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RESEARCH ARTICLE

Assessing the benefits of integrated introduced predator management for recovery of native predators

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Increasingly threatened species and their habitats require multiple successful management actions to ensure persistence. Introduced predator exclusion and suppression programs are key conservation actions used to retain or restore Australian ecosystems. Nevertheless, few direct comparisons are made to ascertain the individual and combined efficacy of multiple introduced predator conservation actions to benefit biodiversity. When colocated, both management actions could generate additive conservation benefits that greatly assist the recovery or persistence of threatened native species. Varanid lizards are key functional components in Australian predator guilds and could benefit, via ecological release, when introduced predator management actions are successful. Here we tested the effects of a colocated predator-exclusion fence and lethal fox baiting on varanid site occupancy in a semiarid protected area. Varanid site occupancy was higher at sites inside ($\Psi = 0.90 \pm 0.26$) compared to sites outside ($\Psi = 0.61 \pm 0.28$) the introduced predator-proof fenced enclosure. There was only weak evidence of increased varanid site occupancy at fox baited sites ($\Psi = 0.037 \pm 0.024$) compared to nonfox baited ($\Psi = 0.00$) sites. Overall, colocated introduced predator management actions achieved some additive benefits via possible spillover fencing effects for native mesopredator populations. However, most potential benefits to varanid populations outside of the predator-proof fenced enclosure were absent due to unsuccessful lethal-baiting effects on fox populations. The predator-proof fenced enclosure nevertheless provides important habitat refugia for future source populations for reintroduction once adjacent protected areas become suitable.

Key words: additive conservation benefits, biodiversity impact, fox baiting, introduced carnivores, multiple management actions, predator exclusion fence

Implications for Practice

- Colocated introduced predator-proof fenced enclosures and landscape-scale predator baiting actions could provide additive benefits to Australian terrestrial ecosystems.
- Native predator populations increased in introduced predator-proof fenced enclosures, producing marginal spillover benefits into an adjacent protected area.
- On its own, landscape-scale fox baiting outside of the fenced enclosure did not provide similar benefits for native predator populations.
- Nevertheless, when introduced predator baiting is ineffective, fenced enclosures will serve as refugia for key species adjacent to the protected area.

Introduction

Australia has undergone well-documented continental-scale biodiversity impacts due to the 19th-century introductions of the European red fox (*Vulpes vulpes*) and the feral cat (*Felis catus*) (Glen & Dickman 2008; Saunders et al. 2010; Woinarski et al. 2019). For several decades, two management strategies—broad-scale poison-baiting programs and predator exclusion fences—have been prioritized to suppress, exclude, or alter the composition and density of introduced predator populations across Australia (Kinnear et al. 2002; Hayward & Somers 2012; Legge et al. 2018). Because of different costs, these management actions vary considerably in their scale and frequency of use. Poison-baiting programs, being more cost-effective, are commonly used at large spatial scales and for open populations (e.g. Western Shield (37,000 km^2) and Southern Ark fox-baiting programs (2,500 km^2) (Gentle et al. 2007; Saunders et al. 2010; Hradsky et al. 2019). Instead, predator-proof fences (i.e. fenced enclosures) are more expensive, so they operate at a considerably smaller scale (<125 km^2) and remain more selective in use (De Tores & Marlow 2012; Dickman 2012; Legge et al. 2018).

Fox baiting and predator-exclusion fencing have produced biodiversity benefits for multiple threatened species, particularly endangered native mammal populations (De Tores & Marlow 2012; Dickman 2012; Legge et al. 2018). More broadly, they

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have had additional benefits for nonthreatened native biodiversity and helped restore ecological processes (Dexter & Murray 2009; Claridge et al. 2010; Stokeld et al. 2018). However, both management actions can fail or produce other unintended or negative consequences (Hayward & Kerley 2009; Doherty & Ritchie 2017; Agarwal & Bode 2019). Nevertheless, without such introduced predator management actions, it is thought that Australia would have witnessed additional extinctions, range and population decline, and greater loss of animal-mediated ecological function (e.g. bioturbation by digging mammals) (De Tores & Marlow 2012; Fleming et al. 2014).

Notwithstanding the large differences in cost and spatial scales at which these two predator management actions operate, it is generally assumed that predator exclusion fencing delivers larger biodiversity benefits than fox baiting (Bode & Wintle 2010; De Tores & Marlow 2012). This result arises because fencing can eradicate or more substantially reduce fox and cat densities, albeit at often much smaller spatial scales, than that achieved by landscape-scale baiting of open fox populations. However, there remains a relatively poor understanding of how colocation and, thus, the integration of both predator exclusion and fox suppression management actions could provide additive biodiversity benefits (Fig. 1). For example, predator exclusion fences limited by their localized biodiversity benefits could improve broader landscape gains from fox-baiting programs if they produced spillover effects (Agarwal & Bode 2019; Moseby et al. 2020). Here, species may disperse out of fenced areas to augment the local abundance of their adjacent wild populations exposed to varying degrees of landscape-scale introduced predator management (Agarwal & Bode 2019).

More broadly, if adjacent fox-baiting programs also provide successful fox control, it would allow introduced predator-proof fenced enclosures to act as source populations of locally threatened or extirpated species for population augmentation or rewilding purposes (Fernández et al. 2017; Perino et al. 2019). This approach could alleviate the common economic and population recovery concerns faced by captive breeding programs or conservation translocations, which often use nonlocally adapted individuals (Slade et al. 2014; Berger-Tal et al. 2020; Jolly & Phillips 2020). Also, introducing individuals from adjacent predator and nonpredator managed areas (i.e. areas of higher introduced predator predation risk) could prevent potentially rapid loss of antipredator traits (Jolly & Phillips 2020). The successful integration of multiple predator management actions could potentially allow for faster restoration of biodiversity at larger spatial scales than that achieved by one action alone. However, if one or both management actions are ineffective, then opportunities for additive conservation benefits would lessen. In such instances, using alternative and stopping ineffective management strategies would be needed to benefit biodiversity or waste conservation resources (McCarthy et al. 2010).

Our study's objective was to compare the effects of colocated predator exclusion fencing and landscape-scale fox-baiting suppression on varanid lizards' site occupancy in a semiarid protected area. Across many of Australia's terrestrial ecosystems, varanid lizards comprise a speciose group of large lizards that have multi-trophic predatory roles (Sutherland et al. 2011) and perform other ecosystem processes, including bioturbation and secondary energy production (Doody et al. 2015; Feit et al. 2020; Jessop et al. 2020). Previous research has indicated that populations of different varanid lizard species can benefit from either introduced predator exclusion or fox suppression programs (Anson et al. 2014; Read & Scoleri 2015; Hu et al. 2019). Thus, in the study area, we would expect varanid lizard site occupancy to increase in line with the effectiveness of each management action to reduce cat or fox densities (Sutherland et al. 2011; Anson et al. 2013; Binny et al. 2020). If so, varanid lizard site occupancy should be highest in the introduced predator exclusion fence (i.e. lowest cats or fox densities); then in fox-baited habitats (i.e. reduced fox densities) and lowest in nonfox-baited habitats where foxes and cats are at higher densities. Such outcomes are important to demonstrate the effectiveness of individual introduced predator management actions and evaluate additive conservation management actions to expedite the recovery and persistence of native biodiversity.

Methods

Study Area

This study was conducted in the Little Desert National Park, the Little Desert Nature Lodge, and some adjacent pastoral properties in Western Victoria. Little Desert National Park (LDNP; 132,000 ha; Fig. S1) is the largest contiguous protected area in the Wimmera region, starting at the South Australian border in the west and running to the Wimmera River at Dimboola in the east (Thorpe 2020). The park comprises three distinctive sections known as the eastern, central, and western blocks, which are surrounded by an agricultural matrix creating a now long-isolated habitat fragment (Clemann et al. 2005). The park contains distinct vegetation communities, including open heath, heathy woodland, woodland, cleared areas, and areas where revegetation was done to restore lost ecological functions. The Little Desert has a semiarid climate, with an average annual rainfall of 406 mm in the east to 518 mm in the west (Bureau of Meteorology 2020). The mean maximum temperature is 29.8°C in January and 13.4°C in July (Bureau of Meteorology 2020). The topography is generally low-lying between 0 and 100 m above sea level, interspersed with dunes and swales with prominent sandstone ridges reaching 220 m (Thorpe 2020).

The Little Desert Nature Lodge is a private reserve located within a fully fenced exclosure that seeks to exclude introduced predators to benefit native species. This reserve abuts the north-western corner of the eastern block in the Little Desert National Park. The reserve maintains a 2.5-m-high electrified wire mesh fence (with a floppy top) that runs the 5.3 km perimeter of the reserve to provide an introduced predator-free fenced enclosure with an area of 1.17 km^2. The reserve contains similar vegetation communities to the adjoining Little Desert National Park.

Fox-Baiting Protocols

The Little Desert National Park has a widespread and abundant fox and cat population subject to regular lethal control in parts of

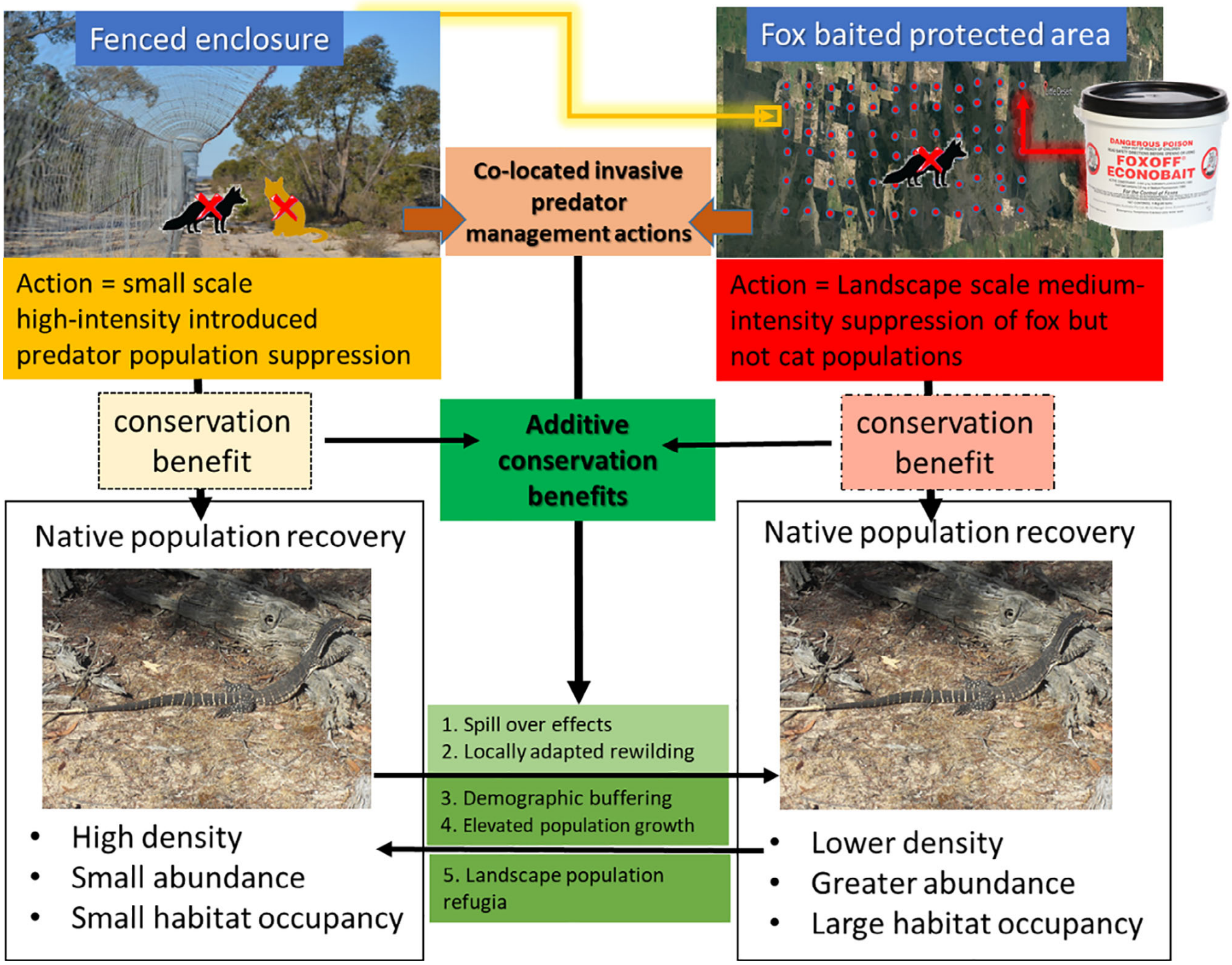

Figure 1. Introduced predator exclusion fencing and lethal fox baiting are key management actions aimed to reduce the ecological impacts of introduced vertebrate predators on Australia's biodiversity. These actions can produce method-specific native species population recovery results. However, if these management actions are colocated, they could promote additive conservation benefits to native biodiversity. Examples of additive conservation benefits from colocated predator management actions include spillover effects from the predator exclusion area into adjacent landscapes. Similarly, colocated predator-proof fenced enclosures could serve as refugia or population sources for native species reintroduction into adjacent protected areas.

the park (Thorpe 2020). Dingoes are largely absent, effectively making the introduced red fox the apex predator in this region and cats a mesopredator alongside varanid lizards. In 2010 a fox-baiting program was commenced in the Little Desert National Park. Initially, 1,080 baits (Foxoff) were deployed at approximately 300 bait stations spaced at 1.5 km intervals in the park's eastern and central blocks. Baiting was conducted over three 9-week periods per year. Baits were buried to 15 cm to reduce nontarget species' take, and bait replacement occurred fortnightly (Robley et al. 2008). In September 2019, Parks Victoria intensified the baiting effort in the eastern block to comprise 179 bait stations positioned 750 m apart (Thorpe 2020). Baits were checked and replaced every 4 weeks in this new schedule.

Study Species

We studied the three species of widely distributed varanid lizards known to occur in the study area (*Varanus varius*, *V. rosenbergi*, and *V. gouldii*), all of which reach considerable lengths (1.2–2.1 m) (Clemann et al. 2005; Jessop et al. 2012; Smissen et al. 2013). The three species have a generalist diet, where typical prey items include small mammals, birds, lizards, snakes, and carrion (Losos & Greene 1988; Sutherland 2011; McCurry et al. 2015). These species are presumed to differentiate niche space through diet and microhabitat use, but otherwise they are likely to co-occur throughout the study area and thus be detected under general monitoring protocols as described below (De Tores et al. 2011; Sutherland 2011).

Testing the Effects of Wildlife Fencing on Varanid Species Site Occupancy

We determined the effects of wildlife fencing by comparing the site occupancy of varanid lizards detected at 22 sites established across the Little Desert Nature Lodge and adjacent areas of the Little Desert National Park and private pastoral land (Fig. S3). These sites were located on average 0.5 km apart, with 10 sites located inside the fenced enclosure and 12 sites located outside of it. In November of 2018 and 2019, we conducted two repeated 6-day surveys to detect varanid lizards. At each site, we concurrently used two different camera-based detection methods to photograph varanid lizards. At each site, we used the following two camera detection deployment protocols:

(1) Baited camera: A single-camera (Reconyx HyperFire 2 or ScoutGuard 560K) was placed within each site fixed at 1.2 m height above the ground. Directly below each downward-facing camera, a scent lure (20 cm polyvinyl chloride tube sealed with perforated caps) was secured to the ground. We placed an attractant comprising corrugated cardboard saturated with peanut and tuna emulsion oil within each scent lure.
(2) Unbaited camera: A single-camera (Reconyx HyperFire 2 or ScoutGuard 560K) was placed within each site facing outwards at 1.2 m height without a scent lure.

This dual-method sampling design (which preceded our fox-baiting surveys) was also used to confirm that each camera deployment protocol could successfully capture images of varanid lizards (Ariefiandy et al. 2014).

Effects of Landscape-Scale Fox-Baiting Protocols on Varanid Species Site Occupancy

To assess the effect of fox baiting on varanid occupancy, we deployed a total of 125 camera monitoring stations (CMS) over three sampling surveys. The survey design was modified across each survey to remedy deployment problems (i.e. camera theft) and improve varanid lizard detection. The survey details were as follows:

Survey 1: In the autumn/winter of 2019, 64 CMS were deployed for between 35 and 61 days. This survey used 33 cameras in the baited eastern block and 31 in the unbaited western block (Fig. S4). All cameras were spaced at intervals of 3–6 km to ensure large scale coverage of the park. Cameras were placed within security boxes attached to metal poles 90–100 cm high and concreted in the ground along with the track network to reduce theft. Positioning cameras along tracks can increase predators' detectability (Hradsky et al. 2017; Geyle et al. 2020; Wysong et al. 2020). Regrettably, on retrieving our cameras, we found that 20 units were stolen, with almost all taken from the unbaited western block.

Survey 2: In the spring/summer of 2019, we deployed 31 CMS for 35–61 days/camera into the study area's eastern block (Fig. S4). No cameras were placed in the unbaited western block due to the theft above. Again, cameras did not use bait lures and were spaced at intervals of 3–6 km to ensure large scale coverage of the national park's fox-baited eastern block.

Survey 3: In the summer/autumn of 2020, 30 CMS were all deployed for 52 days. This survey used 15 cameras in the fox-baited eastern block and 15 in the unbaited western block (Fig. S5). We modified this survey in three ways to account for theft and attempt to improve the low number of varanid detections reported in the prior surveys. First, we deployed all cameras to be off-track to make them inconspicuous and reduce theft. Second, we baited all cameras with a scent lure placed 2 m directly in front of each camera to improve varanid lizard detection. Elsewhere bait lures have been shown to dramatically improve varanid lizard detection on camera traps (Ariefiandy et al. 2013). Third, we reduced the inter-site distance to 1–2 km to concentrate cameras to the core of both baiting and non-baiting areas to survey areas.

Common to all surveys, we used passive motion-sensing cameras (Reconyx Hyperfire 2 or ScoutGuard 560K cameras) that were set to take three consecutive images with a 2-minute time delay between triggers to avoid repeated capturing of the same individual animal (Thorpe 2020). Detections of the same varanid lizard species on the same cameras were deemed independent if they were greater than 30 minutes apart. The camera locations spanned a range of fire histories (0–60+ years post-fire) and vegetation types (mallee-broombush, open woodland, heath, and shrubby woodland) representative of the semiarid mallee ecosystem within the study area.

Detection and Occupancy Modeling. We modeled detectability and occupancy of varanid lizards with either a multi-season or single-season occupancy model using the software Presence (https://www.mbr-pwrc.usgs.gov/software/presence.html). Site occupancy models use patterns of detection and non-detection over multiple surveys (sampling occasions) of a sampling unit (CMS) to estimate detection probabilities (p) and thus produce unbiased estimates of occupancy (ψ) (MacKenzie et al. 2002). We first modeled the effects of four different survey methods on the probability of detection $p(.)$, while keeping $\psi(.)$ constant. We next tested models that considered the effect of fencing and fox baiting on differences in varanid lizard ψ. All models were ranked using AIC, and our model set included a null model (Burnham & Anderson 2004). For inference, we considered any model within ΔAICc <2 of the best-performing model to exhibit strong support for its covariates' effects to influence varanid lizard detection or occupancy. We ran a goodness-of-fit test on the most parameter rich model using 1,000 bootstraps to assess model fit and to demonstrate that our data was not over-dispersed (i.e. $\hat{c}$ >1) (Mackenzie & Bailey 2004).

Results

Effects of Introduced Predator Exclusion Fencing on Varanid Lizard Site Occupancy

We recorded 21 varanid lizard detections from the two different camera monitoring methods deployed over two repeated 6-day surveys at 22 sites within and adjacent to the Little Desert Nature

Table 1. Ranking of occupancy models testing the effects of different survey methods (A), introduced predator exclusion fencing (A) and fox baiting (B) on varanid lizard site occupancy (ψ). AIC, Akaike information criterion; ΔAIC, the difference in value between AIC of this model and the most parsimonious model; and AIC weights (w_i); *K*, the number of estimated parameters; and logLik, log-likelihood. Models in bold fonts are considered to demonstrate strong model support (i.e. ΔAIC <2).

Models	*AIC*	*ΔAIC*	w_i	K	*logLik*
A) Predator exclusion effect on varanid site occupancy					
ψ(fence) θ(.) *p*(survey methods)	**230.58**	**0**	**0.65**	**7**	**216.58**
ψ(.) θ(.) p(survey methods)	**231.16**	**0.78**	**0.35**	**6**	**219.16**
ψ(.) θ(.) *p*(.)	256.66	26.08	0.00	3	219.16
B) Fox-baiting effect on varanid site occupancy					
ψ(fox baiting) *p*(.)	**49.95**	**0**	**0.51**	**3**	**43.95**
ψ(.) *p*(.)	**50.07**	**0.12**	**0.49**	**2**	**46.07**

Lodge predator-proof fenced enclosure. Images were obtained from three species of varanid lizard and comprised the *Varanus varius* ($n = 4$ detections), *V. rosenbergi* ($n = 4$ detections), and *V. gouldii* ($n = 8$ detections). Due to poor camera image quality (e.g. partial body shots), we could not identify to species another five varanid lizard images.

Model ranking indicated that the introduced predator-proof exclusion fence had the most influence on varanid lizard site occupancy (Table 1A). Varanid lizard occupancy was higher at sites located inside ($\Psi = 0.90 \pm 0.26$; 16 detections) the fenced enclosure compared with sites outside ($\Psi = 0.61 \pm 0.28$; 5 detections) it (Fig. 2A). The predator exclusion effect was moderate and significant (untransformed $\beta = 0.73 \pm 0.31$–1.00 [95% confidence interval (CI)]).

Effects of Fox Baiting on Varanid Lizard Site Occupancy

We recorded three independent varanid lizard detections from a total survey effort of 6,557 camera trap days (2 × *V. gouldii* and one varanid lizard of unidentified species) in Little Desert National Park. These varanid lizards were recorded at fox-baited sites in the second ($n = 2$) and third ($n = 1$) surveys. Model ranking indicated that the fox baiting most influenced varanid lizard site occupancy in Little Desert National Park (Table 1A). However, this fox-baiting effect was very small and associated with high uncertainty (untransformed $\beta = 0.22 \pm 0.004$–0.999 [95% CI]). Furthermore, this model's fit was almost indistinguishable from the null model (ΔAIC = 0.12; $w_i = 0.49$). Varanid lizard site occupancy was estimated to be extremely low ($\Psi = 0.037 \pm 0.024$, 3 detections at 79 baited sites) across fox-baited sites and unmeasurable due to the absence of varanid lizard detections in nonbaited control sites ($\Psi = 0.00$, 0 detections at 27 nonbaited control sites; Fig. 2B).

Discussion

Conserving terrestrial biodiversity increasingly relies on integrating management actions to control multiple threatening processes (Gaston et al. 2008; Schulze et al. 2018), which may also interact (Doherty et al. 2015; Geary et al. 2019). For example, protected areas, recognized as the cornerstone of global conservation actions, often use complementary actions to attenuate or eliminate one or more threatening processes (Watson et al. 2014; Kearney et al. 2018). Although multiple actions can co-occur, they often have different chronologies of implementation and vary in technical and logistical capacities to affect environmental outcomes. Furthermore, with inherent response differences among species or ecological communities, it can be difficult to ascertain the individual and additive values of different management actions for conserving biodiversity (Joppa et al. 2016; Binny et al. 2020). Our study indicated that while two colocated introduced predator management actions varied in their respective benefits, they might also provide additive benefits to varanid lizard populations.

Introduced Predator Fencing Benefits for Varanid Lizard Populations

Because varanid lizards, as common native predators across Australia, are predated upon and compete with introduced predators, they are expected to benefit in landscapes where fox and cat populations have been successfully excluded or sufficiently suppressed (Anson et al. 2014; Read & Scoleri 2015; Stokeld et al. 2018). Our study indicated that introduced predator exclusion fencing was far more effective in increasing varanid lizard site-occupancy than was an adjacent fox-baiting program. This result supports evidence that introduced predator exclusion fences are generally the most effective means to elicit population-level responses in many native Australian vertebrates (Legge et al. 2018; Moseby et al. 2020). We recognize that the strength of the predator exclusion fence effect was associated with some degree of uncertainty, reflecting the moderate number of detections collected over the short duration of sampling for this study component. Nevertheless, this result confirms that when introduced predator populations are substantially reduced, native mesopredators can experience ecological release (Ritchie & Johnson 2009; Read & Scoleri 2015; Hu et al. 2019). In semiarid regions, varanid lizards can be reasonably common in the diets for fox and cat (Catling 1988; Woinarski et al. 2018), indicating a potential basis for increased mortality and lower recruitment that would impact varanid lizard populations when sympatric with unmanaged introduced predator populations. Furthermore, introduced predators can elicit indirect and phenotypic effects related to competition that

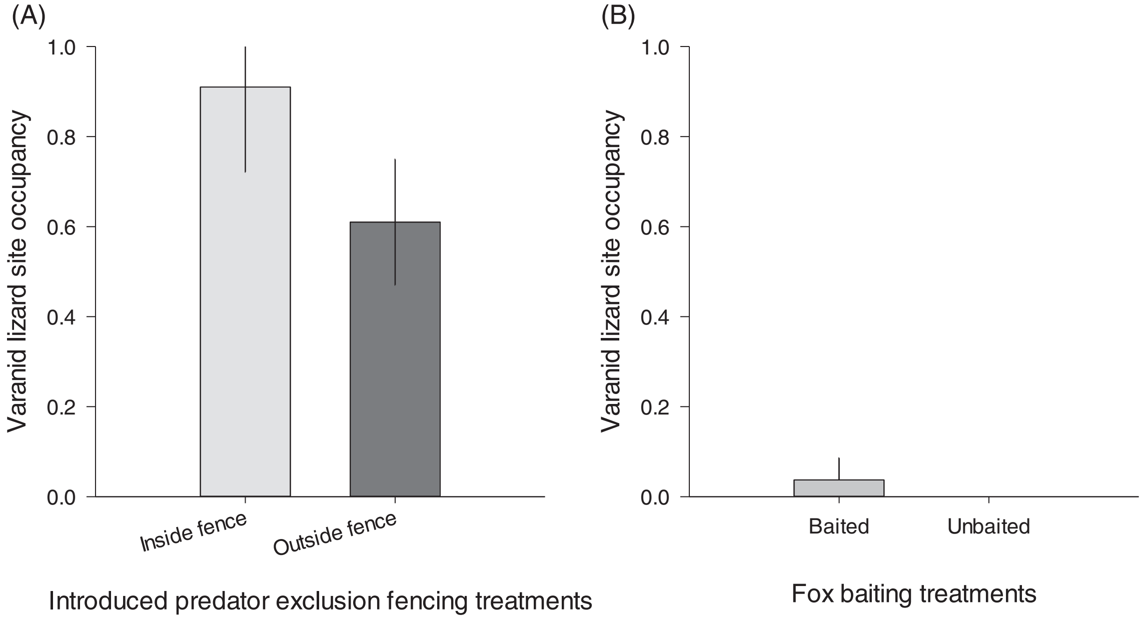

Figure 2. The effects of introduced predator management actions arising from the use of an introduced predator-proof fenced enclosure (A) and a lethal fox-baiting program (B) on the site-occupancy of varanid lizards in the study area. Bars report the mean site occupancy estimate and the error bars are ±SE.

can further impact varanid lizard populations (Anson et al. 2013; Jessop et al. 2015). Thus, exclusion of introduced predators is likely to explain why varanid lizard site occupancy was significantly higher at sites inside than sites outside the fenced enclosure (Anson et al. 2014; Jessop et al. 2015; Read & Scoleri 2015).

Fox-Baiting Benefits for Varanid Lizard Populations

In contrast, fox baiting appeared to produce a very small positive effect on varanid lizard site occupancy across Little Desert National Park. We are extremely cautious in our interpretation of this positive fox-baiting effect for multiple reasons. First, given that the null model received similar model support, any differences in varanid lizard site occupancy may have arisen by chance. Second, the estimated site occupancy of varanid lizards detected in fox-baited sites was approximately 25 times lower than that estimated for sites within the introduced predator-proof fenced enclosure. More concerning was that we could not detect varanid lizards at any nonfox-baited site inside the national park. We thus interpret this result to indicate that varanid lizard species persist at extremely low densities or are indeed absent from significant areas of habitat within the Little Desert National Park.

We also rule out that this fox-baiting result is an artifact of our monitoring design for multiple reasons. First, our camera-based methods detected varanid lizards at sites within and adjacent to the predator-proof fenced enclosure despite much less survey effort. Second, our combined and repeated sampling efforts far exceeded other studies that have used similar methods and reported much higher site occupancy and detection estimates of varanid lizards (Ariefiandy et al. 2013; Jessop et al. 2013; Hu et al. 2019). Third, as ectotherms, varanid lizards can demonstrate densities that are orders of magnitude above those of similar-sized mammalian predators (Phillips 1995; Jessop et al. 2007; Laver et al. 2012). Thus, varanid lizards are expected to be relatively common in those ecosystems where threatening processes are absent or significantly reduced (Doody et al. 2009; Purwandana et al. 2014; Purwandana et al. 2015).

Assessment of Additive Conservation Benefits

We envisaged that if both predator management actions were successful, they could lead to additive conservation benefits for varanid lizard populations within the Little Desert National Park. The first and smaller of these additive benefits would be the potential for a halo or spillover effect where varanid lizards would persist at higher densities in habitats immediately outside of the fenced area (Glen et al. 2013; Russell et al. 2015; Moseby et al. 2020). This prediction was supported because the varanid lizard site occupancy immediately outside the fence, although lower than at sites inside the fenced enclosure, was much higher than at more distal baited and unbaited sites in the national park. At present, we do not understand the mechanism by which this potential spillover effect occurred. However, it is plausible that varanid lizards can climb over or dig under, or that small juveniles pass through, the predator-proof fence in sufficient numbers to elevate local site occupancy in habitats immediately adjacent to the fenced enclosure.

The second and larger additive conservation benefit, contingent on the joint success of both predator management actions, would be the potential for varanid lizards within the predator exclusion fence to act as a source population of locally adapted individuals. These animals could be released to augment the recovery of varanid lizard populations in fox-baited landscapes. However, given the limited effectiveness of fox baiting to increasing varanid lizard populations in the Little Desert National Park, any opportunity for additive introduced predator management benefits is currently untenable. Importantly, we suspect that historically depleted varanid lizard populations have had limited opportunity to recover in the short time since fox baiting began. Also, reserve design issues (e.g. fragmentation) and natural disturbance regimes (e.g. drought and fire) may hinder recovery. Furthermore, the fox-baiting efficacy appears ineffective because of the high ongoing fox site occupancy reported in baited areas of Little Desert National Park (Thorpe 2020). This result confirms that even intensive lethal-baiting programs may not always sufficiently suppress fox populations to low-density levels (Hradsky et al. 2019). Indeed, it may now seem prudent to translocate the low density of varanid lizards present in the national park into the fenced enclosure to prevent any possibility of local extirpation and loss of local genetic diversity in varanid populations. Such an action, if deemed necessary by management authorities, would again emphasize how additive conservation benefit of colocated introduced predator management actions arise, as when fox baiting is ineffective, fenced enclosures will serve as refugia for species that are otherwise unlikely to be able to persist in introduced predator-dominated landscapes (Legge et al. 2018).

There is good evidence that Australian animals can demonstrate variable benefits from management actions that seek to reduce the ecological impacts of introduced foxes and cats (Dickman 1996; De Tores & Marlow 2012; Legge et al. 2018). Similarly, varanid lizard populations can suffer minor to severe impacts from the effects of different introduced species across Australia (Griffiths & McKay 2007; Claridge et al. 2010; Hu et al. 2019). We demonstrated that introduced predator management actions had different benefits for varanid populations, with varanid populations increased within an introduced predator-proof fenced enclosure but not in adjacent landscapes with lethal fox baiting. Ideally, the colocation of multiple predator management actions could allow for additive conservation benefits for native biodiversity within protected areas. We acknowledge that in a near absence of any fox-baiting effect on varanid populations, our capacity to test for additive conservation benefits of coupled introduced predator management actions was limited. Nevertheless, our proposed framework is heuristically valuable, and we encourage studies elsewhere to demonstrate the holistic management values that could be realized from integrative predator suppression or elimination actions (Glen et al. 2013).

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Supporting Information

The following information may be found in the online version of this article:

Figure S1. Map of study region encompassing Little Desert National Park, Victoria, Australia and surrounding land-use.

Figure S2. Location of bait stations (solid black dots) in the eastern and central blocks of the Little Desert National Park, Victoria, Australia 2019.

Figure S3. Map of the camera site monitoring locations (dots) used for evaluating effects on introduced predator exclusion.

Figure S4. Map of eastern (top) and western (bottom) block camera site monitoring locations (dots) used for evaluating fox-baiting effects on varanid lizards in surveys 1 and 2.

Figure S5. Map of eastern (top) and western (bottom) block camera site monitoring locations (dots) used for evaluating fox-baiting effects on varanid lizards in survey 3.

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