

Notes on the fungal diets of four *Antechinus* species from south-eastern Australia

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ABSTRACT

Mycophagy is widespread among Australian mammals but has been poorly studied among dasyurids, with only 7 of the 61 Australian species having been shown to disperse fungi. Using spirit collections at the Australian Museum, we analysed the faecal material of brown antechinus (*Antechinus stuartii*), yellow-footed antechinus (*A. flavipes*), swamp antechinus (*A. minimus*) and mainland dusky antechinus (*A. mimes*) collected from south-eastern Australia between 1970 and 2003. All species consumed fungi, with a total of 19 fungal taxa detected. This is the first published record of mycophagy by *A. minimus* and *A. mimes*. We recommend that further research is undertaken on the fungal diets of dasyurids, as many species are likely performing important ecosystem functions through the consumption and dispersal of fungi.

Keywords: Dasyuridae, diet, fungal ecology, mammal ecology, marsupial, mycophagous, mycorrhizal, spore dispersal.

Introduction

Mycophagous mammals perform an important ecosystem service by consuming and dispersing mycorrhizal fungi, particularly hypogeous fungi which fruit underground and requires manual dispersal by animals (Fogel and Trappe 1978). Fungal spores remain viable after passage through the gut, with digestion often increasing the likelihood of mycorrhiza formation (Claridge *et al.* 1992; Caldwell *et al.* 2005; Ori *et al.* 2021). Mycorrhizal fungi form symbiotic relationships with plants, increasing nutrient and water uptake (Allen 2007), improving drought tolerance (Rapparini and Peñuelas 2014) and enhancing disease resistance (Branzanti *et al.* 1999). At an ecosystem level, mycorrhizal fungi help to prevent erosion (Rillig and Mummey 2006), act as carbon decomposers (Talbot *et al.* 2008; Simard and Austin 2010) and convert soil and atmospheric nitrogen into a usable form for plants (Maser *et al.* 2008). Hence, the dispersal of mycorrhizal fungi by mycophagous mammals is important for maintaining ecosystem health.

Fungal dispersal via mycophagy can take place over a scale of several metres to kilometres and is vital for transporting fungal spores to uncolonised habitats and across environmental gradients (Cázares and Trappe 1994; Ashkannejhad and Horton 2005; Danks *et al.* 2020; Elliott *et al.* 2024). Mycophagous mammals contribute differentially to the dispersal of fungi, depending on the diversity, quantity and composition of the spores that they consume, as well as the distance that spores are dispersed (Schickmann *et al.* 2012). Given that different species inhabit different microhabitats and exhibit behavioural differences that affect the location of spore deposition, a diverse community of mycophagous mammals is beneficial to the ecosystem (Vernes *et al.* 2015).

Mycophagy has been widely documented among Australian mammals, with at least 88 species (74 native, 14 introduced) recorded to consume fungi (Gaskin 2002; Nuske *et al.* 2017; Elliott *et al.* 2022, 2023; Nest *et al.* 2023). However, there are likely still many species for which mycophagy remains undiscovered, given that fungi can be difficult to detect in the diet if not specifically targeted (Allison *et al.* 2006). Fungal specialists, species for which fungi can comprise up to 90% of their diet, have been the subject of many studies due to their significant roles as fungal dispersers and ecosystem engineers

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(Nuske *et al.* 2017). One family that has received relatively little attention as mycophagists is the Dasyuridae, a family comprising 81 extant species of marsupial carnivores and insectivores found only in Australia (61 species) and New Guinea (22 species) (AMTC 2024). Whilst dasyurids are primarily regarded as carnivorous or insectivorous, there is increasing evidence that fungi forms part of their diet, either primarily or secondarily through the consumption of mycophagous prey (Nest *et al.* 2023).

In this study, we examined the fungal dietary components of four species of antechinus found in south-eastern Australia, the brown antechinus (*Antechinus stuartii*), yellow-footed antechinus (*A. flavipes*), swamp antechinus (*A. minimus*) and mainland dusky antechinus (*A. mimetes*). *A. stuartii* and *A. flavipes* have been previously reported to consume fungi, but our understanding of their fungal diets remains limited (Elliott *et al.* 2022). We aimed to provide further evidence of mycophagy by these two species and to determine whether *A. minimus* and *A. mimetes* also consume and disperse mycorrhizal fungi.

Methods

Antechinus specimens were collected between June 1970 and July 2003 from sites in NSW, Victoria and the ACT, and are currently stored in the wet collection at the Australian Museum in Sydney. Australian Museum specimen numbers and collection data are listed in Appendix 1. For dietary analysis, we followed the same methods used by Elliott and Vernes (2021), which involved using forceps to remove faecal material from the rectum where possible. Alternatively, we made a small incision in the stomach and used forceps to extract a small sample of stomach contents; these were placed in a vial containing 70% alcohol. At the University of New England, a small amount of these stomach contents was then prepared as permanent slide mounts using Safety Mount No. 7 (Thermo Fisher Scientific Australia). Slides were systematically scanned under an Olympus CX41 light microscope at 400× magnification, with 10 random fields of view examined per slide. Morphological characteristics such as size, shape, ornamentation, symmetry and wall-thickness were used to identify spore types to the lowest taxonomic level possible. Several spore types could not be reliably identified, but were distinctive enough to be classed as a separate dietary fungal taxon and were classed as 'Unknown 1', 'Unknown 2' etc. We only list fungal taxa that appeared in at least two fields of view for each sample.

Results and discussion

Fungal spores were detected in the diet of all four antechinus species, with 37.5% of individuals sampled consuming fungi. Fungi were most frequently detected in the diet of

A. minimus (3/3 samples) followed by *A. stuartii* (5/10 samples), *A. flavipes* (3/12 samples) and *A. mimetes* (1/7 samples). We identified 19 fungal taxa consumed by the four antechinus species (Table 1). The diet of *A. stuartii* contained the greatest number of fungal taxa and *A. mimetes* the fewest (Table 1), but the limited sample sizes and large variation in collection locations, season and local climates preclude any further conclusions.

As antechinus and other dasyurids consume many mycophagous prey species, including coleopterans, dipterans and larger vertebrate prey such as rodents, it is likely that they are consuming some fungal spores incidentally from the gut contents of their prey (Elliott *et al.* 2023; Santamaria *et al.* 2023). Given the presence of hypogeous fungal taxa such as *Hydnangium*, *Hymenogaster* and *Mesophellia* in the diets of antechinus, deliberate excavation and consumption of sporocarps must be occurring, either by antechinus or their mycophagous prey. Large numbers of spores were observed in several of the samples in this study, which would suggest at least some primary mycophagy is occurring, a finding common to previous research (Vernes *et al.* 2015; Nest *et al.* 2023). Regardless of whether consumption is primary or secondary, antechinus are still performing an important ecosystem service as fungal dispersers.

Fungi have been reported in the diet of *A. stuartii* in several prior studies; with Vernes and Dunn (2009) recording one fungal taxon in 1/17 faecal samples, O'Malley (2013) recording 28 fungal taxa in 17/33 faecal samples, Vernes *et al.* (2015) recording 23 fungal taxa in 61 faecal samples, Elliott *et al.* (2023) recording fungal spores in 1/3 faecal samples and Nest *et al.* (2023) recording 30 fungal taxa in 37/44 faecal samples. *A. flavipes* has also been previously reported to consume fungi; with Gaskin (2002) recording an average of 70 fungal spores and 13 spore types per faecal sample, Nuske *et al.* (2018) recording fungi in 1/1 faecal samples, York *et al.* (2022) recording fungi in 7/25 faecal samples and Nest *et al.* (2023) recording 36 fungal taxa in 50/76 faecal samples. Fungal consumption by *A. minimus* has been mentioned in a previous study (K. Annett pers. comm. in Allison *et al.* 2006), but this is the first definitive evidence of mycophagy by this species. This is also the first record of mycophagy for *A. mimetes*. The Atherton antechinus (*A. godmani*) is the only other antechinus species for which fungal consumption has been recorded (Reddell *et al.* 1997, 1/14 faecal samples). Within the Dasyuridae more broadly, the common dunnart (*Sminthopsis murina*, 1/1 faecal samples; Nest *et al.* 2023), Gilbert's dunnart (*S. gilberti*, average of 70 fungal spores and 17 spore types per faecal sample) and western quoll (*Dasyurus geoffroii*, average of 210 fungal spores and 18 spore types per faecal sample) are the only other known fungal consumers (Gaskin 2002).

The four antechinus species sampled in this study are regarded as generalist carnivores which primarily feed on invertebrates including Coleopterans (beetles), Araneae (spiders), Lepidopterans (moths and butterflies) and Blattodeans

Table 1. Fungal taxa detected in the diets of four antechinus species from south-eastern Australia.

Order	Taxon name	Mammal species			
		<i>A. flavipes</i> <i>n</i> = 12	<i>A. mimetes</i> <i>n</i> = 7	<i>A. minimus</i> <i>n</i> = 3	<i>A. stuartii</i> <i>n</i> = 10
Basidiomycota					
Agaricales	Bolbitiaceae 1		x	x	
	Bolbitiaceae 2				x
	<i>Cortinarius</i> 1				x
	<i>Cortinarius</i> 2	x			
	<i>Cortinarius</i> 3				x
	<i>Cortinarius</i> 4				x
	<i>Cortinarius</i> 5				x
	<i>Descolea</i>	x			
	<i>Hydnangium</i>	x			
	<i>Hymenogaster</i>			x	x
Boletales	<i>Boletellus</i>	x			x
	Boletoid			x	x
	<i>Scleroderma</i> 1				x
	<i>Scleroderma</i> 2				x
Hysterangiales	<i>Mesophellia</i>				x
Russulales	Russulaceae				x
Unidentified taxa					
	Unknown 1		x		x
	Unknown 2			x	x
	Unknown 3		x		
Total taxa consumed	19	4	3	4	14

(cockroaches) (Hall 1980; Fox and Archer 1984; Green 1989; Sale *et al.* 2006; York *et al.* 2022). However, nectar-feeding can be very common in some locations (Goldingay *et al.* 1991) and they have also been recorded feeding on seeds, other plant material, reptiles, amphibians, birds and other small mammals, including members of their own species (Green 1989; Allison *et al.* 2006; Glen and Dickman 2014; Baker *et al.* 2024). This generalist foraging strategy is shared with many of the Dasyuridae, including much larger species like quolls (Jarman *et al.* 2007; Glen *et al.* 2010; Glen and Dickman 2014). Given the high diversity, abundance and availability of fungi across much of Australia (Bougher and Lebel 2001), it is possible that many of the generalist foraging species within the Dasyuridae consume fungi but have yet to be appropriately studied to be identified as mycophagous.

We have provided the first evidence of mycophagy for *A. mimetes* and *A. minimus*, but further investigation into the fungal diets of these species is recommended due to the small sample sizes in this study and limited prior research. Given the rich diversity and abundance of dasyurids in

Australia, further studies should be undertaken to determine the extent of mycophagy within the family, as many species of dasyurids may be performing an important role as fungal dispersers. Research determining whether fungal consumption and dispersal distance varies between species would further elucidate the roles of dasyurids as fungal dispersers. Future research on the viability of fungal spores after dispersal by primary and secondary consumers would also improve our understanding of mammal–fungal relationships.

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Data availability. All available data is presented in the paper.

Conflicts of interest. Karl Vernes is an Associate Editor of *Australian Mammalogy* but was not involved in the peer review or any decision-making process for this paper. The authors have no further conflicts of interest to declare.

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Appendix 1. Collection data for antechinus specimens examined in this study

Species	Sex	Australian Museum no.	Location	Date
<i>Antechinus flavipes</i>	Male	M.11743	Australia, New South Wales, Bowna and Table Top area, 10 km NE of Albury (35°56'S, 147°05'E)	17/11/1977
	Female	M.11751	Australia, New South Wales, Cumberland, Baradine (30°52'S, 148°58'E)	09/06/1970
	Male	M.12425	Australia, New South Wales, Balargorang Wildlife Reserve, 3 km SE of Mudgee (32°38'S, 149°36'E)	08/01/1982
	Female	M.12525	Australia, New South Wales, Pilliga East State Forest, 65 km N of Coonabarabran (30°48'S, 149°35'E)	12/06/1982
	Male	M.12526	Australia, New South Wales, Pilliga East State Forest, 65 km N of Coonabarabran (30°48'S, 149°35'E)	12/06/1982
	Female	M.12527	Australia, New South Wales, Pilliga East State Forest, 65 km N of Coonabarabran (30°21'S, 148°53'E)	17/06/1982
	Female	M.12533	Australia, New South Wales, Mountain Vale Property, near Murrumbateman (34°58'S, 149°02'E)	15/07/1978
	Female	M.37346	Australia, New South Wales, 4 km NW of West Wyalong 'Racecourse Farm' (33°55'55"S, 147°12'04"E)	April 2001
		M.37549	Australia, New South Wales, Wagga Wagga (35°07'S, 147°22'E)	
	Female	M.38537	Australia, New South Wales, Mendooran Farm (31°48'54"S, 149°07'05"E)	23/07/2003
<i>Antechinus mimetes</i>	Female	M.38575	Australia, New South Wales, Inverell Resource Centre, Warialda Rd, Inverell (-29.774480, 151.100139)	12/12/2002
	Female	M.38576	Australia, New South Wales, Middle Creek, Goonooowigall Reserve Inverell	12/12/2002
	Female	M.25750	Australia, New South Wales, Smiggin Holes, Kosciuszko National Park (36°24'S, 148°26'E)	
	Female	M.25751	Australia, Australian Capital Territory, Bushranger Creek (B4)	21/07/1981
	Female	M.25753	Australia, New South Wales, Smiggin Holes, Kosciuszko National Park (36°24'S, 148°26'E)	
	Male	M.26059	Australia, New South Wales, Nadgee Nature Reserve, Newtons Visitors Centre (37°22'S, 149°57'E)	18/01/1973
	Male	M.26061	Australia, New South Wales, Nadgee Nature Reserve, Newtons Visitors Centre (37°22'S, 149°57'E)	18/01/1973
<i>Antechinus minimus</i>	Male	M.26062	Australia, New South Wales, Nadgee Nature Reserve, Newtons Visitors Centre (37°22'S, 149°57'E)	18/01/1973
	Male	M28315	Australia, New South Wales, New England National Park (30°31'13"S, 152°23'25"E)	05/02/1992
	Female	M.18739	Australia, Victoria, Cape Liptrap near Lighthouse (38°54'S, 145°55'E)	13/05/1981
	Male	M.18741	Australia, Victoria, Cape Liptrap near Lighthouse (38°54'S, 145°55'E)	14/05/1981
	Male	M.23622	Australia, Victoria, 500M SW of Cape Liptrap Lighthouse (38°54'S, 145°55'E)	15/05/1981
<i>Antechinus stuartii</i>	Female	M.36531	Australia, New South Wales, Robertson (34°35'24"S, 150°35'35"E)	09/06/1992
	Female	M.36532	Australia, New South Wales, Robertson (34°35'24"S, 150°35'35"E)	09/06/1992
	Female	M.36533	Australia, New South Wales, Robertson (34°35'24"S, 150°35'35"E)	09/06/1992
	Male	M.36535	Australia, New South Wales, Tomago (32°48'S, 151°42'E)	20/05/1999
	Male	M.36960	Australia, New South Wales, Gap road Woodburn, Lismore district (35°22'23"S, 150°22'34"E)	19/07/2002
	Male	M.39012	Australia, New South Wales, Werrikimbe National Park/Carrai Plateau (31°12'S, 152°18'E)	03/08/1998

(Continued on next page)

Species	Sex	Australian Museum no.	Location	Date
	Female	M.39017	Australia, New South Wales, Royal National Park/Heathcote National Park area	27/08/2000
	Male	M.39018	Australia, New South Wales, Royal National Park/Heathcote National Park area	27/08/2000
	Male	M.39021	Australia, New South Wales, Royal National Park/Heathcote National Park area	01/09/2000
	Male	M.39022	Australia, New South Wales, Royal National Park/Heathcote National Park area	01/09/2000