280 km west of Townsville in north Queensland, Australia. Blackbraes was gazetted as a National Park in 2002, and encompasses approximately 52,000 ha (Figure 1). It extends from about 800 m to 1,056 m altitude and lies on the western boundary of the Einasleigh Uplands, on the edge of the Gulf Plains bioregion, some of which falls within Blackbraes. The landscapes of Blackbraes are floristically, geomorphologically and topographically diverse. In the lower altitude areas, vegetation is largely *Eucalyptus crebra* open woodland, over gently undulating basalt hills. Sandstone escarpments and granite boulder outcrops are significant features of the higher altitude areas. The main vegetation community on the deeper soils of the sandstone plateaux is *E. crebra* and *Corymbia citriodora* open forest; and on the shallower soils, a mix of woodlands with species including *E. similis*, *C. leichhardtii*, *E. exilipes*, *E. crebra*, and *Callitris intratropica*. The granite outcrops typically support *C. intratropica* and *E. shirleyi* open woodland, while the sandy outwashes between the outcrops are dominated by *E. crebra* and/or *E. exilipes* woodland. Along creek lines and around the relatively low lying moist areas is *E. brownii* open woodland. In the east, there are limited areas of open grassland and dense *Melaleuca bracteata* closed forest to woodland on deeply cracking black soil.

Sampling

Vertebrate fauna surveys were conducted at the end of the wet and end of the dry season (wet and dry season surveys, respectively). The wet season survey was conducted from 19 March to 1 April 2003 and the dry season survey from 23 November to 6 December 2004. A total of 36 sites (Figure 1) were established and surveyed over a 4 night and 5 day interval. Each site was sampled using a standard quadrat that comprised a nested trap and search array (Kutt and Fisher 2011). This incorporated four pitfall traps, 10 m apart, arranged in a 'T' configuration and connected by drift fence, twenty Elliott traps placed in a 50 x 50 m square, and two cage traps. All Elliott and cage traps were baited with a mix of peanut butter, oats and honey and every second Elliott trap and all cage traps had dry dog food added. For the second (dry season) sampling period, trap effort was increased with the addition of two large (430 x 250 x 250 mm) and two small (700 x 170 x

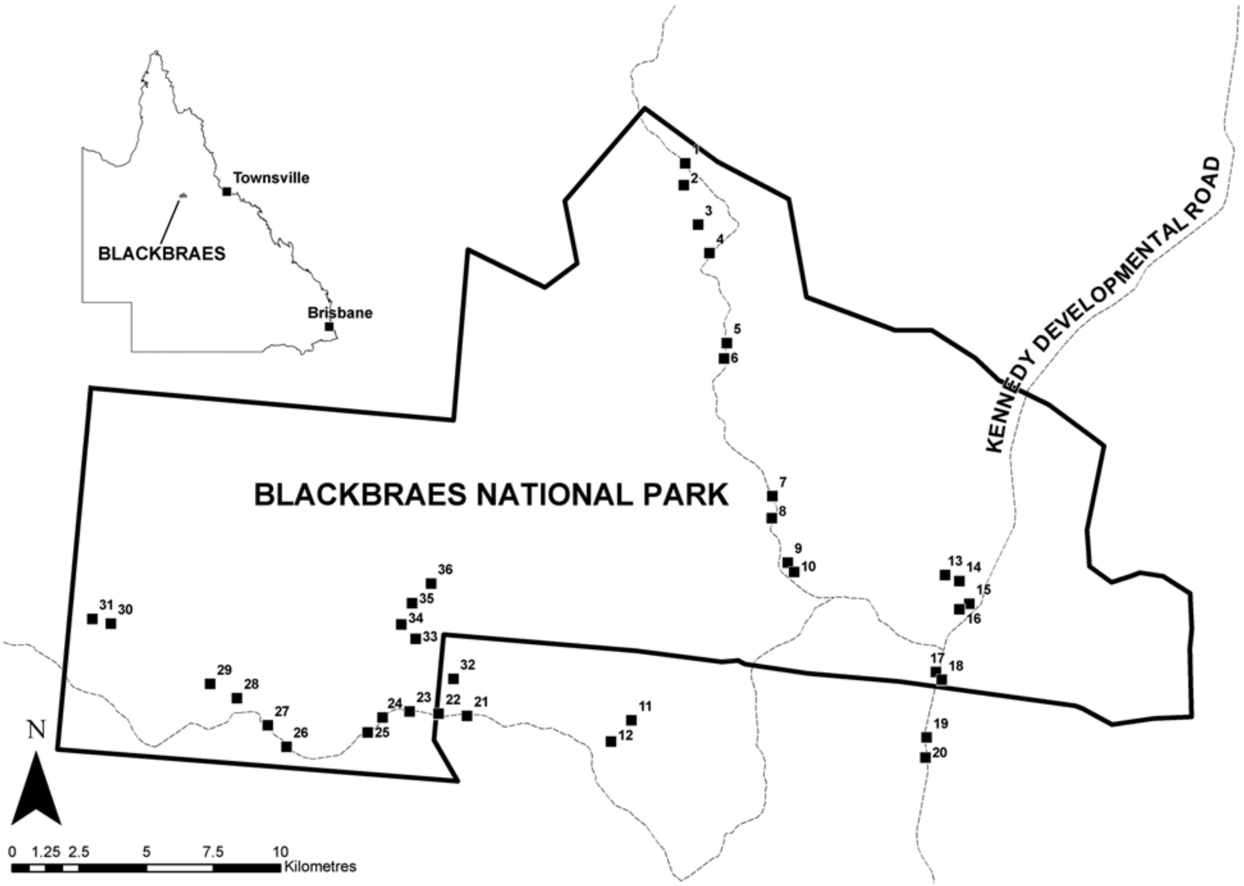

Figure 1. Location of sampling sites within Blackbraes National Park and the indicative location of the park in Queensland.

170 mm) funnel traps to the pitfall/drift fence array. All traps were checked each day in the early morning, around midday and in the afternoon. Microchiropteran bats were sampled opportunistically by searching roosting caves and by harp trapping along suitable flyways.

At each site standardised searches were undertaken. Eight bird counts were conducted within a hectare based along the pitfall array. These counts were theoretically instantaneous, though in practice up to ten minutes were allowed for each count. Timing of bird counts was rotated to reduce early morning (i.e. favourable condition) bias. Three active searches were conducted at each site, within the same hectare as for bird counts, generally one in the morning, one around midday, and one in the afternoon. Active searches involved 20 person-minutes turning logs and rocks, raking leaf litter and grass cover, peeling bark and shuffling through undergrowth. Two spotlight searches, each of 20 person-minutes, were conducted at each site. These were restricted to the same hectare as for the bird counts.

For species that were recorded outside or at the limit of their previously known range as reported in Cogger (2000), Wilson (2005) and Wilson and Swan (2010), data downloads from Australian museums' databases (OZCAM 2011) were undertaken, as was comparison with records stored in a cumulative CSIRO database of vertebrate fauna records for Queensland (CSIRO, unpubl. data). Geolocated incidental records were also gathered, typically during transit between sites. Mostly these were of species that were not seen commonly during site surveys.

For each site a range of biophysical factors were measured, including floristic (species presence and cover), structural (foliage projective cover (FPC) of strata and canopy cover), landscape (landform, position, slope, aspect and the location of water-bodies) and habitat (soil type and structure, rock, litter, hummock grass, tussock grass, sedge, forb and log cover) data. Detailed methods are presented in (Kutt *et al.* 2005).

Taxonomy

Standard common names for birds follow Christidis and Boles (2008). Scientific names are used for all other taxa.

Voucher specimen(s) were collected for identification by the Queensland Museum for species with dubious taxonomic characters. Four species of reptile and one frog recorded during our surveys remain of uncertain identification despite vouchering specimens for the Queensland Museum, and will be referred to as follows. Later references to these species in this paper should be considered with this taxonomic uncertainty in mind.

***Furina* sp.** Individuals from Blackbraes had fully enclosed (*F. diadema*), open (*F. ornata*) or partially enclosed red to orange marks on the nape. Two specimens have been collected from Blackbraes subsequent to the surveys reported here, and submitted to the Queensland Museum (EV, unpubl. data 2011). One was 'typical' *F. diadema*, and the other 'typical' *F. ornata* (Figure 2). It is hoped that genetic information from these may help clarify the status of *Furina* from Blackbraes. The two were collected 3.2 km from each other.

Figure 2. *Furina* spp. from Blackbraes showing typical *F. diadema* (top) and *F. ornata* (bottom).

***Eremiascincus* sp.** Six individuals captured presented 10-14 bands on the body and 14-17 intermediate width bands on entire or substantially intact tails, (Figure 3). Characters presented in guides (Cogger 2000; Wilson 2005; Wilson and Swan 2010) suggest this specimen is *E. richardsonii*. Queensland Museum staff identified the voucher specimen (QMJ80383) as *E. fasciolatus*, on the basis of width of the bands (Andrew Amey, pers. comm.).

***Lerista* sp.** The Blackbraes *Lerista* sp. key to *Lerista vittata* in Cogger (2000). Patrick Couper (Qld Museum, pers. comm.) suggested *Lerista* sp. from Blackbraes may be an undescribed species and specimens vouchered with the Queensland Museum were identified as *Lerista* cf. *vittata* (QMJ1773) and *Lerista* sp. (QMJ79057-79060).

Figure 3. *Eremiascincus* sp. with 13 - 14 bands on body and 15 bands on an incomplete tail. Arrow marks the point of tail regeneration.

***Acanthophis* sp.** We vouchered one specimen (QMJ80382) and recorded a second (Figure 4). A third was vouchered (QMJ80723) by Steve Christie (then Ranger of Blackbraes). QMJ80382 had moderate to strongly rugose head shields and anterior dorsal scales and raised outer edges on each supraocular indicative of *A. praelongus*, while our second individual had smooth head shields and smooth to weakly keeled anterior dorsal scales (Figure 4), indicative of *A. antarcticus* (Cogger 2000). All had 21 midbody scales. Wuster *et al.* (2005) confirmed the similarity of *A. antarcticus* and *A. praelongus* using genetic evidence and emphasise that *A. praelongus* is restricted to northeast Queensland, but without defining a limit to this distribution. The Queensland Museum identified QMJ80382 as *Acanthophis* sp. and QMJ80723 as *A. praelongus*.

Figure 4. Acanthophis sp. with smooth to very weakly keeled dorsal scales and smooth head shields.

***Uperoleia* sp.** These were recorded from three sites, but were not heard calling which is critical for the identification of some species. Calls have been heard and specimens collected during a subsequent visit (EV, unpubl. data 2011). The calls are indistinguishable to the human ear from *U. rugosa*. The specimens are not yet registered but genetic evidence suggests they are similar to *U. rugosa* (R. Catullo, pers. comm. 2012, ANU).

Analysis

All site and incidental data were assigned a regional ecosystem (Sattler and Williams 1999) by field assessment and referral to the current Einasleigh Uplands Bioregion regional ecosystem mapping available for the region (Queensland Herbarium 2009). Site descriptions and mapped regional ecosystems are given in Table 1.

The seasonal variation in abundance of species recorded in the wet season and dry season surveys was examined using the Wilcoxon matched pairs test. Only species recorded in three or more sites were examined. Records obtained by the use of funnel traps were not used in this analysis because this method was not employed in the first (wet season) survey.

We examined if there was any spatial variation in fauna assemblage between sites via multivariate analysis in PRIMER/PERMANOVA version 6 (Clarke and Gorley 2006). Firstly we constructed a site by species table populated by the abundance of each species; square-root transformed the data and constructed a Bray-Curtis resemblance (similarity) matrix. We tested the strength of this *a priori* categorisation of the site composition by mapped landzone (Sattler and Williams 1999) using ANOSIM. We then explored the correlation of

Table 1. Descriptions for Blackbraes survey sites. Regional ecosystem (RE) is given; the second number (underlined) is the landzone as used in the assemblage analysis.

Site(s)	RE	Description
1,2,5,6	9.11.16	*Eucalyptus crebra* (*sens. lat.*) +/- *Corymbia pocillum* +/- *C. terminalis* woodland on steep metamorphic hills on red to red brown soils.
3	9.3.5	*Eucalyptus brownii* open woodland to woodland +/- *Eucalyptus* spp. +/- *Corymbia* spp. on alluvial plains.
4	9.3.3a	Mixed woodland dominated by *Corymbia* spp. and *Eucalyptus* spp. on alluvial flats, levees and plains.
7-10, 17-20	9.8.1a	*Eucalyptus crebra* (sens. lat.) or *E. cullenii* +/- *Corymbia erythrophloia* +/- *E. leptophleba* woodland on plains and rocky rises of basalt geologies
11, 12	9.11.14	*Eucalyptus crebra* (*sens. lat.*) +/- *Corymbia citriodora* woodland on metamorphic hills and mountains in far southwest of bioregion.
13, 14	9.3.27a	*Iseilema* sp., *Dichanthium* sp. grassland +/- *Eucalyptus* spp. or *Corymbia* spp. emergents on alluvials on basalt geologies.
15, 16	9.3.10	*Melaleuca bracteata* +/- *Eucalyptus* spp. emergents or vine thicket species open forest to dense shrubland on creeks and swamps in basalt plains.
21-24	2.5.6x10e	*Eucalyptus crebra* +/- *Eucalyptus* spp. +/- *Corymbia* spp. open-woodland to open forest on gently undulating sandplain on plateaus.
25	9.12.18	Semi-evergreen vine thicket on rocky outcrops and shallow soils of acid volcanic rocks.
26-29	2.10.3	*Eucalyptus* spp., *Corymbia citriodora* and *Eucalyptus acmenoides* open-forest on high plateaus on earths and sands.
30, 31	9.12.14	*Eucalyptus crebra* (*sens. lat.*) and *E. similis* low open woodland on hills on acid and intermediate volcanic rocks.
32, 33, 35	9.11.17	*Eucalyptus crebra* (*sens. lat.*), *Corymbia peltata* +/- *E. shirleyi* woodland to open woodland on metamorphic hills.
34, 36	9.12.4a	*Eucalyptus shirleyi* or *E. melanophloia* with *Corymbia peltata* and/or *C. leichhardtii* low open woodland to low woodland on acid volcanic rocks.

habitat attributes in each group using a constrained canonical analysis of principle coordinates (CAP) and vector fitting of habitat attributes using Spearman rank correlations (cut-off R = 0.2). CAP analysis is designed to find the strongest axes of variable correlation through a multivariate cloud to characterise and maximise group differences (Anderson *et al.* 2008). As we had 13 habitat variables, we first tested for colinearity via Spearman rank correlations and one member of each pair of explanatory variables with Spearman pair-wise correlation coefficients >0.5 or <-0.5 was excluded.

We characterised dominant species for each landzone using SIMPER (similarity percentages) in Primer (Clarke and Gorley 2006), which decomposes average Bray-Curtis dissimilarities between all pairs of samples into percentage contributions for each species to the within group (i.e. landzone) similarity. Finally, we identified the most abundant species recorded in each landzone via non-parametric one way analysis of variance. We also examined variation in the habitat variables recorded across the sites in each landzone, and variation in the species richness and abundance for each class of fauna.

Results

Species

Families, scientific names and common names (where applicable) are listed for all species in Table 2. A total of 4432 records representing at least 167 species of vertebrate fauna were recorded using standardised sampling techniques employed in the sites. These comprised 24 mammal species, 86 birds, at least 49 reptiles and eight amphibians. An additional 51 species were only recorded incidentally during our surveys. 102 species were recorded in site counts in both the dry and wet season surveys.

The mammal and reptiles communities were exceptionally abundant and diverse (Table 2) and include mammals that are under threat, declining or very poorly known in northern Australian savannas (Fitzsimons *et al.* 2010), such as *Trichosurus vulpecula*, *Lagorchestes conspicillatus* and *Sminthopsis archeri*. Among reptiles, numerous restricted range species, species at the very edge of their known range, poorly defined and threatened species were recorded. Examples include *Acanthophis* sp., *Anomalopus gowi*, *Diplodactylus vittatus*, *Egernia rugosa*, *Eremiascincus*

Table 2. Species recorded during Blackbraes surveys. Systematic totals are summed across all 36 sites and should be considered an index of abundance and detectability rather than actual abundance. Frequency is total number of sites at which the species was recorded (i.e. maximum of 36). Incidental totals are for species not recorded during systematic surveys.

Family	Scientific name	Common name	Systematic		Inc.
			Tot.	Freq.	
Mammals					
Tachyglossidae	*Tachyglossus aculeatus*	Short-beaked Echidna	3	3	
Dasyuridae	*Planigale ingrami*	Long-tailed Planigale	2	1	
Dasyuridae	*Planigale maculata*	Common Planigale	9	6	
Dasyuridae	*Sminthopsis archeri*	Chestnut Dunnart	1	1	
Peramelidae	*Isoodon macrourus*	Northern Brown Bandicoot	3	2	
Phascolarctidae	*Phascolarctos cinereus*	Koala			1
Phalangeridae	*Trichosurus vulpecula*	Common Brushtail Possum	47	15	
Petauridae	*Petaurus breviceps*	Sugar Glider	8	7	
Pseudocheiridae	*Petauroides volans*	Greater Glider	93	16	
Potoroidae	*Aepyprymnus rufescens*	Rufous Bettong	36	16	
Macropodidae	*Lagorchestes conspicillatus*	Spectacled Hare-wallaby	3	3	
Macropodidae	*Macropus giganteus*	Eastern Grey Kangaroo	41	9	
Macropodidae	*Macropus robustus*	Common Wallaroo	1	1	
Macropodidae	*Macropus rufus*	Red Kangaroo			13
Macropodidae	*Petrogale assimilis*	Allied Rock-wallaby	1	1	
Pteropodidae	*Pteropus scapulatus*	Little Red Flying-fox	1	1	
Rhinolophidae	*Rhinolophus megaphyllus*	Horseshoe Bat			>100
Vespertilionidae	*Miniopterus australis*	Little Bent-wing Bat			1
Vespertilionidae	*Miniopterus schreibersii*	Eastern Bent-wing Bat			2
Vespertilionidae	*Nyctophilus gouldi*	Gould's Long-eared Bat			1
Vespertilionidae	*Scotorepens balstoni*	Inland Broad-nosed Bat			2
Vespertilionidae	*Vespadelus troughtoni*	Eastern Cave Bat			2
Muridae	*Hydromys chrysogaster*	Water Rat			1
Muridae	*Leggadina lakedownensis*	Lakeland Downs Mouse	6	5	
Muridae	*Mus musculus*	House Mouse	20	7	
Muridae	*Pseudomys delicatulus*	Delicate Mouse	3	3	

Family	Scientific name	Common name	Systematic		Inc.
			Tot.	Freq.	
Muridae	*Pseudomys gracilicaudatus*	Eastern Chestnut Mouse	18	7	
Muridae	*Pseudomys patrius*	Eastern Pebble-mound Mouse	15	4	
Canidae	*Canis lupus*	Dingo	3	2	
Felidae	*Felis catus*	Cat	1	1	
Equidae	*Equus caballus*	Horse	2	2	
Bovidae	*Bos taurus*	European Cattle			1
Suidae	*Sus scrofa*	Pig	2	2	
Leporidae	*Oryctolagus cuniculus*	Rabbit	12	9	
Birds					
Casuariidae	*Dromaius novaehollandiae*	Emu	3	3	
Phasianidae	*Coturnix pectoralis*	Stubble Quail	1	1	
Phasianidae	*Coturnix ypsilophora*	Brown Quail	25	8	
Anseranatidae	*Anseranas semipalmata*	Magpie Goose			1
Anatidae	*Dendrocygna arcuata*	Wandering Whistling-duck			1
Anatidae	*Cygnus atratus*	Black Swan			1
Anatidae	*Chenonetta jubata*	Australian Wood Duck			1
Anatidae	*Nettapus coromandelianus*	Cotton Pygmy-goose			>200
Anatidae	*Anas superciliosa*	Pacific Black Duck			1
Anatidae	*Aythya australis*	Hardhead			1
Podicipedidae	*Tachybaptus novaehollandiae*	Australasian Grebe			1
Anhingidae	*Anhinga novaehollandiae*	Australasian Darter			1
Phalacrocoracidae	*Microcarbo melanoleucos*	Little Pied Cormorant			1
Phalacrocoracidae	*Phalacrocorax sulcirostris*	Little Black Cormorant			1
Pelecanidae	*Pelecanus conspicillatus*	Australian Pelican			1
Ardeidae	*Ardea pacifica*	White-necked Heron	1	1	
Ardeidae	*Ardea intermedia*	Intermediate Egret	4	1	
Ardeidae	*Nycticorax caledonicus*	Nankeen Night Heron			1
Ciconiidae	*Ephippiorhynchus asiaticus*	Black-necked Stork			1
Accipitridae	*Aviceda subcristata*	Pacific Baza	1	1	
Accipitridae	*Elanus axillaris*	Black-shouldered Kite	1	1	
Accipitridae	*Lophoictinia isura*	Square-tailed Kite	1	1	
Accipitridae	*Haliastur sphenurus*	Whistling Kite	2	2	
Accipitridae	*Haliaeetus leucogaster*	White-bellied Sea-eagle			2
Accipitridae	*Accipiter fasciatus*	Brown Goshawk	1	1	
Accipitridae	*Aquila audax*	Wedge-tailed Eagle	13	7	
Falconidae	*Falco berigora*	Brown Falcon	2	2	
Falconidae	*Falco longipennis*	Australian Hobby			2
Falconidae	*Falco cenchroides*	Nankeen Kestrel	3	3	
Gruidae	*Grus rubicunda*	Brolga			4
Rallidae	*Porphyrio porphyrio*	Purple Swamphen			1
Rallidae	*Fulica atra*	Eurasian Coot			1
Otididae	*Ardeotis australis*	Australian Bustard	2	2	
Turnicidae	*Turnix pyrrhothorax*	Red-chested Button-Quail	3	3	
Jacanidae	*Irediparra gallinacea*	Comb-crested Jacana			1
Burhinidae	*Burhinus grallarius*	Bush Stone-curlew	4	3	
Recurvirostridae	*Himantopus himantopus*	Black-winged Stilt			1
Charadriidae	*Vanellus miles*	Masked Lapwing			2
Laridae	*Gelochelidon nilotica*	Gull-billed Tern			1
Columbidae	*Phaps chalcoptera*	Common Bronzewing	8	5	

Family	Scientific name	Common name	Systematic		Inc.
			Tot.	Freq.	
Columbidae	*Ocyphaps lophotes*	Crested Pigeon	24	8	
Columbidae	*Geophaps scripta*	Squatter Pigeon	13	4	
Columbidae	*Geopelia cuneata*	Diamond Dove	1	1	
Columbidae	*Geopelia striata*	Peaceful Dove	35	6	
Columbidae	*Geopelia humeralis*	Bar-shouldered Dove	1	1	
Cacatuidae	*Calyptorhynchus banksii*	Red-tailed Black-cockatoo	9	5	
Cacatuidae	*Eolophus roseicapillus*	Galah	149	17	
Cacatuidae	*Cacatua galerita*	Sulphur-crested Cockatoo	3	2	
Cacatuidae	*Nymphicus hollandicus*	Cockatiel	2	1	
Psittacidae	*Trichoglossus haematodus*	Rainbow Lorikeet	45	18	
Psittacidae	*Trichoglossus chlorolepidotus*	Scaly-breasted Lorikeet	3	2	
Psittacidae	*Aprosmictus erythropterus*	Red-winged Parrot	24	6	
Psittacidae	*Platycercus adscitus*	Pale-headed Rosella	107	32	
Cuculidae	*Centropus phasianinus*	Pheasant Coucal	25	24	
Cuculidae	*Eudynamys orientalis*	Eastern Koel			1
Cuculidae	*Scythrops novaehollandiae*	Channel-billed Cuckoo	4	4	
Cuculidae	*Chrysococcyx lucidus*	Shining Bronze-cuckoo	2	2	
Cuculidae	*Chrysococcyx minutillus*	Little Bronze-cuckoo			1
Cuculidae	*Cacomantis pallidus*	Pallid Cuckoo	1	1	
Cuculidae	*Cacomantis variolosus*	Brush Cuckoo	1	1	
Strigidae	*Ninox novaeseelandiae*	Southern Boobook	14	11	
Tytonidae	*Tyto javanica*	Barn Owl	4	3	
Podargidae	*Podargus strigoides*	Tawny Frogmouth	15	12	
Caprimulgidae	*Eurostopodus mystacalis*	White-throated Nightjar	3	3	
Aegothelidae	*Aegotheles cristatus*	Australian Owlet-nightjar	25	16	
Apodidae	*Hirundapus caudacutus*	White-throated Needletail	2	1	
Halcyonidae	*Dacelo novaeguineae*	Laughing Kookaburra	32	23	
Halcyonidae	*Dacelo leachii*	Blue-winged Kookaburra	2	2	
Halcyonidae	*Todiramphus macleayii*	Forest Kingfisher	4	3	
Halcyonidae	*Todiramphus sanctus*	Sacred Kingfisher	2	1	
Meropidae	*Merops ornatus*	Rainbow Bee-eater	5	4	
Coraciidae	*Eurystomus orientalis*	Dollarbird	6	6	
Climacteridae	*Climacteris picumnus*	Brown Treecreeper	2	1	
Maluridae	*Malurus melanocephalus*	Red-backed Fairy-wren	67	9	
Pardalotidae	*Pardalotus punctatus*	Spotted Pardalote	5	2	
Pardalotidae	*Pardalotus rubricatus*	Red-browed Pardalote	2	1	
Pardalotidae	*Pardalotus striatus*	Striated Pardalote	207	31	
Acanthizidae	*Smicrornis brevirostris*	Weebill	241	20	
Acanthizidae	*Gerygone albogularis*	White-throated Gerygone	15	9	
Meliphagidae	*Lichenostomus virescens*	Singing Honeyeater	3	3	
Meliphagidae	*Lichenostomus fuscus*	Fuscous Honeyeater			3
Meliphagidae	*Lichenostomus flavescens*	Yellow-tinted Honeyeater			1
Meliphagidae	*Manorina melanocephala*	Noisy Miner	835	33	
Meliphagidae	*Conopophila rufogularis*	Rufous-throated Honeyeater			1
Meliphagidae	*Lichmera indistincta*	Brown Honeyeater			1
Meliphagidae	*Melithreptus albogularis*	White-throated Honeyeater	51	10	
Meliphagidae	*Entomyzon cyanotis*	Blue-faced Honeyeater	15	9	
Meliphagidae	*Philemon corniculatus*	Noisy Friarbird	22	8	

Family	Scientific name	Common name	Systematic		Inc.
			Tot.	Freq.	
Meliphagidae	*Philemon citreogularis*	Little Friarbird	31	15	
Meliphagidae	*Plectorhyncha lanceolata*	Striped Honeyeater	11	5	
Petroicidae	*Microeca fascinans*	Jacky Winter	14	4	
Pomatostomidae	*Pomatostomus temporalis*	Grey-crowned Babbler	15	6	
Neosittidae	*Daphoenositta chrysoptera*	Varied Sitella	18	2	
Pachycephalidae	*Pachycephala rufiventris*	Rufous Whistler	54	14	
Pachycephalidae	*Colluricincla harmonica*	Grey Shrike-thrush	7	2	
Monarchidae	*Myiagra rubecula*	Leaden Flycatcher	2	2	
Monarchidae	*Myiagra inquieta*	Restless Flycatcher			1
Monarchidae	*Grallina cyanoleuca*	Magpie-Lark	13	7	
Rhipiduridae	*Rhipidura leucophrys*	Willie Wagtail	4	4	
Campephagidae	*Coracina novaehollandiae*	Black-faced Cuckoo-shrike	31	16	
Campephagidae	*Coracina papuensis*	White-bellied Cuckoo-shrike	21	15	
Campephagidae	*Coracina tenuirostris*	Cicadabird	7	4	
Campephagidae	*Lalage sueurii*	White-winged Triller	2	1	
Oriolidae	*Oriolus sagittatus*	Olive-backed Oriole	6	4	
Artamidae	*Artamus cinereus*	Black-faced Woodswallow			6
Artamidae	*Cracticus torquatus*	Grey Butcherbird	274	34	
Artamidae	*Cracticus nigrogularis*	Pied Butcherbird	108	25	
Artamidae	*Cracticus tibicen*	Australian Magpie	220	36	
Artamidae	*Strepera graculina*	Pied Currawong	65	23	
Corvidae	*Corvus coronoides*	Australian Raven	49	15	
Corvidae	*Corvus orru*	Torresian Crow	37	21	
Corcoracidae	*Struthidea cinerea*	Apostlebird	96	15	
Ptilonorhynchidae	*Ptilonorhynchus nuchalis*	Great Bowerbird	1	1	
Alaudidae	*Mirafra javanica*	Horsfield's Bushlark			4
Estrildidae	*Taeniopygia bichenovii*	Double-barred Finch	8	4	
Estrildidae	*Lonchura castaneothorax*	Chestnut-breasted Mannikin			13
Nectariniidae	*Dicaeum hirundinaceum*	Mistletoebird	11	8	
Megaluridae	*Megalurus timoriensis*	Tawny Grassbird	8	2	
Megaluridae	*Cincloramphus mathewsi*	Rufous Songlark			1
Sylviidae	*Cisticola exilis*	Golden-headed Cisticola	28	2	
Reptiles					
Gekkonidae	*Diplodactylus conspicillatus*	Fat-tailed Diplodactylus	3	1	
Gekkonidae	*Diplodactylus vittatus*	Wood Gecko	3	2	
Gekkonidae	*Gehyra dubia*		85	27	
Gekkonidae	*Heteronotia binoei*	Bynoe's Gecko	37	12	
Gekkonidae	*Lucasium steindachneri*	Steindachner's Gecko	1	1	
Gekkonidae	*Oedura castelnaui*	Northern Velvet Gecko	11	4	
Gekkonidae	*Oedura coggeri*	Northern Spotted Velvet Gecko	7	3	
Gekkonidae	*Oedura monilis*		39	11	
Gekkonidae	*Oedura rhombifer*	Zig-Zag Gecko	48	22	
Pygopodidae	*Delma tincta*		10	4	
Pygopodidae	*Lialis burtonis*	Burton's Legless Lizard	2	2	
Pygopodidae	*Pygopus schraderi*	Eastern Hooded Scaly-foot			1
Scincidae	*Anomalopus gowi*		1	1	
Scincidae	*Carlia jarnoldae*		31	8	
Scincidae	*Carlia munda*		15	10	
Scincidae	*Carlia schmeltzii*		39	13	
Scincidae	*Carlia vivax*		9	8	

Family	Scientific name	Common name	Systematic		Inc.
			Tot.	Freq.	
Scincidae	*Cryptoblepharus pannosus*	Ragged Snake-eyed Skink	1	1	
Scincidae	*Cryptoblepharus adamsi*	Adam's Snake-eyed Skink	115	49	
Scincidae	*Cryptoblepharus metallicus*	Metallic Snake-eyed Skink			1
Scincidae	*Ctenotus spaldingi*		2	1	
Scincidae	*Ctenotus taeniolatus*	Copper-tailed Skink	55	17	
Scincidae	*Egernia hosmeri*	Hosmer's Skink	1	1	
Scincidae	*Egernia rugosa*	Yakka Skink	1	1	
Scincidae	*Eremiascincus* sp.	See text	6	4	
Scincidae	*Lerista* sp.	See text	13	2	
Scincidae	*Liburnascincus mundivensis*		2	1	
Scincidae	*Lygisaurus foliorum*		44	17	
Scincidae	*Menetia greyii*		29	17	
Scincidae	*Morethia taeniopleura*	Fire-tailed Skink	26	13	
Scincidae	*Proablepharus tenuis*		3	3	
Agamidae	*Amphibolurus nobbi*	Nobbi	2	1	
Agamidae	*Chlamydosaurus kingii*	Frilled Lizard	3	3	
Agamidae	*Diporiphora australis*	Tommy Roundhead	17	12	
Agamidae	*Pogona barbata*	Bearded Dragon	2	1	
Varanidae	*Varanus panoptes*	Yellow-spotted Monitor			1
Varanidae	*Varanus scalaris*	Spotted Tree Monitor	9	8	
Varanidae	*Varanus storri*	Storr's Monitor	4	3	
Varanidae	*Varanus varius*	Lace Monitor	1	1	
Typhlopidae	*Ramphotyphlops ligatus*		2	2	
Typhlopidae	*Ramphotyphlops unguirostris*		1	1	
Boidae	*Aspidites melanocephalus*	Black-headed Python	4	4	
Colubridae	*Boiga irregularis*	Brown Tree Snake	7	5	
Colubridae	*Dendrelaphis punctulata*	Common Tree Snake	2	2	
Colubridae	*Tropidonophis mairii*	Freshwater Snake	2	2	
Elapidae	*Acanthophis* sp.	See text	1	1	
Elapidae	*Brachyurophis australis*	Coral Snake	1	1	
Elapidae	*Cryptophis boschmai*	Carpentaria Whip Snake	1	1	
Elapidae	*Demansia papuensis*	Papuan Whip Snake			1
Elapidae	*Demansia psammophis*	Yellow-faced Whip Snake	3	2	
Elapidae	*Furina* sp.	See text	4	3	
Elapidae	*Hoplocephalus bitorquatus*	Pale-headed Snake	6	6	
Elapidae	*Pseudonaja textilis*	Eastern Brown Snake	5	4	
Elapidae	*Vermicella annulata*	Bandy-bandy			1
Amphibians					
Bufonidae	*Rhinella marina*	Cane Toad	14	2	
Hylidae	*Litoria caerulea*	Common Green Treefrog	19	10	
Hylidae	*Litoria inermis*	Bumpy Rocketfrog	8	4	
Hylidae	*Litoria nasuta*	Striped Rocketfrog			1
Hylidae	*Litoria novaehollandiae*	Eastern Snapping Frog	1	1	
Hylidae	*Litoria rothii*	Northern Laughing Treefrog			1
Hylidae	*Litoria rubella*	Ruddy Treefrog	1	1	
Limnodynastidae	*Limnodynastes tasmaniensis*	Spotted Grassfrog	94	12	
Limnodynastidae	*Limnodynastes terraereginae*	Scarlet Sided Pobblebonk	1	1	
Myobatrachidae	*Uperoleia* sp.	See text	3	3	

sp., *Lerista* sp., *Ramphotyphlops ligatus* and *Varanus varius* (Wilson 2005). Birds and frogs were less obviously distinct from typical savanna assemblages.

Taxonomic difficulties notwithstanding, *Lerista vittata* is listed as vulnerable under both the federal Environmental Protection and Biodiversity Conservation Act (EPBC) (Australian Government 1999) and the state Nature Conservation Act (NCA) (Queensland Government 2006), while *Acanthophis antarcticus* is near threatened (NCA). *Egernia rugosa* is vulnerable (EPBC, NCA); *Sminthopsis archeri*, Cotton Pygmy-goose *Nettapus coromandelianus*, Black-necked Stork *Ephippiorhynchus asiaticus* and Square-tailed Kite *Lophoictinia isura* are near threatened (NCA).

Seasonal patterns

Twenty species comprising 15 birds and five reptiles varied significantly in abundance between the dry and wet season surveys (Table 4). Twelve species of birds were more often sampled during the dry than wet season survey, while reptile patterns were reversed, with four species more commonly sampled during the dry. Birds showed significantly greater overall abundance and richness in the wet season than dry season. No mammal species showed significant seasonal patterns, although in aggregate, abundance was significantly higher during the dry season survey.

The inclusion of funnel traps in the dry season survey resulted in captures of a new group of fauna which had

Table 3. Draftsman's plot of biophysical factors measured showing correlations between different factors. Row headings in bold were used in the multidimensional scaling. Figures in bold are strong correlations (+ or -) that were used to eliminate biophysical factors from the analysis.

Biophysical factor	Canopy height (m)	Bare ground (%)	Rock cover (%)	Litter cover (%)	Perennial cover (%)	Annual cover (%)	Sedge cover (%)	Forbs cover (%)	Logs >5 cm	FPC (%) >10m	FPC (%) 5-10m	FPC (%) 3-5m
Bare ground (%)	0.31											
Rock cover (%)	-0.43	-0.13										
Litter cover (%)	0.20	-0.08	-0.23									
Perennial cover (%)	0.03	-0.36	-0.46	-0.53								
Annual cover (%)	-0.35	0.22	0.65	-0.19	-0.48							
Sedge cover (%)	0.26	0.03	-0.17	0.60	-0.42	-0.27						
Forbs cover (%)	-0.11	-0.23	0.03	0.20	-0.17	0.02	0.06					
Logs >5 cm	-0.01	-0.14	-0.11	-0.08	-0.07	-0.13	0.21	-0.18				
FPC (%) >10m	0.74	0.40	-0.32	0.32	-0.14	-0.24	0.31	-0.20	-0.13			
FPC (%) 5-10m	-0.08	-0.17	-0.05	0.29	-0.19	0.05	0.12	0.62	-0.06	-0.22		
FPC (%) 3-5m	-0.12	-0.03	0.56	0.21	-0.50	0.31	0.31	-0.17	-0.09	-0.01	0.02	
FPC (%) 1-3m	-0.15	0.40	0.01	0.10	-0.33	0.42	0.01	0.07	-0.09	0.03	0.18	0.12

Table 4. Seasonal differences in abundance for total species richness and abundance, and individual species abundance. Only species indicating significant variation are shown. Data represents mean score across the 36 paired sites. Z = the Wilcoxon matched pairs test statistic. Highest values for each species are indicated in bold. Probability levels are *p<0.1, **p<0.05, ***p<0.01.

Species	Dry	Wet	Z+p
Mammal abundance	5.6	3.5	2.3*
Bird abundance	33.5	52.7	4.6***
Bird richness	8.0	11.3	4.0***
Peaceful Dove	0.5	5.3	2.1*
Galah	1.2	7.4	2.9**
Pale-Headed Rosella	1.1	2.2	2.5*
Australian Owlet-nightjar	0.3	1.3	2.7**
Striated Pardalote	0.5	6.2	4.6***
Weebill	3.8	8.2	2.7**
Noisy Miner	15.4	9.9	3.2**
Noisy Friarbird	2.6	0.0	2.3*
Grey Butcherbird	3.2	4.8	2.1*
Pied Butcherbird	0.5	3.7	3.6***
Australian Magpie	2.6	3.5	2.3*
Pied Currawong	0.3	2.4	3.4***
Australian Raven	0.0	2.9	2.8**
Torresian Crow	0.9	0.5	2.0*
Apostlebird	0.5	5.7	2.4*
Reptile abundance	11.2	7.8	2.0*
Reptile richness	5.5	4.4	2.7**
Oedura rhombifer	2.0	0.2	4.1***
Carlia jarnoldae	3.6	0.3	2.1*
Cryptoblepharus adamsi	5.9	0.0	2.3*
Lygisaurus foliorum	0.7	1.9	2.3*
Menetia greyii	1.3	0.4	2.3*

previously only been recorded during active searches, i.e. snakes large enough to climb out of the pitfall buckets. Six captures (one *Tropidonophis mairii* and five *Pseudonaja textilis*) fall into this category.

Assemblage patterns

For species that were recorded at more than three sites, 35 showed significant differences across the landzones (Table 5). Mammal, reptile and amphibian abundance, and reptile and amphibian richness, varied significantly between landzones. Total richness and abundance differences were not significant across landzones.

The ANOSIM indicated that the grouping of sites via landzone was strong (Global R = 0.415). There was some degree of colinearity between the explanatory variables. In particular there was high correlation between FPC

Table 5. Variation in total species richness, species abundance and habitat variables between the six landzones. Data tabulated represent the means. For individual species, only those recorded at ≤ 3 sites were used in analysis, and only those with p <0.1 are presented here. Highest values for each species/variable are indicated in bold. H = Kruskal-Wallis ANOVA by Ranks test statistic; p = probability levels.

Species / Habitat variable	Landzone						H	p
	3	5	8	10	11	12		
Canopy height (m)	9.8	23.8	21.4	22.8	15.6	11.6	23.6	<0.001
Bare ground (%)	7.8	17.9	21.8	24.0	23.0	19.9	14.2	0.014
Rock cover (%)	2.3	0.0	1.8	2.7	6.1	28.3	12.4	0.030
Litter cover (%)	27.7	23.8	21.3	46.2	22.2	20.2	10.5	0.063
Perennial grass cover (%)	47.8	51.9	51.7	18.9	42.4	23.7	14.2	0.014
Annual grass cover (%)	0.0	1.0	0.6	0.1	1.9	4.1	15.7	0.008
Sedge cover (%)	0.6	0.0	0.1	2.5	0.0	0.0	26.5	<0.001
FPC (%) >10 (m)	3.1	24.7	17.4	30.8	15.6	11.9	17.3	0.004
FPC (%) 3-5 (m)	1.2	2.9	3.6	9.4	2.4	9.2	14.3	0.014
All species richness	28.8	24.5	26.3	23.8	30.4	30.6	5.9	ns
All species abundance	151.3	102.0	111.1	98.5	118.6	125.0	3.7	ns
Mammals richness	3.9	3.3	2.1	3.3	4.2	3.6	9.2	ns
Mammals abundance	12.3	9.5	3.0	20.0	7.4	9.6	21.1	<0.001
Birds richness	16.6	10.5	16.1	12.0	14.4	16.0	7.1	ns
Birds abundance	97.3	67.8	93.5	58.0	85.9	85.6	8.8	ns
Reptiles richness	5.7	10.3	6.9	8.0	10.1	10.2	16.6	0.005
Reptiles abundance	18	24.3	12.6	20	22.6	27.4	11.0	0.051
Amphibians richness	1.9	0.5	1.1	0.5	1.7	0.8	9.7	0.084
Amphibians abundance	16.0	0.5	2.0	0.5	2.7	2.4	17.4	0.004
Isoodon macrourus	0.0	0.8	0.0	0.0	0.0	0.0	16.5	0.006
Trichosurus vulpecula	0.0	0.3	0.0	1.8	0.9	6.0	22.5	<0.001
Petauroides volans	0.8	5.8	0.1	13.8	0.4	1.0	23.2	0.000
Macropus giganteus	4.3	0.3	0.1	0.0	1.4	0.0	10.5	0.062
Mus musculus	3.2	0.0	0.1	0.0	0.0	0.0	30.7	<0.001
Pseudomys patrius	0.0	0.0	0.0	3.0	0.1	0.4	9.3	0.097
Peaceful Dove	2.5	0.0	0.0	0.0	0.4	3.2	10.7	0.057
Galah	15.2	0.3	4.8	0.0	1.8	0.0	17.0	0.005
Striated Pardalote	4.0	4.0	0.5	7.5	7.9	9.4	11.5	0.042
Noisy Miner	5.5	35.8	28.3	22.0	27.9	18.6	13.1	0.020
Jacky Winter	0.0	0.0	1.8	0.0	0.0	0.0	15.3	0.009
Rufous Whistler	6.0	1.5	0.3	0.0	0.0	0.0	14.0	0.015
Grey Shrike-thrush	1.2	0.0	0.0	0.0	0.0	0.0	10.3	0.068
Cicadabird	0.5	0.0	0.0	0.0	0.0	0.8	10.1	0.074
Grey Butcherbird	2.8	10.0	8.3	9.3	10.3	4.0	13.8	0.017
Pied Butcherbird	2.7	0.0	4.8	0.3	3.6	3.8	15.1	0.010

Species / Habitat variable	Landzone						H	p
	3	5	8	10	11	12		
Pied Currawong	0.2	3.0	0.8	2.3	1.2	4.4	12.4	0.030
Mistletoebird	0.5	0.0	0.6	0.8	0.0	0.0	10.1	0.074
Tawny Grassbird	1.3	0.0	0.0	0.0	0.0	0.0	10.3	0.068
Golden-headed Cisticola	4.7	0.0	0.0	0.0	0.0	0.0	10.3	0.068
Heteronotia binoei	0.2	0.8	0.0	0.3	0.4	5.6	11.9	0.036
Oedura coggeri	0.0	0.0	0.0	0.3	0.0	1.2	10.4	0.065
Oedura monilis	0.0	5.3	1.4	0.5	0.4	0.2	17.9	0.003
Oedura rhombifer	0.0	0.5	1.4	2.5	1.3	2.6	14.1	0.015
Carlia munda	0.3	0.0	0.4	0.0	0.3	1.4	10.5	0.063
Carlia schmeltzii	0.7	4.3	0.1	1.8	0.6	1.0	14.4	0.013
Cryptoblepharus adamsi	3.5	1.8	2.1	0.0	3.0	0.4	10.5	0.062
Ctenotus taeniolatus	0.0	0.8	0.3	2.3	3.6	1.8	16.4	0.005
Eremiascincus sp.	0.0	1.0	0.0	0.0	0.0	0.4	19.1	0.001
Lerista sp.	0.0	0.0	0.0	3.3	0.0	0.0	16.5	0.005
Lygisaurus foliorum	0.3	3.0	0.6	3.5	1.1	0.2	10.5	0.061
Morethia taeniopleura	0.2	1.5	0.4	0.0	1.1	1.2	10.6	0.058
Diporiphora australis	0.2	0.3	0.0	0.8	1.0	0.6	9.4	0.094
Rhinella marina	2.3	0.0	0.0	0.0	0.0	0.0	10.3	0.067
Limnodynastes tasmaniensis	14.0	0.0	0.3	0.0	0.9	0.0	22.5	<0.001

over 10 m in height and canopy height (r = 0.74), annual and rock cover (r = 0.65) and sedge and litter cover (r = 0.62) (Table 3). After taking these relationships into account, the final subset of explanatory variables used for the ordination vector fitting was: percentage values for bare ground, rock and litter cover, FPCs (>10 m, 5-10 m and 1-3 m) and number of logs greater than 5 cm diameter. In the ordination, the canonical analysis of principle coordinates suggested some clear gradients of change in biophysical factors across different landzones. For example, there was clear change from low bare ground percentage to high percentage from landzones 3 (low lying alluvia) to 12 (granite hills and slopes). Sites on landzones 5 (sandy and loamy plains) and 10 (sandstone ranges) were clearly differentiated from those on landzone 11 (metamorphic hills) on a gradient of litter cover and FPC (>10 m) (Figure 5).

From 12 to 30 species contributed 90% of within-landzone similarity for the ANOSIM. The three highest contributors to this similarity from each taxonomic class are listed below along with their average abundance per site and their contribution to similarity:

Landzone 3: Alluvium (river and creek flats). N = 6; *Mus musculus* (1.7, 10.6%), *Macropus giganteus* (1.6, 5.4%), *Aepyprymnus rufescens* (0.9, 1.5%), Australian Magpie *Cracticus tibicen* (2.6, 12.1%), Apostlebird *Struthidea cinerea* (2.0, 5.4%) Rufous Whistler *Pachycephala rufiventris* (1.7, 4.0%), *Carlia vivax* (0.5, 2.1%), *Menetia greyii* (0.5, 1.8%), *Cryptoblepharus adamsi* (1.4, 1.3%), *Limnodynastes tasmaniensis* (3.2, 15.1%).

Landzone 5: Old loamy and sandy plains. N = 4; *Petauroides volans* (2.4, 9.1%), Noisy Miner *Manorina melanocephala* (6.0, 22.6%), Grey Butcherbird *Cracticus torquatus* (3.2, 11.9%), Australian Magpie (2.4, 8.1%), *Oedura monilis* (2.3, 8.7%), *Carlia schmeltzii* (2.0, 6.2%), *Gehyra dubia* (1.4, 4.3%).

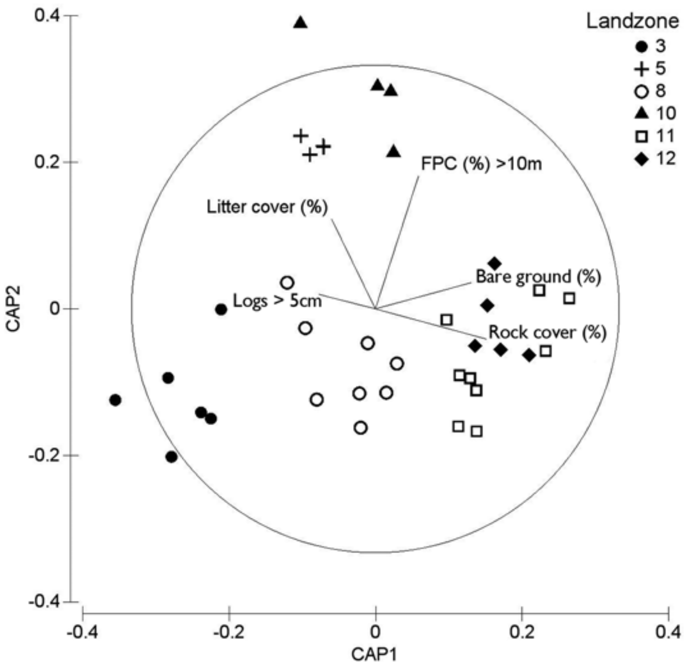

Figure 5. Spearman rank correlations of habitat attributes represented as vector overlain on constrained canonical analysis of principle ordination of fauna composition (square-root transformed abundance and Bray-Curtis similarity matrix) of each of the 36 sites sampled. The groups are defined by landzone.

Landzone 8: Basalt plains and hills. N = 8; Noisy Miner (5.2, 20.3%), Australian Magpie (2.8, 11.7%), Grey Butcherbird (2.8, 10.6%), *Cryptoblepharus adamsi* (1.3, 4.5%), *Oedura rhombifer* (1.0, 2.5%), *Gehyra dubia* (0.9, 2.4%).

Landzone 10: Sandstone ranges. N = 4; *Petauroides volans* (3.6, 13.4%), Noisy Miner (4.7, 19.2%), Grey Butcherbird (3.0, 12.6%), Striated Pardalote *Pardalotus striatus* (2.7, 10.0%), *Oedura rhombifer* (1.6, 6.3%), *Lygisaurus foliorum* (1.6, 4.0%), *Gehyra dubia* (1.1, 2.6%).

Landzone 11: Hills and lowlands on metamorphic rocks. N = 9; *Trichosurus vulpecula* (0.8, 2.8%), Noisy Miner (5.1, 19.1%), Grey Butcherbird (3.2, 12.5%), Australian Magpie (2.0, 7.4%), *Ctenotus taeniolatus* (1.7, 4.6%), *Gehyra dubia* (1.6, 3.9%), *Cryptoblepharus adamsi* (1.5, 3.9%).

Landzone 12: Hills and lowlands on granite rocks. N = 5; *Trichosurus vulpecula* (2.3, 8.0%), Striated Pardalote (2.9, 9.7%), Noisy Miner (3.7, 9.5%), Australian Magpie (2.2, 7.6%), *Gehyra dubia* (1.4, 5.0%), *Oedura rhombifer* (1.4, 3.6%), *Ctenotus taeniolatus* (1.2, 3.5%).

Discussion

This survey is the first systematic vertebrate survey of a large, upland (>800 m altitude) area of Australian tropical savanna and recorded many species with disjunct distributions, threatened species and species thought to be declining in other tropical savanna locations. The survey was notable for the extreme abundance of some taxa. Arboreal mammals, for example, were very numerous; for example *Petauroides volans* was recorded 93 times from 16 sites and *Trichosurus vulpecula* 47 times from 15 sites. Ground-dwelling mammals were high in abundance and richness, including species in the weight range that are especially vulnerable to feral carnivore (fox and cat) predation (approximately 0.1 - 5 kg Johnson and Isaac 2009; Kutt 2011). Compared to other regions in northern Queensland, the mammal fauna recorded in this survey is largely intact and therefore Blackbraes is a significant refuge for mammals in the tropical savannas.

Upland rainforest areas of Queensland have rightly received a great deal of attention because of their high levels of endemism (Graham *et al.* 2006). As potential refuges these areas are similarly important for rainforest species (Schneider *et al.* 1998; Williams *et al.* 2003). Mesic and seasonally very dry ecosystems have received far less attention both in terms of studies in endemism and as refuges, and what attention they do receive is generally in the context of rock refuges (Couper and Hoskin 2008; Ford 1977; Freeland *et al.* 1988). Blackbraes is a refuge area aside from values that might exist within its rock habitats, as it provides an unusual example of cooler, higher altitude and tall savanna woodlands. In this respect it is unique in the Australian tropical savannas (Bowman *et al.* 2010). The Einasleigh Upland region has previously been recognised as a significant biogeographic barrier responsible for the vicariant evolution of a number of birds and is the confluence of many northern and southern variants (Ford 1978; Ford 1986; Schodde and Mason 1999). We also found a number of endemic or highly disjunct reptile species, though none were recorded from 'typical' rock refuges, that is, sites where there is sufficient boulder cover to provide climatic buffering (Couper and Hoskin 2008). For example the fossorial skink *Eremiascincus* sp. (sandswimmer), a species typical of extensive arid inland dune fields, was caught in isolated upland plateaux (>1000 m) in deep tertiary red sandy soils.

As suggested by the five inconclusive identifications obtained in this survey despite the presence of voucher specimens, several taxonomic issues are unresolved and further clarification may require genetic and morphological examination of more specimens, especially from the Einasleigh Uplands and surrounds. Resolution of these taxonomic difficulties is important because in some cases, the taxa are beyond their generally recognised range, have restricted ranges or are threatened at some level.

Though there were few threatened species recorded, they were highly significant due to their distribution or the taxonomic uncertainly associated with the record. The chestnut dunnart *Sminthopsis archeri* was a significant and very unusual range extension from the previous Austro-Papuan distribution (Kutt 2008). A minimum of 200 Cotton Pygmy-geese was observed at Emu Swamp on 3 December 2004. Total Australian population estimates in the 1960s were around 1500 birds (Lavery 1966), and no population trend is obvious between the two Australian Bird Atlases (Barrett *et al.* 2003; Blakers *et al.* 1984). More recent, and probably more accurate, estimates are 'less than 10000' (Briggs 2011), 'estimated … at 7500' (Briggs 2011; Wetlands International 2006). Nevertheless, because of the large number observed, Emu Swamp at Blackbraes is likely to be a very important area for this species in Australia. This record is also near the western-most area where Cotton Pygmy-geese have been observed in Australia.

Other significant records and the reason for their significance are:

The skink *Anomalopus gowi* - the most westerly documented record and substantially filling in the known range by about 115 and 150 km from nearest records to the south and north respectively.

The gecko *Diplodactylus vittatus* – the northern most documented record. This species has a generally southern distribution and its presence at Blackbraes may be an example of a southern species persisting in cool upland areas.

The skink *Egernia rugosa* – part of a previously reported (Cogger 2000; Wilson 2005; Wilson and Swan 2010) geographically isolated population. However, there are no museum records from this population and no database records with 200 km, suggesting that *E. rugosa* may be rare in this part of the Einasleigh Uplands.

The skink *Eremiascincus* sp. – the most northern Queensland record for banded sand-swimmers (*E. fasciolatus* and *E. richardsonii*) and a geographic isolate from both species by over 300 km.

The frog *Uperoleia* sp. – if indeed it is *U. rugosa*, then the records presented here are from a previously unknown, and possibly isolated population. The nearest records of this species are over 700 km to the south (R. Catullo, pers. comm. 2012, ANU).

There was strong separation of the fauna assemblage with the changing vegetation composition on the different geologies. Where the vegetation change was stark (e.g. grassland swamp to woodland) the shift in fauna species is understandable; but in other cases (e.g. alluvium to basalt plains and hills to metamorphic and granite hills), where the vegetation change was subtle, the fauna strongly patterned with change in substrate and associated habitat resources (i.e. gradients of rock cover, log cover or bare ground). This is in contrast with other descriptions of a lack of change, across extensive tropical savanna transects in northern Australia (Woinarski *et al.* 1999). In our study there were some discrete patterns of assemblage evident across the different landzones over short distances. The ironbark forests on the high plateau (comprising a mosaic of loamy and sandy plains, sandstone ranges, metamorphic and granitic hills) were especially abundant and species rich in mammals. The high incidence of *P. volans* in this area is probably as a result of the large tracts of intact, tall (20-30 m) ironbark forest, with very numerous hollows and diverse suitable food tree species present (e.g. *Eucalyptus mediocris*, *E. intermedia*, *Corymbia intermedia*; Comport *et al.* (1996)). In fact, no particular landzone was especially species rich in mammals, despite the total mammal richness for the reserve being high, suggesting a consistent mammal fauna across the extent of the study area.

Among the reptiles a number of obvious substrate associations were apparent. The gecko *Oedura coggeri* is well known to be associated with emergent rock habitats (Cogger 2000; Wilson 2005) and was most abundant in landzone 12 (granite) sites. In contrast, the very similar *O. monilis*, usually considered arboreal (Cogger 2000; Wilson 2005) was most abundant on sandy plains with the greatest canopy height, and no emergent rocks. The sand-swimming skink *Eremiascincus* sp. was, not surprisingly, also most abundant in this habitat. *Lerista* sp. is also a sand-swimmer but was most abundant on sandstone, where it occurred in the deep weathered sandy soils. More common species such as *Carlia* spp., *Lygisaurus foliorum* and *Ctenotus* spp. were distributed at highest abundances in different land zones, with the greatest species richness of all reptiles in the upland sandy and rocky habitats. The relationship between high species richness and the most complex microhabitat (i.e. saxicolous, sandy) associations has been described previously for tall near-coastal woodlands in northern Queensland (Kutt *et al.* 2011).

Because of the relatively low richness of frogs observed, few patterns emerged and those that do were obvious ones. Abundance was greatest in the lower, heavy cracking soils of alluvial areas, which become seasonally inundated swamps. These areas provide abundant shelter (soil cracks, grass cover and fallen logs) and hold moisture longer which is a strong determinant of amphibian survival and abundance (Mac Nally *et al.* 2009; Tracy *et al.* 2007). The total observed richness was low, a function of multi-taxa surveillance surveys that require adequate access and therefore a relatively restricted period for survey. Amphibians typically need targeted surveys, with specific methods in peak periods of activities, during periods of high rainfall (Vanderduys *et al.* 2011).

In this study 20% of bird species varied significantly in abundance between wet and dry season surveys suggesting a majority of the avifauna was year round residents and equally observable across seasons. The species that were more abundant in the wet season survey were mostly granivorous, omnivorous or raptorial species (e.g. Peaceful Doves *Geopelia striata*, Galahs *Eolophus roseicapillus* and Pale-headed Rosellas *Platycercus adscitus*), and many of them were relatively large, flocking and nomadic species that may have moved into the region following food resources after the wet season. Few species were more abundant in the dry season, except Noisy Miners, and they were very abundant across most survey sites. Small birds, less than 25 cm, are generally prone to influence by hyper-aggressive Noisy Miners (Eyre *et al.* 2009), and the high abundance of miners in this season might be having a negative effect on small bird assemblage. Our results indicated that the Weebill *Smicrornis brevirostris* and Striated Pardalote were more abundant during the wet season survey in which Noisy Miners were less abundant, and this relationship has been recorded in other sites across northern Queensland (Kutt *et al.* 2012).

Of the reptiles that showed a difference between surveys all were more abundant during the dry season survey except *Lygisaurus foliorum*. This is because of a number of factors. Firstly, small reptiles are generally more visible in the late dry season, because of reduced cover. Secondly paucity of food resources means they are likely to need to move further e.g. from tree to tree in the case of *Cryptoblepharus adamsi* in order to procure food. This in turn is likely to bring them into contact with pitfall traps and make them more visible to human observers undertaking active searches. Thirdly, in the cool higher altitude and generally wet period at the end of the wet season many reptiles may simply not become active, instead commencing aestivation, or at least staying in close proximity to shelter sites. The significant difference between wet and dry season surveys in detecting large (>50 cm SVL) snakes is almost certainly because of the introduction of funnel traps. This method should continue to be employed in fauna surveys, especially when species inventory is required. Funnel traps associated with drift fences are still the only quantifiable method for surveying this low detectability group.

Conclusion

In this survey we have shown that the nature of northern Australian tropical savannas is much more complex than characterisations of extensive, largely undifferentiated landscape with subtle gradients. Though the largest extent of savannas occur west of the Queensland border, this should not mean that the nature of Australian tropical savannas should be defined by these central and north-western savannas, despite these areas being highly significant and biologically intact (Woinarski *et al.* 2007). The biogeographically and biologically complex savanna landscapes with their diverse and largely intact mammal fauna suggests that these landscapes are quite resilient and may provide significant refuges in the face of climate change. The strong patterning of the fauna across the changing geological components of the survey area also indicates that though vegetation pattern and structure might be largely consistent, the variation in substrate and the allied habitat features are strongly deterministic of the fauna, especially in the plateau sections of the reserve. There are a number of diverse and critical tropical savanna landscapes in northern Queensland that are significant in the biogeographic history of Australia and deserve recognition for this. The Einasleigh Uplands covered here, Desert Uplands, Mt Isa Inlier and Cape York savannas are such landscapes.

Acknowledgements

This project was funded by Australian Government programs now defunct; National Heritage Trust and the Tropical Savannas CRC. A number of people helped with the survey and we particularly thank Adam Tassicker and Sari Mangru (James Cook University), Steve Christie (Queensland Parks and Wildlife Service) and Anders Zimny. Thanks to Dr Andrew Amey and Patrick Couper, of the Queensland Museum, for providing additional information on identification. They also freely allowed access to QM collections for comparisons with specimens collected from Blackbraes National Park. and Renee Catullo of the Australian National University is gratefully acknowledged for sequencing the *Uperoleia* sp. All trapping was conducted under the Queensland Government Scientific Purposes Permit number WITK04645707. The production and writing of this manuscript was supported by funding from the CSIRO Building Resilient Australian Biodiversity Assets Theme. Gen Perkins and Justin Perry (CSIRO) and two anonymous reviewers provided valuable comments to the draft manuscript.

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