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The short-term response of feral cats to rabbit population decline: are alternative native prey more at risk?

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Author contributions

All authors conceived the ideas and designed methodology; HM collected and analyzed the data; HM led writing of the manuscript; and all authors contributed critically to the drafts and gave final approval.

Compliance with Ethical Standards

No authors report any conflict of interest. Data collection fulfilled all legal requirements in Australia, and methods were approved by University of Tasmania Animal Ethics Committee (A0015720).

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Keywords: prey switching, animal-borne video, diet, mesopredator, introduced predator, invasive species, wildlife.

Abstract

The impacts of invasive predators can be amplified by high densities of invasive prey species. This is evidently the case in Australia, where hyperabundant rabbit populations lead to high densities of feral cats and correspondingly high impact of cats on native species, especially small mammals. This suggests that reducing rabbits could also reduce abundance of cats, and thereby alleviate predation on native small mammals. However, cats might respond to the loss of rabbits by prey-switching to native small mammals, resulting in increased predation on those species.

We investigated the short-term effects of an experimental reduction of rabbit abundance on feral cats and their small-mammal prey in arid South Australia. We reduced the rabbit population in a 37 km^2 experimental enclosure by ~ 80% (2,215 rabbits removed from an estimated population of ~2,800), while monitoring an adjacent unmanipulated area as a control. Cats were present in both the experimental and control areas.

Cat activity and survival of VHF-collared cats in the enclosure decreased by 40% following the rabbit reduction. Surviving cats increased their consumption of reptiles, birds and invertebrates, but they nevertheless evinced hunger by increased their intake of experimentally-supplied sausages, and by losing body condition. There was no change in either the proportion of cat scats that contained remains of small mammals, or the rate at which video-collared cats were recorded killing small mammals, even though the activity of small mammals declined.

Our results demonstrate that individual feral cats prey-switch in response to removal of their primary prey. However, we also show that survival and overall activity of cats decreased, which could result in net, long-term benefits for native prey threatened by cats. Management of feral cats using food lures or baits would also be more effective when introduced prey are scarce, as cats are more likely to eat novel food.

Introduction

Invasive predators are a major threat to biodiversity worldwide, often having greater impacts on prey than do native predators (Paolucci et al. 2013). This can be due to several factors, including lack of co-evolution between introduced predators and native prey resulting in prey naïveté (Griffin et al., 2000; Moseby et al. 2016), specific morphological and behavioural traits that give some invasive predators an advantage (Vermeij 1991, Webb 1985), or anthropogenic disturbances that shift habitats or communities to states that favour invasive predators. The latter factor may be especially relevant to the biological invasions accompanying European colonisation across the world over the last 400 years, which has often involved the introduction of novel prey species as well as predators. These novel prey may elevate the densities of invasive predators and lead to hyper-predation on native prey (Abrams et al. 1998, Courchamp et al. 2000).

In Australia, invasive feral cats *Felis catus* and red foxes *Vulpes vulpes* threaten many species of native wildlife, especially native mammals between 35g and 5,500g in body mass (Burbidge and Manly 2002, Woinarski et al. 2015). The regions with the greatest loss of mammals have been the arid and semi-arid zones of southern Australia (Smith and Quin 1996), coinciding with the regions where densities of the invasive European rabbit *Oryctolagus cuniculus* have historically been highest. This suggests that at least part of the explanation for the large impact of invasive predators on native prey in these regions could be the effect of rabbits in sustaining high population densities of feral cats and foxes. Therefore, managing populations of invasive herbivores that are important prey of cats and foxes, such as rabbits, may provide a tool for indirect control of invasive predator populations (Pech et al. 1992, Pedler et al. 2016). Such control could be in the form of direct suppression (for example, by ripping rabbit warrens or poison-baiting) or the introduction of bio-control agents such as Rabbit Haemorrhagic Disease Virus (RHDV).

Reducing the population density of an invasive predator by manipulating populations of invasive prey could reduce the intensity of predation on alternative native prey (Courchamp et al. 2000). It is also possible that as invasive prey decline the predators switch to native prey, and thus increase predation rates on those native species, at least temporarily (Murphy et al. 2005). When RHDV was released as a biocontrol agent to the Australian rabbit population in 1995/96, the resulting epidemic caused widespread decline of rabbits, and associated declines in populations of feral cats and red foxes. During this period, studies investigating the diets of cats and foxes through scat and stomach contents found that the proportion of native animals in their diets increased (Holden and Mutze 2002, Moseby et al. 1998, Pech and Hood 1998, Read and Bowen 2001). The impact of such prey-switching on populations of native prey is disputed (Doherty et al. 2015a, Mutze 2017), mainly because it is not clear whether the magnitude of prey-switching during the period of predator decline is large or sustained enough to drive populations of native prey to local extinction, and whether the eventual benefit of lowered density of invasive predators outweighs the transient impact of prey switching.

Our understanding of the impacts on native prey of prey-switching by feral cats and foxes is limited by the fact that to date all evidence of the phenomenon comes from analysis of diet composition from scats or stomachs of predators. These analyses do not necessarily reveal changes in the rate of predation on prey populations, for three reasons. First, consumption of native prey is measured as frequency in the diet, rather than as an absolute kill rate per unit time. A decline in consumption of invasive prey could increase the frequency of native prey even if the absolute kill-rate of native prey does not change. Second, when cats and foxes are sated, they may still kill surplus prey without consuming them (Kruuk 1972, McGregor et al. 2015, Short et al. 2002). This makes it possible that kill rates per predator may decline following a decline in primary prey, but that intake rates remain the same because predators are eating more of the native animals they have killed. Third, differentiating between freshly-killed prey and carrion is unreliable from scat and stomach analysis. A more detailed understanding of how cats respond when their primary prey populations are reduced is essential to assess the effects on native prey of prey-switching.

The total impacts of prey-switching also depend on the density of predators. A reduction in available food could lead to a reduction in predator numbers, potentially offsetting any impacts of individual-based prey-switching. But understanding the effect of this on populations of native prey depends on knowledge of the factors that affect survival of cats following reduction of food, including whether they move to seek prey elsewhere.

To gain a better understanding of the mechanisms underpinning prey switching by feral cats and their potential impacts on native wildlife, we conducted a Before/After/Control/Impact study of feral cats and their prey during a population reduction of rabbits in central Australia. The study was conducted at the Arid Recovery Reserve in northern South Australia, which includes a landscape-scale (37 km^2) enclosure occupied by feral cats, rabbits and native small mammals. The rabbit population in the enclosure was experimentally reduced by ~80% in a 30-day period, simulating the magnitude and speed of population decline that would be produced by arrival of RHDV. A neighboring unfenced area of similar size and in which no rabbit removal was undertaken was used as a control site. We used this design to answer the following questions about the effects of abrupt declines in rabbits: (i) do cat activity, body condition and survival change? (ii) do cats prey-switch, and do their diets and kill-rates change? and (iii) does abundance of alternative prey such as native small mammals decline?

Methods

Study area

This research was conducted in central South Australia, in and around the 123km^2 Arid Recovery Reserve (30°29′S, 136°53′E). Approximately 60km^2 of this reserve is surrounded by a feral-proof fence completed in 2001, whilst the remaining 62km^2 consists of two fenced areas created by 2008 for the purposes of landscape-scale research. The area has an average annual rainfall of 170ml (Olympic Dam Aerodrome, BOM), and is mostly characterized by swales containing scattered small shrubs, dissected by longitudinal sand-dunes and some ephemeral creeklines. We worked in the 'Dingo Paddock', a 37-km^2 fenced area with a 1.6m high feral-proof fence constructed using 40mm gauge wire and a floppy top that curves outwards (Moseby et al. 2012). This prevented adult rabbits, dingoes, cats and foxes from entering the paddock, but would not prevent feral cats already resident from exiting. The southern boundary of the Dingo Paddock abuts the rest of the Arid Recovery reserve, where there is an abundant population of hopping mice and plains mice. These native mice appeared to be constantly immigrating into the Dingo Paddock across this boundary (Moseby et al. 2019). During the study, there was one dingo present in the Dingo Paddock. The surrounding area was used as a control for the study, mostly on the neighboring Stuart Creek Mulgaria Stations (Figure 1). These areas contain similar types and proportions of habitats, but they are also subject to cattle grazing and have greater detection rates of dingoes, kangaroos and emus (Moseby et al. 2018).

Study design

In late February 2017, 2215 rabbits were removed from the Dingo Paddock over a 12-night period, by shooting from an all terrain vehicle at night as part of Arid Recovery Reserve management. Carcasses were left on the ground. Rabbit abundance was monitored by distance sampling, using a vehicle-mounted spotlight along a fixed transect once a month for three months prior to the reduction effort and for three months afterwards. Surveys followed a 17.5 km route through the Dingo Paddock and a 18.3 km route through the control area.

Only one side of the vehicle was surveyed. For every animal detected, we recorded its distance from the track as well as the position of the vehicle along transect. Densities of rabbits were estimated using ‘Rdistance’. The area was divided into dune and swale zones, densities were estimated separately for the sections of transects passing through these zones. The total population of rabbits was estimated by multiplying the habitat-specific densities by the total area of each zone in each of the experimental and control areas. This was then multiplied by 1.3 to account for animals missed that we determined using a thermal camera. This was based on five nights of spotlighting where temperatures were below 20°C, where we had an additional person using a thermal camera (FLIR scout III 640, FLIR® Systems, Inc., Wilsonville, USA) who recording how many rabbits were missed by the spotlight user. This person typically recorded 31% more (SE = 4%).

Track counts

We measured activity of feral cats, rabbits and native small mammals on 77 track transects (Moseby et al. 2018), 39 inside the Dingo Paddock (20 sand dune, 10 creek-lines and 9 swale) and 38 in the control site (20 dune, 8 creek-line and 10 swale). Each transect was 200m long and swept using a steel drag-bar dragged by an all-terrain vehicle late in the afternoon. The next day we counted the number and species of tracks of all mammals that crossed the transect. Track surveys were conducted once before (November 2016) and once after (April 2017) the rabbit reduction.

Changes in activity between the two time periods were examined separately for cats, rabbits and native mammals. We ran seven different generalized linear mixed models with various combinations of habitat, session, area and session-by-area interaction terms. These assumed a Poisson error distribution, and individual transect was set as the random term. We compared models using the Akaike Information Criterion for small sample sizes (AICc) and selected the model with the lowest AICc score (Burnham and Anderson 1998).

Cat body condition and survival

Cats were captured in the Dingo Paddock using cage traps and soft-jaw leg traps (victor #1.5) with cat urine as lure. Each cat was fitted with a collar containing a VHF beacon (n = 30), and some were also fitted with either a video collar (discussed in further detail below). Cats were re-captured at intervals of 3 to 12 weeks by tracking them to their daytime burrow, placing a cage-trap at the entrance, and digging above the cat's underground location to cause it to run out into the trap. Once captured, cats were placed in a dark bag and processed without sedation. We measured weight and condition (1-5 scale, where 1 denotes close to death and severely malnourished, 5 denotes excellent condition with hip bones and backbone hard to feel through the thick layer of fat). We also collared six cats in the control area. However, two were killed as part of ongoing control around reserve and all others left our study region. Given the difficulty of collecting ranging information from cats in the control area, we instead measured the condition of all cats euthanased during normal cat-control operations within 20km of the Arid Recovery Reserve over the same time period. We compared the condition of cats inside and outside the Dingo Paddock before and after the reduction effort using a generalized linear model.

Survival was analysed for 29 of the 30 cats that were VHF-tracked. The fate of only one cat was unknown, but we believe this cat left the Dingo Paddock as there was still three months of battery life predicted from the collar battery, and it was not detected in the subsequent year despite extensive cat-control and remote-camera trapping. To examine the factors influencing cat survival, we used Cox Survival analysis with log-linear distribution and the 'survival' library in R (Therneau 2014). Models were evaluated using AIC. Explanatory variables considered were pre- *versus* post-reduction, sex, body weight, and whether individual cats were detected on the southern boundary of the Dingo Paddock where small mammals moved through the fence (Moseby et al. 2019).

Prey selection by cats

We measured changes in cat diet and "assumed hunger" by analyzing scat contents, deploying animal-borne video collars and measuring uptake of supplementary food. For analysis of scat content, we collected scats both inside the Dingo Paddock and in the neighboring control area before and after the rabbit reduction effort. All scats were placed in a paper bag, and the location, date, and likely age of scat recorded. We also collected scat from cats killed in the control area that had full colons. Scat was dried and sent for analysis to Georgeanna Story (Scats About Pty Ltd, Majors Creek NSW), who identified vertebrate species, estimated the count of small-mammal individuals and recorded number of invertebrates. We used generalized linear models to examine whether treatment (experimental/control) and time period (pre- and post-reduction) affected the presence of rabbit in scats, the count of small mammals (all species combined), and the number of all other prey species found in scats (hereafter alternative prey).

As scat analysis provides no information on kill rates, and cannot differentiate between carrion and direct kills, we also deployed animal-borne video collars to measure kill rates (Loyd et al 2013, McGregor et al 2015). These were deployed throughout the entire study period. Collars were made with modified GoPro Hero 3 White cameras (GoPro Inc, San Mateo, California, USA), with extra infra-red LEDs placed next to the lens (920 nm), VHF beacon (Sirtrack, Havelock, New Zealand), additional batteries (Lithium-ion 1300mha), and a delay timer created with Ardunio Atiny85 chips (ATMEL, San Jose, California, USA) that would turn the camera on 11 hours post release. After parts were compiled, they were coated in epoxy resin (SC651, Solid Solutions, Bentleigh East, Australia). Working deployments obtained 6–10 hours of footage. All footage was reviewed, and behavior was categorized into one of five classes (still, walking, grooming, investigating a rabbit warren, hunting).

With data from video-collars on cats, we compared hunting rates of cats before and after the experimental rabbit control. We calculated kill rates per hour for rabbits, small mammals and ’alternative’ foods (carrion, insects, small lizards). Each camera deployment was treated as a sample unit. We used only deployments that were active for more than 50 minutes to estimate kill rates for cats. Rates of hunting on small mammals and alternative prey were compared pre- and post- rabbit control using generalized linear models, after log-transformation. We had insufficient sample size of rabbit kills, therefore, we compared visitation rates of cats to rabbit warrens as an index of hunting of rabbits by cats before and after the rabbit reduction.

Finally, we estimated the hunger of cats by measuring their willingness to eat a novel food source: we placed sausages in front of remote cameras and measured rate of uptake by cats. We used skinless beef Chevaps sausages left in the sun for 6 hours, which increased the smell. Sausages were placed 20 sites in the experimental area and 20 in the control area at three time points: three months before, during, and three weeks after the experimental rabbit reduction. For each cat detected on camera when a sausage was available, we recorded whether it ate or ignored it. Cameras were deployed until we obtained at least 15 instances of a cat interacting with a sausage in each of the experimental and control areas. This often involved rebaiting cameras repeatedly until this sample size was reached. The fate of the sausage (eaten, not eaten) was examined using binomial generalized linear models, where the fixed effects were treatment (experimental/control area), time period (pre-/during/ post-rabbit reduction) and their interaction.

Results

Effectiveness of rabbit reduction

Rabbit reduction was undertaken in the study area for 14 days in February/March 2017, removing 2,215 rabbits. Distance sampling based on spotlighting counts of rabbits estimated a population of 2,756 (95% CI = 2430–3082, or 76/km^2) in the paddock before removal, and 448 (95% CI =298–598, or 12/km^2) afterwards. No decline in estimated density was detected in the control area (21/km^2 before, 26/km^2 after, SE = 6). The distance sampling model was best described by a half-normal function (AICc weight of 1) with an effective strip width of 48 m and 33% probability of detection. Rabbit activity from track counts varied among habitats, being higher on dunes and lower in swales, and was also affected by the interaction between treatment and period (Fig. 2, delta AICc 28.6 lower than next model, 1516 from null, and AICc weight of 1). This model showed a significant drop of rabbit activity of 86% in the treatment area following the experimental rabbit control (-2.1, z= -26.1, P<0.001), but no change in the nearby control area (0.01, z=0.2, P=0.86).

Cat activity, body condition and survival

Cat activity was best explained by a model containing session by paddock (delta AICc 9.6 lower than next model, 16.6 from null, and AICc weight of 0.99). In this model, cat activity was initially much higher in the dingo paddock (~5 fold), but the track counts of cats dropped significantly by 32% after the rabbit reduction (95% CI =20–45%, t=-2.29, P=0.024), remaining stable in the control area (Figure 2). Condition of captured cats declined in the experimental area following rabbit reduction (Figure 3), but did not change in the control area (t=4.63, P<0.001). During the radio-tracking period before the rabbit reduction two collared cats were found dead, and both had gained weight since original capture and were in good condition. Of 21 cats that were collared at the time of the reduction, nine were found dead within 5 weeks. Each of these cats was in poor condition and had lost weight since initial capture. One radio-collared cat was never detected after the rabbit reduction and probably left the study area. Survival analysis of radio-collared cats estimated a 24-fold decrease in weekly survival probability following rabbit reduction (95% confidence range = 4-156, z = 3.26, P=0.001). This model also included the variable identifying which cats visited the southern boundary of the study area, where abundances of native mice was likely to be greatest because of the proximity to the rest of the fenced reserve (Moseby et al. 2019). Cats living in this region were significantly more likely to survive (model importance = 0.96; model averaged coefficients: est=2.62, z = 2.16, P =0.031, Figure 4), while initial cat weight or sex had little influence on survival (model importance 0.41 and 0.29 respectively, neither model significant).

Native rodent activity

Activity of native rodents (principally *Notomys alexis* and *Pseudomys australis*) on the track transects was best described using a model that included an interaction term of treatment and before/after rabbit reduction (Fig. 2), and habitat (AICc delta 7.6 lower than next model, 1058 lower than null, AICc weight = 0.98). In this model, activity was initially higher in the experimental area (23 tracks/200m, se = 4.82, z = 5.56, P < 0.001) than the control area (9.5, se = 2.34, z = 5.56, P < 0.001); activity declined in both areas after rabbit reduction (coef = -0.49, se = 0.07, z = -6.67, P<0.001), but substantially more in the experimental area (-2.01, se = 0.13, z=-15.12, P < 0.001).

Cat diet and hunting behaviour

From the 64 cat scats collected, those in the experimental area contained significantly less rabbit after the rabbit reduction, but significantly more alternative prey such as reptiles, insects and birds (Table 1). No significant change was detected in frequency of small mammals (rodents and small dasyurids) (Table 1).

From 27 deployments of video collars on 18 cats, cameras worked on 22, recording a total of 104 hours of footage. However, only 15 of these deployments contained footage where cats were active for over 50 minutes. In total, we recorded 22 hours of cat activity before the rabbit reduction and 33 hours after. After the rabbit reduction there were significantly more instances of cats eating carrion (Table 2, coef = -0.5, se = 0.2, t = -2.46, df = 13, P = 0.028*) and small prey items (coef = -1.36, se = 0.48, t = -2.7, df = 13, P = 0.016*), but no difference in the take of small mammals (coef = 0.07, se = 0.5, t = 0.13, df =13, P = 0.889). The number of rabbit warrens visited per hour of cat activity was non-significantly greater before the rabbit reduction, and this difference was largely driven by footage from one cat who visited

11 warrens in an hour (coef = 0.15, se = 0.58, t = 0.25, df = 13, P = 0.807). Cats were recorded eating two rabbits before the rabbit reduction. Small mammals eaten were spinifex hopping mouse (*Notomys alexis*), fat-tailed dunnart (*Sminthopsis crassicaudata*), and either house mice (*Mus domesticus*) or Bolam's mouse (*Pseudomys bolami*). Reptiles eaten were small geckos and one *Nephurus* spp (Figure 5). There were three instances of cats approaching prey but not eating it, two of sleepy lizards (*Tiliqua rugosa*) and one of a bearded dragon (*Pogona vitticeps*). Carrion was rabbit, and one bearded dragon.

Willingness to consume novel food in the form of sausages increased after the rabbit reduction. From the 120 instances of a feral cat walking past a sausage in the control area (42 before, 45 during and 33 after), no cat ate a sausage. Inside the experimental area, our model including an interaction term of session over paddock indicates cats never ate sausage before the rabbit reduction, but did so after the rabbit reduction (coef = 2.32, se = 0.81, z = 2.89, P = 0.004**).

Discussion

The large and abrupt reduction in abundance of rabbits following rabbit control in this study resulted in a decline of feral cat activity and survival. Half the cats in our collared sample died in the two months following the rabbit decline, and those that survived hunted in an area with a replenishing prey source; small mammals entering the experimental area via the fence adjoining the rest of the reserve (Moseby et al. 2019). Yet even those surviving cats lost condition, and showed greater willingness to eat novel food, indicating elevated levels of hunger.

Rabbits were the dominant food source for feral cats in this study before the rabbit reduction. Their frequency in cat scats was very high compared with studies conducted post calicivirus (Doherty et al. 2015a, Wysong et al. 2019), though similar to those conducted prior (Holden and Mutze 2002, Molsher et al. 1999). The rabbit density in the experimental area (~80km^2) was very high by contemporary standards, and although lower than many of the densities reported before RCHC biocontrol of between 100-300km^2, the high levels of cat activity in this area was likely supported by these high rabbit densities. However, at a continental scale rabbits are not necessarily preferred prey of feral cats, and most studies report preferences for small mammals between 35 g and 400 g (Doherty et al. 2015a, Radford et al. 2018). Rabbits are likely to be harder to hunt and kill than are many other prey species due to their size

(Jones and Coman 1981, Moseby et al. 2015), and it is possible that many individual cats within this population became specialized on rabbits (Dickman and Newsome 2015), and were not as flexible as other individual cats after the reduction in rabbits.

We show that when a large source of rabbit prey was reduced, feral cats prey-switched. They increased their consumption of non-mammalian food. Other studies have also demonstrated this from scat or stomach analysis (Delibes-Mateos et al. 2008, Doherty et al. 2015a, Yip et al. 2015), but we also show using video collars that this also corresponded with an increase in kills per hour.

This prey switching appears to have caused a decline in activity of small mammals (mostly *N. alexis* and *P. australis*), suggesting the potential to threaten other native mammals in similar circumstances. However, complicating this interpretation was small mammals also declined in the control area (though not as pronounced), and we did not find evidence of increased hunting from either scat analysis or animal-borne video. One possible explanation is that cats did increase their targeting of small mammals, but their incidence in the diet didn’t change as small mammals became increasingly rare, as Read and Bowen (2001) and Saunders et al. (2004) found with rabbits. Another explanation could be cats always prefer small mammals and there was no change before and after, but the high abundance of cats with the experimental paddock caused a greater rate of attrition of small mammals than outside in the control zone. Also, our diet sample sizes were small and only large changes would have been detected. Therefore, although we highlight prey-switching has the potential to threaten native mammals, we were not able to demonstrate the underlying mechanistic process.

Sudden removal of prey from a potentially destructive predator is both a transient threat to native wildlife and an opportunity for management. Prey switching can greatly increase the likelihood of cats eating novel food sources and carrion, as demonstrated here. This also means cats would be more susceptible to control techniques that rely on hunger, such as poison baiting or trapping with food lures. This has also been shown by Christensen et al. (2013) and Algar et al. (2007) who found the impact of poison baiting via a similar novel food source was greatest when the density of cats was high relative to prey availability. We suggest conservation managers aiming to reduce cat populations should take advantage of declines in rabbit abundance by targeting baiting programs to such times. Not only could this result in more effective reductions in cat density, but it could also help protect native species during a potential prey-switching period. Alternatively, artificially reducing rabbit abundance prior to control would likely improve the uptake of control methods or help naturally reduce cat abundance.

The decrease in survival of cats reported here occurred within weeks of reduction of rabbit abundance. The rapidity of this change might have been increased by the extreme heat and humidity around the time of the rabbit reduction, potentially giving cats a greater need for energy and moisture. Cats that did not hunt near the boundary of the Arid Recovery Reserve were not sustained on the alternative prey available. Given the potential period for prey-switching is immediate, managers need to be prepared to react quickly to protect vulnerable wildlife at such times, and/or take advantage of the increased cat hunger at such times to use cat control options like baiting most effectively.

This experimental study supports the descriptive research of the aftermath of the original calicivirus release in 1995-1996, which resulted in an increase in occurrence of alternative prey in diet of feral predators (Molsher et al. 1999, Mutze et al. 1998, Read and Bowen 2001), but an overall decrease in cat density that would ultimately be beneficial for many species (Pedler et al. 2016). However, it contradicts a recent study by Scroggie et al. (2018) that found no decrease in fox activity despite levels of rabbit reduction similar to our study. Our contrasting results might be due to our enclosing perimeter fence, which prevented any cats from the outside getting in, while the study of Scroggie et al. (2018) was conducted in an open landscape in which control areas could be quickly reinvaded by dispersing animals. It is possible that the results of this study would not be replicated in an open landscape. Even if inherent carrying capacity is locally reduced, predators from outside would continue to come in looking for food. However, if the scale of the rabbit decline and resultant reduction in predator density is very large, such as with calicivirus releases, then even immigration into focal areas could not compensate for local mortality.

When changes to prey availability occur and there are few alternative prey sources, new equilibriums of predator – prey are soon met (Pech and Hood 1998). The subsequent lower predator densities may allow secondary prey species that couldn’t survive previous cat densities to again survive. Overall, alternative prey sources for predators should be removed whenever possible, with this management integrated with further predator control.

Interactions between introduced prey and predators can cause synergistic impacts on native species (Doherty et al. 2015b). When those predators take relatively fewer native prey per capita but predator densities are elevated, then the cumulative predation toll on native species would exceed that if predators are at lower density. Even though individual cats consumed more rabbits and less native prey before the rabbit reduction, it is unlikely that maintaining a large population of feral prey (e.g. rats, rabbits) would mitigate impacts to native species in the long term. Reducing major food sources like rabbits, introduced rodents or artificial food sources (e.g. town dumps) should be considered as valuable management tools resulting in long-term benefits, whilst impacts of prey-switching would be short-term and potentially mitigated. If we can manage processes that interact synergistically with feral predators, we should have a greater change of reducing the overall impact of invasive predators.

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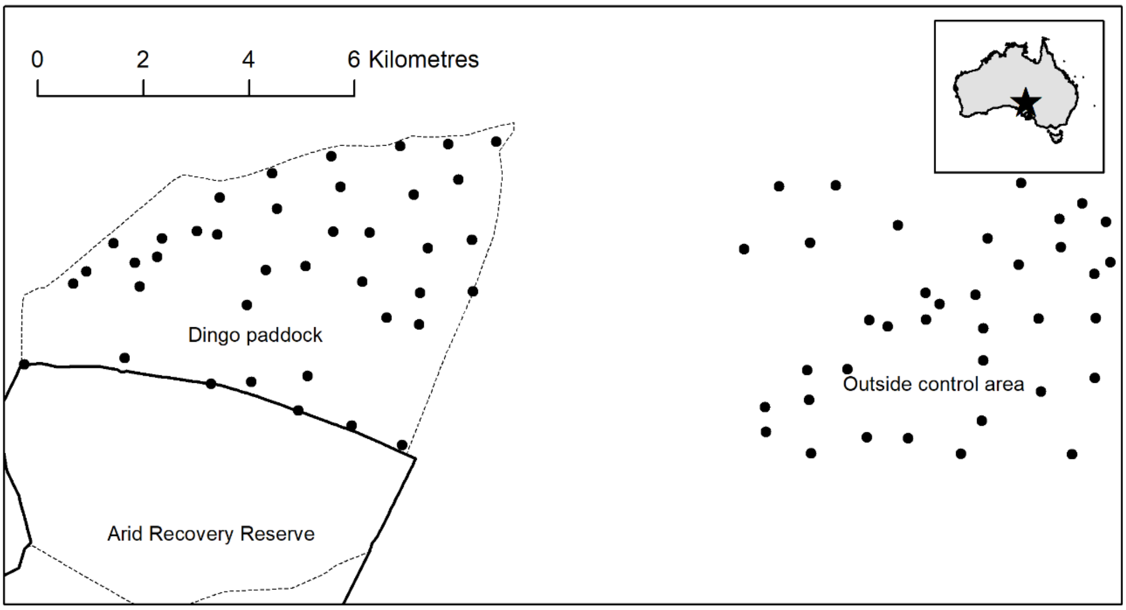

Figure 1. Map of the study area, showing the Dingo Paddock where experimental removal of rabbits was conducted, the adjoining fenced reserve, and the area outside the reserve used as the control. The position of all track transects used to measure activity of cats, rabbits and small mammals are shown with dots. Inset shows the general location of the study area.

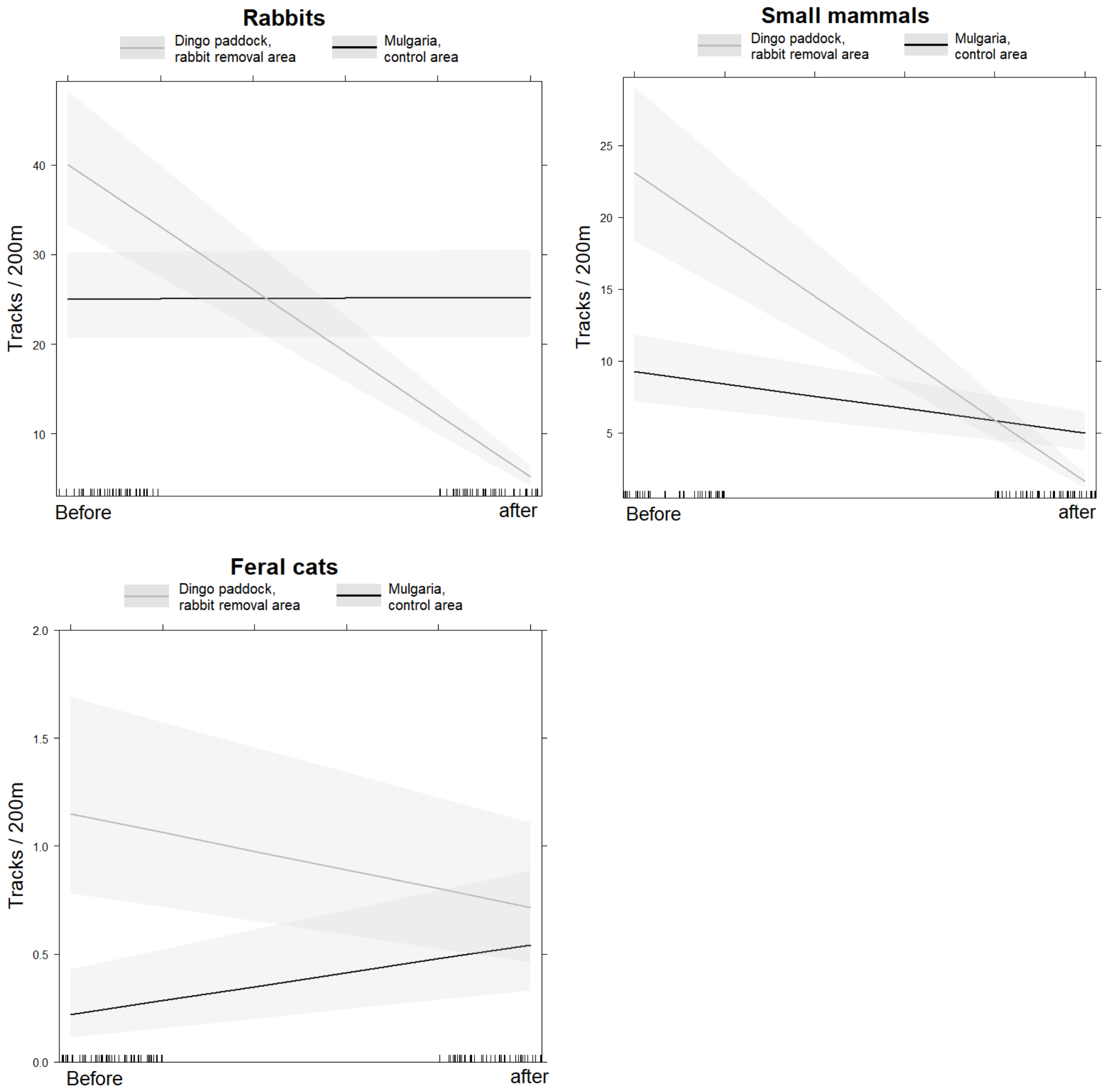

Figure 2. Changes in track counts of rabbits, small mammals and feral cats inside the Dingo Paddock (rabbit removal area) and Mulgaria (nearby control zone) before and after a major rabbit reduction effort was conducted in the Dingo Paddock. Grey shading indicates 95% confidence intervals

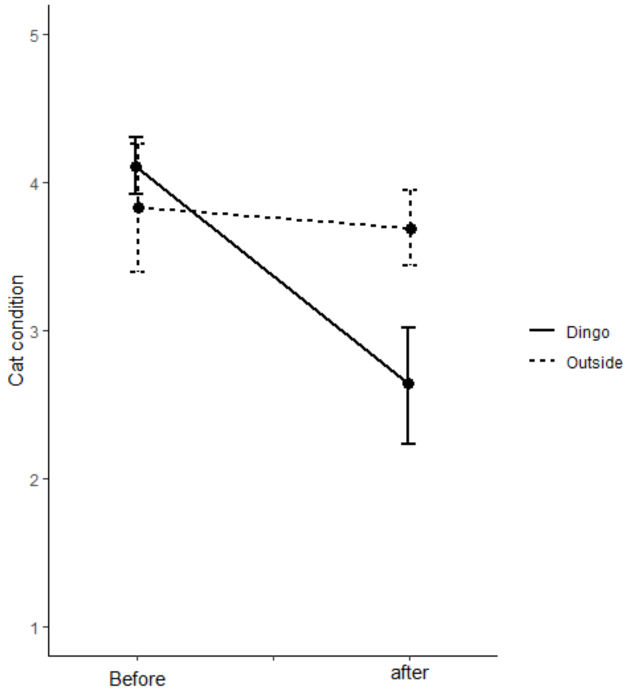

Figure 3. Changes in cat condition before and after the rabbit reduction effort within Dingo Paddock experimental, compared to nearby control area.

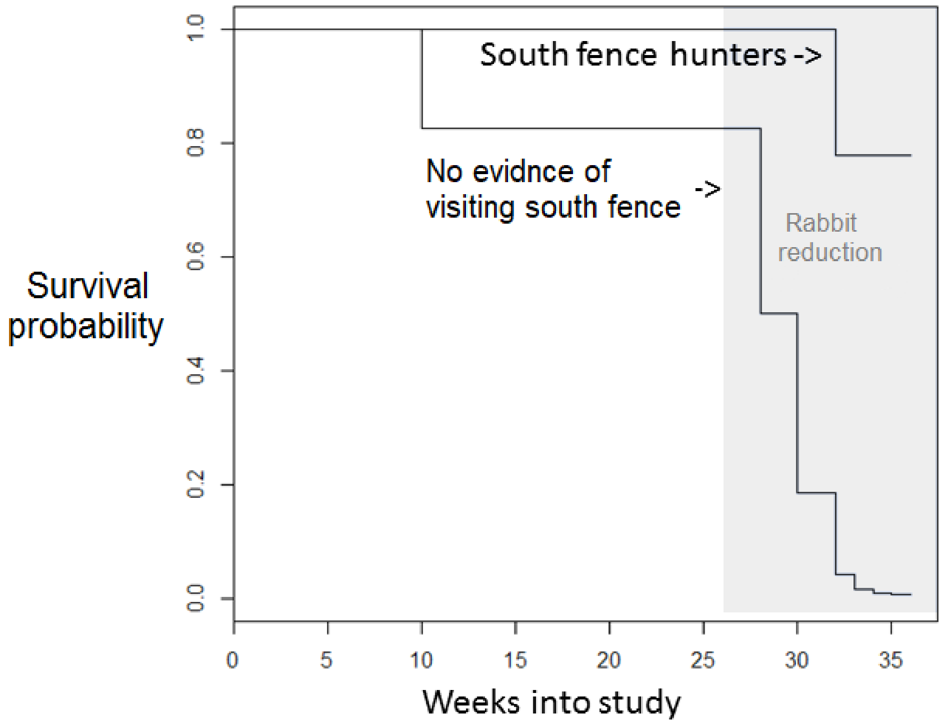

Figure 4. Survival of cats in the experimental area following rabbit reduction. ‘South fence hunters’ were those that were detected on remote cameras on the southern boundary of the study paddock, where availability of small mammals would have been greatest after the rabbit reduction effort. This southern boundary abuts the rest of the reserve, where there are high densities of native rodents; these rodents easily pass through the fence.

Figure 5. Images from video-collars deployed on cats, of a cat investigating but not eating a bearded dragon (a), eating a *Nephurus* spp. (b), consuming the intestines of a rabbit (c), and catching a spinifex hopping mouse (d).

Table1. Count of prey in scats collected from cats before and after the rabbit reduction in the Dingo Paddock, and a nearby control area where rabbit populations remained stable over the same time period.

	Dingo Paddock		Outside			
	before	after	before	after	t	P
Scats (n)	26	12	14	12		
rabbits	0.81	0.42	0.57	0.25	-2.21	0.031*
alternative prey[1]	0.81	2.67	0.79	1.42	4.33	0.001***
small mammals[2]	0.88	0.58	0.57	1.17	-0.4	0.688

1 Includes birds, reptiles and insects. 2 Includes rodents and small dasyurids

Table 2. Hunting and food consumption events by feral cats witnessed on animal-borne video-collars before and after a major rabbit reduction effort.

	Events witnessed		Events per hour of activity	
	Before	After	Before	After
Rabbits	2	0	0.12	0
Small mammals	5	3	0.19	0.2
Alternative prey [1]	2	30	0.11	0.37
Carrion	0	5	0	0.13
Investigate rabbit warren	37	22	3.56	0.98

1 Includes reptiles, insects and small unidentified items consumed.