Population density estimates of brushtail possums (*Trichosurus vulpecula*) in dry grassland in New Zealand

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Abstract: The introduced brushtail possum (*Trichosurus vulpecula*) is the most important wildlife host of bovine tuberculosis in New Zealand and is considered to be a major environmental and agricultural pest. Dry grassland ecosystems in New Zealand include some of the least protected and most threatened native biota. Drylands cover 19% of the country, but there is little published information on the population density of invasive brushtail possums in these environments, and previous estimates are not based on quantitative methods. We surveyed possum density in two open dry grassland habitats on hilly slopes in the southern South Island. One site had higher shrub and rock cover than the other. We used a spatially explicit capture–mark–recapture method to estimate possum density. Possum densities were slightly higher at the more shrubby and rocky site; estimates (±SE) from capture–mark–recapture using maximum likelihood were 0.69 (±0.05) per hectare, compared with 0.44 (±0.03) per hectare in the less shrubby and rocky site. Density estimates were similar to those recorded in radiata pine (*Pinus radiata*) and beech (*Nothofagus* spp.) forests in New Zealand, but were 5- to 29-fold lower than those in podocarp–broadleaved forest. Maximum likelihood home range estimates derived from spatial trap data were larger in the less shrubby and rocky site (54.07 ha cf. 36.19 ha). These home ranges are much larger than those recorded in native forest, and probably reflect the lower abundance and more patchy distribution of food resources and shelter in dryland environments. The ecological information provided here is useful for wildlife managers planning to target possum control in dryland environments.

Keywords: capture–mark–recapture; drylands; pest species; spatially explicit capture–recapture method; trap-catch index

Introduction

The common brushtail possum (*Trichosurus vulpecula*) is a nocturnal phalangerid marsupial (approximately 2–4 kg). It is an introduced pest in New Zealand, where it damages native forests and wildlife (Cowan & Moeed 1987; Payton 2000; Innes et al. 2004) and acts as the main wildlife vector for bovine tuberculosis (Morris & Pfeiffer 1995; O'Neil & Pharo 1995; Coleman & Caley 2000). The biology, impacts and management of possum populations have been widely studied in New Zealand in many different habitat types (Montague 2000), but rarely in dry grassland/shrubland ecosystems typical of the eastern South Island (although see Glen et al. 2012). Possum density is probably the single most important predictor of the degree of impact on other biota and on livestock disease (Efford 2000). Foliage consumption, nest predation, and disease transmission are greater in absolute terms with increasing possum densities (Efford 2000). An understanding of patterns of possum density, and the processes controlling these, is therefore fundamental for managing possum impacts (Efford 2000).

Despite the fact that 19% of New Zealand's land mass is dryland habitat (Rogers et al. 2005) (Fig. 1), no information has been published on the population density of possums in these environments using quantitative methods that provide a precise and accurate estimate of abundance (e.g. distance or capture–mark–recapture sampling). Given the low rainfall and extreme variation in seasonal temperatures, possum densities in dryland habitats ma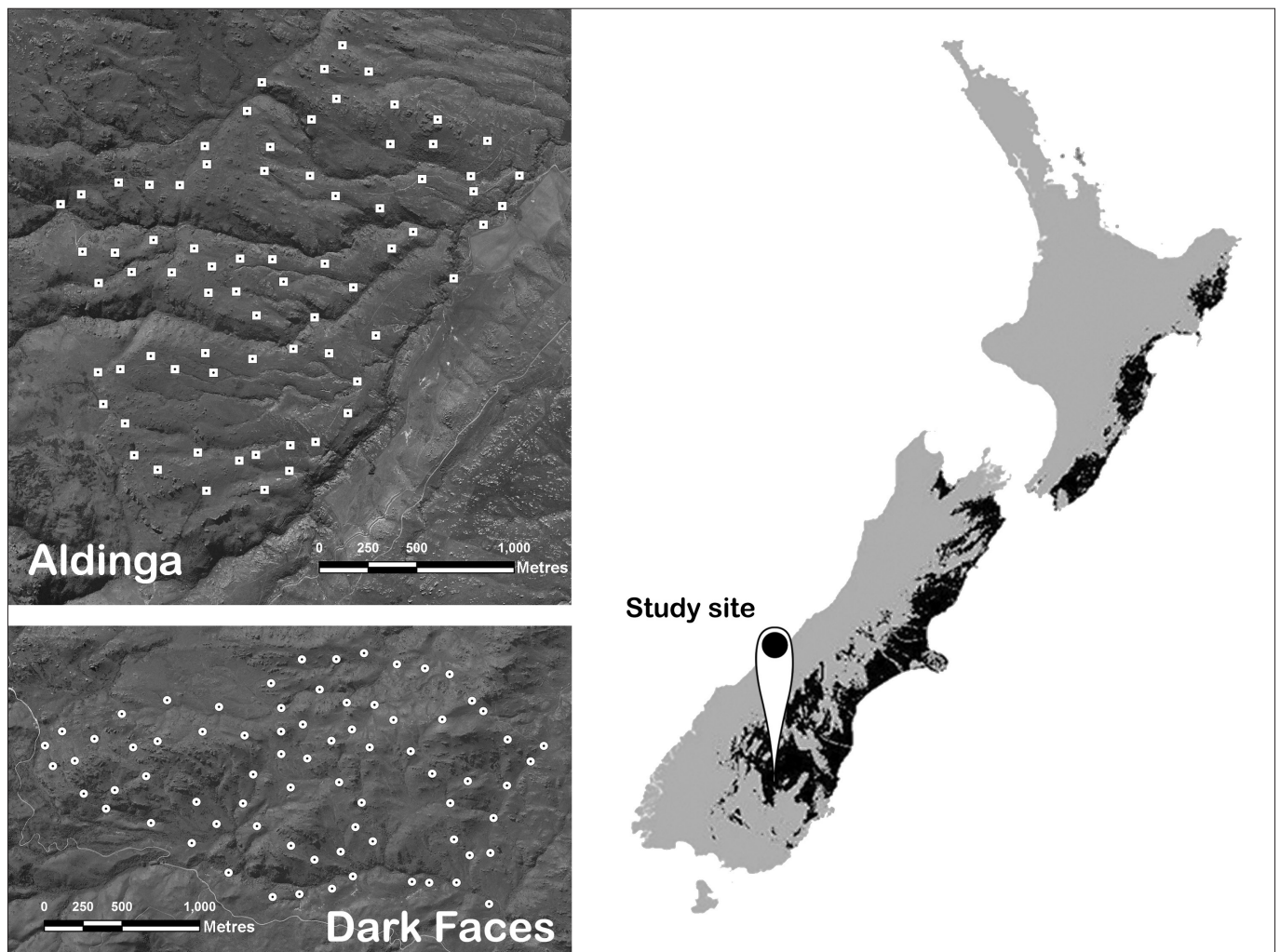y differ substantially from those in other environments. New Zealand's dryland ecosystems are located in the rain-shadow area east of the main mountain ranges. Drylands in the South Island consist of grassland and shrubland, often with exotic pasture species (Rogers et al. 2005). These ecosystems have undergone high degrees of modification and land-use change, mainly from the combined effects of burning, pastoral use, and grazing by feral mammals over the last 150 years (Walker 2000; Walker et al. 2008). Moreover, they include some of the most threatened native ecosystems and species (Walker et al. 1995; Reardon et al. 2012), and are poorly represented in protected reserves. They are therefore the subject of increasing conservation attention and research (Walker et al. 2008).

We hypothesise that possum densities are generally lower in dryland habitats than in more mesic environments because of the lower abundance of food or shelter, and more extreme climatic conditions. Our aim was to provide the first density estimate, based on a spatially explicit capture–recapture method, of possums in dryland ecosystems, in particular on hillslope, open, dry grassland in the southern South Island of New Zealand. We carried out density surveys using spatially explicit capture–recapture data gathered by live capture of possums. This allowed us to compare population density estimates with those from other studies in different habitat types.

Materials and methods

Study sites

The study was undertaken in March 2010 at two sites in

Figure 1. Black shading shows extent of dryland habitats in New Zealand (after Rogers et al. 2005). Location of live-capture traps in the two study sites (Aldinga and Dark Faces) are indicated by white symbols.

Central Otago, southern South Island (45°17′S, 169°17′E) – Aldinga Conservation Area (managed by the New Zealand Department of Conservation) and Dark Faces (part of the Earnscleugh Station leasehold grazing property) (Fig. 1). The area is surrounded by mountainous terrain (altitude 300–1600 m a.s.l.) and has a continental climate of extreme temperature fluctuations between summer, when temperatures can exceed 30°C, and winter, when snow is not uncommon and temperature often drops below 0°C. Both sites consist of highly modified semi-arid grassland/shrubland habitat at a mean elevation of 370 m a.s.l. The sites were c. 400 ha and approximately 5 km apart to ensure independence (on the basis of previously published home range movements of possums in dryland habitat; Glen et al. 2012). Both sites contained three major habitat types (rocky outcrops, open grass, dense shrub) representative of typical dry grassland/shrubland ecosystems across the southern South Island. Shrub vegetation varied from scattered clumps to dense thickets of exotic sweet briar (*Rosa rubiginosa*), as well as native matagouri (*Discaria toumatou*) and mingimingi (*Coprosma propinqua*). Pasture species included introduced sweet vernal (*Anthoxanthum odoratum*), brown top (*Agrostis capillaris*), and hare's foot trefoil (*Trifolium arvense*). Neither possum population had

ever been subject to control.

Quantifying cover of vegetation and topographic features

The proportions of rock, grass, and shrub habitat were estimated using the Digital Sampling Method software, version 1.00 (Landcare Research, New Zealand) and February 2007 imagery from Google Earth. This software has been used by others (e.g. Paynter et al. 2006) to estimate proportion of foliage cover. Sample images (6-ha; $n = 20$) from each site were randomly selected using the digital sampling software. The scale of these images allowed individual shrubs to be identified. One hundred random sample points were superimposed on each image and each point was visually assigned to a habitat class. Two observers independently estimated the proportion of the different types of habitat from images, and no differences were found in the proportions of habitat type estimated between observers. The average proportion and 95% confidence intervals (CI) ($1.96 \times s/\sqrt{n}$, where **s** is standard deviation and ***n*** is sample size) of each habitat type were calculated for each site.

Live-trapping of possums

Live-capture traps ($n = 74$) were placed at 200-m intervals along tracks and ridges at each site. The minimum convex polygon areas enclosing the traps were 331 ha for Aldinga and

355 ha for Dark Faces. We used Grieve wire cage traps (60 × 26 × 28 cm) with a spring-assisted folding door triggered by a pendulum hook (Montague & Warburton 2000). Traps were set on the ground, baited each evening with apple sprinkled with powdered sugar and flour lured with cinnamon oil, and checked every day. We carried out trapping sessions for 12 consecutive nights respectively at Aldinga and Dark Faces. When first captured, possums were weighed to the nearest 50 g, sexed, ear-tagged with a numbered metal tag on each ear (National Band & Tag Co. size 3, Kentucky, USA), and released at the point of capture. Differences in body weights between sites were tested with ANOVA.

Estimating possum density

We used maximum likelihood in version 4.4 of Program DENSITY (Efford et al 2004; Borchers & Efford 2008; http://www.otago.ac.nz/density/) to estimate possum density from the trapping data, using spatially explicit capture–recapture (SECR). The probability of catching an animal was modelled based on the distance between the trap and the home range centre. We used the simplest spatial detection function presented by Efford (2004), which has two parameters corresponding to a measure of home range size (σ) and the one-night probability of capture at the centre of a home range (g_0). This approach is robust when there is low or moderate trap saturation, when animal captures are clustered, or where traps span a gradient in animal density (Efford et al. 2009).

Possum populations were regarded as 'closed' (negligible births, deaths, immigration, emigration; Otis et al. 1978) during our late-summer period of trapping. For each site we compared alternative 'within-session' models of variation in spatial detection parameters. We used corrected Akaike's information criterion (AICc) values to choose between a null model with g_0 and σ constant – **Model (0)**, and models in which both parameters varied according to (1) temporal variation in detection parameters (g_0 and σ) over the 12 nights of trapping – **Model (t)**, (2) behavioural response to capture, either permanent – **Model (bp)** (lasting the entire trapping session) – or temporary – **Model (bc)** (affecting only the next capture), and (3) considering sex differences in g_0 and σ – **Model (sex)** (Borchers & Efford 2008).

The detection function was assumed to be half normal. We used the default settings in DENSITY 4.4 for all the computations, except for 'buffer width'. Buffer width was set to 500 m. We checked retrospectively that this was sufficient (i.e. that the density estimate did not change as buffer width was increased), using the spatially explicit capture–recapture log likelihood tool.

For comparison with other studies, we calculated a trap-catch index (TCI). The national Trap-Catch Protocol (NPCA 2011) was developed in response to Animal Health Board, regional council and Department of Conservation requirements for a standardised method for estimating the relative abundance of possums. In our study, TCI was modified for recaptures according to the formula (modified from NPCA 2011):

$$\text{TCI} = \frac{\text{Total number unique possums caught}}{\text{Total number trap nights} - 0.5(S + NT + R)} \times 100,$$

where S denotes traps that were sprung but empty, NT denotes traps that caught non-target species, and R denotes traps that caught tagged possums.

Results

Mean possum density (±SE) was estimated to be 0.69 (±0.05) per hectare for Aldinga and 0.44 (±0.03) for Dark Faces (Table 1). There was very strong support for the top models, **Model (t)** (Aldinga) and **Model (bc)** (Dark Faces), as they were more than 10 AICc units from the second best model (Table 1). Assuming a circular bivariate normal shape for the home range, home range areas derived from σ (2.45 × σ = 95% home range radius; Efford et al. 2005) were 36.19 ha for Aldinga and 54.07 ha for Dark Faces. Trap-catch indices based on the number of unique possums live-captured were 29.2% at Aldinga and 28.9% at Dark Faces. Using the conversion equation of Ramsey et al. (2005), these indices translate to 5.89 and 5.83 possums per hectare, respectively.

Open grassland was the dominant habitat type at both study sites, comprising 60% [95% CI 54.8–65.2%] of the land area at Aldinga and 77% [72–82%] at Dark Faces. This was followed by rock (Aldinga 23.1% [19.5–26.7%] and Dark Faces 13.3% [9.7–16.9%]) and shrub (Aldinga 19.9% [14.7–25.1%] and Dark Faces 9.6% [4.6–14.6%]). In general, the Aldinga site contained less open grassland than Dark Faces, and more shrub and rock habitat.

Possums were significantly heavier at Aldinga than at Dark Faces ($F_{(1, 357)} = 5.4052$, $P = 0.02$). The weight of trapped possums ranged from 350 g to 4750 g, with 90% of possums heavier than 1500 g. There were no sex differences in weight ($F_{(1, 355)} = 0.04$, $P > 0.05$) at either site. At Aldinga the average weight (g) (±SE) was 2912.4 (±76.7) for females and 2867.9 (±93.9) for males. At Dark Faces the average weight was 2696.9 (±77.8) for females and 2686.7 (±96.6) for males. Of the 370 possums live-captured, the sex ratio was close to parity (Aldinga, 53.1% females; Dark Faces, 53.3% females) and the dominant fur colour was grey (82.5%) followed by brown (9.2%) and black (8.3%).

Discussion

Possum density

Our density estimates of less than one per hectare for possums in dry grassland habitats are generally much lower than for other ecosystems in New Zealand. In particular, the density of possums in podocarp–broadleaved forest varies between 3 and 16 per hectare (Table 2); those estimates are 4- to 36-fold higher than these in our study. The highest possum density recorded for uncontrolled populations in New Zealand (Montague 2000) was 25.4 per hectare (Coleman et al. 1980) in a narrow forest fringe where possums were able to forage extensively on adjacent pasture. Estimates of possum density in other habitat types are similar to our estimates from dry grassland; e.g. radiata pine (*Pinus radiata*) (0.9–3.0 per hectare) and southern beech forest (*Nothofagus* spp.) (0.5 per hectare) (Clout 1977; Clout & Gaze 1984). These forest types contain foliage that is mostly unpalatable to possums, and contain a low diversity of alternative food species. Possum densities in the vegetation types reviewed by Montague (2000) (i.e. podocarp–broadleaved, *Nothofagus* spp., and *Pinus radiata*) did not differ from those that we reviewed in the present study (Table 2).

We are confident that there were negligible births, deaths, immigration and emigration (i.e. population closure) during trapping because trapping was carried out during a short period

Table 1. Estimates of possum density $\widehat{D}$ (per hectare) and parameters of a half-normal detection function $\widehat{g}_0$ and $\widehat{\sigma}$. Estimated standard errors are shown in brackets. ΔAICc is the difference between the corrected AIC of the model in question and the best model (with lowest AICc). See methods section for explanation of models. Total number of possums captured was 205 at Aldinga and 165 at Dark Faces. Numbers of recaptures were 152 and 126, respectively.

Model	$\widehat{D}$ (ha^{-1})	$\widehat{g}_0$	$\widehat{\sigma}$ (m)	AICc	ΔAICc
Aldinga					
(t)	0.69 (0.05)	0.083 (0.009)	107.33 (4.83)	2429.3	0
(bc)	0.75 (0.05)	0.074 (0.009)	104.67 (5.81)	2443.0	13.7
(bp)	0.94 (0.07)	0.038 (0.013)	119.66 (11.96)	2443.4	14.1
(sex)	0.71 (0.05)	0.085 (0.009)	104.53 (4.71)	2448.2	18.9
(0)	0.69 (0.05)	0.083 (0.008)	106.03 (4.73)	2448.8	19.5
Dark Faces					
(bct)	0.44 (0.03)	0.074 (0.009)	131.19 (6.79)	2047.7	0
(tbc)	0.48 (0.04)	0.09 (0.01)	112.96 (5.35)	2058.0	10.3
(bp)	0.48 (0.04)	0.088 (0.01)	114.6 (5.51)	2067.6	19.9
(sex)	0.56 (0.04)	0.036 (0.012)	146.75 (11.31)	2071.1	23.4
(0)	0.46 (0.04)	0.087 (0.01)	116.51 (5.54)	2081.1	33.4

Table 2. Mean home range sizes and population densities of brushtail possums (*Trichosurus vulpecula*) in various habitat types in New Zealand studies conducted since 2000*.

Habitat	Site	Mean home range area (ha)[1]	Method[2]	Density (possum ha^{-1})[3]	Method[4]	Reference
Podocarp–broadleaved	Auckland Region	-	-	3.3–4.1	LT	Ji et al. 2005
Podocarp–broadleaved	Waikato Region	0.5[KHR]	G	14	RT	Blackie et al. 2011
Podocarp–broadleaved	Orongorongo Valley	-	-	9–12	LT	Arthur et al. 2004
Podocarp–broadleaved	Orongorongo Valley	0.7[KHR]	R	-	-	Ramsey & Cowan 2003
Podocarp–broadleaved	Dunedin Region	-	-	16	LT	Efford et al. 2000
Nothofagus spp.	Kaimanawa Range	3.1[KHR]	G	5.6	RT	Pech et al. 2010
Nothofagus spp.	Craigieburn Range	-	-	2	RT	Sweetapple 2008
Mixed podocarp	Maungatautari	-	-	5.2[TCI]	RT	Forsyth et al. 2005
Mixed broadleaved	Wanganui area			10.8	LT	Nugent et al. 2010
Pinus radiata	Waitarere	4.4[σ]	LT	1.7–2.5	LT	Efford et al. 2005
Farmland	Miranda	-	-	4.4[TCI]	RT	Forsyth et al. 2005
Mixed farmland and beech forest	Mount Somers	6.0[KHR]	R	-	-	Ball et al. 2005
Grassland/shrubland	Molesworth Station	5.1[MCP]	R	1.7[TCI]	RT	Glen et al. 2012
Grassland/shrubland	Molesworth Station	23.1[KHR]	G	-	-	Nugent et al. unpubl. data
Grassland/shrubland	Central Otago	36.2–54.1[σ]	LT	0.4–0.7	LT	This study

*Information prior to 2000 is summarised in Montague (2000).
[1] 95% kernel home range KHR (except for Ramsey & Cowan (2003), which uses 80% kernel home range), minimum convex polygon MCP, sigma home range σ.
[2] Home ranges estimated by: GPS collar G (which represents night-time movements), radio-tracking R (usually day-time movements, except for Ball et al. (2005), which represents night-time movements).
[3] TCI = estimated density based on formula (Residual Trap-Catch Index − 0.55)/4.86 (Ramsey et al. 2005).
[4] Density estimates based on: removal trapping RT, or live trapping LT.

after the main annual pulse of recruitment and dispersal (Efford 1998; Cowan 2005). Also, population turnover is generally slow for brushtail possums (annual disappearance in the order of 10–20%, e.g. Efford 1998), and there were no harsh weather conditions or other reasons to expect the population to have changed dramatically during this short period. It is important to note that this was a one-off study carried out during only one season (autumn). Densities may be different in other seasons and/or other years. For instance, we could expect higher densities during the late spring and summer recruitment phase when young possums become independent (Montague 2000).

Trap-catch indices (TCI) at our sites (c. 29%) were 2–3 times higher than those in beech forest (c. 10%) and mixed podocarp forest (c. 15%), but similar to those found in forest/pasture margins (c. 20%) (Thomas & Brown 2000). Our estimates were also approximately three times higher than the 9% TCI observed by Glen et al. (2012) in dryland habitat, although they reported variation in TCI ranging from 0% to 38%, suggesting that possum distributions can be patchy at a landscape scale depending on microhabitat types such as shrub cover or the presence of forest remnants and rock outcrops.

Open habitats, such as those studied here, might allow for easier capture of possums using traps with lures. This may account for the fact that our density conversions derived from TCI (>5 per hectare) were an order of magnitude higher than those derived from SECR methods (<1 per hectare). Therefore, we recommend caution when using lured traps to estimate possum density based on TCI, because the results could be overestimated.

Possum movements and habitat

Home range sizes of possums in our study were much larger than those recorded in podocarp–broadleaved forest, pine forest, and modified urban forest (Table 2). Our estimates were slightly higher than those derived from GPS-collared possums in dry grassland habitat at Molesworth Station in the northern South Island (Nugent et al. unpublished data). Comparisons with other studies, however, must be done with caution as home range estimates based on sigma parameters (from SECR methods – this study and the pine forest study) can differ from estimations that used more direct methods (e.g. radio-tracking or GPS collars).

Possums are mainly arboreal, although they do live in extensive tussock grassland habitat and other open country (Montague 2000; Glen et al. 2012). Because previous research has demonstrated that food resources strongly influence the density and reproduction of possums in New Zealand (Nugent et al. 2000; Ramsey et al. 2002; Cowan 2005; Harper et al. 2008), our hypothesis was that possum densities would generally be lower in dryland habitats than in more mesic environments due to the relative paucity of high-quality foods or den sites, and colder winters with temperatures often below 0°C. Our results are consistent with this resource hypothesis because greater possum densities, slightly smaller home ranges, and greater body weights were found at the Aldinga site, which had more food and shelter (i.e. more shrubs and rocks). The availability of these resources for possums might be important determinants of the carrying capacity of dryland ecosystems for possums. Shrub leaves and fruit comprised about 28% of the dry weight of the food possums consumed in a dryland environment in the southern Marlborough region of the South Island (Glen et al. 2012). Holes under the root systems at the base of shrubs were the most frequently used type of daytime den in that study (Glen et al. 2012). Shrub habitat may therefore be a key driver of possum abundance in this environment because it provides both cover and food resources. Many areas of the South Island are dominated by invasive shrub species, and their removal may be an indirect means of reducing possum abundance. Further research on this topic would be useful for developing new control strategies for possums in dry grassland habitats.

Conclusion

In summary, population densities of brushtail possums based on live capture in hillslope, open, dry grassland habitats in Central Otago were low compared with those in podocarp–broadleaved and farmland ecosystems in New Zealand. However, TCI values were relatively similar to those from dryland habitats in the northern South Island. Possums also ranged over wider areas in dry grasslands. These differences may reflect lower availability and distribution of resources, as well as different climatic conditions, in dry grasslands. The ecological information provided here, in particular the potential relationship between possum abundance and shrubby habitats, is useful for wildlife managers for targeting population control in dryland environments.

Acknowledgements

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