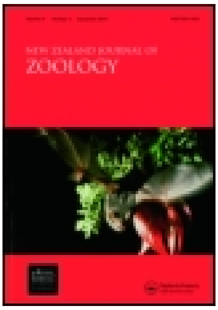

New Zealand Journal of Zoology
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tnzz20

No evidence that brushtail possums (Trichosurus vulpecula) forage on dung beetles (Coleoptera: Scarabaeidae) in New Zealand

SA Forgie[a], JJ Dymock[b] & DM Tompkins[c]
[a] Landcare Research, Auckland, New Zealand
[b] 29A Seaview Rd, Cable Bay, Taipa 0420, Northland, New Zealand
[c] Landcare Research, Dunedin, New Zealand
Published online: 10 Feb 2014.

New Zealand Journal of Zoology, 2014
http://dx.doi.org/10.1080/03014223.2013.854815

RESEARCH ARTICLE

No evidence that brushtail possums (*Trichosurus vulpecula*) forage on dung beetles (Coleoptera: Scarabaeidae) in New Zealand

SA Forgie[a]*, JJ Dymock[b] and DM Tompkins[c]

[a]*Landcare Research, Auckland, New Zealand;* [b]*29A Seaview Rd, Cable Bay, Taipa 0420, Northland, New Zealand;* [c]*Landcare Research, Dunedin, New Zealand*

(*Received 10 July 2013; accepted 27 September 2013*)

Additional species of exotic dung beetle have been approved for unconditional release onto New Zealand pastures by New Zealand's Environmental Protection Authority. We investigated whether brushtail possums (*Trichosurus vulpecula*) forage on dung beetles; such behaviour could have implications for efforts to control bovine tuberculosis in New Zealand. The gut contents of possums trapped on farmland adjacent to pastures with abundant Mexican dung beetles (*Copris incertus*) were screened for dung beetle parts. While high proportions of grass in possum guts (up to 80% of total contents) indicated extensive foraging activity on pasture, no dung beetle parts were recovered. With no evidence that possums use dung beetles as a food source, we conclude that releases of additional dung beetle species are unlikely to alter possum foraging behaviour.

Keywords: bovine tuberculosis; diet; disease risk; dung beetle; gut content; invertebrate; brushtail possum

Introduction

Eleven exotic species of dung-burying beetle (Scarabaeinae) have been approved for release onto New Zealand agricultural pastures by New Zealand's Environmental Protection Authority (EPA; ERMA 2010). These species will join four previously introduced species—the Mexican dung beetle (*Copris incertus*) (Fig. 1), two Australian species (*Onthophagus granulatus* and *Onthophagus posticus*), and one South African species (*Epirinus aeneus*). *Copris incertus* has persisted in Northland since its intentional introduction in 1956 (Thomas 1960); *O. granulatus* and *O. posticus*, accidentally introduced over a century ago, are now patchily distributed over much of the country (Emberson & Matthews 1973); *E. aeneus* was also accidentally introduced and is possibly established near Christchurch (Dymock 1993). Approval for release was based on the benefits of dung beetle activity on agricultural land (Fincher 1981; Dymock 1993; Nichols et al. 2008; ERMA 2010). These include reductions in nutrient runoff, waterway pollution, greenhouse gas emissions and parasitism of livestock, as well as increased soil health and fertility, all principally due to the rapid mechanical transport of cattle dung underground for the creation of brood balls (Hanski & Cambefort 1991). The rationale for releasing 11 species is so that each pasture type/climate zone in New Zealand will be able to support at least one of them (DBRSG 2010; Edwards 2010).

A key component of the EPA review process was a risk assessment of the possible adverse effects of release, including the potential for: 1. greater nutrient leaching leading to increased eutrophication, 2. the displacement of native beetle species, and 3. increases in some parasites (DBRSG 2010). These effects were considered either

*Corresponding author. Email: forgies@landcareresearch.co.nz

Figure 1 Mexican dung beetle (*Copris incertus*), male. Montage Image courtesy of Birgit Rhode, NZAC, Landcare Research, 2012.

unlikely or negligible based on: 1. international literature, 2. no observed or published adverse effects of dung beetle introductions to New Zealand in over half a century, and 3. all species chosen for release having both narrow habitat preferences (open grassland) and specific host preferences (ungulate dung; DBRSG 2010, and references therein). Over 20 exotic dung beetle species have been introduced to both Australia and the USA, with no adverse effects being reported (DBRSG 2010). The approval for release by the EPA was therefore made unconditionally (i.e. with no requirement for controls of any form).

Despite the risk assessment process, the decision to grant approval for unconditional release has been questioned. Concerns raised include the spread of infectious diseases (Tompkins et al. 2012), with a key issue being the potential for increased livestock disease through influences on the transmission of *Mycobacterium avium* subsp. *pseudotuberculosis* (MAP, the causative agent of Johne's disease) and *Mycobacterium bovis* (the causative agent of bovine tuberculosis, TB). One potential mechanism is that dung beetle presence may affect the feeding behaviour of brushtail possums (*Trichosurus vulpecula*), the primary wildlife reservoir of TB in New Zealand (Clout & Ericksen 2000; Nugent 2011).

Possums living in forest within foraging range of pasture obtain at least 20% of their food from introduced grasses and clover (Gilmore 1967; Harvie 1973; Coleman et al. 1985; cited in Nugent et al. 2000), with their diet frequently including invertebrates (Fitzgerald 1976; Clout 1977; Cowan & Moeed 1987; Owen & Norton 1995; Nugent et al. 2000; Glen et al. 2012). Dung beetle presence on pasture could therefore influence their behaviour, with implications for disease transmission to cattle. While captive trials have shown that possums most likely will not forage for dung beetles (Tompkins et al. 2012), the captive setting means that this finding may not be representative of the wild. Hence, here we investigate further the risk of dung beetle presence affecting possum foraging behaviour through a diet survey of free-living individuals in an area of high dung beetle availability.

Methods

Study sites and dung beetle survey

The Mexican dung beetle (Fig. 1) was chosen as our test prey species because it is highly abundant in pastures around Whangarei, Northland, where it was introduced. Dung beetle activity and abundance were surveyed at three sites in Maunu, southwest Whangarei (35°45′S, 174°17′E). Each site (Site 1, Maunu Heritage Park; Site 2, opposite Maunu Tennis Club; Site 3, Te Hape Road) comprised pasture interspersed with bush fragments. The sites were surveyed in April 2013 when beetles are still seasonally active (Blank et al. 1983; Forgie, Dymock pers. obs.).

Chemical odours emitted from fresh cowpats attract dung beetles. The number of fresh cowpats ranged from 80/ha and 85/ha at sites 1 and 2, respectively, to 150/ha at site 3. A total of 156 cowpats up to 1 week old were assessed for signs of beetle activity and abundance by counting the number of: 1. beetle-created soil extrusions around each cowpat, 2. tunnels around and under each cowpat, and 3. beetles present in either the tops of tunnels or within each cowpat. Additionally, each cowpat was checked for mechanical disturbance from possum foraging (or that of other vertebrates, including birds).

Brushtail possum trapping

A professional possum trapper was commissioned to trap possums across the sites. Humane kill-traps were placed in native trees along the fringes of bush patches adjacent to surveyed pastures at sites 1 and 3, and set for two consecutive nights shortly after dung beetle surveys were carried out. Traps were not set at site 2 because the majority of cowpats surveyed in the paddock adjacent to the proposed trap line were shredded and no longer contained *C. incertus* adults.

Gut content analysis

The contents were extracted from the stomach, small intestine, caecum and colon of 30 trapped possums (Table 2), using established methods (Sweetapple & Nugent 1998). The contents of each stomach were emptied into an Endecott sieve (0.5-mm aperture size), rinsed with water to remove small pieces of leaf material, and assessed for the presence of pasture species clover, rye and kikuyu fragments (quantified as a proportion of stomach contents to the nearest 5%). Contents from the rest of the digestive tract were combined with the stomach contents, rinsed, emptied into a shallow white plastic container, and immersed in water for examination of floating or sunk invertebrate fragments. Fragments were identified where possible using a Leica MZ7 stereomicroscope and diagnostic keys and comparisons with reference material held in the New Zealand Arthropod Collection. A subsample of material from each gut, including any associated invertebrates, was preserved in 95% ethanol. Prevalence statistics (and 95% confidence intervals) were calculated in OpenEpi v3.01 (Dean et al. 2013).

Results

Dung beetle survey

The colonization of cowpats by Mexican dung beetles varied across the three sites (Table 1). Site 1 cowpats were recently colonized (i.e. less than 1 day) with little soil extrusion on their borders and relatively few tunnels underneath; site 2 cowpats were completely shredded by dung beetle activity and weathered by rain at least 5 days post-colonization; site 3 cowpats were colonized for an intermediate time (an estimated 2–4 days) and with substantial soil extrusion on their borders and numerous tunnels beneath. Only one cowpat (at site 3) showed any sign of mechanical disturbance from foraging by an unknown animal, with its crust divided into four.

Thirty of 49 fresh to 1-week-old cowpats examined at site 1 contained a total of 141 dung beetles. Ninety-four dung beetle tunnels were observed beneath 32 of the cowpats (including the 30 fresh to 1-week-old cowpats), whereas only four of the cowpats had soil extrusions on their borders. All but two of the 25 cowpats examined at site 2 were weathered by rain and shredded by dung beetle activity; nevertheless, eight of the cowpats contained a total of 46 dung beetles. Seventy-five of the 82 cowpats examined at site 3 had soil extrusions on their borders, of which 53 contained a total of 159 dung beetles. Only four of the cowpats examined at site 3 did not have any tunnels underneath, with 438 tunnels observed beneath the other 78.

Gut content analysis

No dung beetle remains (exotic or native) were found in the gut contents of any of the 30 possums examined (Table 2). The 95% Fisher Exact (Clopper–Pearson) confidence interval for the proportion of possums foraging on dung beetles in the scenario examined was 0–12%. Other invertebrate taxa occurred in the gut contents of 19 (63%, 95% confidence interval 44–80%) possums. The lack of dung beetles in the diet contrasts with the grass content: 18 of the individuals examined had been feeding on pasture, with pasture grass species

Table 1 Findings of the Mexican dung beetle (*Copris incertus*) survey at three sites in Maunu, Whangarei.

Site 1				Site 2			Site 3				Site 3 continued			
cowpat	soil extrusions	tunnels	dung beetles	cowpat	soil extrusions	dung beetles	cowpat	soil extrusions	tunnels	dung beetles	cowpat	soil extrusions	tunnels	dung beetles
1	0	0	0	1	shredded	14	1	4	5	5	51	2	2	0
2	0	6	1	2	shredded	10	2	4	4	0	52	1	1	0
3	0	5	1	3	shredded	7	3	3	3	0	53	4	5	0
4	0	3	0	4	shredded	1	4	2	2	1	54	1	1	1
5	0	10	1	5	shredded	1	5	1	4	3	55	4	4	0
6	0	0	0	6	shredded	2	6	4	6	0	56	0	0	1
7	0	0	0	7	shredded	9	7	2	6	0	57	1	1	1
8	0	0	8	8	shredded	0	8	5	5	0	58	0	2	1
9	0	8	0	9	1	0	9	2	3	0	59	0	0	1
10	0	0	0	10	shredded	0	10	1	2	0	60	4	9	3
11	0	2	1	11	shredded	0	11	2	2	0	61	4	4	3
12	0	0	0	12	shredded	0	12	4	4	0	62	3	3	1
13	0	3	3	13	1	0	13	4	4	0	63	7	9	2
14	0	2	2	14	shredded	0	14	4	5	0	64	7	8	1
15	1	3	3	15	shredded	0	15	7	10	0	65	3	4	2
16	0	3	3	16	shredded	2	16	4	7	0	66	5	5	4
17	0	5	4	17	shredded	0	17	4	2	1	67	6	15	6
18	0	2	2	18	shredded	0	18	1	1	1	68	5	12	3
19	0	10	20	19	shredded	0	19	3	8	1	69	shredded	4	1
20	0	0	0	20	shredded	0	20	5	5	2	70	3	7	2
21	0	0	0	21	shredded	0	21	4	4	0	71	2	3	3
22	0	4	3	22	shredded	0	22	0	4	2	72	4	5	3
23	1	1	2	23	shredded	0	23	0	0	2	73	6	8	0
24	1	3	5	24	shredded	0	24	5	6	0	74	5	6	1
25	0	0	0	25	shredded	0	25	4	8	0	75	0	0	3
26	0	1	1				26	4	10	0	76	4	5	0
27	0	0	1	***Total***	**2**	**46**	27	5	10	2	77	3	5	4
28	0	0	2				28	0	6	9	78	1	1	2
29	0	0	2				29	4	5	3	79	2	6	2
30	1	2	7				30	4	7	0	80	8	10	1
31	0	0	4				31	3	8	4	81	3	3	0

Table 1 (*Continued*)

Site 1				Site 2			Site 3				Site 3 continued			
cowpat	soil extrusions	tunnels	dung beetles	cowpat	soil extrusions	dung beetles	cowpat	soil extrusions	tunnels	dung beetles	cowpat	soil extrusions	tunnels	dung beetles
32	0	0	0				32	5	10	6	82	5	6	2
33	0	1	14				33	4	10	3				
34	0	0	1				34	3	3	1	***Total***	**270**	**438**	**159**
35	0	2	4				35	6	7	0				
36	0	0	0				36	7	8	0				
37	0	2	13				37	5	6	4				
38	0	0	0				38	4	5	4				
39	0	5	11				39	3	4	1				
40	0	6	15				40	4	4	2				
41	0	0	0				41	1	2	11				
42	0	0	3				42	2	3	7				
43	0	0	0				43	shredded	15	4				
44	0	0	0				44	shredded	20	14				
45	0	0	1				45	3	4	0				
46	0	0	0				46	3	4	7				
47	0	0	0				47	7	8	2				
48	0	0	0				48	2	2	1				
49	0	5	3				49	6	10	0				
							50	3	3	2				
Total	**4**	**94**	**141**											

Table 2 Gut contents of brushtail possums (*Trichosurus vulpecula*) trapped at Maunu, Whangarei, showing grass (%), Mexican and native dung beetles (DB), and other invertebrates.

Sample #	Grass %	Mexican DB	Native DB	Other invertebrates
1	20	0	0	2× stick insects (1× body: *Clitarchus hookeri*, 1× leg fragments: *Clitarchus* sp. or *Acanthoxyla* sp.), 1× ant (*Pachycondyla* sp. (native))
2	50	0	0	3× beetles (2× fungal feeding Scaphidiinae: *Brachynopus latus;* 1× weevil, *Mandalotus* sp.)
3	60	0	0	15× ants (*Prolasius advenus* (native))
4	0	0	0	1× ant (*Prolasius advenus*), 1× stick insect body fragments (*Acanthoxyla* sp.)
5	20	0	0	0
6	0	0	0	2× beetle fragments (Steel blue ladybird: *Halmus chalybeus*)
7	10	0	0	13× ants (*Prolasius advenus*)
8	15	0	0	1× moth larva (Noctuidae: Indet.)
9	5	0	0	0
10	0	0	0	1× stick insect leg fragments (*Clitarchus* sp. or *Acanthoxyla* sp.)
11	0	0	0	0
12	0	0	0	0
13	0	0	0	1× aphid nymph (Aphididae: Indet.)
14	50	0	0	1× fly (*Hyberpygia varia*)
15	10	0	0	0
16	0	0	0	0
17	0	0	0	1× ant (*Pachycondyla* sp.)
18	20	0	0	7× ants (*Prolasius advenus*), 2× gnats (Diptera: Mycetophilidae: Indet.)
19	0	0	0	0
20	0	0	0	0
21	20	0	0	1× stick insect leg fragments (*Clitarchus* sp. or *Acanthoxyla* sp.)
22	10	0	0	1× fly leg (Syrphidae: *Eristalis* sp.)
23	0	0	0	0
24	40	0	0	1× stick insect leg fragments (*Clitarchus* sp. or *Acanthoxyla* sp.)
25	0	0	0	1× stick insect body fragments (*Acanthoxyla* sp.), 1× weevil (*Microcryptorhynchus* sp.)
26	60	0	0	1× stick insect body fragments (*Acanthoxyla* sp.)
27	70	0	0	1× beetle fragments (*Odontria* sp.)
28	40	0	0	1× mite (Oribatidae: Indet.)
29	80	0	0	0
30	20	0	0	0

accounting for 5–80% of their stomach contents (Table 2).

Discussion

Several studies to date have documented invertebrates in brushtail possum diets (through either gut content or scat analysis). For example, Fitzgerald (1976) reported 1–8% occurrence of invertebrates in 4 years of sampling, Glen et al. (2012) reported 16% occurrence, Rickard (1996; cited in Nugent et al. 2000) reported 17% occurrence, Cowan & Moeed (1987) reported 45% occurrence, and Clout (1977) reported fly larvae in 30 of 31 possum stomachs. The wide taxonomic spread of observed species strongly suggests that possum predation on invertebrates is commonplace (although there is probably some co-ingestion with plant material). With small amounts of invertebrate remains identified in 63% of 30 possum gut contents in our study, our results concur with previous studies (Table 2).

Invertebrates recovered from possum gut contents in our study covered a range of taxa, from smaller species (including aphids, mites and ants) to larger species (including weevils, [non-dung] beetles and stick insects). Although our dung beetle surveys show a high abundance of Mexican dung beetles in pasture adjacent to where possums were trapped (Table 1), plus the fact that the grass content of the trapped possum guts demonstrated that they were foraging on pasture (Table 2), no dung beetle remains were recovered. With the Mexican dung beetle being a medium-sized beetle (12–15 mm, i.e. within the size range of the invertebrate species recovered from possum guts) that is active at night and particularly abundant in spring and late summer/early autumn, the high prevalence of other invertebrates in our gut content analysis suggests that the association of dung beetles with cattle dung makes them unattractive to possums. This hypothesis is supported both by the negligible observed disturbance of cowpats in the possums' foraging range, and by the previous captive trial of Tompkins et al. (2012), in which cowpats containing Mexican dung beetles were also not disturbed.

There are a few reports of dung beetle predation by mammals and birds (Obuch & Kristin 2004; Sleeman & Hutton 2005; cited in Piñero 2007), so we cannot be certain that possums will never eat dung beetles. However, there is now mounting evidence that any such occurrence is likely to be occasional at best. With the Mexican dung beetle being highly active and of medium–large body size, this species is a good model organism that is representative of the dung beetles approved by the EPA for unconditional release onto New Zealand pastures. Our study confirms that the release of new dung beetle species onto New Zealand pasture is unlikely to alter possum foraging behaviour.

Acknowledgements

The authors would like to thank Stephen Allen for setting trap lines and supplying possums. Thanks also to Phil Cowan, Grant Norbury, Al Glen and an anonymous referee for useful comments on this manuscript, and to Chris Winks, Darren Ward, Robert Hoare, Richard Leschen and Thomas Buckley for invertebrate identifications. This study was kindly supported by Northland Regional Council Envirolink Advice Grant #1296-NLRC161.

References

Blank RH, Black H, Olson MH 1983. Preliminary investigations of dung removal and flight biology of the Mexican dung beetle *Copris incertus* in Northland (Coleoptera: Scarabaeidae). New Zealand Entomologist 7: 360–364.

Clout MN 1977. The ecology of the possum (*Trichosurus vulpecula* Kerr) in *Pinus radiata* plantations. Unpublished PhD Thesis. University of Auckland, Auckland, New Zealand.

Clout M, Ericksen K 2000. Anatomy of disastrous success; the brushtail possum as an invasive species. In: Montague TL ed. The Brushtail Possum: biology, impact and management of an introduced marsupial. Lincoln, Canterbury, New Zealand. Manaaki Whenua Press. Pp. 1–9.

Coleman JD, Green WQ, Polson JG 1985. Diet of brushtail possums over a pasture-alpine gradient in Westland, New Zealand. New Zealand Journal of Ecology 8: 21–35.

Cowan PE, Moeed A 1987. Invertebrates in the diet of brushtail possums, *Trichosurus vulpecula*, in lowland podocarp/mixed hardwood forest, Orongorongo Valley, New Zealand. New Zealand Journal of Zoology 14: 163–177.

Dean AG, Sullivan KM, Soe MM 2013. OpenEpi v.3.1: open source epidemiologic statistics for public health, version. http://www.openepi.com (updated continuously, accessed 6 April 2013).

Dung Beetle Release Strategy Group (DBRSG) 2010. Importation and release of up to 10 beetles (Scarabaeinae) to bury livestock waste. Wellington, ERMA Application for Approval.

Dymock JJ 1993. A case for the introduction of additional dung burying beetles (Coleoptera: Scarabaeidae) into New Zealand. New Zealand Journal of Agricultural Research 36: 163–171.

Edwards P 2010. Biological control of pastoral dung in New Zealand. A report on the climatic suitability of exotic dung beetle species for introduction to New Zealand. Landcare Australia. 39 p.

ERMA 2010. Environmental risk management authority decision: application ERMA200599. Wellington,

New Zealand, Environmental Risk Management Authority.
Emberson RM, Matthews EG 1973. Introduced Scarabaeinae (= Coprinae) (Coleoptera) in New Zealand. New Zealand Entomologist 5: 346–350.
Fincher GT 1981. The potential value of dung beetles in pasture ecosystems. Journal of the Georgia Entomological Society 16: 316–333.
Fitzgerald AE 1976. Diet of the possum *Trichosurus vulpecula* (Kerr) in the Orongorongo valley, Wellington, New Zealand, in relation to food-plant availability. New Zealand Journal of Zoology 3: 399–419.
Glen AS, Byrom AE, Pech RP, Cruz J, Schwab A, Sweetapple PJ, et al. 2012. Ecology of bushtail possums in a New Zealand dryland ecosystem. New Zealand Journal of Ecology 36: 29–37.
Gilmore DP 1967. Foods of the Australian possum (*Trichosurus vulpecula* Kerr) on Banks Peninsula, Canterbury, and a comparison with other selected areas. New Zealand Journal of Science 10: 235–279.
Hanski I, Cambefort Y eds 1991. Dung Beetle ecology. Princeton, NJ, Princeton University Press. 481 p.
Harvie AE 1973. Diet of the possum (*Trichosurus vulpecula* Kerr) on farmland northeast of Waverley, New Zealand. Proceedings, New Zealand Ecological Society 20: 48–52.
Nichols E, Spector S, Louzada J, Larsen T, Amezquita S, Favila ME 2008. Ecological functions and ecosystem services provided by Scarabaeinae dung beetles. Biological Conservation 141: 1461–1474.
Nugent G 2011. Maintenance, spillover and spillback transmission of bovine tuberculosis in multi-host wildlife complexes: a New Zealand case study. Veterinary Microbiology 151: 34–42.
Nugent G, Sweetapple PJ, Coleman J, Suisted P 2000. Possum feeding patterns: dietary tactics of a reluctant folivore. In: Montague TL ed. The brushtail possum: biology, impact and management of an introduced marsupial. Lincoln, Canterbury, New Zealand, Manaaki Whenua Press. Pp. 10–33.
Obuch J, Kristin A 2004. Prey composition of the little owl *Athene noctua* in an arid zone (Egypt, Syria, Iran). Folia Zoologica 53: 65–79.
Owen HJ, Norton DA 1995. The diet of introduced brushtail possums *Trichosurus vulpecula* in a low-diversity New Zealand *Nothofagus* forest and possible implications for conservation management. Biological Conservation 71: 339–345.
Piñero FS 2007. Predation of *Scarabaeus cristatus* F. (Coleoptera, Scarabaeidae) by jerboas (*Jaculus* sp.: Rodentia, Dipodidae) in a Saharan sand dune ecosystem. Zoologica Baetica 18: 69–72.
Rickard CG 1996. Introduced small mammals and invertebrate conservation in a lowland podocarp forest, South Westland, New Zealand. Unpublished MForSc Thesis. University of Canterbury, Christchurch, New Zealand.
Sleeman DP, Hutton SA 2005. Dung beetles *Geotrupes stercorarius* (L.) (Coleoptera: Geotrupidae) detected in diet of mink on Gola Island, Co. Donegal. Irish Naturalists' Journal 28: 136.
Sweetapple PJ, Nugent G 1998. Comparison of two techniques for assessing possum (*Trichosurus vulpecula*) diet from stomach contents. New Zealand Journal of Ecology 22: 181–188.
Thomas WP 1960. Notes on a preliminary investigation into the habits of the life cycle of *Copris incertus* Say (Coprini: Coleoptera) in New Zealand. New Zealand Journal of Science 3: 8–14.
Tompkins D, Forgie S, Aislabie J, Nugent G, Gourlay H, McGill A, et al. 2012. Informing the infectious disease risks of dung beetle releases into New Zealand. Landcare Research Internal Report LC908. 17 p. http://dungbeetle.org.nz/wp-content/uploads/2012/08/Tompkins_Dung_Beetle_Disease_Report.pdf (accessed 5 December 2013).