

Run rabbit run: spotted-tailed quoll diet reveals invasive prey is top of the menu

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Abstract. Information about the ecological functional roles of native predators may help inform the conservation of wildlife and pest management. If predators show preferences for certain prey, such as invasive species, this could potentially be used as a conservation tool to help restore degraded (e.g. overgrazed) ecosystems via the reintroduction of native predators and suppression of exotic prey (e.g. introduced herbivores). The diet of spotted-tailed quolls was studied in a fenced reserve in south-eastern Australia where native mammals have been reintroduced, foxes and cats removed, but invasive European rabbits still persist. A total of 80 scats were collected over 12 months and analysis of macroscopic prey remains was conducted to determine diet. Rabbits were by far the most commonly consumed prey species by volume (~76%) and frequency (~60%), followed by brushtail possums (~11% for both volume and frequency), and other small and medium-sized native mammals in much smaller amounts. Quoll scat analysis revealed 10 mammal species in total, eight of which were native. Bird, reptile and invertebrate remains were uncommon in quoll scats. This suggests that spotted-tailed quolls may show a preference for preying on invasive European rabbits in certain contexts, and this could potentially be used as part of quoll reintroductions to aid rabbit population suppression and ecosystem restoration.

Additional keywords: apex predator, conservation reserve, European rabbit, invasive species, pest management, predator–prey interaction, species reintroduction.

Received 11 December 2019, accepted 27 May 2020, published online 26 June 2020

Introduction

Native predators form an important part of functioning ecosystems by affecting the population ecology of other trophic levels, including their prey. In doing so they may regulate species' populations, meaning they are less likely to become overabundant and, in turn, potentially adversely affect ecosystems (Ritchie and Johnson 2009). Conservation managers could potentially take advantage of this by using predators as a tool to help restore ecosystem function in areas that have undergone dramatic changes related to human modification of the environment (Ritchie *et al.* 2012). Previous reintroductions, such as of the grey wolf (*Canis lupus*) into Yellowstone, suggest that predator restoration can help achieve conservation and management goals for ecosystems (Fortin *et al.* 2005). The dingo (*Canis dingo*) can provide similar ecosystem services in some Australian contexts, in areas where it is not heavily persecuted, by suppressing the activity of introduced mesopredators and/or controlling large native and introduced herbivores (Letnic and Koch 2010; Wallach *et al.* 2010; Brook *et al.* 2012; Letnic *et al.* 2012).

Spotted-tailed quolls (*Dasyurus maculatus*) are the largest extant predatory marsupial on mainland Australia. Once

inhabiting large parts of eastern Australia, their range has contracted resulting from habitat loss and competition with introduced vertebrate predators (Edgar and Belcher 1995; Jones *et al.* 2001). Three genetically distinct populations of spotted-tailed quoll exist: one in northern Australia, another along the eastern coast of Australia, and one in Tasmania (Firestone *et al.* 1999). Being distributed over a large geographic area and diversity of habitat types means that spotted-tailed quolls are also able to exploit a wide variety of potential prey (Glen and Dickman 2006; Attard *et al.* 2011). Previous dietary analysis of spotted-tailed quolls has found that both arboreal and terrestrial medium-sized mammals, especially the invasive European rabbit (*Oryctolagus cuniculus*), constituted the bulk of their diet (Glen and Dickman 2006; Belcher *et al.* 2007; Jarman *et al.* 2007; Andersen *et al.* 2017). Spotted-tailed quolls are also known to consume a variety of other native prey, opportunistically foraging on birds, reptiles and insects, depending on seasonal differences in prey availability (Belcher 1995; Glen and Dickman 2006; Belcher *et al.* 2007; Andersen *et al.* 2017).

Because the spotted-tailed quoll is one of the few remaining medium-sized (mean weight of adult males 2.8–4.6 kg, and of

adult females 1.5–2 kg) native marsupial predators in Australia (Green and Scarborough 1990; Jones 1997; Belcher 2003; Körtner *et al.* 2004), understanding its diet will help inform not only its conservation and management in the wild, but also potential plans for (and outcomes of) its reintroduction. However, to date, all known dietary studies have been conducted in environments where the traditional predatory role of spotted-tailed quolls is affected by competition with invasive and/or larger native predators (feral cats, red foxes and/or dingoes), and often also a greatly diminished native prey guild due to the local and regional extinction of marsupials (Glen and Dickman 2006; Belcher *et al.* 2007; Jarman *et al.* 2007).

We examined the diet of spotted-tailed quolls in a fenced conservation reserve where locally indigenous reintroduced native mammalian species and introduced European rabbits persist, as well as native and introduced small mammals which were present before reserve construction. We aimed to identify and quantify which species were being preyed on, and compare this to previous dietary studies. Using this information we briefly discuss how spotted-tailed quolls could be used as a potential conservation tool to control rabbit populations where introduced predators are absent or are slated for eradication.

Methods

Study area

We conducted this study in Victoria's largest fenced reserve, Mt Rothwell, a 453-ha privately owned sanctuary located 65 km south-west of Melbourne, adjacent to the You Yang Ranges. Native mammalian species were successfully reintroduced into the reserve (largely between 2002 and 2005), and have since increased in densities (Rypalski, pers. obs.). Reintroduced species include: eastern barred bandicoot (*Perameles gunnii*), southern brown bandicoot (*Isoodon obesulus*), eastern quoll (*Dasyurus viverrinus*), long-nosed potoroo (*Potorous tridactylus*), rufous bettong (*Aepyprymnus rufescens*), Tasmanian pademelon (*Thylogale billardierii*), brush-tailed rock-wallaby (*Petrogale penicillata*) and red-necked wallaby (*Macropus rufogriseus*). The fat-tailed dunnart (*Sminthopsis crassicaudata*), common ringtail possum (*Pseudocheirus peregrinus*), common brushtail possum (*Trichosurus vulpecula*), black (swamp) wallaby (*Wallabia bicolor*) and eastern grey kangaroo (*Macropus giganteus*) all occur naturally in Mt Rothwell reserve. Introduced species – feral cat (*Felis catus*) and the red fox (*Vulpes vulpes*) – have been removed. The house mouse (*Mus musculus*) and black rat (*Rattus rattus*) are present; however, European rabbits were common and persist in fluctuating abundance (A. Rypalski, reserve manager, 2019, pers. comm.). Rabbits were present in all three habitat types within the reserve (remnant box woodlands (177 ha), basalt grasslands (147 ha) and granite outcrops (129 ha)) and commonly used burrows. Four captive-bred male spotted-tailed quolls (*D. maculatus*) were released into the reserve from surplus stock in 2014 and a male was added in 2015.

Scat collection and analysis

We opportunistically collected scats from intermittent targeted searches of known latrines and denning sites between June 2014 and August 2015 (a study limitation being that most scats were

collected during the cooler months, May–September). Scats were identified by their shape and appearance, and only fresh scats at each latrine site were collected. Scats that were not confidently identified were not included in the analysis. Scats were placed in a paper bag with location and date of collection recorded.

Scats were placed in an oven for 12 h at 100°C to ensure that any potential parasites were killed. Scat samples were then washed with water through a fine sieve (0.125 mm), leaving only hair, bone, feathers and any other undigested biological material. Samples were then dried for 12 h at 60°C. To identify prey we separated scats into components, including hair, scales, feathers, insects and other, and estimated their volume compared to total components to the nearest 5%.

Data analysis

We classified prey items into categories: small mammals (<500 g), medium-sized mammals (500–6999 g), large mammals (>7000 g), birds, reptiles, arthropods, and human refuse. We classified mammal remains to species level while other items were assigned broader (higher-level) categories. Grouping mammals into weight categories was based on maximum weights from Menkhorst and Knight (2001). We calculated the percentage frequency of occurrence and volume for individual prey species and prey categories. We considered these analyses together as frequency of occurrence may overestimate small items of food that occur commonly and the percentage of volume may underestimate easily digestible food items (Klare *et al.* 2011). The Brillouin index was used to ensure that scat sample size was sufficient to describe spotted-tailed quoll diet relative to the potential prey available (Brillouin 1956).

Results

In total, 80 spotted-tailed quoll scats were collected and analysed. Scats contained 13 different prey taxa, consisting of 10 mammalian species, of which eight were native (Table 1). The mean number of prey items identified in each sample was 1.42 ± 0.59 (s.d.), with 64% of scats containing a single species, 31% of scats containing two species and 5% containing three species. Mammals were the most common source of prey in terms of average volume and frequency of occurrence (99.95% and 96.49%, respectively). Medium-sized mammals comprised the largest proportion of identified species in scats (Table 1). The most commonly consumed mammal species by average volume was the European rabbit, and, to a much lesser degree, the common brushtail possum, the rufous bettong and the common ringtail possum (Table 1). Introduced mammal species (rabbits and house mice) made up 77% of the average volume of scats and 62% of the frequency of occurrence, compared with native species making up 23% of the average volume of scats and 34% of the frequency of occurrence.

Both small and large mammals made up very little of the volume of scats (<3% for both). Non-mammalian prey was exceedingly rare in quoll scats, consisting of 0.04% of the average volume, and 0.01% of the volume of scats each contained bird, reptile or invertebrate remains (Table 1). The Brillouin index of diversity of spotted-tailed quoll diet began to reach an asymptote at a sample size of ~45–50 scats (Appendix 1).

Table 1. Dietary analysis of prey found within spotted-tailed quoll (*Dasyurus maculatus*) scats from Mt Rothwell, south-eastern Australia

	<i>n</i>	Average volume (%)	Frequency of occurrence (%)
Small mammals	3	0.04	2.63
<i>Mus musculus</i>	3	0.04	2.63
Medium-sized mammals	105	97.41	92.11
<i>Oryctolagus cuniculus</i>	68	76.51	59.65
<i>Trichosurus vulpecula</i>	13	11.12	11.40
<i>Aepyprymnus rufescens</i>	6	3.69	5.26
<i>Pseudocheirus peregrinus</i>	4	3.25	3.51
<i>Perameles gunnii</i>	2	1.37	1.75
<i>Isodon obesulus</i>	7	1.19	6.14
<i>Dasyurus maculatus</i>	5	>0.01	4.39
Large mammals	2	2.51	1.75
<i>Macropus giganteus</i>	1	1.25	0.88
<i>Thylogale billardieri</i>	1	1.25	0.88
Birds	1	0.01	0.88
Reptiles	1	0.01	0.88
Arthropods	1	0.01	0.88
Human refuse	1	0.01	0.88

Discussion

The diet of spotted-tailed quolls in our study consisted primarily of medium-sized mammals, particularly the non-native European rabbit, both in terms of average volume and frequency of occurrence. In Victoria, dietary studies of spotted-tailed quolls found the most common species taken were the common brushtail possum (*Trichosurus vulpecula*), the common ringtail possum (*Pseudocheirus peregrinus*) and the European rabbit (*Oryctolagus cuniculus*) (Belcher 1995). Studies in New South Wales found that macropods and the greater glider (*Petauroides volans*) were the most common prey species (Glen and Dickman 2006; Belcher *et al.* 2007; Jarman *et al.* 2007). Our results are consistent with previous studies that have found that European rabbits can constitute an important part of spotted-tailed quoll diet, but previous studies also show that quolls differ in the reliance on this prey species depending on geographical location (Glen and Dickman 2006; Belcher *et al.* 2007; Dawson *et al.* 2007). The diet of spotted-tailed quolls in our study also included native mammals, such as common brushtail possum, common ringtail possum, rufous bettong and southern brown bandicoot, but these were relatively small components of quoll diet.

The observed preference for medium-sized mammals as prey at Mt Rothwell is supported by previous dietary analysis in the literature (Glen and Dickman 2006; Belcher *et al.* 2007; Jarman *et al.* 2007). Previous dietary studies reveal that spotted-tailed quolls will broadly favour prey groups based on weight but remain opportunistic and flexible in response to seasonal fluctuations in prey availability (Glen and Dickman 2006; Belcher *et al.* 2007). Our findings differ in some respects from previous work as rabbits constituted a very large proportion of the diet, suggesting that spotted-tailed quoll diets may focus on fewer, abundant prey species, even in cases where the diversity of potential prey is high. Selection of medium-sized mammals as prey, especially rabbits, is probably best explained by optimal foraging theory that predicts predators will choose prey based on

their availability, energetic profitability and ease of capture (Fryxell and Lundberg 1994).

The presence of large mammals in quoll diet is likely due to foraging on carrion, which has been observed previously (Glen and Dickman 2006; Belcher *et al.* 2007; Cunningham *et al.* 2018). The very low presence of birds, reptiles, and invertebrates in our study differs from other work that suggests these prey groups are important for spotted-tailed quolls (Glen and Dickman 2006; Belcher *et al.* 2007; Jarman *et al.* 2007). The lack of reliance on birds, reptiles and insects may be related to an apparent preference for abundant rabbits and scat collection occurring, in part, during cooler months when reptiles and insects are less active and available.

We found that spotted-tailed quolls preyed on a mix of both terrestrial and arboreal species. Scat analysis revealed that arboreal species constituted the greatest proportion of the diet of spotted-tailed quolls in a different study (Glen and Dickman 2006). Two arboreal species were preferred by the spotted-tailed quolls in our study, the common brushtail possum and the common ringtail possum. However, common brushtail possums within Mt Rothwell are semi-arboreal, spending large amounts of time on the ground (Linley, pers. obs.), as foxes and cats are absent. This suggests that spotted-tailed quolls are spending much of their time hunting on the ground. Changes in diet may be caused by spotted-tailed quolls adjusting to their environment to maximise energy reward of prey versus energy expended in its capture, and the absence of other competing or dominant terrestrial predator species.

Conclusion and conservation implications

The high proportion of rabbit in spotted-tailed quoll diet suggests that quolls may be a promising conservation tool, via reintroduction, for controlling rabbit populations and aiding ecosystem recovery (Pedler *et al.* 2016; Lurgi *et al.* 2018), particularly in areas free of feral cats and foxes. Adding weight to this idea is that, historically, the introduction of the rabbit into Australia was hindered due to the high predation rates by quolls (*Dasyurus* spp.) (Peacock and Abbott 2013). In Australia, rabbits reduce their activity in response to predators they have evolved with, whilst no avoidance behaviour has been observed when confronted by novel, allopatric predators (Barrio *et al.* 2010). When prey species have not coevolved with predators they have reduced antipredator responses and are more likely to be exploited by predators (Emlen 1966; Chesson 1978; Sih *et al.* 2010). We encourage spotted-tailed quoll reintroduction and rabbit suppression experiments as a positive means by which to help combat and redress Australia's poor conservation record (Woinarski *et al.* 2019).

A high proportion and amount of rabbit in the diet of spotted-tailed quolls suggests that they may prefer rabbits as a food source over abundant, sympatric native mammal prey species. Future dietary studies on spotted-tailed quolls should examine whether their diet changes before and after invasive predator control and in relation to dingo presence or absence. Our study provides the first insight into the dietary ecology of spotted-tailed quolls in the absence of introduced competitors and apex predators (feral cats, red foxes and dingoes), but where rabbits and a diverse native prey guild remain. Acknowledging the limitation of having only five male spotted-tailed quolls for scat analysis, we show, like previous studies, that quolls are generalist and flexible predators.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgements

Thanks to Mt Rothwell and its staff who helped collect data. Thanks to Mike Weston for providing helpful comments on a draft of this manuscript. This research did not receive any specific funding.

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Appendix 1. Cumulative diversity of prey species with increasing number of scat samples from spotted-tailed quolls (*Dasyurus maculatus*) at Mt Rothwell, south-eastern Australia

