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Use of artificial bark covers to investigate the distribution and abundance of arboreal lizards in a floodplain environment

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ABSTRACT

Arboreal lizards, especially species that inhabit flood-prone environments, have been poorly surveyed worldwide. We examined spatiotemporal patterns in arboreal lizard abundance and factors driving detection rates in floodplain environments using artificial bark covers, a non-destructive and cost-effective survey method. In total, 112 flexible, closed-cell foam bark covers were installed on eucalypt trees in 13 wetlands in the Murrumbidgee River floodplain of southern New South Wales, Australia, stratified by two inundation frequency treatments. Of four arboreal lizard species detected, the southern marbled gecko (*Christinus marmoratus*) ($n = 41$) and the tree dtella (*Gehyra versicolor*) ($n = 8$) were restricted to the mid-Murrumbidgee region, whereas the crevice skink (*Egernia striolata*) ($n = 19$) was restricted to the lower-Murrumbidgee region and did not co-occur with either gecko species. Mean detection rates of lizard species did not differ between frequently and infrequently inundated treatments but their abundance beneath covers varied significantly by month. For all detected lizard species, the presence/absence of the arachnid *Holconia murrayensis* represented a significant variable in explaining lizard occurrence patterns, particularly that of *C. marmoratus*. Artificial bark covers are a useful survey method for collecting distribution, abundance, and occupancy data on floodplain reptiles, although detection rates can be affected by the month, predator–prey interactions, and survey effort. Adopting passive, non-destructive reptile survey methods would greatly improve our knowledge of species' distributions and abundance patterns in vegetation communities subject to disturbance events.

Keywords: arboreal lizards, artificial refuges, environmental water, floodplain environment, Murray–Darling Basin, occupancy patterns, species distribution, survey methods.

Introduction

Reptiles are a species-rich group of vertebrates that play important roles as predators and prey in a broad range of ecosystems, yet they remain one of the most poorly studied vertebrate groups worldwide (Roll *et al.* 2017). The lack of research and conservation attention is concerning considering reptile populations are declining on a global scale due to habitat loss, land use change, invasive predators, and a warming climate (Gibbons *et al.* 2000; Böhm *et al.* 2013; Tingley *et al.* 2019). A key premise in maintaining biodiversity is understanding species diversity and distribution patterns across different ecosystems. Selecting appropriate survey methods to enable robust detection estimates in different environments is paramount to achieving these goals (Ribeiro-Júnior *et al.* 2008; Michael *et al.* 2012).

Conventional methods for surveying reptiles include active searches or visual encounter surveys (Garden *et al.* 2007; Dodd 2016) which involve collecting individuals from shelter sites such as beneath logs, rocks, or exfoliating bark. This search strategy can provide a representative sample of the species present in a defined area (Ribeiro-Júnior *et al.* 2008), but is biased towards observer ability and topographical constraints, and may cause localised destruction of critical microhabitat (Button *et al.* 2020). Exfoliating bark of mature trees is a key microhabitat commonly utilised by a range of tree-dwelling fauna, but this resource is often a limiting factor in human-modified landscapes (Michel and Winter 2009; Michael et al. 2015). Many arboreal species are dependent on exfoliating bark for shelter, thermoregulation, and nesting sites (Parmar 2020, Riedel et al. 2020; Taylor et al. 2020; Putra et al. 2021; Schwarz et al. 2021). For instance, nocturnal arboreal geckos will use bark to thermoregulate by changing their posture to maximise contact with the substrate while remaining beneath the safety of cover (Kearney 2001; Nordberg and Schwarzkopf 2019*a*). Consequently, many arboreal species are impacted by human activities that result in habitat loss or microhabitat disturbance. To mitigate human impacts on a bark-dwelling species in the USA, researchers developed an artificial roost called BrandenBark™ designed to mimic the exfoliating bark of Indian bat (*Myotis sodalist*) roost trees (Adams et al. 2015). The construction of this type of artificial shelter not only provided suitable conditions to facilitate population recovery for an endangered species, but also provided a passive method useful in fauna surveys.

Similar passive survey methods have been used for over four decades in reptile surveys, including the use of artificial cover objects or artificial refuges to provide supplementary sheltering sites that can be periodically inspected without disturbing the natural habitat (Michael et al. 2004; Hoare et al. 2009; Michael et al. 2012). Artificial bark covers (ABCs) are a relatively recent survey method used to survey invertebrates (Hodge et al. 2007) and reptiles in Australia and New Zealand (Bell 2009; Nordberg and Schwarzkopf 2015; Michael et al. 2018; Shelton and Goldingay 2021). Comparative studies have found that ABCs are particularly effective for increasing capture rates of gecko species (Nordberg and Schwarzkopf 2015; Shelton and Goldingay 2021) and for detecting arboreal snakes in vegetation communities where habitat resources are limited (Shelton and Goldingay 2021). ABCs may also have broader application in long-term occupancy studies where presence and absence are the inferred objectives rather than evaluating habitat requirements (Ali et al. 2018; Shelton and Goldingay 2021). However, the use of ABCs to survey arboreal reptiles is a method still in its infancy and has yet to be tested on a wide range of taxa across structurally different ecosystems. The application of this survey method in landscapes subject to periodic inundation has not previously been documented but is of particular interest to floodplain land managers in Australia. Surveying fauna in remote or dynamic ecosystems such as flood prone environments can be challenging, largely because conventional methods to survey reptiles can be labour intensive (e.g. pitfall traps) or not feasible (e.g. during inundation events): or they require some level of habitat disturbance (e.g. active searches: Ali et al. 2018).

One ecosystem where terrestrial reptiles have received relatively little attention is the floodplain environments of the Murray–Darling Basin (MDB). The MDB is the largest river catchment in Australia and supports extensive stands of floodplain forest vegetation communities. Freshwater ecosystems within the MDB are under threat from changing patterns of water availability, declining tree condition, land clearing and land use change (Kingsford 2000; West et al. 2008; Pittock and Finlayson 2011). More than 260 reptile species from 12 families occur in the MDB, where they occupy a variety of environments, including floodplains and wetlands (Swan 2020). Although the detection rates and suitability of different survey methodologies have been tested on other floodplain herpetofauna, including frogs (Wassens et al. 2017) and turtles (Howard et al. 2017; Ocock et al. 2018; Van Dyke et al. 2019; Price et al. 2020), survey methods to assess the distribution and abundance of terrestrial floodplain reptile communities have received far less attention. It is not known how abundance and distribution of lizard species in the MDB floodplain respond to inundation frequency as inundation can drive increases in floodplain productivity and food availability but can also inundate large areas of suitable habitat, limiting movement and stranding individuals.

To address this ecological knowledge gap, we used ABCs to investigate the distribution and abundance of arboreal lizards from an ecologically significant part of the MDB floodplain ecosystem. We addressed the following three questions: (1) does the abundance and composition of lizard species increase and change respectively with more frequent inundation or among different broad vegetation communities; (2) are there temporal changes in species detection patterns over time; and (3) what is the optimal number of visits required to attain 95% confidence in detecting arboreal lizard species, given their presence at a site in this system?

Materials and methods

Study area

This study was conducted in the Murrumbidgee catchment (81 527 km^2) within the Murray–Darling Basin in southern New South Wales (NSW) between Darlington Point and Balranald (a map of these areas can be found in the supplementary material: Supplementary Material Fig. S1). Significant stands of river red gum (*Eucalyptus camaldulensis*) forest occur along the Murrumbidgee River, although various sections have been subject to intensive logging activity in the past. Contemporary land use is predominantly associated with dryland and irrigated cropping, grazing and small-scale hobby farming. We located our study sites within three regions reflecting broad wetland vegetation communities. The regions included: (1) mid-Murrumbidgee, characterised as lagoons fringed with river red gum, (2) Gayini Nimmie-Caira (GNC), characterised as creeks and palaeochannels dominated by lignum (*Duma florulenta*) and lignum–black box (*Eucalyptus largiflorens*) communities, and (3) Redbank, characterised by river red gum–spike rush (*Eleocharis* spp.) vegetation communities. All sites were located within Yanga National Park, Murrumbidgee Valley National Park or on private property and were situated between 500 m and 22 km from the main river channel and within the core floodplain system.

Study design

In August 2019, 112 ABCs were installed on river red gum (*E. camaldulensis*) (n = 108) or black box (*E. largiflorens*) trees (n = 8) at 13 wetlands across the study area. At each wetland, two or three plots were established, where a plot represented a grid of four trees spaced approximately 100 m apart (1 ha). Inundation regimes derived from spatial layers (Hall *et al.* 2019) were used to select two trees that experienced frequent inundation (>17/20 occasions from 1990 to 2010, termed 'wet' treatment) and two trees that experienced infrequent inundation (<3/20 occasions from 1990 to 2010, termed 'dry' treatment). We chose to stratify tree selection based on inundation frequency as we were initially interested in the influence of managed watering actions on lizard movement and occupancy patterns. However, this study was conducted during a below average water allocation year and subsequently few (n = 5) trees were inundated, preventing us from performing the before–after control–impact experimental component of this study.

As this study focused on species detection and not microhabitat preferences, trees with a diameter at breast height (DBH) ranging from 60 to 120 cm were selected, as this size cohort hosts more species and individuals of arboreal lizards than smaller trees (Michael *et al.* 2018). The ABCs consisted of closed cell foam (Neolon™ Foiled Foam) and were attached to each selected tree using rope and shock cords (Fig. 1). To standardise the cover area, the closed cell foam was cut into 60 × 200 cm strips and placed 1.5 m above the ground, oriented to the north. Each tree was marked with a semipermanent tag and given a unique code identifying the site, plot, treatment, and tree number. The first survey was conducted in September 2019, one month after the ABCs were installed. Temperature outside and underneath the ABCs was recorded using Thermochron iButtons programmed to record hourly over a six-month period. Thermochron iButtons were placed on trees at four sites within the mid-Murrumbidgee area (MAN, DAR, GOO, SUN). iButtons were not deployed at Nimmie-Caira or Redbank. One tree from each treatment was chosen within each site, the exception for this being at DAR where iButtons were installed on one 'wet' tree. Two iButtons housed in fobs were nailed to each tree oriented to the north, one above the cover to record ambient temperature, and the second beneath the ABC to record temperature within the shelter. The ABCs remained *in situ* throughout the entire study.

Reptile surveys

Reptile surveys were conducted on five occasions in the mid-Murrumbidgee area (September 2019, November 2019, January 2020, March 2020, and June 2020) and on four occasions in the GNC and Redbank areas due to access restrictions (September 2019, November 2019, January 2020, and March 2020). During each survey period, the ABCs were carefully removed from the tree and any sheltering lizards were captured by hand (when feasible) and sexed before being released back under the reinstated cover. We did not individually mark lizards in this study.

Data analysis

We modelled the number of animals of each species captured under ABCs during each survey in relation to tree treatment (wet versus dry) and survey period (month) using generalised linear mixed models (GLMMs). To examine treatment effects, the number of individuals was modelled as a Poisson distribution with treatment included as a two-level categorical variable with site included as a random

Fig. 1. Example of artificial bark covers (ABC) attached to a river red gum (left and right) and black box tree (middle) in areas that experience frequent or infrequent inundation.

effect (Zuur *et al.* 2009). To explore survey period (months) effects, the number of individuals was modelled as a Poisson distribution with month as a covariate and site ID as a random effect, which we compared to an intercept-only model using a Likelihood Ratio Test (Bates 2005). To evaluate occupancy and detection probabilities for arboreal lizards found beneath the ABCs, single season occupancy models were produced for each species in R using the package 'unmarked' (Fiske and Chandler 2011). Single season occupancy models assume independence between sites and detections, no changes in occupancy within sites and no false positive records (MacKenzie *et al.* 2002). Although not all species were distributed evenly across the three wetland areas, data from all areas were used to calculate detection probabilities at the site-level for *E. striolata* (Redbank area), *C. marmoratus* and *G. versicolor* (mid-Murrumbidgee area). *Cryptoblepharus pannosus* was excluded from the analysis due to infrequent records across all areas.

A null occupancy model was calculated for each species, allowing an estimate of detectability and occupancy across all sites. This model was then back transformed in both the detection and occupancy parts of the model, allowing us to estimate the number of repeat site visits required to attain high confidence in detecting the species, given its presence (Kery 2002). The only exception to the null model was the inclusion of the detection of a large arachnid (*Holconia murrayensis*) during surveys for the three common lizard species, as field observations indicated that these animals rarely co-occurred, suggesting some form of predator–prey interaction. Thus, the presence/absence of *H. murrayensis* was included as a survey level covariate of lizard occupancy.

To evaluate ABC temperature profiles, we modelled the temperature from iButtons in relation to whether the iButton was located underneath or above the ABC (i.e. ambient temperature) using cyclic Generalised Additive Mixed Models with time of day as a cyclic smoothed term, iButton location (underneath/outside) as a fixed effect, and tree ID as a random effect (to acount for repeated measures of temperature at trees over time). A by function was used to allow a separate smoothed term for each level of iButton location. All analyses were performed using R Studio.

Results

Summary statistics

From five surveys involving 552 ABC inspections, four arboreal lizard species, two frog species, one unidentified bat species and several spider species were detected (Table 1). Numerous other invertebrates were also observed but these taxa were not recorded in this study. *Christinus marmoratus* was the most recorded species and accounted for 44% of total lizard detections, followed by *Cryptoblepharus pannosus* (27% of observations), *Egernia striolata* (20%) and *Gehyra versicolor* (9%). Two frog species (*Litoria peronii* and *Litoria raniformis*) were recorded under the ABCs but were detected too infrequently to include in the analysis.

Species distribution by treatment

The composition and abundance of reptiles beneath the ABCs was not evenly distributed across the study area (Fig. 2). For example, *E. striolata* was found only in river red gum within the Redbank system in the Lower Murrumbidgee, where it was detected at nine of ten sites and the two gecko species were found only in river red gum in the mid-Murrumbidgee area, where *C. marmoratus* was detected on five of six sites and *G. versicolor* was detected on three of six sites. *Cryptoblepharus pannosus* was the only species found across all three wetland areas, although it was infrequently detected beneath ABCs on most sites. There was no difference in the mean number of lizard observations between treatments (inundated 'wet' trees versus infrequently inundated 'dry' trees) for any species (Table 2).

Temporal trends in species abundance

The mean number of observations for three of four species varied significantly among survey periods (Fig. 3). The

Table 1. List of faunal species and total number of detections beneath artificial bark covers in the Murrumbidgee study area between September 2019 and April 2020.

Family	Species	Common name	Total observations
Gekkonidae	*Christinus marmoratus*	Southern marbled gecko	41
Gekkonidae	*Gehyra versicolor*	Tree dtella	8
Scincidae	*Cryptoblepharus pannosus*	Ragged snake-eyed skink	25
Scincidae	*Egernia striolata*	Tree crevice skink	19
Arachnidae	*Holconia murrayensis*	Murray tree huntsman	201
Hylidae	*Litoria peronii*	Peron's tree frog	45
Hylidae	*Litoria raniformis*	Southern bell frog	7
Microchiroptera	*Vespadalus* spp.	unidentified bat species	1

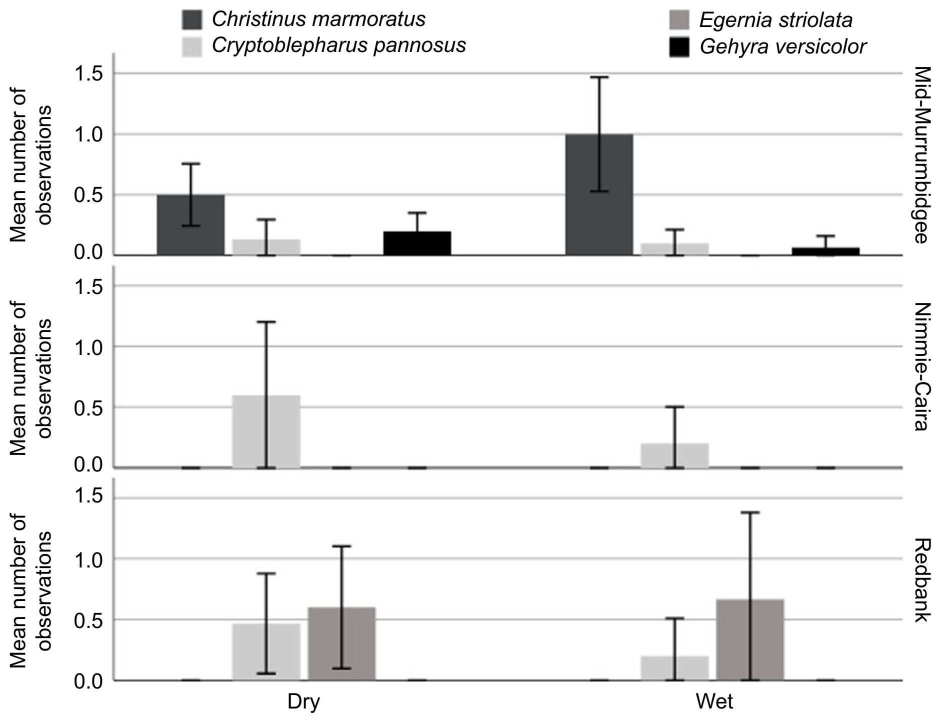

Fig. 2. Mean number of observations per site between treatments (wet versus dry) for four arboreal lizard species detected beneath ABCs across three wetland areas.

Table 2. Results from generalised linear mixed models comparing mean observations of four lizard species in relation to inundation treatment (wet/dry).

Predictors	*Christinus marmoratus*			*Cryptoblepharus pannosus*			*Egernia striolata*			*Gehyra versicolor*		
	Log-mean	CI	*P*	Log-mean	CI	*P*	Log-mean	CI	*P*	Log-mean	CI	*P*
(Intercept)	−0.79	−1.45 to −0.14	0.018	−1.28	−1.89 to −0.67	<0.001	−0.59	−1.37 to 0.19	0.138	−2.21	−3.88 to −0.54	0.009
Treatment (wet/dry)	0.55	−0.08 to 1.18	0.086	−0.75	−1.59 to 0.09	0.079	0.11	−0.79 to 1.00	0.817	−1.10	−2.70 to 0.50	0.178
Observations		60			110			30			60	
Marginal R^2/ Conditional R^2		0.061/0.237			0.066/0.186			0.003/0.121			0.071/0.375	

mean number of *C. marmoratus* observations ($P = 0.015$) were highest during the first survey in September 2019 and the last survey in June 2020. In contrast, the mean number of *E. striolata* observations ($P = 0.024$) were highest during the warmer months of November, February, and March (Fig. 3). *Cryptoblepharus pannosus* was not detected during the winter months ($P = 0.02$) and *G. versicolor* abundance did not differ significantly across months ($P = 0.458$).

ABC thermal properties

Across all seasons, the temperature beneath the covers fluctuated less and remained warmer between 2200 and 1000 hours compared with the ambient temperature above the covers (Fig. 4). During the winter months, temperatures beneath the covers rarely exceeded 30°C, whereas, during the summer and autumn months, both the ambient temperature and temperatures under the ABCs consistently rose above 35°C, although mean values remained below the known preferred body temperature of all lizard species (e.g. *G. versicolor* 34.0°C, *E. striolata* 32.7°C, *C. marmoratus* 27.6°C) (Bennett and John-Alder 1986; Angilletta and Werner 1998).

Species detection probabilities

Gehyra versicolor was the most detectable lizard species, requiring an estimated two surveys to reach 95% confidence of detecting the species, given its presence at a

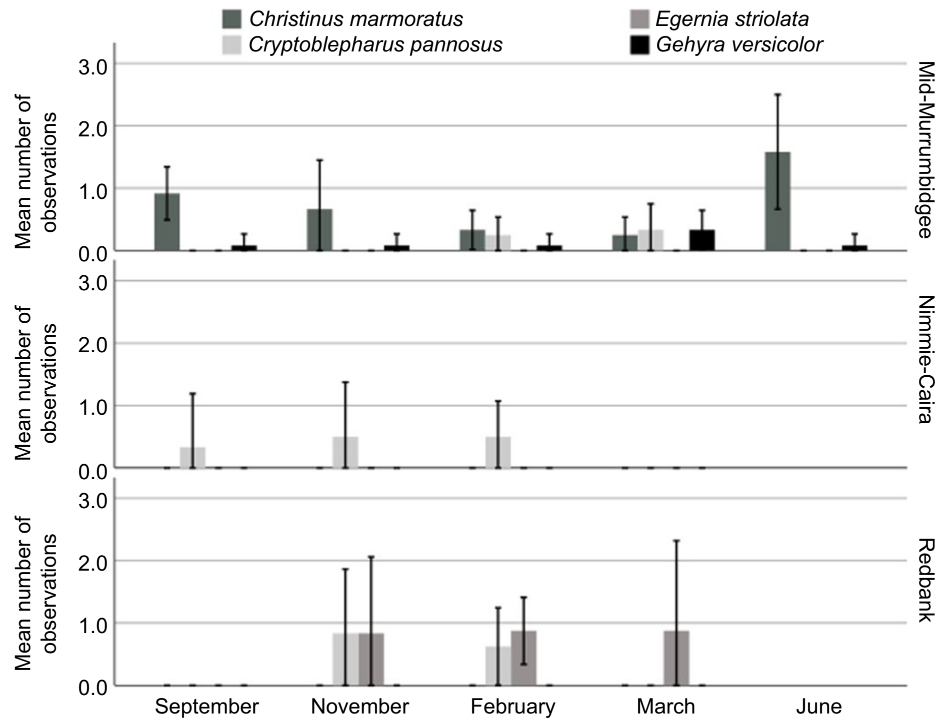

Fig. 3. Mean number of observations per month for four arboreal lizard species detected beneath ABCs across three wetland areas.

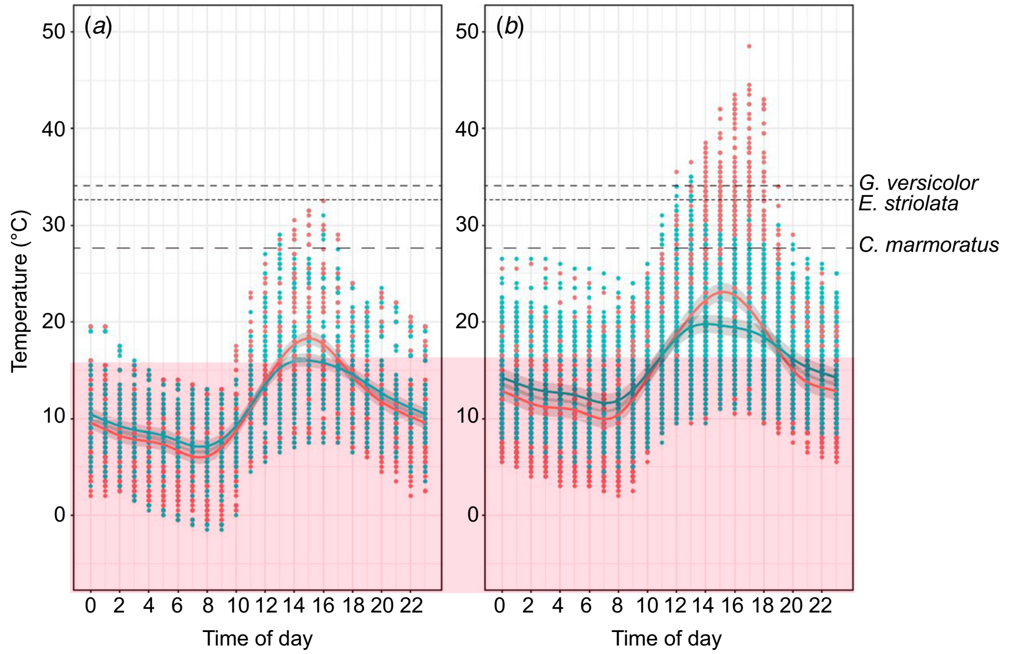

Fig. 4. Mean temperature underneath ABCs (blue line) and outside of the ABCs (ambient temperature – red line) during (*a*) winter and (*b*) summer/autumn. The dashed line represents the preferred body temperature of *Egernia striolata* (32.7°C: Bennett and John-Alder 1986), *Christinus marmoratus* (27.6°C) and *Gehyra versicolor* (34.0°C: Angilletta and Werner 1998).

site (Fig. 5*a*). *Christinus marmoratus* and *E. striolata* both had similar detection probabilities, requiring four and five visits respectively to reach a 95% confidence of detection, given their presence at a site (Fig. 5*b*, *c*). The arachnid *H. murrayensis* had a 95% confidence of detection after five surveys (Fig. 5*d*). Overall, the probability of detecting all arboreal lizard species was lower when *H. murrayensis* was present during a survey. Specifically, we found a significant negative interaction between *H. murrayensis* presence and the probability of detecting *C. marmoratus* ($P < 0.01$) (Fig. 6). Two *C. marmoratus* were observed on the same tree on four occasions.

Discussion

Monitoring wildlife is fundamental for making sound conservation management decisions (Nichols and Williams 2006). An important component of wildlife monitoring and compiling species inventories is using effective survey methods to obtain robust estimates of species diversity or occurrence patterns (Kéry and Schmidt 2008; Shelton and Goldingay 2021). In the present study, we used artificial bark covers (ABCs) to obtain distribution and abundance data on arboreal lizards and evaluate occupancy patterns in a temperate floodplain ecosystem. Our passive survey method identified four arboreal lizard species, two frog species and one microbat. Of the lizard species detected, all four species were expected to occur within the study area, although unanticipated regional and temporal patterns in species distributions and occupancy patterns were evident.

Species distribution patterns

Based on range boundaries and habitat preferences, we predicted that all four species would be detected across the study area, as location records for all species exist from along the Murrumbidgee River to the east and west of our study area (Atlas of Living Australia 2021). However, we detected only *E. striolata* in the western region (Redbank), and *G. versicolor* and *C. marmoratus* in the eastern region (mid-Murrumbidgee). *Cryptoblepharus pannosus* was widely

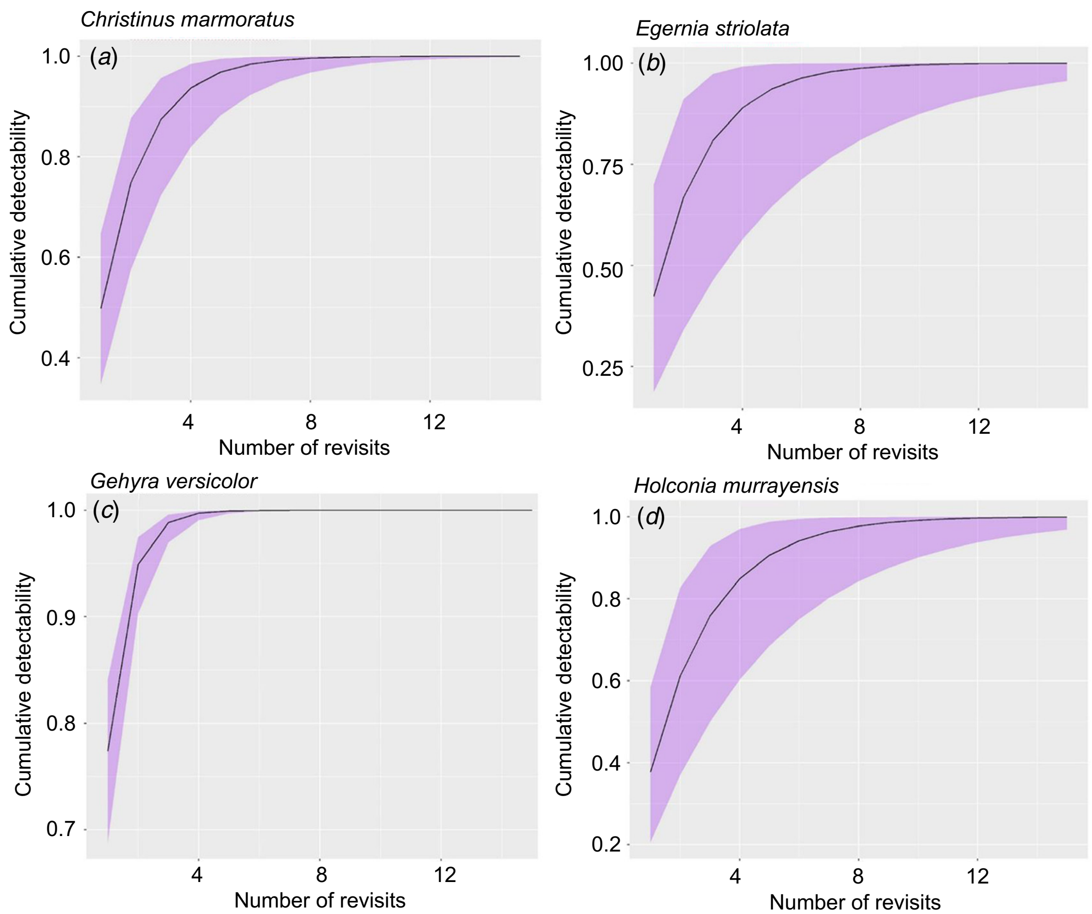

Fig. 5. The cumulative probability of detecting (*a*) *Christinus marmoratus*, (*b*) *Egernia striolata*, (*c*) *Gehyra versicolor*, and (*d*) *Holconia murrayensis* against the number of site visits required to obtain a 95% confidence of detection (light shading = 95% confidence intervals) when number of ABCs = 112.

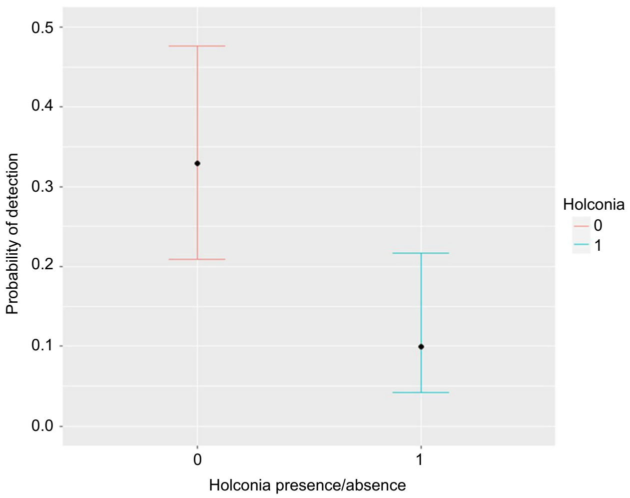

Fig. 6. The probability of detecting *Christinus marmoratus* in absence (0) and in presence (1) of the tree huntsman spider *Holconia murrayensis*.

distributed across all three areas but was detected in low numbers. The absence of *E. striolata*, *G. versicolor* and *C. marmoratus* in GNC could be a function of distance to the main river channel, as several black box dominated wetlands in this area were more than 20 km from the main river corridor and surrounded by potentially unsuitable chenopod shrubland and grassland habitat. These species are also naturally uncommon in black box vegetation communities in southern NSW (Michael *et al.* 2011).

The absence of *E. striolata* in the mid-Murrumbidgee is more intriguing, as suitable *E. camaldulensis* habitat exists, including preferred microhabitats such as cut stumps and logs (Greer 2021). Its absence could be due to the disturbance history within the region, a result of extensive forestry operations that lasted until 2010 (West *et al.* 2008). Tree-dwelling populations of *E. striolata* in New South Wales exhibit kin-based sociality (Duckett *et al.* 2012), making it possible that past disturbances have resulted in the destabilisation of social groups causing localised extinctions from heavily disturbed sections of the Murrumbidgee River floodplain. The observed niche overlap in mid-Murrumbidgee between *G. versicolor* and *C. marmoratus* is also worth exploring further. These two species co-occurred on two sites and were detected on the same plot on two occasions but were encountered on the same tree on one occasion. Intraspecific competition for resources between these similar species is unknown but may explain their local distribution patterns (Nordberg and Schwarzkopf 2019*b*; Petford and Alexander 2020). *Gehyra versicolor* is an arid-adapted species found further north of the study area, whereas *C. marmoratus* is a temperate species found predominantly south of the study area. Both species reach their geographical range limits at the Murrumbidgee River. Exploring their microhabitat preferences considering potential competitive interactions requires further research.

The role of wetland inundation frequency was not a significant determining factor for lizard occupancy and species composition in this study. Geckos were found in equal measure on both dry and inundated trees. However, this experiment was conducted in a below average water allocation year and only five of our 'wet' treatment trees were truly inundated. A limitation to the experimental design of this study was its dependence on a larger water allocation for the 2019–2020 water year.

Temporal trends in species abundance

We found differing temporal trends in species observations over the eight-month temperature sampling period. *Christinus marmoratus* was observed more frequently in the cooler months of September and June (austral spring and winter). During warm weather, this species may move from trees to seek more thermally stable terrestrial environments or may seek shelter beneath deeper bark layers. In a study from central Victoria, Kearney and Predavec (2000) found that *C. marmoratus* moved from trees to rock crevices during the warmer months. The reduction in *C. marmoratus* observations during the summer months in this study also suggests that this species may shift shelter sites, or retreat beneath the deeply fissured bark layers. As we did not remove bark in this study, or individually mark animals, we were unable to determine where this species moved to during the warmer months. During the winter months, the mean temperature beneath the ABCs remained higher than the ambient temperature between 2000 and 1000 hours. As *C. marmoratus* is nocturnally active, retreat sites that provide relatively stable temperature gradients will enable individuals to retain an optimal body temperature range (Kearney and Predavec 2000), and potentially extend their activity patterns. By contrast, observations of *E. striolata* increased during the warmer months, consistent with a diurnally active heliothermic species (Bennett and John-Alder 1986).

Detection and occupancy patterns

Of the arboreal lizard species detected in this study, some required more survey effort than others, when $n = 112$ ABCs. *Gehyra versicolor* required only two visits to achieve 95% confidence of detection, whereas *C. marmoratus* and *E. striolata* had similar detection probabilities requiring four and five visits respectively to achieve 95% confidence of detection. For both inventory studies and monitoring programs, it is important to understand how much survey effort is required to determine if a species is present to optimise survey effort (Garden *et al.* 2007; Sewell *et al.* 2012). For studies using artificial cover objects or artificial refuges, understanding species' detection probabilities can inform how many objects or covers need to be installed to maximise detection rates. Our results suggest that detecting arboreal species in this system using a limited number of covers (e.g. four per site) is a sufficient amount, although multiple visits are still required to achieve high confidence in establishing species presence. This is because some arboreal species may be present beneath deeply fissured bark and not detected beneath the ABCs during a survey event. Installing more covers at a site is a better approach to help improve detection of cryptic arboreal lizards in future studies rather than physically removing bark habitat to increase detection rates.

Some colonisation effects may have also contributed to the variation in gecko detections over time. Michael *et al.* (2018) found that *C. marmoratus* detections increased over a four-year period, providing further evidence of long-term residency within a population. In contrast, *E. striolata* was observed more often during the warmer months of November, February, and March. This species is a diurnally active, heliothermic skink with a preferred body temperature of 32.7°C (Bennett and John-Alder 1986). Thus, we expected *E. striolata* would be detected after the ABCs had been in place for some time. The species also forms small social groups, so it was not unexpected to find an adult pairing. Overall, mostly single adults were detected beneath the covers, again suggesting the ABCs were being colonised by dispersing individuals.

Another outcome of this study was the co-occurrence interactions within and between species. Two *C. marmoratus* individuals were seen on the same tree on four occasions, with a sex ratio of two females to four males. Two of these individuals were subadults and could not be sexed. These results are congruent with those of another study that found a conspecific aggregation is more likely with an adult–adult interaction versus an adult–subadult interaction (Pereira *et al.* 2019). Additionally, there were no observations of a female co-occurrence, which aligns with the literature that aggression and territorialism between females prevents them from aggregating (Kearney *et al.* 2001). There was a negative relationship between the presence of the arachnid *H. murrayensis* and all lizard species (but especially *C. marmoratus*). Many species avoid conspecifics due to competitive exclusion or because of differences in their niche requirements (Letten *et al.* 2017). Similarly, prey will attempt to avoid potential predators and use chemical scent cues to minimise the risk of encountering predators (Webster *et al.* 2018). *Christinus marmoratus* is known for its avoidance behaviour in areas where predators are present (Webster *et al.* 2018). For example, Webster *et al.* (2018) found *C. marmoratus* ate significantly less food when exposed to the scent of mammalian predators. Furthermore, although *C. marmoratus* is prey for the redback spider (*Latrodectus hasselti*) (O'Shea and Kelly 2017) and geckos are considered easier prey than other reptile groups (Nordberg *et al.* 2018; Valdez 2020) there is little published information on the relationship between *C. marmoratus* and other arachnid species such as large tree huntsman spiders (*Holconia* sp.). Taylor *et al.* (2016) found that the presence of huntsman spiders did not influence the likelihood of *C. marmoratus* detection and concluded that huntsman spiders were most likely a low-risk predator. However, that study was conducted only in the winter. Our results from the warmer months suggest that *H. murrayensis* may prey upon *C. marmoratus* as geckos avoided using ABCs when one or more huntsman spiders were present. During the colder months, *C. marmoratus* was found under ABCs with *H. murrayensis* more often than during the summer (Moore *et al.*, unpublished data), suggesting that both species may co-occur beneath ABCs when their metabolic rates are slower, similar to the results of Taylor *et al.* (2016).

Implications for research and management

This study adds to the paucity of literature on reptile use of artificial bark covers in Australia. Specifically, this study shows that artificial bark covers are an effective method for compiling an inventory of arboreal lizards in a floodplain system and could be used across other dynamic ecosystems to better understand arboreal lizard distribution patterns. ABCs may also be a useful tool in long-term monitoring programs as they are less destructive than traditional active search methods which often require some level of micro-habitat disturbance. However, our results also suggest that more research is essential to determine the optimal number of ABCs required to improve detection rates and fully understand lizard occupancy patterns. Further research using ABCs could explore population demographics, movement patterns and predator–prey interactions to inform the use of artificial cover in ecological research.

Supplementary material

Supplementary material is available online.

References

Adams J, Roby PL, Sewell P, Schwierjohann JH, Gumbert MW, Brandenburg M (2015) Success of Brandenbark™, an artificial roost structure designed for use by Indiana bats (*Myotis sodalis*). *Journal of the American Society of Mining and Reclamation* **4**, 1–15. doi:10.21000/JASMR15010001

Ali W, Javid A, Bhukhari SM, Hussain A, Hussain SM, Rafique H (2018) Comparison of different trapping techniques used in herpetofaunal monitoring: a review. *Punjab University Journal of Zoology* **33**, 57–68. doi:10.17582/pujz/2018.33.1.57.68

Angilletta MJ, Werner YL (1998) Australian geckos do not display diel variation in thermoregulatory behavior. *Copeia* **1998**, 736–742. doi:10.2307/1447806

Atlas of Living Australia (2020) Open access to Australia's biodiversity data. Available at http://www.ala.org.au. [Accessed 14 August 2020]

Bates D (2005) Fitting linear mixed models in R. *R News* **5**(1), 27–30.

Bell TP (2009) A novel technique for monitoring highly cryptic lizard species in forests. *Herpetological Conservation and Biology* **4**, 415–425.

Bennett AF, John-Alder H (1986) Thermal relations of some Australian skinks (Sauria: Scincidae). *Copeia* **1986**, 57–64. doi:10.2307/1444888

Böhm M, Collen B, Baillie JEM, *et al.* (2013) The conservation status of the world's reptiles. *Biological Conservation* **157**, 372–385. doi:10.1016/j.biocon.2012.07.015

Button ST, Bodinof Jachowski CM, Case BF, Groffen J, Hopkins WA (2020) The influence of multiscale habitat variables and population density on artificial shelter use by hellbenders (*Cryptobranchus alleganiensis*). *Herpetologica* **76**(4), 355–365.

Dodd CK (Ed) (2016) 'Reptile Ecology and Conservation: A Handbook of Techniques.' (Oxford University Press: Oxford, UK)

Duckett PE, Morgan MH, Stow AJ (2012) Tree-dwelling populations of the skink *Egernia striolata* aggregate in groups of close kin. *Copeia* **2012**, 130–134. doi:10.1643/CE-10-183

Fiske I, Chandler R (2011) unmarked: an R package for fitting hierarchical models of wildlife occurrence and abundance. *Journal of Statistical Software* **43**, 1–23. doi:10.18637/jss.v043.i10

Garden JG, McAlpine CA, Possingham HP, Jones DN (2007) Using multiple survey methods to detect terrestrial reptiles and mammals: what are the most successful and cost-efficient combinations? *Wildlife Research* **34**, 218–227. doi:10.1071/WR06111

Gibbons JW, Scott DE, Ryan TJ, Buhlmann KA, Tuberville TD, Metts BS, Greene JL, Mills T, Leiden Y, Poppy S, Winne CT (2000) The global decline of reptiles, Déjà vu amphibians: reptile species are declining on a global scale. Six significant threats to reptile populations are habitat loss and degradation, introduced invasive species, environmental pollution, disease, unsustainable use, and global climate change. *BioScience* **50**, 653–666. doi:10.1641/0006-3568(2000)050[0653:TGDORD]2.0.CO;2

Greer AE (2021) 'Encyclopedia of Australian Reptiles.' Version 1 June 2021. (Australian Museum: Sydney, NSW, Australia)

Hall A, Thomas RF, Wassens S (2019) Mapping the maximum inundation extent of lowland intermittent riverine wetland depressions using LiDAR. *Remote Sensing of Environment* **233**, 111376. doi:10.1016/j.rse.2019.111376

Hoare JM, O'Donnell CF, Westbrooke I, Hodapp D, Lettink, M (2009) Optimising the sampling of skinks using artificial retreats based on weather conditions and time of day. *Applied Herpetology* **6**(4), 379. doi:10.1163/157075309X12531848432985

Hodge S, Vink CJ, Banks JC, Bowie MH (2007) The use of tree-mounted artificial shelters to investigate arboreal spider communities in New Zealand nature reserves. *Journal of Arachnology* **35**, 129–136. doi:10.1636/ST-06-19.1

Howard K, Beesley L, Ward K, Stokeld D (2017) Preliminary evidence suggests freshwater turtles respond positively to an environmental water delivery during drought. *Australian Journal of Zoology* **64**, 370–373. doi:10.1071/ZO16076

Kearney M (2001) Postural thermoregulatory behavior in the nocturnal lizards *Christinus marmoratus* and *Nephrurus milii* (Gekkonidae). *Herpetological Review* **32**(1), 11.

Kearney M, Predavec M (2000) Do nocturnal ectotherms thermoregulate? A study of the temperate gecko *Christinus marmoratus*. *Ecology* **81**, 2984–2996. doi:10.1890/0012-9658(2000)081[2984:DNETAS]2.0.CO;2

Kearney M, Shine R, Comber S, Pearson D (2001) Why do geckos group? An analysis of "social" aggregations in two species of Australian lizards. *Herpetologica* **57**, 411–422.

Kery M (2002) Inferring the absence of a species: a case study of snakes. *The Journal of Wildlife Management* **66**, 330–338. doi:10.2307/3803165

Kéry M, Schmidt B (2008) Imperfect detection and its consequences for monitoring for conservation. *Community Ecology* **9**, 207–216. doi:10.1556/ComEc.9.2008.2.10

Kingsford RT (2000) Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. *Austral Ecology* **25**, 109–127. doi:10.1046/j.1442-9993.2000.01036.x

Letten AD, Ke P-J, Fukami T (2017) Linking modern coexistence theory and contemporary niche theory. *Ecological Monographs* **87**, 161–177. doi:10.1002/ecm.1242

MacKenzie DI, Nichols JD, Lachman GB, Droege S, Andrew Royle J, Langtimm CA (2002) Estimating site occupancy rates when detection probabilities are less than one. *Ecology* **83**, 2248–2255. doi:10.1890/0012-9658(2002)083[2248:ESORWD]2.0.CO;2

Michael DR, Lunt ID, Robinson WA (2004) Enhancing fauna habitat in grazed native grasslands and woodlands: use of artificially placed log refuges by fauna. *Wildlife Research* **31**, 65–71. doi:10.1071/WR02106

Michael DR, Lindenmayer DB, Crane M, MacGregor C, Montague-Drake R, McBurney L (2011) Reptilia, Murray catchment, New South Wales, south-eastern Australia. *Check List* **7**, 25–29. doi:10.15560/7.1.25

Michael DR, Cunningham RB, Donnelly CF, Lindenmayer DB (2012) Comparative use of active searches and artificial refuges to survey reptiles in temperate eucalypt woodlands. *Wildlife Research* **39**, 149–162. doi:10.1071/WR11118

Michael DR, Kay GM, Crane M, Florance D, MacGregor C, Okada S, McBurney L, Blair D, Lindenmayer DB (2015) Ecological niche breadth and microhabitat guild structure in temperate Australian reptiles: implications for natural resource management in endangered grassy woodland ecosystems. *Austral Ecology* **40**, 651–660. doi:10.1111/aec.12232

Michael DR, Florance D, Crane M, Blanchard W, Lindenmayer DB (2018) Barking up the right tree: comparative use of arboreal and terrestrial artificial refuges to survey reptiles in temperate eucalypt woodlands. *Wildlife Research* **45**, 185–192. doi:10.1071/WR17117.

Michel AK, Winter S (2009) Tree microhabitat structures as indicators of biodiversity in Douglas-fir forests of different stand ages and management histories in the Pacific Northwest, U.S.A. *Forest Ecology and Management* **257**, 1453–1464. doi:10.1016/j.foreco.2008.11.027

Nichols JD, Williams BK (2006) Monitoring for conservation. *Trends in Ecology & Evolution* **21**, 668–673. doi:10.1016/j.tree.2006.08.007

Nordberg EJ, Schwarzkopf L (2015) Arboreal cover boards: using artificial bark to sample cryptic arboreal lizards. *Herpetologica* **71**, 268–273. doi:10.1655/HERPETOLOGICA-D-15-00016

Nordberg EJ, Schwarzkopf L (2019*a*) Heat seekers: a tropical nocturnal lizard uses behavioral thermoregulation to exploit rare microclimates at night. *Journal of Thermal Biology* **82**, 107–114. doi:10.1016/j.jtherbio.2019.03.018

Nordberg EJ, Schwarzkopf L (2019*b*) Reduced competition may allow generalist species to benefit from habitat homogenization. *Journal of Applied Ecology* **56**(2), 305–318. doi:10.1111/1365-2664.13299

Nordberg EJ, Edwards L, Schwarzkopf L (2018) Terrestrial invertebrates: an underestimated predator guild for small vertebrate groups. *Food Webs* **15**, e00080. doi:10.1016/j.fooweb.2018.e00080

O'Shea M, Kelly K (2017) Predation on a weasel skink (*Saproscincus mustelinus*) (Squamata: Scincidae: Lygosominae) by a redback spider (*Latrodectus hasselti*) (Araneae: Araneomorpha: Theridiidae), with a review of other *Latrodectus* predation events involving squamates. *Herpetofauna* **44**, 49–55.

Ocock JF, Bino G, Wassens S, Spencer J, Thomas RF, Kingsford RT (2018) Identifying critical habitat for Australian freshwater turtles in a large regulated floodplain: implications for environmental water management. *Environmental Management* **61**, 375–389. doi:10.1007/s00267-017-0837-0

Parmar DS (2020) Notes on eggs and hatchlings of the oriental garden lizard, *Calotes versicolor* (Daudin 1802), and the common house gecko, *Hemidactylus frenatus* (Schlegel 1836) in Gujarat, India. *Reptiles & Amphibians* **26**(3), 245–247. doi:10.17161/randa.v26i3

Pereira JJ, Lopes EP, Carretero MÁ, Vasconcelos R (2019) Insular geckos provide experimental evidence on refuge selection priorities by ectotherms. *Behavioural Processes* **164**, 260–267. doi:10.1016/j.beproc.2019.03.008

Petford MA, Alexander GJ (2020) Microhabitat selection and niche partitioning in two syntopic geckos. *Austral Ecology* **45**(3), 319–328. doi:10.1111/aec.12857

Pittock J, Finlayson CM (2011) Australia's Murray–Darling Basin: freshwater ecosystem conservation options in an era of climate change. *Marine and Freshwater Research* **62**, 232–243. doi:10.1071/MF09319

Putra DP, Herwina H, Janra MN (2021) Breeding efforts on wild honey bee *Apis cerana* Fabr. within coconut plantations in Padang Pariaman, west Sumatra. *IOP Conference Series: Earth and Environmental Science* **757**(1), 012024. doi:10.1088/1755-1315/757/1/012024

Price A, Balcombe S, Humphries P, King A, Zampatti B (2020) Murray–Darling Basin environmental water knowledge and research project: fish theme research report. Report prepared for the Department of the Environment and Energy, Commonwealth Environmental Water Office, La Trobe University, Centre for Fresh Water, Victoria. Available at https://ltu-figshare-repo.s3.aarnet.edu.au/ [Accessed July 2020].

Ribeiro-Júnior MA, Gardner TA, Ávila-Pires TCS (2008) Evaluating the effectiveness of herpetofaunal sampling techniques across a gradient of habitat change in a tropical forest landscape. *Journal of Herpetology* **42**, 733–749. doi:10.1670/07-097R3.1

Riedel J, Nordberg E, Schwarzkopf L (2020) Ecological niche and microhabitat use of Australian geckos. *Israel Journal of Ecology and Evolution* **66**(3-4), 209–222. doi:10.1163/22244662-bja10002

Roll U, Feldman A, Novosolov M, *et al.* (2017) The global distribution of tetrapods reveals a need for targeted reptile conservation. *Nature Ecology & Evolution* **1**, 1677–1682. doi:10.1038/s41559-017-0332-2

Schwarz R, Stark G, Antonopolous A, Itescu Y, Pafilis P, Chapple DG, Meiri S (2021) Specialist versus generalist at the intraspecific level: functional morphology and substrate preference of *Mediodactylus kotschyi* geckos. *Integrative and Comparative Biology* **61**(1), 62–75. doi:10.1093/icb/icab066

Sewell D, Guillera-Arroita G, Griffiths RA, Beebee TJC (2012) When is a species declining? Optimizing survey effort to detect population changes in reptiles. *PLoS ONE* **7**, e43387. doi:10.1371/journal.pone.0043387

Shelton MB, Goldingay RL (2021) Comparative survey techniques for a cryptic Australian snake (*Hoplocephalus bitorquatus*). *Australian Journal of Zoology* **68**(2), 68–75. doi:10.1071/ZO20062

Swan M (2020) 'Frogs and Reptiles of the Murray–Darling Basin: a Guide to their Identification, Ecology and Conservation.' (CSIRO Publishing: Melbourne, Vic., Australia)

Taylor D, Daniels CB, Johnston G (2016) Habitat selection by an arboreal lizard in an urban parkland: not just any tree will do. *Urban Ecosystems* **19**(1), 243–255. doi:10.1007/s11252-015-0480-6

Taylor DA, Perry RW, Miller DA, Ford WM (2020) Forest management and bats. White-Nose Syndrome Response Team, Hadley, MA, USA.

Tingley R, Macdonald SL, Mitchell NJ, Woinarski JCZ, Meiri S, Bowles P, Cox NA, Shea GM, Böhm M, Chanson J, Tognelli MF, Harris J, Walke C, Harrison N, Victor S, Woods C, Amey AP, Bamford M, Catt G, Clemann N, Couper PJ, Cogger H, Cowan M, Craig MD, Dickman CR, Doughty P, Ellis R, Fenner A, Ford S, Gaikhorst G, Gillespie GR, Greenlees MJ, Hobson R, Hoskin CJ, How R, Hutchinson MN, Lloyd R, McDonald P, Melville J, Michael DR, Moritz C, Oliver PM, Peterson G, Robertson P, Sanderson C, Somaweera R, Teale R, Valentine L, Vanderduys E, Venz M, Wapstra E, Wilson S, Chapple DG (2019) Geographic and taxonomic patterns of extinction risk in Australian squamates. *Biological Conservation* **238**, 108203. doi:10.1016/j.biocon.2019.108203

Valdez JW (2020) Arthropods as vertebrate predators: a review of global patterns. *Global Ecology and Biogeography* **29**(10), 1691–1703. doi:10.1111/geb.13157

Van Dyke JU, Spencer R-J, Thompson MB, Chessman B, Howard K, Georges A (2019) Conservation implications of turtle declines in Australia's Murray River system. *Scientific Reports* **9**, 1998. doi:10.1038/s41598-019-39096-3

Wassens S, Hall A, Spencer J (2017) The effect of survey method on the detection probabilities of frogs and tadpoles in large wetland complexes. *Marine and Freshwater Research* **68**, 686–696. doi:10.1071/MF15183

Webster C, Massaro M, Michael DR, Bambrick D, Riley JL, Nimmo DG (2018) Native reptiles alter their foraging in the presence of the olfactory cues of invasive mammalian predators. *Royal Society Open Science* **5**, 180136. doi:10.1098/rsos.180136

West PW, Cawsey EM, Stol J, Freudenberger D (2008) Firewood harvest from forests of the Murray–Darling Basin, Australia. Part 1: long-term, sustainable supply available from native forests. *Biomass and Bioenergy* **32**, 1206–1219. doi:10.1016/j.biombioe.2008.02.017

Zuur AF, Ieno EN, Walker N, Saveliev AA, Smith GM (2009) 'Mixed Effects Models and Extensions in Ecology with R.' (Springer: New York, NY, USA)

Data availability. The data that support this study will be shared upon reasonable request to the corresponding author.

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