Responses of Birds and Reptiles in Warrumbungle National Park after the Extensive 2013 Wildfire

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In 2013 extensive wildfire burnt 90% (22104 ha) of Warrumbungle National Park in New South Wales, Australia. In 2014 – 2016 we assessed how species composition and abundance of birds and reptiles varied with fire severity and habitat characteristics. Of 91 bird species observed during surveys of 35 sites, 47 were more often on low severity sites. Bird species composition did not differ among vegetation communities although activity levels (species per 10 minutes) were reduced in woodland on sedimentary geology as compared with volcanic areas. With increasing fire severity bird activity and total number of species detected decreased, and species composition changed. Differences in species composition were due mainly to lower numbers of detections of small to medium-sized insectivores and nectarivores on high severity sites. Results were more complicated for the 36 species of reptiles observed during surveys than for birds. Reptile species composition varied with fire severity, geology, presence of rock outcrops and between vegetation communities. Species richness and abundance of many reptile groups, as well as the total number of individuals, decreased with increasing fire severity, but for reptiles overall and diurnal reptiles, presence of rock outcrops had a stronger effect on number of species and abundance. Differences between reptiles and birds and among reptile groups suggest that fire management for conservation needs to be at a range of scales and consider habitat attributes.

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INTRODUCTION

High severity forest fires that kill most of the above ground vegetation and consume much of the organic matter are spectacular, capturing public attention, and giving the impression of total habitat destruction. Public concern is further heightened as the expectation is that such fires are increasing in extent and frequency as a result of climate change (Bradstock et al. 2008). These concerns impact upon land managers who not only have to make decisions about managing the active fire, but also about how much intervention should be used during the recovery phase. Post-fire management of fauna populations comes under widespread scrutiny because of the role of fauna as pollinators and seed dispersers, and because of great public interest, particularly in highly visible species such as many bird species. Compounding post-fire management in many vegetation types are other threatening processes, such as land clearing, which may interact with fire to affect fauna (Friend 1979).

The woodlands of south-eastern Australia are recognised as critically endangered habitat on an international scale (Hoekstra et al. 2005), largely due to extensive clearing and fragmentation (Yates and Hobbs 1997). Loss of woodland vegetation over the past century has been accompanied by declines in abundance of many species, raising concerns about resilience of fauna populations to subsequent large disturbance events (birds: Ford 2011; reptiles: Driscoll 2004; Brown et al. 2008).

The wide range of ecological requirements of birds would suggest a diversity of responses to fire extent and intensity, both positive and negative (Brown et al. 2015). Indeed, studies of fire effects have varied in their findings and implicate a range of factors explaining diverse responses of birds. There is evidence for Australian forests of negative impacts of severe fire on detection frequencies of many bird species and depressed species richness (Lindenmayer et al. 2014; Robinson et al. 2014). However, studies in woodlands point to more variation in response to severe fire where some large generalist species may be favoured by fires (Prowse et al. 2017).

Reptile species may differ to birds in susceptibility to mortality during fires due to their diverse sheltering strategies (Smith et al. 2012). Reptiles show a wide range of relationships with time since fire with some species reaching peak abundances shortly after fire while others may take decades (Taylor and Fox 2001; Smith et al. 2013). This response is unlikely to be tied directly to time *per se*, but rather to associated changes in the habitat such as leaf litter cover and vegetation density (Taylor and Fox 2001). A response to habitat rather than time *per se* would also explain why some studies have found a poor relationship between reptiles and fire history but found vegetation type to be a strong driver of the reptile fauna (e.g., Lindenmayer et al. 2008).

The impacts of single fires should not be confused with the long-term impacts of fire history and its interaction with other disturbances. Within Australian woodlands and forests, long-unburnt areas are critical to maintaining a diversity of specialised birds (Woinarski and Recher 1997; Taylor et al. 2012; Croft et al. 2016; Prowse et al. 2017). Additionally, any impacts of a single high-severity fire may be compounded by existing declines resulting from other factors such as clearing, drought, or structural changes in vegetation, and incursions by predatory or dominating species (Ford 2011; Keinath et al. 2017).

In this study we examined: (i) the extent and magnitude of impact of an extensive wild fire, with large areas burnt at high severity, on bird and reptile diversity; (ii) whether effects differed with type of vegetation; and (iii) in the light of these results whether remedial actions were warranted to ensure conservation of fauna following the fire.

MATERIALS AND METHODS

Study area

Our study was conducted in Warrumbungle National Park (-31.2781° S, 148.9975° W) which encompasses a western extension of the Great Dividing Range in central New South Wales, Australia (Appendix 3 Fig 1). This area is the remains of a volcanic system that had penetrated sedimentary strata and has now eroded leaving plugs and dykes along a series of ridgelines reaching 1200 m altitude with the valley floors about 700 m lower (Appendix 3 Fig 2). The park is composed of a series of ex-farming properties covering 23,311 ha, with clearing for past grazing or cropping on level areas (Appendix 3 Fig 3), and evidence of ring barking and logging impacting the vegetation structure throughout much of the remaining woodland (Taylor and Ellis 2018). Since gazettal as a national park in 1953, some of the cleared areas have undergone active revegetation in addition to the natural regeneration of woodland trees and shrubs.

The four dominant woodland vegetation communities in terms of area mapped by Hunter (2008) in the park are: *Callitris endlicheri* (Black Cypress Pine) - *Eucalyptus crebra* (Narrow-leaved Ironbark) Woodland (C2); *Eucalyptus albens* (White Box) – *Eucalyptus crebra* (Narrow-leaved Ironbark) – *Callitris glaucophylla* (White Cypress Pine) Forest and Woodland (C3); *Angophora floribunda* (Rough-barked Apple) – *Eucalyptus melliodora* (Yellow Box) – *Eucalyptus blakelyi* (Blakely's Red Gum) Woodland (C4) along riparian zones within gullies and across plains; and, *Eucalyptus crebra* (Narrow-leaved Ironbark) – *Corymbia trachyphloia* (White Bloodwood) – *Eucalyptus rossii* (Inland Scribbly Gum) Sandstone Woodland (C7). Additionally, there is remnant farmland undergoing active revegetation in the central valley of the park (C5). Other woodland and shrubland communities occurring on the higher volcanic hilltops, and anthropogenic grassland communities on areas of level ground, make up the remainder of the vegetation types (Hunter 2008). The underlying geology of the park has both volcanic and sedimentary sources.

Fire

In January (summer) 2013 almost 90% of the National Park was burnt in wildfire, followed by heavy rain and flash flooding in February 2013. Over 50% of the burn was high severity, killing most above ground stems of woody vegetation (BAAT 2013; Denham et al. 2016), leading to concerns about the survival of the native biota of the park. The fire and subsequent scorched landscape generated much media interest and dramatic headlines such as "Reserve burnt to a cinder" (Sydney Morning Herald, 20 January 2013).

For this study, we categorised the severity of the burn into one of three levels: 'high' where tops of

Table 1. For each vegetation community / fire severity combination: the number of sites surveyed on volcanic (Vol) or sedimentary (Sed) substrate; altitudinal range of sites; range of distance from river; and range of slope values.

Veg. Comm		Low		Moderate		High	
		Vol.	Sed.	Vol.	Sed.	Vol.	Sed.
C2	# sites	0	2	0	0	0	1
C2	Alt (m)	-	680-740	-	-	-	610
C2	Riv (m)	-	121-394	-	-	-	469
C2	Slope	-	0.12-0.18	-	-	-	0.13
C3	# sites	4	0	3	1	3	1
C3	Alt (m)	540-730	-	630-860	540	580-740	540
C3	Riv (m)	144-783	-	825-983	524	725-979	135
C3	Slope	0.12-0.49	-	0.13-0.27	0.04	0.14-0.43	0.64
C4	# sites	3	1	1	2	0	0
C4	Alt (m)	620-670	490	610	520-600	-	-
C4	Riv (m)	76-547	43	20	41-392	-	-
C4	Slope	0.03-0.06	0.03	0.02	0.07-0.26	-	-
C5	# sites	1	0	0	1	0	0
C5	Alt (m)	490	-	-	470	-	-
C5	Riv (m)	80	-	-	92	-	-
C5	Slope	0.02	-	-	0.05	-	-
C7	# sites	0	3	1	3	1	3
C7	Alt (m)	-	460-740	650	440-560	640	460-720
C7	Riv (m)	-	48-286	295	97-143	699	124-829
C7	Slope	-	0.27-0.87	0.17	0.26-1.14	0.13	0.12-0.34

trees were killed and any regrowth of eucalypt trees came from the base; 'moderate' where there were epicormic shoots present on the trunks or branches of the eucalypts; and 'low' where the tree crowns remained intact after the fire (Appendix 3 Figs 4, 5 and 6). Mapping of the fire severity across the park and surrounding lands is provided in Gordon et al. (2017).

Site selection

We established one-hectare (100 m x 100 m) sites at 35 locations within the park. The 35 sites spanned the three fire severities: low (14 sites); Moderate (12 sites); or high (9 sites). Sites were selected within each dominant vegetation community (C2, 3, 4, 7) and in the revegetation area in the central valley of the park (C5), at a spacing of at least one kilometre between sites in the same vegetation/severity combination (Table 1; Fig. 1). The underlying geology (volcanic or sedimentary) of each site was taken from mapping by Troedsun and Bull (2018). The two main vegetation communities were C3 of mostly volcanic origin and C7 of mostly sedimentary origin (Table 1). It was not possible to have a completely orthogonal design in

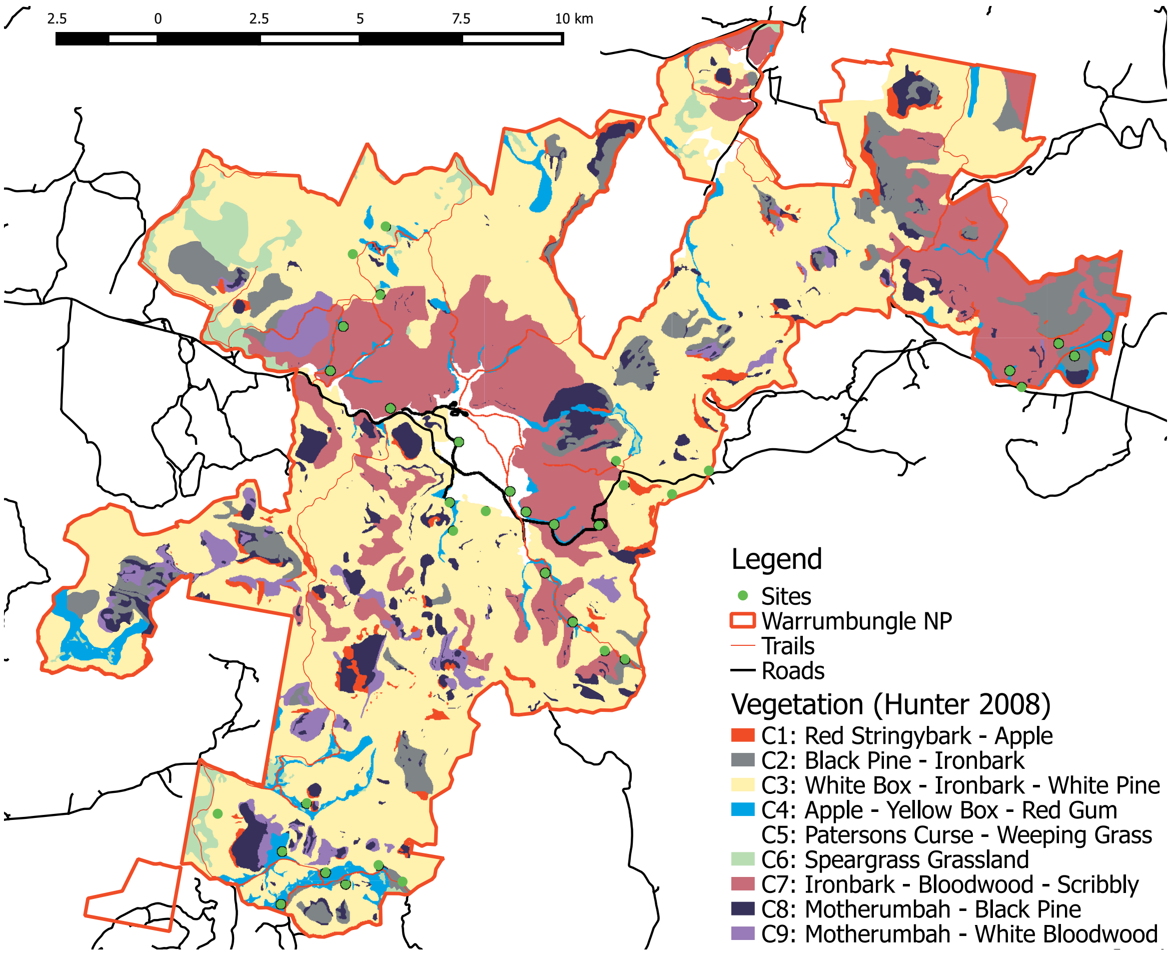

Figure 1. Site locations in relation to vegetation communities (Hunter 2008) and roads.

relation to fire, vegetation community, and underlying geology (Table 1). Distance from main creek lines, slope and altitude of each site were determined from topographic mapping at 1:50,000 scale of the park. Sites were between 440 m and 860 m elevation, and up to 1 km from the main streams in the park (Table 1). Presence or absence of rock outcrops was recorded for each site.

Bird sampling

Due to the mobility of birds in relation to our site size, and the value of repeated surveys across a range of conditions (Ellis and Taylor 2018), each site was surveyed for birds six times in each of two periods, 2014/15 and 2015/16. This spanned the period that the summer migratory birds should be present in the park (survey dates and times in Appendix 4). Each survey was conducted by a single observer (ME or JT) who traversed the site for 10 minutes as per the protocol in Ellis and Taylor (2013). Surveys were conducted during daylight without call playback and recorded all bird species detected on the one-hectare site. The number of individuals of each bird species detected during a survey was recorded where possible, but birds identified by call could not be accurately numerated. For each survey we recorded temperature, wind speed, cloud cover and time since midnight. Bird surveys were done across a range of weather conditions and times to increase the sample size, and the variables for weather and time were factored into our analyses (Ellis and Taylor 2018). To establish a more comprehensive list of species present in the park at the time of the study, we recorded any bird species that we detected whilst we were travelling between sites or in the surrounding landscape while the site searches were being carried out. Analyses included only records from on site within the 10-minute surveys.

Reptile sampling

Each of the 35 sites was searched for reptiles by a team of two people (NW, UK) for one hour during the night between 2 and 9 March 2016, and for one hour during daylight between 19 and 27 April 2016. The site was slowly traversed scanning for reptiles and searching through leaf litter piles and under logs and rocks. The number of individuals of each reptile species detected on the site was recorded as were the weather conditions and time. Species detected while we were travelling between sites and during other activities within the park (e.g. bird surveys) were also recorded to establish a more comprehensive list of reptiles present in the park. Analyses included only records from on site within the 1-hour surveys.

Data analyses

Generalised linear mixed models (GLMM) were fitted to the number of bird species detected per 10-minute survey, hereafter referred to as bird activity. We used the 'lme4' package function 'glmer' in R (R Development Core Team 2012) with the data family set to Poisson with the natural logarithm link, and with site as a random factor due to the repeated sampling. As predictors of bird activity we selected combinations of variables from among: vegetation community, geology, fire severity, distance from creek lines, altitude, survey period, wind speed, time of day, and temperature. Models with significant predictor variables were compared using their Akaike information criteria (AIC) scores, and models with scores within two units of the lowest score are reported. Similarly, generalised linear models were fitted to the total number of species (species richness) detected at each site over the two periods using the 'glm' function.

For reptiles, each species found on the survey sites was classified based on circadian behaviour, and assigned to one or more of the types of refuge site likely to be used when not active (based on Swan et al. 2012; Cogger 2014; Michael et al. 2015). We used the response variables: number of species detected on the site, total number of individuals detected on the site, and number of individuals of each of the behavioural categories. Generalised linear models (GLM) were fitted to each of these response variables using the function 'glm' in R (R Development Core Team 2012) with the data family set to Poisson with the natural logarithm link. Predictor variables were vegetation community, geology, fire severity, presence/absence of rock outcrops, distance from creek lines, altitude, time of day, and temperature. Models with significant predictor variables were compared using their Akaike information criteria (AIC) scores, and models with scores within two units of the lowest score are reported.

We used non-metric multi-dimensional scaling (nMDS), analysis of similarity (ANOSIM), and SIMPER to examine species composition in relation to fire severity levels, vegetation community, underlying geology, and presence of rock outcrops. Separate analyses were performed on abundance data for birds and reptiles. Abundance of each bird species was expressed as number of surveys in which the species was observed on the site. Reptile abundance was expressed as the total number of individuals over all surveys of each species. Prior to analysis using Bray-curtis similarities, reptile and bird data were fourth-root transformed to increase the effects of rarer species and decrease effects of very abundant species on analyses. Not all vegetation communities were present in all fire severities, so analyses of some factors were on subsets of data. Analyses of species composition were conducted using Primer Version 7 (PRIMER-E, Quest Reserch Ltd.).

RESULTS

Birds

Bird surveys were conducted between 0600h and 1920h, with temperatures ranging from 9 °C to 32 °C, wind strengths from Beaufort 0 to Beaufort 4, and cloud cover from 0 to 8 oktas. A total of 136 bird species were recorded across the two survey periods with 120 species in 2014/15 and 119 in 2015/16 (88% of species per period, see Appendix 1). Bird species were mainly Bassian in origin with the Park being towards the western limits of their distributions, but there was no simple taxonomic pattern in the differences between the two periods. Of the species observed, 115 (85%) were recorded during the 10-minute surveys, but only 91 (67%) were actually within the sites during the formal survey times. We recorded a minimum of 3,158 individual birds during the 10-minute surveys of which 1,394 were on the sites. Since over two thirds of identifications were from calls, precise numbers of individuals on each site could not be determined.

The mean number of bird species recorded per 10-minute survey within a vegetation community/fire severity combination ranged from 1.71 to 5.92 (Table 2). The number of bird species found on sites that had experienced low, moderate and high fire severity was 78, 55 and 52 respectively (Appendix 1). Of the 91 species on site, 47 species were more often recorded on low severity sites (Appendix 1). Although, this indicates an overall trend of decreasing number of bird species with increasing fire severity, other factors contributed as significant predictors of the number of species detected.

In the strongest model (lowest AIC), bird activity (number of species per 10 minutes) was best

Table 2. For each vegetation community / fire severity combination (L=low, M = moderate, H = high): the number of sites surveyed; number of bird species recorded per 10 minute survey (mean ± SD) (number of surveys in brackets); total number of bird species recorded per site across all surveys (mean ± SD); and, mean number of reptile species (± SD).

Veg Com	Fire	No. sites	No. bird species (mean ± SD)	Total bird species per site (mean ± SD)	Total no. reptile species per site (mean ± SD)
C2	L	2	3.75 ± 1.70 (24)	22.00 ± 1.41	4.00 ± 1.42
C2	M	0	-	-	-
C2	H	1	2.75 ± 1.48 (12)	18.00	1.00
C3	L	4	4.25 ± 2.12 (48)	23.00 ± 1.83	5.00 ± 3.37
C3	M	4	3.40 ± 1.91 (48)	18.50 ± 4.12	3.25 ± 1.53
C3	H	4	2.19 ± 1.27 (48)	15.25 ± 4.99	3.75 ± 0.50
C4	L	4	4.42 ± 2.58 (48)	24.75 ± 7.93	4.00 ± 2.94
C4	M	3	4.33 ± 2.38 (36)	24.00 ± 1.00	3.00 ± 1.00
C4	H	0	-	-	-
C5	L	1	5.92 ± 2.91 (12)	30.00	3.00
C5	M	1	3.00 ± 1.76 (12)	20.00	2.00
C5	H	0	-	-	-
C7	L	3	3.42 ± 2.23 (36)	22.00 ± 3.46	6.00 ± 2.00
C7	M	4	2.48 ± 1.80 (48)	14.50 ± 3.32	2.50 ± 1.73
C7	H	4	1.71 ± 1.41 (48)	11.50 ± 4.80	4.00 ± 1.41

predicted by a combination of vegetation community, fire severity, wind speed and time of day, but not by temperature or survey period (Table 3). Distance of a site from a creek line and site altitude were not significant predictors of bird activity, nor was there an interaction between vegetation community and fire severity in any of the models tested. Although geology was a significant predictor when substituted for vegetation community, the model was weaker (AIC value four points higher) and was rejected in favour of the model using vegetation community as a predictor.

Table 3. Results of a GLMM explaining number of bird species detected per 10-minute survey. Vegetation community C3, fire severity low and wind strength of Beaufort 0 were the first categorical predictors fitted.

Predictor	Estimate	SE	z value	Prob.
Intercept	1.5587	0.1489	10.468	<<0.0001
Vegetation C2	0.0022	0.1490	0.015	0.9880
Vegetation C4	0.1698	0.1077	1.576	0.1150
Vegetation C5	0.1869	0.1667	1.121	0.2623
Vegetation C7	-0.2579	0.0997	-2.587	0.0097
Severity Moderate	-0.2247	0.0894	-2.513	0.0120
Severity High	-0.6092	0.1094	-5.570	<<0.0001
Wind Beaufort 1	0.1960	0.0892	2.197	0.0281
Wind Beaufort 2	0.1980	0.0960	2.048	0.0405
Wind Beaufort 3	0.1552	0.1022	1.519	0.1287
Wind Beaufort 4	0.5457	0.2026	2.693	0.0071
Time	-0.0299	0.0094	-3.181	0.0015

The best predictors of the total number of species found at a site over the two periods (Table 4) were vegetation community and fire severity, with fewer species on sites in C7 than other vegetation communities, and fewer species on sites with moderate or high severity fire compared to low severity fire. A second model that was almost as good (AIC value 1.9 points higher), used only fire severity to explain the number of species present per site (Table 4). Distance of a site from a creek line and site altitude had no significant effects, nor was there an interaction between vegetation community and fire severity.

Across all sites, bird species composition differed among fire severity levels but did not differ between volcanic and sedimentary

Table 4. Results of the two GLMs (AIC values of 209.9 and 211.8 respectively) of total number of bird species detected at each site over six 10-minute surveys. Vegetation community C3 (model 1 only) and fire severity low were the first categorical predictors fitted.

	Predictor	Estimate	SE	z value	Prob.
Model 1	Intercept	3.1395	0.0819	38.345	<<0.001
	Vegetation C2	0.0137	0.1464	0.094	0.9255
	Vegetation C4	0.1416	0.1051	1.347	0.1780
	Vegetation C5	0.1797	0.1587	1.132	0.2575
	Vegetation C7	-0.1817	0.101	-1.791	0.0734
	Severity Moderate	-0.2118	0.0890	-2.379	0.0174
	Severity High	-0.4333	0.1114	-3.891	<<0.001
Model 2	(Intercept)	3.1631	0.0550	57.547	<<0.001
	Severity Moderate	-0.2363	0.0865	-2.731	0.0063
	Severity High	-0.5320	0.1050	-5.067	<<0.001

Table 5. Results of analysis of similarity (ANOSIM) comparing species composition among fire severities (L = low, M = moderate, H = high), vegetation communities, geology. Data were fourth-root transformed prior to analysis. ANOSIM used all sites (all), or subsets of sites: with rock outcrops (rock), C3 and C7 vegetation communities.

Factors (taxa; data)	Test	R statistic	P
Fire, geology (birds; all)	Global for Geology	-0.08	0.896
	Global for Fire	0.196	0.004
	High, Moderate	0.239	0.014
	High, Low	0.354	0.006
	Moderate, Low	0.072	0.175
Fire, vegetation (birds; C3, C7)	Global for Vegetation	0.035	0.363
	Global for Fire	0.173	0.016
	High, Moderate	0.193	0.062
	High, Low	0.294	0.005
	Moderate, Low	0.131	0.144
Outcrops, geology (reptiles; all)	Global for Geology	0.221	0.006
	Global for Outcrops	0.427	0.001
Fire, geology (reptiles; rock [H,L])	Global for fire (H,L)	0.452	0.034
	Global for geology	0.241	0.087
Fire, vegetation (reptiles; C3, C7)	Global for Fire	0.139	0.124
	High, Moderate	0.146	0.178
	High, Low	0.359	0.026
	Moderate, Low	-0.132	0.783
	Global for vegetation	0.244	0.048

geology (Table 5; Fig. 2). Bird species composition did not differ between C3 and C7 vegetation communities, the only two communities present in all fire severities, but did differ between high and low fire severities and marginally between high and moderate fire severities on this subset of sites (Table 5). A low detection rate (i.e., detected in fewer surveys) of a suite of small and medium-sized bird species on high severity sites contributed most to the differences between high and low severity sites (Table 6).

Reptiles

Thirty-six species of reptile were found during the post-fire survey period (Table 7 and Appendix 2). These reptiles were divided into seven non-exclusive groupings for analysis: diurnal; nocturnal; arboreal; shelter in or under rocks; shelter in or under logs; shelter in the leaf litter layer; or, shelter in the soil (Table 8). On sites with high fire severity there were 71 individuals of 13 species, while on sites with moderate fire severity there were 93 individuals of 17 species, and on sites with low fire severity there were 118 individuals of 25 species.

The variation in total number of individual reptiles found per site was not explained by any of the predictor variables, but there was a negative impact of increasing fire severity and a positive impact by the presence of rock outcrops at a site on the number of species found (Table 9). This pattern occurred in most of the models for the different

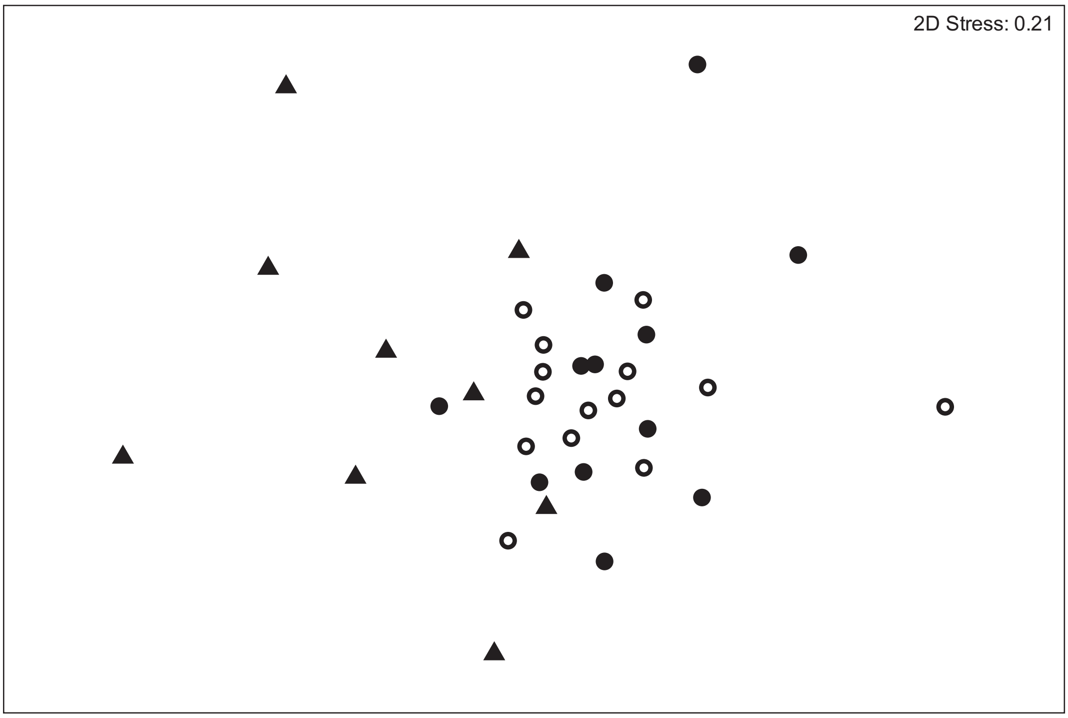

Figure 2. Two-dimensional nMDS ordination of bird species composition for low (open circle), moderate (filled circle) and high (filled triangle) fire severity sites in Warrumbungle National Park. Data were fourth-root transformed and used Bray-Curtis similarities.

Table 6. Summary of SIMPER for C3 and C7 vegetation sites: mean abundance (4th-root transformed no. surveys in which a bird species was observed) typifying high (H) and low (L) fire severity sites, their contribution (%) to the between-group dissimilarity and cumulative total (%) of contributions (50% cut-off).

Species	Group H Mean abund.	Group L Mean abund.	Contrib. (%)	Cum.%
Eastern Yellow Robin	0.00	1.21	4.96	4.96
White throated treecreeper	0.13	1.26	4.75	9.71
Grey fantail	0.42	1.20	3.69	13.40
Weebill	0.57	1.35	3.42	16.82
Rufous whistler	0.70	1.48	3.41	20.23
Striated pardalote	0.25	0.97	3.24	23.47
Eastern Spinebill	0.13	0.77	2.99	26.46
Superb Fairy Wren	0.30	0.71	2.94	29.40
Western Gerygone	0.13	0.63	2.59	31.99
Eastern Rosella	0.29	0.57	2.58	34.57
Sulphur-crested cockatoo	0.16	0.50	2.49	37.05
Buff-rumped Thornbill	0.29	0.64	2.48	39.53
Yellow-tufted Honeyeater	0.56	0.29	2.47	42.00
Speckled Warbler	0.00	0.63	2.43	44.42
Olive-backed Oriole	0.25	0.29	2.37	46.79
Grey Butcherbird	0.38	0.60	2.34	49.14
Spotted Pardalote	0.70	1.20	2.30	51.44

Table 7. Species of reptile detected in Warrumbungle National Park three years post-fire. ‘Incidental’ are records for in the park but not on site during survey times. ‘Total’ is the total number of observations of the species including all surveys and incidental observations.
***indicates recorded adjacent to the park.**

		No. sites	**1**	**5**	**4**	**3**	**3**	**1**	**4**	**2**	**4**	**4**	**1**	**3**	**Incidental**	**Total**
		Fire severity	**H**	**H**	**H**	**M**	**M**	**M**	**M**	**L**	**L**	**L**	**L**	**L**		
		Vegetation community	**2**	**3**	**7**	**3**	**4**	**5**	**7**	**2**	**3**	**4**	**5**	**7**		
Family	**Common Name**	**Scientific Name**														
Carphodactylidae	Thick-tailed Gecko	*Underwoodisaurus milii*		1		1			1		2	2		6		13
Diplodactylidae	Wood Gecko	*Diplodactylus vittatus*		1	2	9	2			4	3			2		23
Diplodactylidae	Robust Velvet Gecko	*Nebulifera robusta*								1	1			1		3
Diplodactylidae	Ocellated Velvet Gecko	*Oedura monilis*					1				1	1		1	1	5
Diplodactylidae	Eastern Spiny-tailed Gecko	*Strophurus williamsi*			1	1					3	1			1	7
Gekkonidae	Marbled Gecko	*Christinus marmoratus*										1		2		3
Gekkonidae	Northern Dtella	*Gehyra dubia*									1					1
Gekkonidae	Tree Dtella	*Gehyra variegata*									2	6			1	9
Gekkonidae	Prickly Gecko	*Heteronotia binoei*							1		1	1		3		6
Pygopodidae	Leaden delma	*Delma plebia*									1					1
Pygopodidae	Burton’s Legless Lizard	*Lialis burtoni*													1	1
Scincidae	Red-throated Skink	*Acritoscincus platynota*			2										1	3
Scincidae	Two-clawed Worm-skink	*Anomalopus leuckartii*						1			1					2
Scincidae	Southern Rainbow-skink	*Carlia tetradactyla*		3		2	1			2	2		2		1	13
Scincidae	Barred-sided Skink	*Concinnia tenuis*								1					1	2
Scincidae	Wall Skink	*Cryptoblepharus pulcher*		3	1		1								1	6
Scincidae	Robust Ctenotus	*Ctenotus robustus*		4	1		1			2	1	1			1	11
Scincidae	Copper-tailed Skink	*Ctenotus taeniolatus*		4	1		1		1		3			2	1	13

Table 7 continued

Scincidae	Warrumbungle's Black Rock Skink	*Egernia saxatilis saxatilis*			1				7					5	1	14
Scincidae	Tree Skink	*Egernia striolata*			1	1						1			1	4
Scincidae	Bougainville's skink	*Lerista bouganvillii*												1		1
Scincidae	White's Skink	*Liopholis whitii*		25	14		15		12	2		3		16	1	88
Scincidae	Tree-base Litter-skink	*Lygisaurus foliorum*							1					6		7
Scincidae	South-eastern Morethia Skink	*Morethia boulengeri*	3	3	3	7	6	7	1	1	3	7	1		1	43
Scincidae	Eastern Blue-tongued Lizard	*Tiliqua scincoides*													1	1
Agamidae	Jacky Lizard	*Amphibolurus muricatus*					2			1	1				1	5
Agamidae	Nobbi	*Diporiphora nobbi*		5			1					2	3		1	12
Agamidae	Bearded Dragon	*Pogona barbata*			1							1			1	3
Varanidae	Sand goanna	*Varanus gouldii*													1	*
Varanidae	Lace Monitor	*Varanus varius*													1	1
Typhlopidae	Proximus Blind Snake	*Ramphotyphlops proximus*													1	1
Boidae	Murray/Darling Carpet Python	*Morelia spilota metcalfei*												1	1	2
Elapidae	Yellow-faced Whip Snake	*Demansia psammophis*													1	1
Elapidae	Red-naped Snake	*Furina diadema*		1							1				1	3
Elapidae	Spotted Black Snake	*Pseudechis guttatus*													1	1
Elapidae	Red-bellied Black Snake	*Pseudechis porphyriacus*													1	1

Table 8. Groupings of reptiles used in the analyses.

Common Name	Scientific Name	Diurnal	Nocturnal	Arboreal	Rocks	Logs	Litter	Soil
Marbled Gecko	*Christinus marmoratus*		Yes	Yes	Yes	Yes	Yes	
Wood Gecko	*Diplodactylus vittatus*		Yes		Yes	Yes	Yes	
Northern Dtella	*Gehyra dubia*		Yes	Yes				
Tree Dtella	*Gehyra variegata*		Yes	Yes	Yes	Yes		
Prickly Gecko	*Heteronotia binoei*		Yes		Yes	Yes	Yes	
Ocellated Velvet Gecko	*Oedura monilis*		Yes	Yes				
Robust Velvet Gecko	*Oedura robusta*		Yes	Yes	Yes			
Eastern Spiny-tailed Gecko	*Strophurus williamsi*		Yes	Yes		Yes		
Thick-tailed Gecko	*Underwoodisaurus milii*		Yes		Yes	Yes		
Leaden delma	*Delma plebia*		Yes		Yes	Yes	Yes	
Burton's Snake-lizard	*Lialis burtonis*	Yes	Yes		Yes		Yes	
Red-throated Skink	*Acritoscincus platynota*	Yes			Yes		Yes	
Two-clawed Worm-skink	*Anomalopus leuckartii*	Yes	Yes		Yes	Yes		
Southern Rainbow-skink	*Carlia tetradactyla*	Yes			Yes	Yes	Yes	
Elegant Snake-eyed Skink	*Cryptoblepharus pulcher*	Yes		Yes		Yes		
Robust Ctenotus	*Ctenotus robustus*	Yes			Yes	Yes	Yes	Yes
Copper-tailed Skink	*Ctenotus taeniolatus*	Yes			Yes	Yes	Yes	Yes
Warrumbungles Black Rock Skink	*Egernia saxatilis saxatilis*	Yes			Yes			
Tree Skink	*Egernia striolata*	Yes		Yes	Yes			
Barred-sided Skink	*Eulamprus tenuis*	Yes		Yes	Yes			
Bougainville's skink	*Lerista bouganvillii*	Yes			Yes	Yes	Yes	Yes
White's Skink	*Liopholis whitii*	Yes			Yes			

Table 8 continued

Tree-base Litter-skink	*Lygisaurus foliorum*	Yes			Yes	Yes	Yes	
South-eastern Morethia Skink	*Morethia boulengeri*	Yes			Yes	Yes	Yes	
Eastern Blue-tongue	*Tiliqua scincoides*	Yes			Yes	Yes		
Jacky Lizard	*Amphibolurus muricatus*	Yes		Yes	Yes	Yes		
Nobbi	*Diporiphora nobbi*	Yes		Yes		Yes		
Bearded Dragon	*Pogona barbata*	Yes		Yes		Yes		
Gould's Goanna	*Varanus gouldii*	Yes						Yes
Lace Monitor	*Varanus varius*	Yes		Yes	Yes	Yes		
Proximus Blind Snake	*Ramphotyphlops proximus*		Yes		Yes	Yes		Yes
Murray/Darling Carpet Python	*Morelia spilota metcalfei*	Yes	Yes	Yes	Yes	Yes		
Yellow-faced Whip Snake	*Demansia psammophis*	Yes			Yes	Yes	Yes	
Red-naped Snake	*Furina diadema*		Yes		Yes	Yes	Yes	

Table 9. A summary of the response to the predictor variables for the number of reptile individuals or species in each grouping found on sites.

Grouping	Severity	Outcrop	Vegetation
All Individuals	0	0	0
All Species	-ve	+ve	0
Diurnal Individuals	+ve or 0	+ve	0
Diurnal Species	0	0	0
Nocturnal Individuals	-ve	+ve	0
Nocturnal Species	-ve	+ve	0
Arboreal Individuals	-ve	+ve	+C4 -C7
Arboreal Species	-ve	0	0
Rock Individuals	0	+ve	0
Rock Species	-ve	+ve	0
Log Individuals	-ve	0	-C7
Log Species	-ve	+ve	0
Litter Individuals	-ve	0	-C7
Litter Species	-ve	+ve	0
Soil Individuals	0	0	0
Soil Species	0	+ve	0

groupings analysed but outcrops were not a predictor of the number of arboreal species and fire severity was not a predictor of the number of soil species. The three models that contained vegetation community as a predictor, all did so due to a reduced number of individuals from each grouping being found in Community 7 (woodland on Pilliga Sandstone) (Table 9). Details of the model coefficients are provided in Table 10.

Reptile species composition differed between sites of volcanic and sedimentary origin, and between sites with and without rocky outcrops (Table 5; Fig. 3). There were two sites of high severity without rock outcrops, both of sedimentary origin, and one site of volcanic origin with moderate fire severity. The subset of sites with rock outcrops and high or low fire severity differed in reptile species composition, but there was no effect of underlying geology (Table 5). For C3 and C7, the vegetation communities with all fire severities, there was no overall effect of fire, but reptile species composition differed between C3 and C7 (Table 5; Fig. 4).

The most common and widespread species were *Liopholis whitii* and *Morethia boulengeri*, both diurnal terrestrial skinks. Relative abundances of these two species were important contributors to identified differences between sites with and without rock outcrops, between high and low fire severities on sites with rocky outcrops, and between C3 and C7 vegetation communities (Table11). *Liopholis whitii* was more characteristic of rocky sites in the C7 vegetation community that had experience high severity fire (Table 11). In the C3 vegetation community we found 97 individuals from 19 species while the C7 vegetation community contained 98 individuals from 19 species, but with only 12 species in common.

Virtually all gecko records were from low fire severity sites, except for *Diplodactylus vittatus*, which was found across the range of fire severities (Table 7) and was the most frequently encountered gecko. Geckos were important contributors to differences in species composition with fire severity, and together with five skink species were important in the distinctiveness of C3 and C7 vegetation communities (Table 11).

DISCUSSION

Our results showed a strong negative impact of increasing fire severity on bird activity and species composition. Although reptile abundance was reduced and species composition altered with increasing fire severity, for some groups the presence of rock outcrops was a stronger predictor of abundance.

Once the variation in weather and timing of surveys were accounted for, activity levels were significantly lower in the Ironbark Woodlands growing on the Pilliga Sandstone (C7), but the avifauna of Warrumbungle National Park were very similar in composition across the woodland vegetation communities. The structure of the vegetation across the communities during the period of our study was generally similar within fire severity classes, and this pattern of bird activity may be driven by low nutrient soil influencing productivity of the vegetation (Watson 2011). This may account for the cumulatively (over 12 surveys) lower number of species found on vegetation community C7 sites than other vegetation community sites.

Unlike Lindenmayer et al. (2014), we found a high overlap in bird species composition between riparian (vegetation community 4) and other major woodland vegetation communities in the park. This difference between studies may again reflect an overall greater structural similarity among vegetation communities in our study, whereas in their study area, gullies contained rainforest elements thought to suppress bird diversity compared to the surrounding eucalypt forests.

The type of broad negative response of avifauna to increasing fire severity seen in Warrumbungle National Park has been found in forests in Australia (Lindenmayer et al. 2014) and North America (Kotliar et al. 2007). Conversely, a wide variety of positive responses of birds to high severity fires have been seen in mixed pine/hardwood forests in Texas (Brown et al. 2015) when removal of a closed canopy made habitat more suitable for colonising species or species that prefer open woodlands. Such an effect would not be expected in the woodlands of the Warrumbungle National Park which have naturally open canopies and understories compared to many vegetation types.

The limited impact of low to moderate fire severity compared to high fire severity on bird community composition, combined with the similarity of avian composition across vegetation communities, makes fire management for species conservation simpler. In terms of avifauna and prescribed fire, the woodlands of our study area can be managed as a single system since we now know that any areas with retained canopy post-fire should hold a wide diversity of bird species. This suggests that prescribed burns done to limit the severity of future wildfires are likely to have the least impact on the avifauna of Warrumbungle National Park. Such prescribed fires are usually of small size

Table 10. Results for the GLMs (1-3) for the number of reptile individuals or species of each grouping found on the survey sites. The first fitted value for the severity variable was 'low', for outcrop was 'no', and for vegetation was 'community C3 woodland'. AIC score is provided in brackets when multiple suitable models for the same response were identified.

	Estimate	SE	z value	Probability
All Species				
Intercept	1.2571	0.1711	7.346	<<0.0001
Severity Moderate	-0.4526	0.2122	-2.132	0.0330
Severity High	-0.3934	0.2203	-1.785	0.0742
Outcrop Yes	0.4957	0.1897	2.612	0.0090
Diurnal Individuals (206.97)				
Intercept	1.3153	0.1525	8.624	<<0.0001
Severity Moderate	-0.2805	0.1650	-1.700	0.0891
Severity High	-0.2313	0.1743	-1.327	0.1846
Outcrop Yes	0.5436	0.1514	3.589	0.0003
Diurnal Individuals (206.29)				
Intercept	1.4759	0.1195	12.348	<<0.0001
Outcrop Yes	0.5495	0.1457	3.771	0.0002
Nocturnal Individuals				
Intercept	0.6558	0.2401	2.731	0.0063
Severity Moderate	-0.8080	0.2829	-2.856	0.0043
Severity High	-2.0378	0.4724	-4.314	<<0.0001
Outcrop Yes	0.9397	0.2669	3.520	0.0004
Nocturnal Species				
Intercept	0.0973	0.3187	0.305	0.7601
Severity Moderate	-0.9952	0.3794	-2.623	0.0087
Severity High	-1.6288	0.4852	-3.357	0.0008
Outcrop Yes	1.104	0.3505	3.151	0.0016
Arboreal Individuals				
Intercept	0.2168	0.4282	0.506	0.6126
Vegetation C2	-0.4851	0.8181	-0.593	0.5531
Vegetation C4	0.6894	0.3855	1.788	0.0738
Vegetation C5	0.6041	0.7117	0.849	0.3960
Vegetation C7	-0.7367	0.4032	-1.827	0.0677
Severity Moderate	-1.1394	0.3993	-2.853	0.0043
Severity High	-0.4855	0.3854	-1.260	0.2078
Outcrop Yes	0.8944	0.3846	2.326	0.0200
Arboreal Species				
Intercept	0.4520	0.2132	2.120	0.0340
Severity Moderate	-0.9910	0.4339	-2.284	0.0224
Severity High	-0.7033	0.4339	-1.621	0.1051
Rock Individuals				
Intercept	1.5581	0.1147	13.584	<<0.0001
Outcrop Yes	0.6736	0.1371	4.911	<<0.0001
Rock Species				
Intercept	1.0064	0.1924	5.231	<<0.0001
Severity Moderate	-0.4340	0.2301	-1.886	0.0593
Severity High	-0.4633	0.2423	-1.912	0.0559
Outcrop Yes	0.6271	0.2105	2.979	0.0029
Log Individuals				
Intercept	1.98558	0.15224	13.042	<<0.0001
Vegetation C2	-0.37298	0.30837	-1.210	0.2265
Vegetation C4	-0.23094	0.21312	-1.084	0.2785
Vegetation C5	0.09827	0.29823	0.329	0.7418

Table 10 continued

Vegetation C7	-0.46863	0.20284	-2.310	0.0209
Severity Moderate	-0.29798	0.17858	-1.669	0.0952
Severity High	-0.52457	0.22134	-2.370	0.0178
Log Species (127.2)				
Intercept	1.0421	0.1935	5.387	<<0.0001
Severity Moderate	-0.5040	0.2456	-2.052	0.0402
Severity High	-0.5829	0.2697	-2.161	0.0307
Outcrop Yes	0.4183	0.2189	1.911	0.0560
Log Species (128.9)				
Intercept	1.2730	0.1414	9.001	<<0.0001
Severity Moderate	-0.5390	0.2449	-2.200	0.0278
Severity High	-0.4745	0.2646	-1.793	0.0729
Litter Individuals				
Intercept	1.5068	0.1875	8.034	<<0.0001
Vegetation C2	0.0092	0.3327	0.028	0.9780
Vegetation C4	-0.4185	0.2684	-1.559	0.1190
Vegetation C5	0.0906	0.3525	0.257	0.7973
Vegetation C7	-0.4052	0.2355	-1.720	0.0854
Severity Moderate	0.0240	0.2105	0.114	0.9092
Severity High	-0.4539	0.2644	-1.717	0.0861
Litter Species				
Intercept	0.6555	0.2340	2.802	0.0051
Severity Moderate	-0.5039	0.2978	-1.692	0.0907
Severity High	-0.4853	0.3163	-1.534	0.1250
Outcrop Yes	0.4198	0.2638	1.592	0.1114
Soil Species				
Intercept	-1.3863	0.5000	-2.773	0.0056
Outcrop Yes	1.0809	0.5669	1.907	0.0566

compared to the area of the park, and generally have minimal impact on the canopy. This is in keeping with existing research that shows that refugia of appropriate habitat and overall fire regime are the keys to post-fire recovery of avifauna (Woinarski and Recher 1997; Robinson et al. 2014; Keinath et al. 2017). In Warrumbungle National Park C4 vegetation provides a natural network of refugia for a diversity of avian species after fires, since it tended to experience only low to moderate fire severity due to its position in the landscape, in gullies or along creek lines crossing cleared former farmland. There is also evidence that gully vegetation, even when burnt, is valuable for maintenance and recovery of avifauna after wildfire (Robinson et al. 2016).

The effects of the large fire were more complicated for reptiles than birds. Fire severity usually had a negative impact on the number of reptile species and abundance of individuals at a site, but the strength of impact varied among reptile groupings. The negative effect of fire severity was greatest on nocturnal species and individuals, severe fire reducing both by over 80 percent compared to low fire severity areas. For other groupings this reduction was less marked but was often in the order of a third. Based on other studies of reptiles (Taylor and Fox 2001; Santos et al. 2016), these effects of fire severity seem likely to relate to differences in available habitat among levels of fire severity.

In fact, the strongest predictors of reptile species richness and abundance related to habitat. The presence of rock outcrops at a site meant that the number of species and individuals detected in some reptile groups were 50 to 200 percent higher than in sites lacking outcrops. While this would be expected for the saxicolous grouping, it also applied to the arboreal grouping, but this may be partly driven by the number of species that use both rock outcrops and arboreal sites for shelter. Additionally, rock outcrops may be breaking up the impact of fire at a fine scale by interrupting the fuel load and disrupting fire spread, allowing pockets of unburnt leaf litter and unheated soil in an otherwise scorched landscape. For species that have large home ranges and/or food requirements small pockets may not be able to support the individuals that survived the fire. Many reptiles however have low food requirements and have small home ranges tied to burrows, rock crevices, or hollows, so small refugia may be able to support some individuals immediately after fires, and consequently may be the

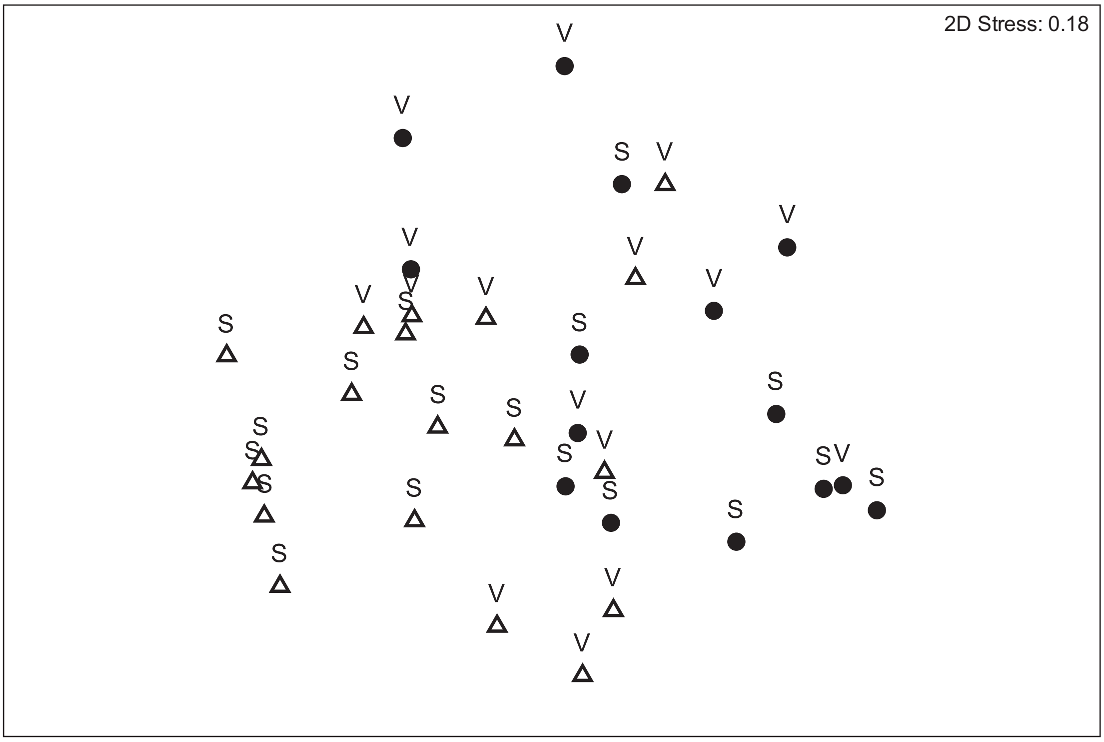

Figure 3. Two-dimensional nMDS ordination of reptile species composition for all sites, showing underlying geology (volcanic, V; sedimentary, S) and presence (open triangles) and absence (closed circles) of rock outcrops in Warrumbungle National Park. Data were fourth-root transformed and used Bray-Curtis similarities.

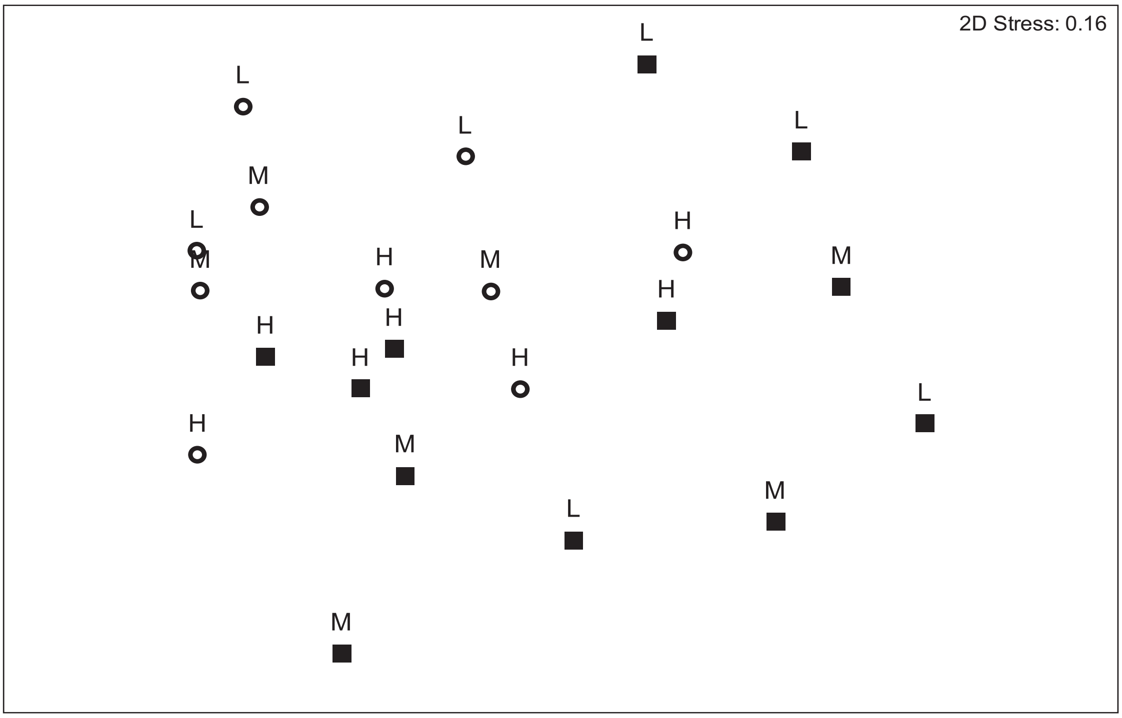

Figure 4. Two-dimensional nMDS ordination of reptile species composition for the subset of sites of the two dominant vegetation communities C3 (filled square) and C7 (open circle) in Warrumbungle National Park labelled for fire severity (L = low, M = moderate, H = high). Data were fourth-root transformed and used Bray-Curtis similarities.

Table 11. Summary of SIMPER results showing relative abundance typifying reptile species for: presence (R) versus absence (N) of rock outcrops; volcanic (V) versus sedimentary (S) underlying geology; for high (H) versus low (L) fire severities in sites with rock outcrops; and in vegetation communities C3 and C7 for high versus low fire severity. Contribution (%) to between group dissimilarity and cumulative total (%) of contributions (at least 50% cut-off). Groups shown as approximately equal if average abundance was within 0.05.

Factors in SIMPER [sites used in analysis]	Outcrops, geology [All]	Outcrops, geology [All]	Fire, geology [Outcrops (H,L)]	Fire, vegetation [C3, C7]	Fire, vegetation [C3, C7]
Groups compared:	**R, N**	**V, S**	**H, L**	**H. L**	**C3, C7**
	Group with highest abundance (% contribution to dissimilarity)				
Species					
Liopholis whitii	R (14.16)	S (11.59)	H (10.53)	H (13.69)	C7 (13.36)
Morethia boulengeri	N (13.06)	S (11.53)	L (5.48)	≈ (5.90)	C3 (7.18)
Diplodactylus vittatus	≈ (8.65)	≈ (9.59)	L (4.94)	L (7.95)	C3 (8.85)
Ctenotus taeniolatus	R (6.88)	≈ (5.19)	≈ (7.06)	L (6.79)	C3 (7.13)
Ctenotus robustus	R (6.04)	V (6.73)	H (6.08)	H (6.92)	--
Underwoodisaurus milii	R (5.41)	≈ (4.98)	L (10.53)	L (8.36)	C7 (6.95)
Carlia tetradactyla	N (5.37)	V (7.13)	--	--	C3 (5.46)
Diporiphora nobbi	--	V (5.28)	--	H (4.61)	--
Strophurus williamsi	--	--	L (5.16)	--	--
Egernia saxatilis	--	--	--	--	C7 (7.98)
Heteronotia binoei	--	--	L (4.98)		
Cumulative (%)	59.57%	57.03%	52.97	54.13%	56.91%

source populations in landscapes with recurring fires. The widespread occurrence of outcrops in the park must give its reptile community a level of resilience to the immediate impacts of bushfires even when broad areas are severely burnt.

However, the presence of rock outcrops cannot be considered a panacea to all the impacts of fire as reptile species composition across severely burnt sites was different to the less severely burnt areas. This is exemplified by few geckoes being recorded outside of the low fire severity areas indicating the need to maintain unburnt refugia under future fire management planning. Furthermore, unlike the situation for birds, the two dominant vegetation communities in the park contained differing reptile communities, similar to the division encountered by Lindenmayer et al. (2008) in their post-fire study near Jervis Bay, NSW. Consequently, conservation of reptile species will need to occur at a finer scale than for birds, with a pattern of refugia needing to be maintained across the dominant vegetation communities if the diversity of the park's reptile fauna is to be maintained under future fire management.

Although a wide range of species survived the widespread fire within Warrumbungle National Park this should not be taken as a guarantee of their long-term survival. There is increasing evidence from forests and woodlands that it is the fire history, including hazard reduction burning, that will dictate the species that survive in a landscape (Taylor et al. 2012; Croft et al. 2016; Prowse et al. 2017). Only when a comprehensive and accurate fire history map exists will the status of the fauna of the park be able to be more closely examined.

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APPENDIX 1

List of the bird species recorded in the park across the two study periods, and the number of times each species was recorded during 10-minute surveys on plots at each fire severity level.

Species Name	Common Name	Period 2014/15	2015/16	Severity Low	Medium	High
Dromaius novaehollandiae	Emu	Y	Y	0	0	0
Anas superciliosa	Pacific Black Duck	Y	Y	0	0	0
Chenonetta jubata	Australian Wood Duck	Y	Y	0	0	0
Aegotheles cristatus	Australian Owlet-nightjar	Y	Y	0	0	0
Eurostopodus mystacalis	White-throated Nightjar		Y	0	0	0
Eurostopodus argus	Spotted Nightjar	Y		0	0	0
Podargus strigoides	Tawny Frogmouth	Y		0	0	0
Vanellus miles	Masked Lapwing	Y	Y	0	0	0
Ardea pacifica	White-necked Heron	Y		0	0	0
Egretta novaehollandiae	White-faced Heron	Y	Y	0	0	0
Threskiornis spinicollis	Straw-necked Ibis	Y	Y	0	0	0
Geopelia striata	Peaceful Dove	Y	Y	2	0	0
Geopelia humeralis	Bar-shouldered Dove	Y	Y	0	0	0
Ocyphaps lophotes	Crested Pigeon	Y	Y	0	0	1
Phaps chalcoptera	Common Bronzewing	Y	Y	1	4	2
Dacelo novaeguineae	Laughing Kookaburra	Y	Y	2	2	3
Todiramphus sanctus	Sacred Kingfisher	Y	Y	2	0	0
Merops ornatus	Rainbow Bee-eater	Y	Y	0	0	0
Cacomantis flabelliformis	Fan-tailed Cuckoo	Y	Y	3	4	1
Cacomantis pallidus	Pallid Cuckoo		Y	0	0	0
Chrysococcyx basalis	Horsfield's Bronze-cuckoo		Y	0	0	0
Chrysococcyx osculans	Black-eared Cuckoo	Y	Y	1	1	0
Eudynamys orientalis	Eastern Koel		Y	0	0	0
Scythrops novaehollandiae	Channel-billed Cuckoo	Y	Y	0	0	0
Accipiter fasciatus	Brown Goshawk		Y	1	0	0
Aquila audax	Wedge-tailed Eagle	Y	Y	0	0	1

Circus assimilis	Spotted Harrier	Y		0	0	0
Elanus axillaris	Black-shouldered Kite	Y	Y	0	0	0
Falco cenchroides	Nankeen Kestrel	Y	Y	0	0	0
Falco peregrinus	Peregrine Falcon		Y	0	0	0
Falco berigora	Brown Falcon	Y		0	0	0
Coturnix ypsilophora	Brown Quail	Y	Y	0	1	1
Cacatua galerita	Sulphur-crested Cockatoo	Y	Y	14	10	5
Cacatua sanguinea	Little Corella	Y	Y	0	0	0
Eolophus roseicapillus	Galah	Y	Y	1	0	0
Nymphicus hollandicus	Cockatiel	Y	Y	0	0	0
Alisterus scapularis	Australian King-parrot	Y	Y	12	4	0
Barnardius zonarius	Australian Ringneck		Y	0	0	0
Glossopsitta concinna	Musk Lorikeet		Y	0	0	0
Melopsittacus undulatus	Budgerigar		Y	0	0	0
Neophema pulchella	Turquoise Parrot	Y	Y	1	0	1
Neophema chrysostoma	Blue-winged Parrot	Y	Y	0	0	0
Northiella haematogaster	Blue Bonnet	Y	Y	0	0	0
Platycercus elegans	Crimson Rosella	Y	Y	15	12	0
Platycercus eximius	Eastern Rosella	Y	Y	13	7	7
Psephotus haematonotus	Red-rumped Parrot	Y	Y	0	0	0
Ninox novaeseelandiae	Southern Boobook	Y	Y	0	0	0
Acanthiza reguloides	Buff-rumped Thornbill	Y	Y	19	18	8
Acanthiza nana	Yellow Thornbill	Y	Y	6	3	1
Acanthiza chrysorrhoa	Yellow-rumped Thornbill	Y	Y	4	5	0
Acanthiza lineata	Striated Thornbill	Y	Y	3	0	0
Acanthiza pusilla	Brown Thornbill	Y	Y	3	6	3
Acanthiza uropygialis	Chestnut-rumped Thornbill	Y	Y	2	1	1
Chthonicola sagittata	Speckled Warbler	Y	Y	11	7	0
Gerygone olivacea	White-throated Gerygone	Y	Y	10	19	1
Gerygone fusca	Western Gerygone	Y	Y	6	2	2

Hylacola pyrrhopygia	Chestnut-rumped Heathwren	Y	Y	1	1	1
Sericornis -frontalis	White-browed Scrubwren	Y	Y	3	1	0
Smicrornis brevirostris	Weebill	Y	Y	54	18	13
Mirafra javanica	Horsfield's Bushlark		Y	0	0	0
Artamus cyanopterus	Dusky Woodswallow	Y	Y	1	0	1
Artamus superciliosus	White-browed Woodswallow	Y	Y	3	1	1
Artamus cinereus	Black-faced Woodswallow	Y	Y	0	0	1
Cracticus tibicen	Australian Magpie	Y	Y	3	5	1
Cracticus nigrogularis	Pied Butcherbird	Y	Y	2	1	0
Cracticus torquatus	Grey Butcherbird	Y	Y	8	7	5
Strepera graculina	Pied Currawong	Y	Y	9	13	3
Coracina novaehollandiae	Black-faced Cuckoo-shrike	Y	Y	6	5	2
Coracina tenuirostris	Cicadabird		Y	0	0	0
Coracina papuensis	White-bellied Cuckoo-shrike	Y		1	0	1
Coracina maxima	Ground Cuckoo-shrike	Y		0	0	0
Lalage sueurii	White-winged Triller	Y	Y	7	5	0
Climacteris picumnus	Brown Treecreeper	Y	Y	1	0	1
Cormobates leucophaea	White-throated Treecreeper	Y	Y	29	12	1
Corcorax melanorhamphos	White-winged Chough	Y	Y	3	0	0
Struthidea cinerea	Apostlebird	Y	Y	0	1	0
Corvus coronoides	Australian Raven	Y	Y	2	0	0
Corvus mellori	Little Raven	Y		0	0	0
Corvus bennetti	Little Crow	Y		0	0	0
Neochmia temporalis	Red-browed Finch	Y	Y	5	5	0
Neochmia modesta	Plum-headed Finch		Y	1	0	0
Stagonopleura guttata	Diamond Firetail	Y	Y	0	0	0
Taeniopygia bichenovii	Double-barred Finch	Y	Y	3	0	1
Taeniopygia guttata	Zebra Finch	Y		0	0	0
Hirundo neoxena	Welcome Swallow	Y	Y	0	0	1
Petrochelidon nigricans	Tree Martin	Y		0	0	0

Petrochelidon ariel	Fairy Martin	Y	Y	0	0	0
Malurus cyaneus	Superb Fairy-wren	Y	Y	27	25	6
Malurus lamberti	Variegated Fairy-wren	Y	Y	1	1	1
Cincloramphus mathewsi	Rufous Songlark	Y	Y	10	4	0
Cincloramphus cruralis	Brown Songlark	Y	Y	1	0	1
Acanthagenys rufogularis	Spiny-cheeked Honeyeater	Y	Y	2	0	5
Acanthorhynchus tenuirostris	Eastern Spinebill	Y	Y	9	4	1
Anthochaera carunculata	Red Wattlebird	Y		1	0	1
Entomyzon cyanotis	Blue-faced Honeyeater	Y	Y	1	4	0
Epthianura tricolor	Crimson Chat		Y	1	0	0
Gavicalis virescens	Singing Honeyeater		Y	0	0	0
Grantiella picta	Painted Honeyeater	Y	Y	0	0	0
Lichenostomus chrysops	Yellow-faced honeyeater	Y	Y	30	37	39
Lichenostomus melanops	Yellow-tufted Honeyeater	Y	Y	4	3	7
Lichmera indistincta	Brown Honeyeater		Y	0	0	0
Manorina melanocephala	Noisy Miner	Y	Y	15	19	3
Manorina flavigula	Yellow-throated Miner	Y	Y	0	0	0
Melithreptus lunatus	White-naped Honeyeater	Y	Y	2	3	0
Melithreptus brevirostris	Brown-headed Honeyeater	Y	Y	5	1	1
Nesoptilotis leucotis	White-eared Honeyeater	Y	Y	9	2	10
Philemon corniculatus	Noisy Friarbird	Y	Y	46	29	17
Philemon citreogularis	Little Friarbird	Y	Y	5	6	0
Plectorhyncha lanceolata	Striped Honeyeater	Y	Y	3	0	0
Ptilotula penicillatus	White-plumed Honeyeater	Y	Y	10	2	1
Sugomel niger	Black Honeyeater	Y		0	0	1
Grallina cyanoleuca	Magpie-lark	Y	Y	1	2	0
Myiagra inquieta	Restless Flycatcher	Y	Y	1	1	0
Myiagra rubecula	Leaden Flycatcher	Y	Y	2	0	0
Anthus novaeseelandiae	Australasian Pipit	Y	Y	0	0	0
Dicaeum hirundinaceum	Mistletoebird	Y	Y	1	0	0

Daphoenositta chrysoptera	Varied Sittella	Y	Y	2	0	0
Oriolus sagittatus	Olive-backed Oriole	Y	Y	11	2	2
Colluricincla harmonica	Grey Shrike-thrush	Y	Y	31	15	12
Falcunculus frontatus	Crested Shrike-tit	Y		1	0	0
Pachycephala rufiventris	Rufous Whistler	Y	Y	69	30	9
Pardalotus punctatus	Spotted Pardalote	Y	Y	28	31	13
Pardalotus striatus	Striated Pardalote	Y	Y	20	16	4
Eopsaltria australis	Eastern Yellow Robin	Y	Y	25	7	0
Melanodryas cucullata	Hooded Robin	Y	Y	0	0	0
Petroica goodenovii	Red-capped Robin	Y	Y	3	0	2
Petroica rosea	Rose Robin	Y		0	0	0
Microeca fascinans	Jacky Winter	Y	Y	1	0	0
Pomatostomus superciliosus	White-browed Babbler	Y		0	0	0
Pomatostomus temporalis	Grey-crowned Babbler	Y	Y	0	0	0
Cinclosoma punctatum	Spotted Quail-thrush	Y	Y	0	0	0
Ptilonorhynchus maculatus	Spotted Bowerbird		Y	0	0	0
Rhipidura leucophrys	Willie Wagtail	Y	Y	11	3	0
Rhipidura albiscapa	Grey Fantail	Y	Y	29	42	9
Sturnus vulgaris	Common Starling	Y		0	0	0
Zosterops lateralis	Silvereye	Y	Y	3	2	1

APPENDIX 2

A photographic checklist of the reptiles recorded in Warrumbungle National Park after the 2013 bushfire.

Geckos and their relatives

☐ Thick-tailed Geckoes, *Underwoodisaurus milii,* are widespread in the park favouring the sandstone areas, and their use of rock slabs for shelter probably led to them surviving in some intensely burnt areas. Photo Narawan Williams.

☐ Wood Geckoes, *Diplodactylus vittatus,* occur across much of south-eastern Australia and were the most frequently recorded geckoes during the surveys, occurring in all fire severities and most vegetation communities. They were often seen standing on fallen sticks or logs, presumably part of their hunting strategy. Photo Narawan Williams.

☐ Robust Velvet Geckoes, *Nebulifera robusta*, are large, highly arboreal geckoes that have a tendency to live on large trees and shelter in hollow limbs. They were rarely encountered during the surveys and only in low fire severity areas. Photo Narawan Williams.

☐ Ocellated Velvet Geckoes, *Oedura monilis,* are arboreal geckoes which frequent the forests of the Great Dividing Range extending into tropical Queensland. During the surveys they were predominantly found in the north of the park, mostly in low fire severity sites. They have also been found living around the buildings within the park. Photo Narawan Williams.

☐ Eastern Spiny-tailed Geckoes, *Strophurus williamsi*, were found in trees and shrubs. They need to be distinguished by the arrangement of the spines on their backs and tails from their similar looking relative, the Southern Spiny-tailed Gecko *Strophurus intermedius*, which may also occur in the park. Photo Narawan Williams.

☐ Marbled Geckoes, *Christinus marmoratus,* are delicately camouflaged and shelter during the day either in trees or in rock crevices and occupied low fire severity sites. Superficially they are similar to Tree Dtellas but can be easily distinguished by their toes, all of which have claws arising from their tips. Photo Narawan Williams.

☐ Northern Dtellas, *Gehyra dubia*, occur in the trees of the dry forests and woodlands from central NSW to the top of Cape York and on adjacent islands. This species was found at one low fire severity site in the park. Photo Narawan Williams.

☐ Tree Dtellas, *Gehyra variegata,* can also be encountered hunting on the ground even though their elaborate toes make them excellent climbers, even on smooth surfaces. They live throughout inland NSW and are often found on buildings. Within the park they were mostly found in low severity riparian sites. Photo Narawan Williams.

☐ Prickly Geckoes, *Heteronotia binoei,* are widespread, occupying all of Australia except the extreme southern margins. They hunt on the ground during the night, and hide under rocks and debris during the day. They favoured sandstone and lower fire severity areas in the park. Photo Murray Ellis.

☐ Leaden Delmas, *Delma plebia,* may look like snakes but are closely related to Diplodactylidae geckos. They have broad tongues, external ear openings and vestigial back legs that can be seen as flaps, usually held close to the body. Only one animal was found in the park in a low fire severity site. Photo Narawan Williams.

☐ Burton's Legless Lizards, *Lialis burtoni*, are widespread in Australia. This one was photographed among rocks on top of Mount Exmouth in the leaf litter that has accumulated since the fire, where it was probably hunting small reptiles. Photo James Lawson.

Skinks

☐ Red-throated Skinks, *Acritoscincus platynota,* usually have the orange-red colouring on the sides of their face that is visible as they forage through the leaf litter. This makes most individuals easy to distinguish from the other small brown skinks in the park. Photo Narawan Williams.

☐ Two-clawed Worm-skinks, *Anomalopus leuckartii,* are rarely encountered, usually living buried below rocks or logs. Their front legs are small while their hind legs are almost non-existent, allowing them to wriggle through soft soil. They occur in and adjacent to the forests and woodlands along the Great Dividing Range from the park to south east Queensland. The live individual found in the park was in a low fire severity site. Photo Narawan Williams.

☐ Southern Rainbow-skinks, *Carlia tetradactyla,* are usually dull coloured making them hard to see while they hunt through the ground debris for invertebrates, but during the breeding season the males develop two bright orange lines along their sides. They occurred across the range of fire severities and in most vegetation communities. Photo Narawan Williams.

☐ Barred-sided Skinks, *Concinnia tenuis,* are agile climbers of both trees and rock piles so have extensive habitat within the park but were only recorded once during these surveys. Conversely, they are known to live in and around some of the buildings in the park. The species extends east of the park and occupies most of coastal subtropical Queensland and NSW. Photo Ulrike Kloecker.

☐ Wall Skinks, *Cryptoblepharus pulcher,* belong to a genus referred to as Snake-eyed or Shining skinks. This species can be seen moving rapidly on live or dead trees and fallen logs, often taking shelter in cracks or under bark if disturbed. They were found in high and moderate severity fire sites. Photo Narawan Williams.

☐ Robust Ctenotus, *Ctenotus robustus*, are large active diurnal skinks that can be seen foraging on the ground across the range of fire severities and in most vegetation communities. They retreat under rocks and debris or into burrows if disturbed, but you may be able to see them looking out from such safe spots. Photo Narawan Williams.

☐ Copper-tailed Skinks, *Ctenotus taeniolatus,* are found across the Dividing Range and down to the east coast in a variety of habitats. Within the park they can be found hunting and sheltering in and around the rocky outcrops in both intensely and lightly burnt areas. Photo Ulrike Kloecker.

☐ Warrumbungles Black Rock Skinks, *Egernia saxatilis saxatilis,* as the name suggests live among or adjacent to the rock piles throughout the Warrumbungles, most commonly in the Ironbark Woodlands. The second subspecies occurs in rocky habitats in south east New South Wales and adjacent parts of Victoria. They look similar to Tree Skinks but have darker lips and throats. Photo Narawan Williams.

☐ Tree Skinks, *Egernia striolata,* are usually arboreal but will venture onto the ground, rapidly retreating to the trees or fallen logs if threatened. They may be occasionally seen with their heads poking out of tree hollows in any of the woodlands within the park. This pose lets you see their white lips and speckled throats allowing them to be identified. Photo Narawan Williams.

☐ Bougainville's Skinks, *Lerista bouganvillii,* are also known as the South-eastern Sliders, which describes their distribution and lifestyle. They have small front legs enabling them to spend much of their active time pushing through loose soil and leaf litter, only occasionally coming to the surface, making them difficult to detect. One animal was found in a sandstone site. Photo Narawan Williams.

☐ White's Skinks, *Liopholis whitii,* is widespread long the Great Dividing Range and down to the east coast, and was the most frequently encountered skink in the park, occurring in all fire severities and vegetation communities. The park population is the most inland one of this species and is very variable in colouring. They are terrestrial and usually shelter in burrows under rock slabs and logs, often in close proximity to one another. Photo Ulrike Kloecker.

☐ Tree-base Litter-skinks, *Lygisaurus foliorum,* inhabit deep leaf litter in the forests of central eastern Australia where they hunt for invertebrates during the day. Within the park they were found in light to moderately burnt areas in Ironbark Woodlands. Photo Ulrike Kloecker.

☐ South-eastern Morethia Skink, *Morethia boulengeri*, is widespread and common across the park, hunting on the ground and fallen timber. Occasionally they may get an orange tinge on their throats and tails but the white stripe along the face and side should allow them to be distinguished from Red-throated Skinks. Photo Narawan Williams.

☐ Eastern Blue-tongued Lizards, *Tiliqua scincoides,* are omnivorous, generally feeding during the day and sheltering under debris or in logs for the night. Despite their short legs they manage to clamber through the ground debris and rocky scree within the park searching for food, but their slow speed when they bask on roads makes them vulnerable to cars. Photo Murray Ellis.

Dragons

☐ Jacky Lizards, *Amphibolurus muricatus,* can be found on the ground or in elevated positions on branches and stumps. Boulders and logs within the park are ideal places for these lizards to sunbathe. The inside of their mouth is yellow. Photo Murray Ellis.

☐ Nobbi Dragons, *Diporiphora nobbi,* look and behave much like the Jacky Lizard but are pink inside their mouths rather than yellow. Additionally, the adult males can have a pink tinge around the base of their tail. They were rarely found at the same sites as Jacky Lizards. Photo Narawan Williams.

☐ Bearded Dragons, *Pogona barbata,* are one of the most commonly encountered reptile species within the park because of their frequent use of the main road for basking. Additionally, the adult males can be seen perched on posts and stumps along the roads and around the camping areas. In this photograph a delicately patterned juvenile is resting on a small tree trunk for the night. The pattern becomes less clear as animals mature but the spines around the head and sides become more pronounced. Photo Narawan Williams.

Goannas

☐ Sand Goannas, *Varanus gouldii,* are large terrestrial lizards that favour the inland of Australia. They have pale lines running along the sides of their face and neck. This species was recorded a kilometre west of the park in the Wambelong Creek valley in December 2016. Photo Murray Ellis.

☐ Lace Monitors, *Varanus varius,* are widespread within the park and can be distinguished from Sand Goannas by their face markings and arboreal habits. Even the massive adults are fast runners and readily climb trees to escape their pursuers. Park visitors often encounter these goannas attempting to scavenge around the camping and picnic sites. Photo Murray Ellis.

Snakes

☐ Proximus Blind Snakes, *Ramphotyphlops proximus,* are burrowing animals that feed on subterranean colonial insects and are unlikely to be encountered by park visitors (no image).

☐ Murray/Darling Carpet Pythons, *Morelia spilota metcalfei,* occur in both woodlands and boulder fields within the park where they hunt warm-blooded prey. Their large size makes them easy to spot when they are crossing roads in the park, but their camouflage makes it easy for them to disappear once they reach vegetation. Photo Jennifer Taylor.

☐ Yellow-faced Whip Snakes, *Demansia psammophis,* are fast snakes that hunt through the leaf litter and undergrowth for diurnal skinks throughout a wide range of vegetation types. Photo Michael McFadden.

☐ Red-naped Snakes, *Furina diadema,* are small and with a colour pattern that can be confused with hatchling brown snakes (*Pseudonaja* spp.). They were found across a range of fire severities but fortunately they are nocturnal and rarely encountered by park visitors. Photo Michael McFadden.

☐ Spotted Black Snakes, *Pseudechis guttatus,* are also known as Blue-bellied Black Snakes. They are mainly restricted to the tablelands and western slopes of the Great Dividing Range in NSW, but can be found in a wide variety of habitats in that range (no image).

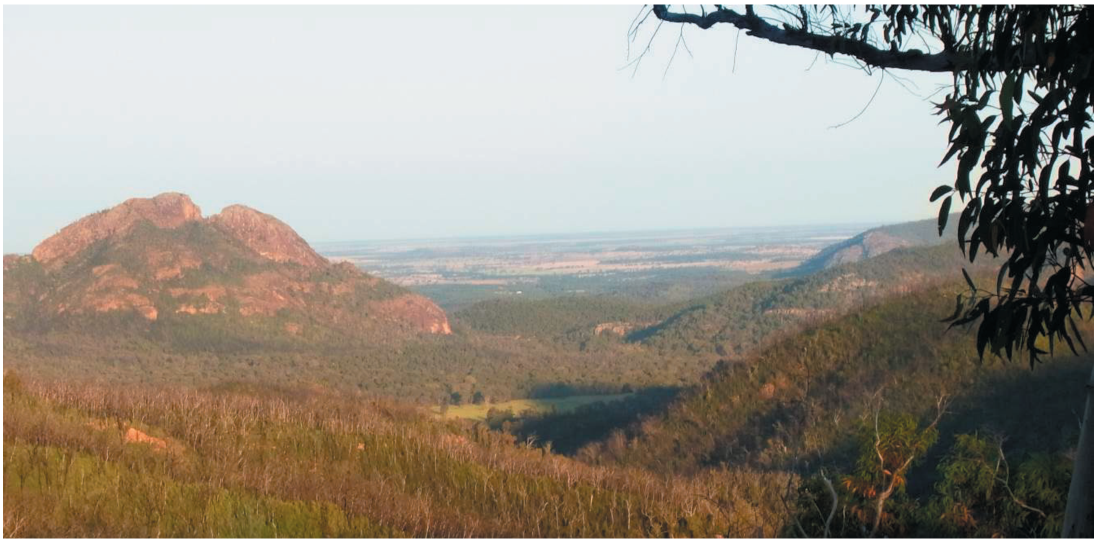
☐ Red-bellied Black Snakes, *Pseudechis porphyriacus*, are active diurnal hunters that favour wetter areas such as creek lines where their preferred prey, frogs, can be found. Photo Narawan Williams.

APPENDIX 3

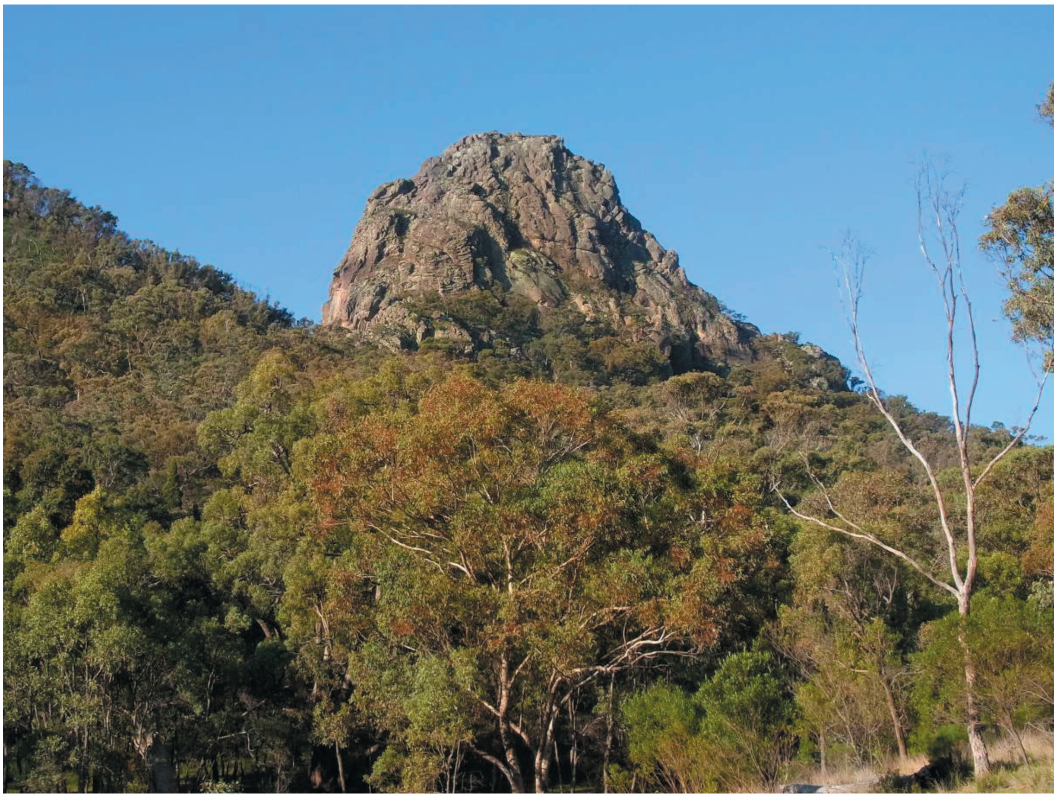
Images of the park's landscape and the impact of fire on its vegetation.

Appendix 3 Figure 1. The western edge of the Great Dividing Range with Warrumbungle National Park, NSW viewed from the adjacent western plains, with Siding Spring Observatory visible as a white dot on the horizon.

Appendix 3 Figure 2. Volcanic remnants forming the central ridge in the park known as the Grand High Tops.



Appendix 3 Figure 3. View from Whitegum Lookout down the centre of the park, showing the remains of cleared farmland that is undergoing restoration planting in the valley floor and the extensively cleared western plains beyond.



Appendix 3 Figure 4. Low severity fire left the woodland with an intact canopy. In the background is a naturally bare volcanic outcrop.

Appendix 3 Figure 5. Moderate severity fire resulted in epicormic resprouting along tree trunks and branches with the development of grassy ground cover and shrubby understorey

Appendix 3 Figure 6. In an area of high fire severity *Eucalyptus* trees show basal resprouting among dead stems, interspersed with flowering shrubs and vines that had regenerated from seed.

APPENDIX 4

Dates and starting time of the 10-minute bird surveys at the 35 sites in Warrumbungle National Park

Site/date	Time
WNP001	
6/09/2014	16:25
29/09/2014	10:15
17/10/2014	11:15
20/10/2014	7:15
11/03/2015	18:44
1/04/2015	12:00
9/10/2015	8:00
12/10/2015	11:00
15/10/2015	7:25
7/11/2015	9:11
10/11/2015	6:45
18/03/2016	11:35
WNP002	
6/09/2014	16:00
29/09/2014	10:40
17/10/2014	11:45
20/10/2014	6:45
11/03/2015	8:20
1/04/2015	11:15
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