Information supporting the application to amend the List of Specimens Suitable for Live Import to include fourteen new species of dung beetles (Coleoptera: Scarabaeidae and Geotrupidae) as suitable for import and for release

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Table of Contents

Rationale

This proposal provides information supporting the application to amend the List of Specimens Taken to be Suitable for Live Import to include fourteen species of dung beetles (*Geotrupes stercorarius, Ateuchetus laticollis, Cheironitis scabrosus, Copris incertus, Copris integer, Copris lunaris, Euoniticellus triangulatus, Gymnopleurus humanus, Onitis minutus, Onthophagus medius, Onthophagus nuchicornis, Onthophagus opacicollis, Scarabaeus sacer* and *Sisyphus schaefferi*) as suitable for importation.

The objective of introducing these species is to enhance dung burial and bush fly control in the major sheep, beef and milk producing areas of Australia to fill existing seasonal and geographical gaps in dung beetle activity.

Adult beetles will be collected from various locations in Europe, Africa and New Zealand, and air-freighted to Australia. The beetles will be handled similarly to the previous projects in the early 1990s, 2011-2015 and 2018-current. Briefly, in-coming adult beetles will be held in an Approved Arrangements site (AA) in a quarantine facility in Canberra. Their eggs will be treated with disinfecting agent (Virkon®), removed from quarantine, reared to adulthood, and used for the establishment of mass-rearing colonies, the progeny of which will be released. Release sites will be chosen by selecting climatically optimal sites on properties whose owners are committed to doing everything necessary to maximise the beetles' establishment, such as avoiding the use of parasiticides. Beetles will be released when they are sexually mature and physiologically synchronised with the local season. Release numbers will vary according to the numbers reared, but at any given site the aim will be to release a minimum of 500 male-female pairs of each species.

1. Taxonomy

All dung beetles fall under the same classification, up to family.
Phylum: Arthropoda
Class: Insecta
Order: Coleoptera
Table 1 provides information on the taxonomy of each of the species, beginning with family. It includes synonyms, subspecies and a taxonomic reference.

Table 1. Taxonomy of selected species

Family	Genus	Species	Synonyms and Subspecies	Taxonomic Reference
Geotrupidae	*Geotrupes*	*stercorarius* (Linnaeus, 1758)	*Geotrupes bannani* Bromfield, 1834 *Geotrupes chalybaeus* Mulsant, 1842 *Geotrupes exaratus* Mulsant, 1842 *Geotrupes fimicola* Mulsant 1855 *Geotrupes intermedius* Ferrari, 1852 *Geotrupes juvencus* Mulsant, 1842 *Geotrupes punctatostriatus* Stephens, 1830 *Geotrupes punstatostrius* Stephens, 1830 *Geotrupes putridarius* Erichson 1848 *Geotrupes stercorarius* subsp. *chalybaeus* Mulsant, 1842 *Geotrupes stercorarius* subsp. *exaratus* Mulsant, 1842 *Geotrupes stercorarius* subsp. *juvencus* Mulsant, 1842 *Geotrupes stercorarius* subsp. *quartanarius* Costa 1853 *Geotrupes stercorarius* subsp. *subrugulosus* Mulsant, 1842 *Geotrupes stercorarius* subsp. *subviolaceus* Mulsant, 1842 *Geotrupes subrugulosus* Mulsant, 1842 *Geotrupes subviolaceus* Mulsant, 1842 *Geotrupes virescens* Mulsant, 1842 *Geotrypes stercorarius* subsp. *montanus* Olsoufieff, 1918 *Scarabaeus foveatus* Marsham, 1802 *Scarabaeus foveolatus* Marsham, 1802 *Scarabaeus stercorarius* Linnaeus, 1758	[1]

Family	Genus	Species	Synonyms and Subspecies	Taxonomic Reference
Scarabaeidae	*Ateuchetus*	*laticollis* (Linnaeus, 1767)	*Ateuchus laticollis* subsp. s*emilunatus* Xambeu, 1893 *Ateuchus semilunatus* Xambeau, 1893 *Copris serratus* Fourcroy, 1785 *Copris serratus* Geoffroy, 1785 *Scarabaeus alluaudi* Théry, 1932 *Scarabaeus laevicollis* Mulsant, 1842 *Scarabaeus laticollis* Linnaeus, 1767 *Scarabaeus laticollis* subsp. *alluaudi* Thery, 1932 *Scarabaeus laticollis* subsp. *laevicolli* Mulsant, 1842 *Scarabaeus laticollis* subsp. *minor* Seabra, 1907 *Scarabaeus laticollis* subsp. *striatopunctatus* Leoni, 1910 *Scarabaeus laticollis* subsp. *striolatus* Reitter, 1892 *Scarabaeus minutus* Seabra, 1907 *Scarabaeus serratusm* (Geoffroy, 1785) *Scarabaeus striolatus* Reitter, 1893	[2; 3]
	Cheironitis	*scabrosus* (Fabricius, 1776)	*Scarabaeus apelles* Fabricius 1781 *Scarabaeus scabrosus* Fabricius, 1776	[4]
	Copris	*incertus* Say, 1835	*Copris procidua* Say, 1835 *Corpus incertus* Say, 1835 *Corpus incertus* subsp.*incertus* *Corpus incertus* subsp.*prociduus* Say, 1835	[5]
	Copris	*integer* Reiche, 1847	*Copris pronus* Gerstaeker, 1884 *Copris troglodytarum* Roth, 1851	[6; 7]
	Copris	*lunaris* (Linnaeus, 1758)	*Copris belisama* Schrank, 1798 *Copris castaneus* Mulsant, 1842 *Copris corniculatus* Mulsant, 1842 *Copris deletus* Mulsant, 1842 *Copris gistelianu* Gistel, 1857 *Copris jenisonianus* Gistel, 1857 *Copris lunaris subsp. castaneus* Mulsant, 1842 *Copris lunaris subsp. corniculatus* Mulsant, 1842 *Copris lunaris subsp. deletus* Mulsant, 1842 *Copris lunaris subsp. obliteratus* Mulsant, 1842 *Copris obliteratus* Mulsant, 1842 *Scarabaeus belisama* Schrank, 1798 *Scarabaeus bifidus* Poda, 1761 *Scarabaeus emarginatu* Olivier, 1789 *Scarabaeus lunaris* Linnaeus, 1758	[8]

Family	Genus	Species	Synonyms and Subspecies	Taxonomic Reference
Scarabaeidae	*Copris*	*lunaris* (Linnaeus, 1758) (continued)	*Scarabaeus lunus* Schrank, 1798 *Scarabaeus quadridentatus* De Geer, 1778	[8]
	Euoniticellus	*triangulatus* (Harold, 1873)	*Oniticellus triangulatus* Harold, 1873	[9]
	Gymnopleurus	*humanus* MacLeay, 1821	*Gymnopleurus modestus* van Lansberge, 1886 *Gymnopleurus modestus* Péringuey, 1888 *Gymnopleurus peringueyi* Shipp, 1895 *Gymnopleurus sericatus* Erichson, 1843 Gymnopleurus *sericatus* var. *modestus* (van Lansberge) *Gymnopleurus humanus* var. *modestus* (Péringuey, 1888)	[10; 11 p278; 12]
	Onitis	*minutus* Lansberge, 1875		[11 p372; 13]
	Onthophagus	*medius* (Kugelann, 1792)	*Copris affinis* Sturm, 1800 *Copris medius* Kugelann, 1792 *Onthophagus confluens* Gistel, 1857 *Onthophagus vacca* subsp. *basalis* Mulsant, 1842 *Onthophagus vacca* subsp. *intermedius* Mulsant, 1842 *Onthophagus vacca* subsp. *propinquus* Mulsant, 1842 *Onthophagus vacca* subsp. *sublineolatus* Mulsant, 1842 *Onthophagus vacca* subsp. *vicinus* Mulsant, 1842	[14]
	Onthophagus	*nuchicornis* (Linnaeus, 1758)	*Copris acornis* Geoffroy, 1785 *Onthophagus alpinus* Kolenati, 1846 *Onthophagus dillwyni* Stephens, 1830 *Onthophagus immaculatus* Mulsant, 1842 *Onthophagus indistinctus* Mulsant, 1842 *Onthophagus nuchicornis subsp. asimmetricus* Negrobov, 2003 *Onthophagus nuchicornis subsp. elenius* Negrobov, 2003 *Onthophagus nuchicornis subsp. immaculatus* Mulsant, 1842 *Onthophagus nuchicornis subsp. indistinctus* Mulsant, 1842 *Onthophagus nuchicornis subsp. rubripes* Mulsant, 1842 *Onthophagus nuchicornis subsp. rufipes* Negrobov, 2003 *Onthophagus nuchicornis subsp. submarginalis* Sahlberg, 1926 *Onthophagus nuchicornis subsp. vulneratus* Mulsant, 1842 *Onthophagus rhinoceros* Melsheimer, 1845 *Onthophagus rhinocerus* Melsheimer, 1846 *Onthophagus rubripes* Mulsant, 1842 *Onthophagus submarginalis* Sahlberg, 1926 *Onthophagus vulneratus* Mulsant, 1842 *Scarabaeus nuchicornis* Linnaeus, 1758	[15]

Family	Genus	Species	Synonyms and Subspecies	Taxonomic Reference
Scarabaeidae	*Onthophagus*	*nuchicornis* (Linnaeus, 1758) (continued)	*Scarabaeus planicornis* Herbst, 1789 *Scarabaeus trituberculatus* Schrank, 1798 *Scarabaeus verticicornis* Fabricius, 1775 *Scarabaeus xiphias* Fabricius, 1792	[15]
	Onthophagus	*opacicollis* Reitter, 1892	*Onthophagus schatzmayeri* Pierotti, 1959 *Onthophagus schatzmayeri* subsp. *fumatus* Schaefer, 1965 *Onthophagus schatzmayri* Pierotti, 1959	[16]
	Scarabaeus	*sacer* Linnaeus, 1758	*Ateuchus acuticollis* Motchulsky, 1849 *Ateuchus clypeatus* Motchulsky, 1849 *Ateuchus europaeus* Motchulsky, 1849 *Ateuchus impius* Fabricius, 1801 *Ateuchus platychilus* Fischer von Waldheim, 1823 *Ateuchus retusus* Brullé, 1832 *Ateuchus sacer* (Linnaeus, 1758) *Ateuchus sacer* subsp. *peregrinus* Kolbe, 1886 *Scarabaeus confluidens* Fleischer, 1925 *Scarabaeus crenatus* Degeer, 1778 *Scarabaeus degeeri* MacLeay, 1821 *Scarabaeus dufresneri* MacLeay, 1821 *Scarabaeus dufresnii* MacLeay, 1821 *Scarabaeus edentulus* Mulsant, 1842 *Scarabaeus europaeus* Motschulsky, 1849 *Scarabaeus impius* Fabricius, 1801 *Scarabaeus inermis* Mulsant, 1842 *Scarabaeus peregrinus* Kolbe, 1896 *Scarabaeus rufipes* Seabra, 1907 *Scarabaeus sacer* subsp. *confluidens* Fleischer, 1925 *Scarabaeus sacer* subsp. *edentulus* Mulsant, 1842 *Scarabaeus sacer* subsp. *inermis* Mulsant, 1842 *Scarabaeus sacer* subsp. *rufipes* Seabra, 1907 *Scarabaeus spencii* MacLeay, 1821	[17]

Family	Genus	Species	Synonyms and Subspecies	Taxonomic Reference
Scarabaeidae	*Sisyphus*	*schaefferi* (Linnaeus, 1758)	*Copris arachnoides* Fourcroy, 1785 *Scarabaeus longipes* Scopoli, 1763 *Scarabaeus schaeffer* Linnaeus, 1758 *Sisyphus capensis* Gory, 1833 *Sisyphus schaefferi* subsp. *boschniaki* Fischer von Waldheim, 1823 *Sisyphus schaefferi* subsp. *minutus* Seabra, 1907 *Sisyphus schaefferi* subsp. *morio* Arrow, 1909 *Sisyphus schaefferi* subsp. *schaefferi* (Linnaeus, 1758) *Sisyphus schaefferi* subsp. *subemarginatus* Mulsant, 1842 *Sisyphus schaefferi* subsp. *subinermis* Mulsant, 1842 *Sisyphus tauscheri* Fischer von Waldheim, 1823	[18]

1.1 Common Names

Common English names for species that have them are as follows:

- *Ateuchetus laticollis* is also known as the scarab dung beetle [19]
- *Geotrupes stercorarius* is also known as the dor beetle, dung beetle or lousy watchman beetle in the United Kingdom [20; 21]
- *Copris incertus* is known as the black dung beetle or uncertain dung beetle in Hawaii [22]; and is referred to as the Mexican dung beetle in New Zealand [23; 24]
- *Copris lunaris* is also called the horned dung beetle [25-27]
- *Onthophagus nuchicornis* is also known as the small black and brown dung beetle [28]
- *Scarabaeus sacer* is also known as the sacred scarab beetle [29 p133]

1.2 Genetic modification

None of the species have been genetically modified or engineered.

2. Status of species under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)

None of the selected species are listed on any of the CITES appendices. Four species were found on the IUCN Red List of Threatened Species, all ranked as of Least Concern. A summary of these species is provided in Table 2.

Table 2. Species on IUCN Red List of Threatened Species

Species	Assessment Date	Notes	Reference
Ateuchetus laticollis	22 July 2014	Wide distribution, locally abundant subpopulations	[3]
Cheironitis scabrosus	30 July 2013	Widely distributed in southwest southern Africa; regularly found in cattle dung; unlikely to be threatened as farming is common in its range	[30]
Gymnopleurus humanus	30 July 2013	Dominant member of assemblages within its range; found with a wide range of dung types	[31]
Onthophagus opacicollis	23 July 2014	Wide distribution; associated with sheep and cattle dung; only considered rare in Italy; elsewhere abundant and frequent	[32]

3. Ecology of species

3.1 Longevity

Longevity depends on the species, with a few species living two or more years, but most having a shorter lifespan. Specific information found on the longevity of each of the 14 species is provided in Table 3.

Table 3. Longevity of dung beetle species

Species	Longevity
Geotrupes stercorarius	One- to two-year lifecycle in the UK [33] and France [34] Two-year life cycle in North America [35 p264]
Ateuchetus laticollis	Potentially up to two years, as most large beetles have lifespans allowing at least two breeding seasons [36 p110]
Cheironitis scabrosus	Unknown for this species; however, *C. furcifer* is univoltine, with a single annual generation [37]
Copris incertus	Female lifespan under laboratory conditions is 580 $\pm$ 159 days [38]; hence complete lifecycle will be around 2 years
Copris integer	Unknown for this species, but other *Copris* adults can live for 2 years (see *C. incertus* and *C. lunaris*)

Species	Longevity
Copris lunaris	Adults survive 2 years [39; 40]
Euoniticellus triangulatus	Unknown
Gymnopleurus humanus	Unknown
Onitis minutus	Unknown
Onthophagus medius	Likely one year, [41]
Onthophagus nuchicornis	One year [42; 43]
Onthophagus opacicollis	Unknown
Scarabaeus sacer	Potentially up to two years, as most large beetles have lifespans allowing at least two breeding seasons [36 p110]
Sisyphus schaefferi	Longevity of 360-400 days [36 p110]

3.2 Weight and length

Lengths range from 5-27 mm and dry weights from 9-671 mg. There are no data available to distinguish males and females on the basis of size. Information found on the size of each of the 14 species is provided in Table 4.

Table 4. Length and weight

Species	Length (mm)	Length References	Weight (mg) dry wt unless specified	Weight References
Geotrupes stercorarius	12–27	[33; 34 p372; 35 p262; 44 p411; 45 p57; 46 p245]	163.5 ± 60.2	[47]
Ateuchetus laticollis	15–25	[34 p26; 44 p381; 45 p319; 46 p52; 48; 49 p8]	172–173 670 ± 140 fresh wt	[44 p411; 48; 50; 51 p36] [52]
Cheironitis scabrosus	Average for the genus is 10.2-16.5	[29 p161]	63	[53]
Copris incertus	12–20	[22; 44 p411; 54]	175	[44 p411]
Copris integer	13–24	[7 p414]	Unknown	
Copris lunaris	15–24	[34 p42; 45 p326; 46 p61; 48; 49 p8]	228 286 ± 50	[48; 49 p8] [55]
Euoniticellus triangulatus	7–9	[11 p308; 56]	9	[53]
Gymnopleurus humanus	8.21–10.97	[10]	185 ± 19 fresh wt	[57]
Onitis minutus	8–19	[11 p372; 58; 59]	Unknown	
Onthophagus medius	8–13	[60]	Unknown	
Onthophagus nuchicornis	6–10	[28; 34 p112; 45 p379; 46 p93; 49 p9; 61; 62 p123-124]	22–76	[43]
Onthophagus opacicollis	5–8	[34 p102; 45 p380]	6–22	[47; 51 p113; 55]
Scarabaeus sacer	21–40	[34 p18; 45 p317; 46 p44; 49 p8; 61; 63]	671.2 ± 248.8 2570 ± 540 fresh wt	[51 p40; 55] [52]
Sisyphus schaefferi	6–13	[34 p40; 44 p381; 45 p321; 46; 48; 49 p8; 64-66]	29 10–280 wet wt	[44 p381; 48; 49 p8; 51 p44; 67] [66]

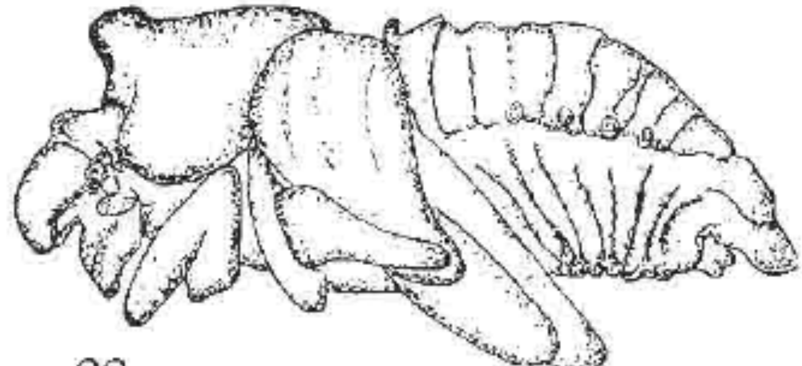
3.3 Identification: description, sexual dimorphism and similar species

The eggs and larvae of Scarabaeinae species generally look similar [e.g., various figures in 68]. Images of the egg (Figure 1) and late instar larva of *Bubas bubalus* (Figure 2) are included as representative examples.

Figure 1. Egg of *Bubas bubalus* in brood ball (photo by Patrick Gleeson, CSIRO)

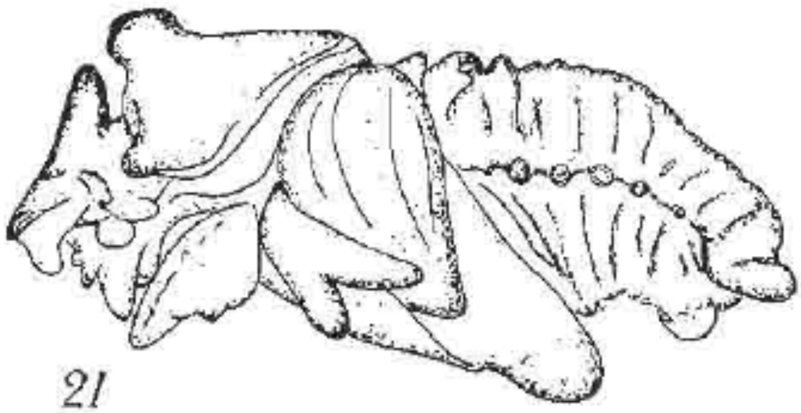
Figure 2. Late instar larva of *Bubas bubalus* (photos by Patrick Gleeson, CSIRO)

Whilst the pupae of different dung beetle species tend to look different, they also have many similarities [e.g., various figures in 68]. Diagrams of the pupa of female (Figure 3) and male (Figure 4) *Onthophagus andalusicus* are included as examples.



22

Figure 3: Female pupa of *Onthophagus marginalis* subsp. *andalusicus* [69, used with permission from the authors]



21

Figure 4: Male pupa of *Onthophagus marginalis* subsp. *andalusicus* [69, used with permission from the authors]

Adults can be identified based on their morphological characteristics. Table 5 summarises information found for each of the 14 species in terms of adult descriptions and sexual dimorphism. Many species have major and minor males. The major males tend to be larger and have well-developed cephalic horns, whilst the minor males tend to be smaller and have either very reduced or absent horns [70 p56]. In the reproductive season, major males tend to combat with other large males, whilst minor males sneak past these competing males to copulate with the female [70 p56].

Table 5. Photos and description of species, with sexual dimorphism noted if applicable or known

Male	Female	Description	Sexual Dimorphism
Geotrupes stercorarius. Photo of male by Udo Schmidt (https://www.flickr.com/photos/coleoptera-us/19372749035/); Creative Commons, freely available; photo of female by Alberto Zampogna, CSIRO Montpellier, France			
		Large elongate beetle with almost parallel-sided elytra; upper surface black with green or blue reflection and often with brighter and more strongly metallic borders to the pronotum and elytra; the underside metallic blue, violet, green or a mixture of these colours and with dense black hairs evenly distributed across the abdomen; abdominal sternites evenly punctured and pubescent throughout; [33]	Male protibia with two ridges on the underside, outer one bearing 1 - 3 large teeth; 3rd outer tooth directed downward; posterior trochanters spiny at apex; metafemurs with a strong tooth at basal third of posterior margin; female legs have no distinctive features [45 p57]
Ateuchetus laticollis. Photos by Alberto Zamprogna, CSIRO Montpellier, France			
		Shiny black beetle; shiny and smooth pronotum with a few large indentations; elytra with lightly engraved stripes [45 p319]	No sexual dimorphic traits
Cheironitis scabrosus. Photos by Christian Deschodt, supplied by Adrian Davis; University of Pretoria, South Africa			
		Medium beetle, copper head with a bronze shield; short erect horn; thorax with wrinkled hair and a pale green margin; elytra rust-coloured with black dots; black body; legs pale red, black at the apex and base [71 p209]	For the genus *Cheironitis*: anterior legs lack tarsi in males but not in females; pronotal disc with raised, transverse sub-anterior ridge distinct in females and unclear in males [29 p161]

<table>
<tr><th>Male</th><th>Female</th><th>Description</th><th>Sexual Dimorphism</th></tr>
<tr><td colspan="4">Copris incertus. Photos of males by Emmy Engasser, Wichita State University, Hawaiian Scarab ID, USDA APHIS PPQ, Bugwood.org. Image numbers 5539215, 553922, 5539716; photo of female from PaDIL (https://www.padil.gov.au/maf-border/pest/main/140404/31192); Creative Commons, freely available. Minor male looks like female.</td></tr>
<tr><td>
Major Male</td><td></td><td rowspan="2">Large beetle; shiny black oval body; elytra have 9 stria, with 8th stria incomplete and never reaching the posterior margin of the elytra [22]</td><td rowspan="2">Cephalic horn is long and well-developed in major males, reduced in minor males, and truncate or missing in females; pronotum of major males has four horn-like protuberances, which are much reduced in minor males and females [22]</td></tr>
<tr><td>
Major Male</td><td>
Minor Male</td></tr>
<tr><td colspan="4">Copris integer. Photos from http://www.entomoboutique.weonea.com/produit/160206/; Permission to use these was granted by Emmanuel Bonnard, 27 September 2021; photo of female cropped from a photo of a male and female together; photos edited to make background white</td></tr>
<tr><td></td><td></td><td rowspan="2">Large black and shiny beetle; intermediate femurs with numerous apical bristles extending in a long longitudinal row; terminal spur on anterior tibias [7 p414]</td><td rowspan="2">Males present significant horns while females have flattened, reduced horns terminating in two distinct teeth [7 p414]</td></tr>
<tr><td></td><td></td></tr>
</table>

Male	Female	Description	Sexual Dimorphism
Copris lunaris. Photos of males by Udo Schmidt https://www flickr.com/photos/coleoptera-us/15582233562/in/photostream/; https://www flickr.com/photos/coleoptera-us/15557710616/in/photostream/); photos of females from UKBeetles [27]; Creative Commons, freely available; lateral photos cropped			
 	 	Large, shiny black beetle; widely expanded anterior margin of the head; pronotum densely and strongly punctured; elytra slightly transverse, each with five striae that continue into the apical third and often to the apex, with broad, weakly convex interstices; legs long and very robust; anterior tibiae with four broad external teeth and a long spur at the internal apical angle; middle and hind tibiae broadly expanded towards the apex, each with a single long sharp spur at the inner apical angle [27]	Males have a long and tapering cephalic horn and the anterior margin of the pronotum produces short lateral horns; females have a short and truncate cephalic horn and the pronotum is simply raised above a flat anterior margin [27]; minor males and females do not have long cephalic horns [72]
Euoniticellus triangulatus. Photos by Christian Deschodt; supplied by Adrian Davis; University of Pretoria, South Africa			
		Small brown and black elongated beetle; pronotum tightly punctuated with large umbilicated points and many fine points [56 p49, 55]	Male clypeus folded in a V-shape with thickened frontal sections; apex almost reaches the strong and broadly arched frontal carena, followed by a bead usually effaced in its middle; females have an entire frontal keel, with the vertex finely punctuated [56 p49, 55]
Gymnopleurus humanus. Photo by Christian Deschodt; supplied by Adrian Davis; University of Pretoria, South Africa			
		Smallish metallic blue, green or copper coloured beetle; dorsal surface covered with dense, coarse microgranulation; clypeus bidentate; anterior margins of clypeus and genae with dense microgranulation; foreleg with three large, distal, external teeth; sides of abdomen almost parallel, tapering only slightly [10]	Terminal spur on the foreleg has an acute tip in females and a blunt tip in males [10]

Male	Female	Description	Sexual Dimorphism
Onitis minutus. Photos by Christian Deschodt; supplied by Adrian Davis; University of Pretoria, South Africa			
		Head and pronotum bronze-green; legs and ventral side metallic green; elytra testaceous with greenish sheen; easily recognised by colour, body size, head sculpture of pronotum; legs of male provide good characteristics for distinguishing this species; cephalic surface granulose; clypeal carina almost invisible; pronotum broader than long, somewhat convex, granulose, deep basal impressions; elytra moderately flat, striate, intervals inconspicuously punctuate [59]	Hind legs of males are more sculptured and have a pronounced rectangular terminal spur that is missing in females; terminal spurs on middle legs of males and females are oriented differently; head of female is more triangulate than that of male [59]
Onthophagus medius. Photos from UKBeetles [41]; Creative Commons, freely available; lateral photos cropped			
		Medium sized beetle, with contrasting dark forebody and mottled brown elytra; often with a distinct metallic green lustre to the pronotum and head; continuously curved lateral margins to the pronotum; dark variable and random elytral markings do not extend to the base; head with a curved ridge on the vertex, the surface otherwise densely and strongly punctured [41]	Males have a long, curved horn at the base of the head; females have two small side horns but lack the long median horn of the male [41]
			

Male	Female	Description	Sexual Dimorphism
***Onthophagus nuchicornis*.** Dorsal photos from https://www.coleoptera.org.uk/species/onthophagus-nuchicornis; Creative Commons, freely available; lateral photos by Henri Goulet, Agriculture and Agri-Food Canada, supplied by Kevin Floate, Agriculture and Agri-Food Canada			
 	 	Small to medium sized beetle; head and pronotum black, without a metallic reflection, and finely punctured and pubescent; elytra colouration typically a random series of well-defined dark markings on a pale to dark yellowish-brown ground colour [42]	Males have a single cephalic horn, which can be smaller in minor males; females lack the horn and have a transverse ridge at the base of the head [28; 43]
Onthophagus opacicollis. https://inpn mnhn fr/espece/cd nom/10859?lg=en; Permission to use these was granted by Patrick Prévost, 28 September 2021			
 		Small to medium size beetle; head and pronotum black, more or less tanned or greenish; elytra with abundant irregular and asymmetrical markings; punctuated pronotum, granulated to the base [45 p380]	Males have a single cephalic horn, no frontal carinae; females have a strong, arched frontal carina, but no cephalic horn [45 p380]
Scarabaeus sacer. Photo by Udo Schmidt (https://www.flickr.com/photos/coleoptera-us/28486691625/in/photolist); Creative Commons, freely available			
		Large beetle, entirely black; pronotum unevenly punctured with lateral margins strongly rounded and closely denticulate; elytra lightly striate and punctured; front tibia has four strong external teeth and two small teeth [61 p107]	Unknown

Male	Female	Description	Sexual Dimorphism
***Sisyphus schaefferi*.** Photos by Alberto Zamprogna, CSIRO Montpellier, France			
		Medium sized beetle; entirely black or dark brown elytra may have a metallic lustre; dorsal surface with short, curved, dark setae; v; antennae orange with a dark club; pronotum very convex, with strong micro-sculpture and wide and shallow punctures; elytra strongly tapered towards the apex, with 7 shiny striae with a single row of punctures; fore tibiae well developed, with three large teeth and several smaller ones externally, and a large internal apical spur; hind femur angled internally to form a backward-pointing tooth [65]	Males and females can be distinguished by the shape and size of the metafemoral tubercle [66]

Dung beetle species can look similar to each other: more than half of the species have been flagged as being similar to other species. This information is summarised in Table 6.

Table 6. Similarity to other species

Species	Other species that could be mixed up due to similarity
Geotrupes stercorarius	Similar to *Geotrupes spiniger*: the two species can be separated and identified by the morphology of the pronotum, the abdominal sternites and the hind tibia [33]
Copris incertus	Extremely similar to *Copris remotus*: the two species can be separated by examining the elytra [22] Originally confounded with *Copris amazonicus, Copris brevicornis*, *Copris moroni*, and *Copris susanae*, all of which can now be identified by morphological differences and their discontinuous isolated populations [73]
Copris lunaris	Similar to *Copris hispanus cavolinii* (Petagna, 1792): the two species can be distinguished by the shape of the pronotum [74] Similar to *Typhaeus typhoeus*: can be distinguished by their horns and the anterior margin of the head [42]
Gymnopleurus humanus	Very similar and closely related to *Gymnopleurus humeralis*: the two species can be identified by morphological differences and their different, discontinuous distributions [10]
Onthophagus medius	Very similar to *Onthophagus vacca*: the two species can be identified by a series of morphological traits related to horn shape and position [60; 74]
Onthophagus nuchicornis	Similar to *Onthophagus similis* (Scriba, 1790) in the UK: the two species can be identified by pronotum morphology [42] Similar to *Onthophagus foliaceus* and *Onthophagus granulatus* in Hawaii: males can be distinguished by their horns; females can be identified by pronotum morphology [28]
Onthophagus opacicollis	Similar to *Onthophagus fracticornis*: the two species can be clearly distinguished from one another morphologically [75] and identified by the structure of the clypeus [74]; genetic analysis shows a high degree of difference between *O. fracticornis* and both *O. similis* and *O. opacicollis* [75] Also very similar to *Onthophagus similis*: morphological differences and differences in their distributions (although there are regions of overlap) have been used to separate the species [75; 76]
Scarabaeus sacer	Similar to *Scarabaeus typhon*: the two species can be identified by morphology of the pronotum and frontal suture [61]

3.4 Natural geographic range

The native range of each of the species is summarised in Table 7. This information excludes regions to which species may have been introduced, even if they are now common and well-established in these areas. Information regarding successful introductions to new areas is covered later (Section 5.1). Additional information of factors limiting populations in their natural range is provided below.

Table 7. Natural geographic range of selected species (excluding areas of deliberate introduction)

Species	Natural Geographic range
Geotrupes stercorarius	From Great Britain to Russia [1; 33; 35 p263; 45 p57] Also China and Japan [77]
Ateuchetus laticollis	Northern Africa and Europe: Morocco, Algeria, Spain, Portugal, France, Italy, Corsica, Sardinia [2; 3; 34; 45 p319]
Cheironitis scabrosus	South Africa and Namibia [11 p341]
Copris incertus	Eastern Mexico [73]
Copris integer	East Africa: Burkina Faso [78], Burundi [6; 78], Democratic Republic of Congo [78], Ethiopia [7; 78; 79], Malawi [6], Rwanda [6; 78], Kenya, Tanzania [6; 7; 78-80], Uganda [7; 79] and Zimbabwe [78]

Species	Natural Geographic range
Copris lunaris	All of Europe (except for the northern regions), extending westwards to Iran, Kazakhstan and western Asia [34; 78], into Russia [8] and extending from southern Siberia to China [27]
Euoniticellus triangulatus	East and southern Africa: Kenya [80; 81], Mozambique [82], South Africa [53; 83], Tanzania [9; 80] and Zaire [84] Also Angola, Botswana, Ghana, Lesotho, Malawi and Namibia [9]
Gymnopleurus humanus	Angola, Namibia and South Africa [11 p278]
Onitis minutus	South Africa [11 p372; 13]
Onthophagus medius	Europe; absent from Mediterranean islands; extending eastwards into Turkey, Iran, Kazakhstan and Russia [41; 60]
Onthophagus nuchicornis	Europe; from Portugal to the northern provinces of Fennoscandia; through Asia Minor and Russia to China [28; 34; 42; 61]
Onthophagus opacicollis	Southern Europe, Asia Minor, Syria, Iran and North Africa [34; 74]
Scarabaeus sacer	North Africa, Europe, Asia and Middle East: Afghanistan, Ethiopia, France, Hungary, northern India, Iran, Israel, Kazakhstan, Romania; Palestine, Portugal, Russia and Spain [61] Also Albania, Bulgaria, Greece and Montenegro [85] Also Arabia, Armenia, Corsica, Cyprus, Italy (including Sardinia and Sicily), Syria, Turkey and Yugoslavia [45 p317]
Sisyphus schaefferi	From northern Africa and the Iberian Peninsula to China and Korea [48; 64; 74; 86-88] Does not extend into northern regions, including the UK [65]

3.4.1 Predation

Although there is limited data on predation of dung beetles [89], it is likely to be important [e.g., 37; 90], and substantially underestimated [91]. Predators of dung beetles in general include many kinds of birds, mammals and even reptiles and amphibians [91]. Kingfishers have been recorded aggressively pursuing *S. sacer*, numerous bird species have been recorded eating *G. stercorarius* and *C. lunaris*, and bats and mink have been recorded eating *G. stercorarius* [91]. Overall, the extent of predation as a limiting factor of dung beetle populations is unclear, and further research is recommended [89].

3.4.2 Resource availability

One of the most important population limiting factors for dung beetles is resource (dung) availability [89; 92]. The availability of dung is essential both as a food source for adults and larvae, and for nest construction [e.g., 57; 93]. Adult beetles of some species have been observed on other food sources (Sections 7.1 and 8.3), but as these are not limiting or essential, they are not included as a resource in this section. Preferences for dung type are shown in Section 3.8.1, Table 9.

3.4.3 Competition

Dung beetle species occupying the same niche will compete for both dung and space [94 p37-38]. Roller beetles only compete for dung: competition for space is eliminated as dung balls are moved away from the source [93 p306]. Roller beetles also appear to have an advantage in dung collection over tunnelling beetles, as they do not have to construct their burrow before collecting dung [93 p323]. However, both intra- and inter-specific ball stealing behaviour has been observed in rollers [93 p306-309]. Tunneller beetles compete for both food and for space below the dung pad [94 p37-38].

Nonetheless, a dung pad can host and feed large numbers of dung beetles [70 p54, 65-66; 95 p5; 96 p67-68], with multiple species co-occurring [47; 97-101]. Co-existence can occur because the species of beetles utilise dung differently: feeding and breeding behaviours differ, and patterns of activity differ in terms of flight times (nocturnal, diurnal or crepuscular) and seasonal activity (i.e., when they are most active and breeding) [100]. In general, larval competition for food is largely avoided, as adult beetles provide for each of their offspring, whether they are tunnellers or rollers, and competition for space is avoided by rollers as they relocate dung for feeding or breeding [94 p37]. Interspecific differences in behaviours can also reduce competition. In many temperate dung beetle communities, temporal separation helps account for an apparent lack of competition [e.g., 92]. For example, competition between *A. laticollis* and *S. schaefferi* is decreased by differences in their emergence and breeding periods [50 p114]. In some species, beetles actively avoid the nests of other beetles whilst tunnelling [102]. Flight at different times reduces competition between species, favouring intraspecific rather than interspecific encounters [58], thereby potentially also enhancing mate-finding.

3.4.4 Climate, land use and soil type

Climate necessarily plays a key role in local population dynamics and in determining distributions of beetles [29 p28; 34 p13; 55; 83; 103], as do land use and vegetation [34 p13; 83; 104-106] and soil type [29 p29; 83; 104]. As shown below (Section 3.8.1, Table 9), each species has a preference for particular soil types.

3.5 Migration

Dung beetles are not migratory as such, but will disperse to find dung. For example, *C. incertus* can fly distances in excess of 50 m [23], and *S. schaefferi* can fly upwind for 40-60 m [96 p89-90]. Furthermore, *G. stercorarius* may fly considerable distances from apparently suitable habitats, possibly disoriented by lights [33].

3.6 Ability to hibernate in winter or aestivate in summer

Many species of dung beetle engage in diapause at different times during their life history, as an evolutionary adaptation to tolerate seasonal conditions [50 p109-111; 107 p341], and diapause is sometimes required before breeding can begin [108 p26-50]. Many species have an overwintering period, either as adults or late instar larvae. Overwintering appears to be obligatory for reproduction in *O. nuchicornis* [43; 109]; in other species, it is facultative [40; 41]. Still other species appear capable of reducing activity in inclement weather [23; 55; 65; 81; 110 p17]. The information available on the 14 species is summarised in Table 8.

Table 8. Ability to hibernate, aestivate, and survive adverse conditions

Species	Overwintering stage	Information on hibernation, aestivation and surviving adverse conditions	References
Geotrupes stercorarius	Larva and adult	Third instar larvae overwinter before pupating in summer; adults emerge in fall and overwinter	[33-35]
Ateuchetus laticollis	Adult		[36 p93; 50 p110]
Cheironitis scabrosus	Unknown	Adults only collected during the dry season (April, May and September) in northern South Africa, implying that there is overwintering and/or aestivation and/or decreased activity in other months	[110 p17]
Copris incertus	Larva and adult	Adults emerge in spring in New Zealand, and can cease activity in hot, dry conditions Adults generally emerge in spring from overwintering third instar larvae in New Zealand, and adults emerging in late summer can also overwinter	[23] (SA Forgie, pers. comm.)
Copris integer	N/A	Found year round in Kenya, suggesting there is no aestivation or overwintering	[79 p147]

Species	Overwintering stage	Information on hibernation, aestivation and surviving adverse conditions	References
Copris lunaris	Adult	Adults remain inactive underground in winter, but will feed on days where it is warm enough	[27; 34 p42; 36 p81; 50 p110; 55] [40]
Euoniticellus triangulatus	N/A	Present at all sampling times, suggesting there is no aestivation or overwintering	[53; 81]
Gymnopleurus humanus	Unknown	Adults only active November to April in northern South Africa, implying an overwintering or inactive period	[110 p9]
Onitis minutus	Unknown	Autumn-active species therefore likely to have some kind of developmental pause in its lifecycle	[58 p449]
Onthophagus medius	Adults	Adults overwinter in the soil	[60 p27; 111]
Onthophagus nuchicornis	Adult	Obligatory winter diapause of adults required for reproduction	[43; 109]
Onthophagus opacicollis	Unknown	Adults trapped throughout the year in western Spain (Salamanca), but with much lower numbers in winter No adults trapped in autumn or winter in southwest Spain (Olivenza) Adults have reduced activity in dry period of summer in France	[55] [112] [34]
Scarabaeus sacer	Adult	No adults trapped in winter	[34 p18; 55; 85; 113]
Sisyphus schaefferi	Adult	Adults overwinter Adults may shelter under logs or among litter during bad weather	[34, p40; 48 p578-9; 49, p35; 66] [65]

3.7 Breathing atmospheric air

Being land animals, dung beetles necessarily breathe atmospheric air.

3.8 Habitat requirements

Dung beetles have defined habitat preferences, whether this be for open pastures or forests, specific soil, dung types or climate. Table 9 details the habitat requirements for each of the 14 species listed.

3.8.1 Physical parameters

Information on the physical traits (soil type and dung used) of the natural habitat is summarised in Table 9.

Table 9. Physical parameters of natural habitat important to dung beetles

Species	Habitat	Soil Type	Dung Used
Geotrupes stercorarius	Pasture [20; 34 p372; 47] Forest/woodland [20; 34 p372]	Varied soil types, but often heavy and clay rich [34 p372]	cow [33; 34 p372; 35 p263; 86] sheep [47] horse [33; 34 p372; 35 p263] human, goat, fox and deer [34 p372]
Ateuchetus laticollis	Pasture and light woodland [34 p26; 49; 51 p36-37]	Little preference for soil type [3; 34 p26; 36 p92; 49 p23; 50 p105]	cow [34 p26; 48; 105], sheep [34 p26; 105] horse [3; 34 p26] human [34 p26; 96 p17] dog [34 p26]
Cheironitis scabrosus	Grassland and shrubland [11 p341; 30; 53; 83] Crop fields [11 p341]	Primarily sand [83; 98]	cow [11 p341; 30; 53; 98; 110; 114] sheep, horse [11 p341; 98] goat, gemsbok, blesbok and springbok [98]
Copris incertus	Pasture [115]	Volcanic and clay soils [23] Clays and loams [24]	cow, sheep, horse [23; 24] alpaca [24] human and pig [73]
Copris integer	Savanna [79]	Sandy to clay soils [79; 80]	generalist [79]
Copris lunaris	Open pasture, woodland, moor and heathland [27; 55]	Deep, humid soils [36 p80] Sandy clay [49] Sandy or chalky soils [27]	cow [34 p42; 36 p80; 40; 48; 55; 74; 86] sheep [34 p42; 49] horse [27]
Euoniticellus triangulatus	Grassland [11 p308; 53; 81; 84] Only rarely in wetland [81]	Sandy soils [11 p308; 53; 80; 81; 83] Clay soils [11 p308; 80]	cow [11 p308; 53; 81] horse and buffalo [11 p308]
Gymnopleurus humanus	Grassland and shrubland [11 p278; 31; 110]	Primarily sandy type soils [31; 98] Deep stony soils [97]	wide range of dung types [31] cow, sheep, horse, donkey, zebra, baboon [11 p278] pig [11 p278; 97]
Onitis minutus	Grassland, scrub, shrubland, pasture and fallow crop fields [11 p372]	Mostly sandy loam with few records on sand, sandy clay and clay [11 p372; 83]	cow [11 p372]
Onthophagus medius	Pasture and meadow [74] Floodplains [41]	Sandy soils [74; 111] Alluvial soils [41]	cow, sheep, horse [41; 74] donkey [74]
Onthophagus nuchicornis	Rangeland and grassland [42; 43; 109; 116] Coastal dunes and open areas [34; 42]	Sandy soils [34; 42; 49]	generalist [43] cow [34 p112; 62 p126; 109] sheep [34 p112; 49] horse [34 p112; 62 p126] human [34 p112]

Species	Habitat	Soil Type	Dung Used
Onthophagus opacicollis	Grassland/pasture [34 p102; 47; 51 p114; 74] Shrubland/woodland [34 p102; 51 p114; 105; 117] wetlands [105; 117]	Limestone sediments [74] Light to heavy soils [34; 61 p43; 118]	cow [34 p102; 55; 105; 117] sheep [34 p102; 105] horse [34 p102; 117; 118] human, wild boar [34 p102; 117] dog [34 p102] fallow deer [117]
Scarabaeus sacer	Exclusively in open environments [51 p41], including lawns, dune ridges and river banks [34 p18; 61 p108] Shrubland and marsh [117]	Light sandy clay and silty sands [34 p18; 36 p92; 49; 50 p105; 113; 117]	diverse [113] cow [34 p18; 49; 55; 63] sheep [34 p18; 49] horse [63; 117] dog [113] human [34 p18; 96 p17] deer [63]
Sisyphus schaefferi	Pasture and light woodland [34 p40; 49; 51 p45; 64]	Mostly on clay soils [34 p40; 49 p23; 50 p105; 64]	cow [34 p40; 64; 65; 67; 74; 86; 119] sheep [34 p40; 49; 65; 74; 119] goat [64; 67; 86] horse [34 p40; 64; 74] human [34 p40; 119] fox, badger [34 p40] red deer, wild boar [64] deer [65]

3.8.2 Climatic preferences

Information on the climatic traits of the natural habitat is summarised in Table 10. If known, this also includes any specific temperature requirements for activity.

Table 10. Climatic requirements within natural habitat

Species	Climate/Temperature	Seasonality/Activity
Geotrupes stercorarius	Requires sufficiently high annual rainfall and low annual average temperatures [34 p372] Snowy winters and mild summers [47]	Spring to autumn [50 p110]
Ateuchetus laticollis	Mediterranean climate [3; 34 p26; 48; 49; 50 p107; 105]	February to November, with reduced activity in August (dry) [34 p26] Primarily autumn; minor activity in spring in Morocco [51 p36-37] Activity (ball-rolling implied) occurs between 22-30 °C, [96 p64]
Cheironitis scabrosus	Mediterranean climate [120] Found in areas of winter, bimodal and late summer rainfall [83] Arid ecoregions [30; 98] Annual rainfall to 510 mm, annual mean temperature between 11-21 ˚C [11 p341; 30]	Dry season [53] Spring to autumn (Sept-Apr), but primarily in summer (rainy or dry) [11 p341]
Copris incertus	Native distribution is in tropical (equatorial) climates, based on Köppen-Geiger climate classification [121; 122] temperate wet areas (e.g., New Zealand) [23; 24]	Associated with high rainfall; able to cease activity in hot, dry conditions [23] Spring to early summer and late summer to autumn in New Zealand; in mild winters will breed in July (SA Forgie, pers. comm.)
Copris integer	Semi-arid climate [79] Annual rainfall to 2 000 mm [80]	Found year round in Kenya [79 p147]
Copris lunaris	Mediterranean to temperate climate [27; 48; 50 Table 6.5; 55; 72; 74] Moderate climate, with average temperature of 8 ˚C in winter and 25 ˚C in summer [123]	Spring, with a little activity in summer [55] Summer [48; 50 p110]
Euoniticellus triangulatus	Found in areas of winter, bimodal, and midsummer (highveld to northeast subtropical and tropical) rainfall [83] Annual rainfall < 1 200 mm, annual mean temperature between 4-25 ˚C [11 p308; 81]	Found year round [53; 81] Greatest abundance from late spring to early autumn [11 p308]
Gymnopleurus humanus	Annual rainfall < 800 mm [10; 31; 97] Annual mean temperature between 11-23 ˚C [11 p278; 31]	Late summer rainy season [11 p278]
Onitis minutus	Annual rainfall < 500 mm, annual mean temperature between 14-20 ˚C [11 p372]	October, May and June [11 p372]
Onthophagus medius	Mediterranean climate [74] Humid and temperate climate [41; 60]	Peak in May, short activity period in summer [60] April to autumn, with peaks in May and September [41]
Onthophagus nuchicornis	Temperate [28; 62] Cold temperate regions [116] Egg to adult development occurs between 16-30 ˚C [109]	April to September, with spring and autumn peaks [42]
Onthophagus opacicollis	Mediterranean climate [55; 74; 105]	Primarily in spring and autumn, reduced activity in summer and winter [55] Decreased activity in driest periods of summer [34 p102]

Species	Climate/Temperature	Seasonality/Activity
Scarabaeus sacer	Mediterranean climate [55; 63; 113; 117] Annual rainfall between 200-800 mm [63]	Spring to autumn, depending on the country and its climate [34 p18; 51 p41; 55; 63; 85; 113; 117] Activity (ball-rolling implied) occurs between 22-30 °C [96 p64]
Sisyphus schaefferi	Mediterranean climate [48; 49; 65; 74]	Spring to autumn [34 p40; 48; 51 p45; 64; 66; 87] Ball-rolling begins at 20 °C, peaking between 25-30°C [96 p64]

3.8.3 Use of nest sites

Dung beetles do not use nests as a specific area where individuals return to in order to sleep, bear or rear young. However, the term nest is used to define a cluster of brood balls buried in the soil.

3.8.4 Use of marshes or swamps, estuaries, lakes, ponds or dams, rivers, channels or streams, banks of water bodies, coastal beaches or sand dunes

Dung beetles are primarily found in pastures, savannahs, shrublands, sometimes in forests and crops (see Table 9). A few species may occasionally venture in wetlands (*Euoniticellus triangulatus* [81]) or alongside streams (*Onthophagus opacicollis* [117]). They are unlikely to have a negative impact on these habitats: if anything, they help prevent runoff of excessive nutrients that could lead to eutrophication of these habitats [70 p23; 124].

3.9 Social behaviour and groupings

Dung beetles can occur in groups when feeding on or collecting dung from dung pads for reproduction [70; 93], and large numbers may be found on a single pad [70 p54, 65-66; 95 p5]. In some species, male and female dung beetles will cooperate with one another when breeding or nesting [68]. For example, male-female pairs of *Copris* beetles will work together to transport the dung into the breeding chambers [39; 68 p93-102; 90], and *S. sacer* couples engage in a complex ritual of ball rolling before mating [125]. However, once mated, it may only be the female that forms and buries the brood balls, as in *S. sacer* [125], or both males and females may cooperate in building and provisioning the nest, as in *S. schaefferi* [65].

3.10 Territorial and aggressive behaviour

Dung beetles are not generally aggressive animals, although aggression towards conspecifics may occur during the breeding season. For example, fights are common when *S. sacer* couples engage in ball rolling before mating, [125], and in *S. schaefferi*, successive combats when rolling a ball of dung can last up to 32 minutes [66]. Whilst combat in beetles may widely occur, it is perceived as form of sexual behaviour, with dung being the object of contention, not another individual [96 p162-165].

3.11 Characteristics that may cause harm to humans or any other species

Dung beetles do not pose a bite or injury risk to other animals or humans due to the nature of their mouthparts, which are designed for sucking up liquids and grinding nutritious particles in the dung [126]. Because they are only associated with dung, they do not pose a risk to humans or to native fauna, and they are unlikely to become pests.

4. Reproductive biology

Dung beetles are primarily found in pastures, savannahs, shrublands, sometimes in forests and crops (Table 9), and as such, produce nests on or under the ground of their environment. Details on nest characteristics for each species is summarised in Table 11.

There are four categories of dung beetles: dwellers (endocoprids), tunnellers (paracoprids), rollers (telecoprids) and kleptoparasites (kleptocoprids) [57; 94; 100]. Dwellers spend their entire life cycle in the dung, or possibly part of the lifecycle just under the surface of the soil, and kleptoparasites utilise dung stores of other species [57; 94; 100]. Therefore, these two categories are not considered in this application. Apart from four roller species (*A. laticollis*, *G. humanus, S. sacer* and *S. schaefferi*), all other species in this application are tunnellers (Table 11).

Rollers remove portions of the dung, roll it into a ball, and bury it superficially in the soil or place it in vegetation tussocks some distance away from the dung [57; 94; 100; 127]. Males, females or both may contribute to ball rolling, digging and making the brood chambers [65; 94], and some species also make and roll balls for feeding [57; 94].

Tunnellers burrow into the soil directly underneath or very close to the dung pad. Nest architecture and depth of tunnels vary between species, with a primary tunnel that may branch into secondary tunnels where dung balls or sausages are placed (Table 11). Larger species, such as *G. stercorarius*, can dig tunnels down to 50 cm [33; 127], whilst smaller ones, such as *O. nuchicornis*, only dig tunnels 5-15 cm deep [109]. *Cheironitis* species make a simple or branched tunnel [68 p76], whilst *Copris* species have an enlarged nesting chamber at the end of the main tunnel [36 p81-88; 90].

Table 11. Beetle type and notes on oviposition sites and behaviour

Species	Dung Beetle Category	Nest Location / Other Notes
Geotrupes stercorarius	Tunneller [33; 127]	Both sexes dig the tunnel, and the female then digs a series of horizontal brood chambers (galleries), provisioning each with dung and an egg [33]
Ateuchetus laticollis	Roller [48; 49; 52]	Female may produce two brood balls from a single dung ball [36 p106; 125]
Cheironitis scabrosus	Tunneller [98 p82]	
Copris incertus	Tunneller [44 p411]	Female tunnels 15-35cm deep into the soil, under or near dung pad; mating occurs during excavation; males and females fill the chamber with dung; female seals chamber and makes an average of 5 brood balls with an egg in each, and guards this compound nest from fungi and predators throughout development, only leaving nest just before or when new adults emerge [90] Female lays up to 10 eggs per nest (usually 3-7) [38]
Copris integer	*Copris* species are tunnellers [39; 50]	
Copris lunaris	Tunneller [50 p102; 128]	Female digs oblique tunnel 10-15 cm deep directly below dung; after feeding period, males arrive and couple with females and continue to feed; both sexes build an enlarged brood chamber slightly deeper (to 30 cm) and cooperate to fill brood chamber with dung from the pad above; about a week later the female eventually makes up to 9 brood balls with an egg in each, depending on the amount of dung available; female cares for nest for 4 months [36 p81-88] or until new adults emerge [27; 40]
Euoniticellus triangulatus	Tunneller [81]	*Euoniticellus* species have compound nests, directly below dung, with single brood ovoids in the branched tips of the tunnel [29 p25, 236]
Gymnopleurus humanus	Roller [57]	

Species	Dung Beetle Category	Nest Location / Other Notes
Onitis minutus	Tunneller [29 p172]	*Onitis* species have single tunnels with branched tips; brood ovoids (containing an egg) may be single or clustered together in the branched tips; dung sausages (containing 2 or more eggs laid at intervals in the sausage) may be present in the main tunnel or in the terminal branches; dung burial is often delayed for a number of days [29 p172]
Onthophagus medius	Tunneller [41]	Adults excavate burrows directly below dung; female uses dung to provision brood masses [41]
Onthophagus nuchicornis	Tunneller [28; 43; 116]	Adults burrow beneath or near dung pad; burrows have multiple branches forming brood-chambers; each is provisioned with dung into which a single egg is laid [42; 43; 116] 8-18 brood balls buried per beetle [43] Nests are 5-15 cm deep [109]
Onthophagus opacicollis	Tunneller [47]	
Scarabaeus sacer	Roller [52; 129]	Horizontal tunnel 9-10 cm long ends in an enlarged egg chamber; when brood ball (pear) is complete with an egg inside, female abandons nest; one brood ball per nest [36 p104-108] If there is strong competition (lots of beetles), beetles may roll smaller balls or fragments of dung; food balls may be rolled individually, but commonly as a pair; mating occurs on surface or after burying dung ball; generally male buries ball, then leaves female to search for another mate; female remains with ball until it is eaten; after feeding, female rolls nesting (brood) balls and buries them; each buried ball is transformed into an egg chamber; one brood ball per nest [125] Depth of tunnel depends on soil type: nests in central Asia nesting are 40 cm deep in loose soil and 7-20 cm in more compact or stony soil [96]
Sisyphus schaefferi	Roller [64]	Burrow dug into the soil with horizontal chamber 2-3 cm long ending in an enlarged egg chamber; once brood ball (pear) is complete with an egg inside, female abandons nest [36 p104-108] Brood burrows generally initiated by males; completed by both males and females; fresh dung rolled into burrow by both sexes; female takes it in whilst male guards tunnel; female inserts single egg into the ball; leaves the burrow; both sexes seal tunnel, fly off and start process again [65]

4.1 Sexual maturity, triggers for breeding and frequency of breeding

In general, dung beetles need a feeding phase after emergence from the brood chamber in order to allow gonads to mature [70]. This period of adult feeding is generally lengthy [96 p87-88]. It seems that once this feeding and gonad maturation phase is complete, reproductive behaviour occurs, and sexual encounters occur by accidental contact, with the search for a mate being inextricably linked to the search for food [96 p155-156]. For ball-rolling to occur, the ambient temperature must be suitable, and certain olfactory and tactile stimuli are required [96 p103]. During the breeding season, dung beetles produce multiple offspring, although the numbers of eggs and nests vary per species (Table 12). Information found for each species on the the age at sexual maturity, triggers for breeding and the frequency of breeding is provided in Table 12.

Table 12. Age of sexual maturity, triggers for and frequency of breeding

Species	Age of Sexual Maturity / Triggers for Breeding	Frequency of Breeding
Geotrupes stercorarius	Mating occurs after overwintering [33-35]	3-6 eggs/nest [Spaney 1910 in 127 p206] As females can lay 4-17 eggs [127 p206], females likely to repeat the nesting cycle in a season
Ateuchetus laticollis	Approximately 6 months for gonad maturation phase [36 p95-96] 3-4 weeks feeding and maturation period when beetles emerge in spring [125] Temperature must be between 22-30 °C [96 p64]	Multiple ovipositions in a season [48; 125; 130 p25]
Cheironitis scabrosus	Unknown	Unknown, but *Cheironitis* species have repeated nesting in a season [68 p36-37, 65, 76]
Copris incertus	Copulation occurs 10-40 days after emergence [38; 131]	1-4 nesting cycles per year [38]
Copris integer	Unknown	Unknown. Some *Copris* species build a single nest, others build more [68 p38, 92-102]
Copris lunaris	Mating occurs shortly after emergence in autumn; nesting occurs the following spring after feeding for 3-4 weeks [40] Overwintering adults emerge in May, and have a period of feeding before mating [27] Virgin females mated in spring begin nesting withing a few hours [40]	One nest per year, containing 4-7 brood balls; may reproduce for 2 years [39; 40]
Euoniticellus triangulatus	Unknown; however, *E. intermedius* begins oviposition within 5 days of emergence [68 p69]	Repeated nesting in a season, each with multiple ovipositions [29 p25, 236; 68 p69]
Gymnopleurus humanus	Unknown	Unknown, but will have repeated nesting in a season [68 p39]
Onitis minutus	Unknown	Unknown, but *Onitis* species have multiple nests in a season [68 p36, 65, 70-76]
Onthophagus medius	New generation adults emerge in late summer; overwinter or feed on surface until spring, when breeding occurs [41], implying that there is a maturation period before breeding commences, and there may be a temperature and/or daylength trigger for breeding	Unknown. Likely to be repeated nesting in a season with compound nests [68; 132]
Onthophagus nuchicornis	Mating occurs in spring [42], after adults have overwintered [42; 43; 109]; hence several months to reach sexual maturity Overwintering diapause is required for reproduction [109]	Repeated nesting in a season, each with multiple ovipositions [43; 68 p36, 78]
Onthophagus opacicollis	Breeding only happens in spring [34 p102] despite year round activity [34 p102; 55], implying a temperature and/or daylength trigger for breeding	Single or compound nests with multiple nests in a season [68 p36, 76-78]

Species	Age of Sexual Maturity / Triggers for Breeding	Frequency of Breeding
Scarabaeus sacer	After emerging in spring, both sexes have a 3-4 week feeding period allowing females to reach sexual maturity [125] Mating occurs when males and females cooperate to bury dung for feeding and maturation [125] Ball rolling serves as a sexual attractant [68 p82] and brood ball formation begins immediately after copulation [68 p132] Temperature must be between 22-30 °C [96 p64]	Simple nest with repeated nesting in a season [68 p39, 132]
Sisyphus schaefferi	Adults emerge in summer, overwinter, then have a feeding and maturation period in spring before breeding [65]; therefore 6+ months to sexual maturity Females copulate before each nesting sequence [94 p43] Mating occurs in spring, needs a minimum air temperature of 18 °C [36 p98] Partnered collaboration in rolling and burying of dung is necessary for nesting [66] Ball-rolling begins at 20 °C, peaking between 25-30 °C [96 p64]	Simple nest with repeated nesting in a season [68 p39-40] Female can make up to 12 brood balls in a season [36 p109-110; 65]

4.2 Development period

The time taken for full development from egg to adult in many species is unknown, although it is likely to be temperature-dependent. Development time varies between species, and may even vary within a species, as occurs in *G. stercorarius*, where some larvae pupate and produce adults in the autumn, whilst others overwinter and pupate the following spring [33]. Known development times are provided in Table 13.

Table 13. Development period

Species	Development period
Geotrupes stercorarius	170 days (approximately 5.5 months) to reach third instar [36, p57] Either 6 months or 12 months [calculated from 33] 16-17 months [calculated from 35 p263-264] Development from egg to adult takes 242 days (about 8 months) at 16-20 ˚C [133]
Ateuchetus laticollis	Development from egg to adult takes about 6 months: breeding occurs in spring [36 p95-96; 125]; adults eclose after autumn rains have softened the brood ball [36 p108] Development period of 5 months [50 p110]
Cheironitis scabrosus	Unknown
Copris incertus	Development from egg to adult takes 57-70 days at 24±2 °C [134] Development from egg to adult takes 8-12 weeks (2-3 months) depending on soil temperature [135] Care of brood balls lasts 88±16 days (about 3 months) [115]
Copris integer	Unknown
Copris lunaris	About 90 days (3 months) from egg to adult at 20°C [34 p42] About 4 months from egg to adult [36 p88]
Euoniticellus triangulatus	Unknown for this species. Likely to be relatively quick: development from egg to adult in *Euoniticellus intermedius* takes 5-6 weeks [136]
Gymnopleurus humanus	Unknown
Onitis minutus	Unknown

Onthophagus medius	Development from egg to adult takes 3-5 months [calculated from 41]
Onthophagus nuchicornis	Development from egg to adult takes 3-5 months [calculated from 42] Development is temperature dependent: about 1 month at 30 ˚C and almost 4 months at 16 ˚C [109]
Onthophagus opacicollis	Unknown
Scarabaeus sacer	Unknown
Sisyphus schaefferi	Development from egg to adult takes 3-5 months [calculated from 65] Development from egg to adult takes 4-5 months [calculated from 66] 5 months [50 p111] Development from egg to adult takes 41-49 days [Prasse 1957c in 96 p178-179]

4.3 Ability to hybridise

Hybridisation has only been shown to occur in sibling species of *Onthophagus* beetles. Different authors perceive *O. opacicollis* and *O. similis* as either two sibling species with a wide range of sympatry, or as two morphotypes of a single polymorphic species [76; 137]. In Spain, populations do not interbreed in some areas, but do in others, suggesting that speciation is not complete [76]; however, chromosomal analysis indicates no exchange of chromosomes, suggesting that hybridisation does not occur where the species co-occur [137]. If we consider hybridisation by *O. opacicollis* to still be unresolved, it is nonetheless clear from these two studies that this species only potentially hybridises with *O. similis*, and not even with the next closest species, *O. fracticornis* [76; 137]. As such, it is highly unlikely that *O. opacicollis* will hybridise with another species of dung beetle in Australia, whether it be native or introduced. In general, different species of dung beetles do not breed hybrids due to variance in their genital shape and size: they must have compatible genitals to mate with each other [e.g., see 138].

Although *O. vacca* and *O. medius* were originally identified as two different species by Erichson in 1848 [e.g., see 60], variation in external morphology caused them to be generally treated as a single species [60; 139]. The two species have overlapping distributions [60; 74; 140]. They were finally re-distinguished as different species, based on morphological characteristics [60], and DNA analyses supports the fact that they are two separate species [111; 140] that diverged at least 5 million years ago [140]. Nonetheless, it also appears that whilst a small number of F1 hybrids have been reared in the laboratory, no hybrids have been collected in the field, suggesting that the two species are reproductively isolated [111; 140]. Although *O. vacca* and *O. medius* are commonly found at the same place and at the same time [139; 141], phenological asynchrony also occurs, with *O. vacca* adults generally emerging about two months earlier than *O. medius* adults, both in the laboratory and the field [111]. Hence, whilst it is theoretically possible for hybridisation between *O. vacca* and *O. medius* to occur in the field, it has never been shown to occur and is unlikely to be significant in Australia.

4.4 Are individuals single sexed or hermaphroditic?

Dung beetles are either male or female [45 p11-12, 14], and there is no scientific evidence that dung beetles can change sex during their life.

5. Feral populations

5.1 Established breeding population outside native range

Three of the species included in this application have already been successfully introduced elsewhere. It is not clear whether introductions of *G. stercorarius* were deliberate or accidental, but it now occurs in several places (New Brunswick, Prince Edward Island and Quebec) in Canada [34 p372; 35 p265]. *Copris incertus* has been intentionally and successfully released in numerous countries: Hawaii [22], New Zealand [23; 24; 54; 73; 135], Fiji, New Caledonia, Solomon Islands and Vanuatu [54; 73]. In New Zealand, *C. incertus* is part of a current dung beetle release program to improve soils and rehabilitate waterways [124]. *Onthophagus nuchicornis* was apparently accidentally introduced into North America [42], and it is now well-established across the northern United States of America and southern Canada [42; 142].

5.2 Pest status

None of the species on this application are considered as pests anywhere: as with other introduced dung beetles, the three species that have been introduced elsewhere are all considered to be of benefit in their new environments, by removing dung, reducing negative impacts of other pests, and by improving soil health [e..g., 22; 24; 143]. In addition, imported dung beetles, including *C. incertus*, are considered to be cost-effective, sustainable, non-invasive, and have been approved by the government and the Environmental Protection Agency in New Zealand [124]. For similar reasons, 44 species of dung beetle have been imported and 23 have successfully established in Australia [70 p50; 144 p6], and additional species have been released or are being evaluated [145]. There is no information available to suggest that any of these species are being managed in any way to reduce population numbers. As mentioned above (Section 5.1), New Zealand has an active, ongoing program of releasing *C. incertus*, along with other introduced dung beetles [124].

5.3 Other introductions

Five species on this application have been introduced to new environments but failed to establish. *Onthophagus nuchicornis* was introduced to Hawaii in 1910 to help control the horn fly, but failed to establish [28; 42]. Failure to establish in Hawaii may be due to the fact that this species has an obligatory overwintering diapause period as a requirement for reproduction [109], and this may not be possible in Hawaii.

Cheironitis sp. nr *scabrosus* was introduced in a single release (October 1972) to a single location in New South Wales in 1972 [144 p38]. Failure to establish may have been due to the low number (400) of beetles released.

Copris incertus was released in Guam in 1953 but failed to establish [22]. It is not clear why this introduction failed, as *C. incertus* has successfully been introduced to Hawaii [22]. Insectary-bred beetles from Hawaii were also introduced to northern parts of Australia in 1968 – 1971 [54], and 2 937 beetles from Mexico were released at 20 sites across northern Australia (1969 – 1978), but all failed to establish [144 p6, 39]. Again, failure to establish may have been due to the low numbers of beetles released at the sites: the maximum number of *C. incertus* introduced at any site was 399 [144 p39]. However, it is also possible that *C. incertus* may have failed to establish in northern Australia because of an insufficient volume of high-quality dung available at the release sites when the beetles were released, since a release of only 100 *C. incertus* (50 males and 50 females) resulted in a population explosion northwest of Auckland, New Zealand (SA Forgie, pers. comm.). Some of these releases may also have been made in areas climatically marginal for this species (Section 7.2, Table 14).

Copris lunaris was introduced from Italy and France to a single site in New South Wales (near Uriarra Forest) over a thirteen-month period (December 1982 – January 1984), but failed to establish [144 p2, 39]. However, over that thirteen-month time frame, only 96 beetles were introduced, so it is likely that too few beetles were introduced at any point in time to enable establishment.

Onthophagus opacicollis was introduced from Greece to three sites in southwest Western Australia (April – June 1982) but failed to establish [144 p41]. Although 2 100 beetles were introduced, with all sites receiving at least 500 beetles, and 1 000 beetles released at a single site (near Moora) [144 p41], the introductions were spread over three months [144 p2]. Since it is not clear how many beetles were released at each occasion, it is possible that each release contained an insufficient number of beetles to enable successful establishment.

6. Environmental risk assessments of the species

We have not found any reports of risk assessments done on any of the species in this application. Four species were found on the IUCN Red List of Threatened Species, all ranked as of Least Concern (Section 2). Both *A. laticollis* and *O. opacicollis* are not considered to be threatened due to their wide distributions, locally abundant subpopulations, and their occurrence in several protected areas [3; 32]. *Cheironitis scabrosus* is not considered threatened as it is widely distributed in southwest South Africa, commonly occurs in cattle dung, and cattle farming is common throughout its range [30]. *Gymnopleurus humanus* is adaptable, widely spread, a dominant member of beetle assemblages within its range, and utilises a wide range of dung; therefore, it is not considered to be threatened [31].

Introduced dung beetles are considered beneficial in Australia, with 23 introduced species established to date [70; 144], reducing the density of pest flies, improving pasture quality and soil structure, and potentially reducing eutrophication of waterways [70]. The species were selected to fill spatial and temporal gaps identified by examining current dung beetle distributions in conjunction with data on the distribution of sheep and cattle in Australia. Because dung beetles only feed on dung, and the species selected have strong preference for cattle and sheep dung, they are not expected to pose a risk to humans or to native flora or fauna, and they are unlikely to become pests. They are also unlikely to compete with native beetles for resources.

Most recently, CSIRO successfully applied to have *Bubas bubalus*, *Euonthophagus crocatus*, *Gymnopleurus sturmi*, *Onthophagus vacca* and *Onthophagus marginalis* subsp. *andalusicus* added to the Live Import List, and obtained an importation permit from Department of Agriculture, Water and the Environment for all species. *Bubas bubalus* and *O. vacca* have been released following their importation but are yet to have officially established. *Gymnopleurus sturmi* and *O. m. andalusicus*, have been imported more recently but have not yet been released. Import risks are mitigated by keeping imported adult beetles in an Approved Arrangements facility and sterilising their eggs in Virkon® before removing them from quarantine.

Formal Import Risk Analyses have not been undertaken specifically for any of the species in this application. A permit issued by the Department of Agriculture, Water and the Environment will be required to import these species.

7. Likelihood of establishment in Australia

The aim of importing these species is to release them to establish breeding populations in Australia and fill the current seasonal and geographical gaps in dung beetle activity, so as to better control dung. The following points outline the information required for determining the likelihood that the species could successfully establish in Australia.

7.1 Ability to find food sources

Dung beetles use odour (chemoreception) to locate dung. They either actively fly around and search for dung, or sit and wait for odour trails to reach them and lead them to dung, and once located, the dung is approached by flight [94 p40-42; 96 p88-89]. Exotic dung beetles introduced to Australia seem to disperse depending on where livestock dung is found. For example, introduced *Bubas bison* were found to remain in the original cattle pasture in areas of permanent stocking, only moving between pads a few metres away, whereas in a different area, a colony of the same species was found to leave the original paddock to follow cattle being moved to paddocks up to a kilometre away [70 p60]. Some beetles previously introduced into Australia have spread at a rate of 50-80 kilometres per year (*Digitonthophagus gazella* and *Euoniticellus intermedius*), whilst others have only spread one half to four kilometres per year (*Bubas bison*, *Onitis caffer* and *Geotrupes spiniger*) due to limited flight activity [70 p59]. *Copris incertus* has been recorded to have spread at a rate of 20 km in 20 years in New Zealand (SA Forgie, pers. comm.), and can fly distances in excess of 50 m [23], whilst *Sisyphus schaefferi* can fly upwind for 40-60 m [96 p89-90].

Dung beetles in this application all feed on dung from cattle, sheep and horses, although they may have a wider range (i.e., human, dog, alpaca, etc., see Section 3.8.1, Table 9). As such, they should not compete with native species for food, as native species generally have different dung preferences [70 p74]. Although some native species utilise cattle and horse dung, these species are not considered to be at risk since increased dung availability from increased livestock production is thought to have increased their population numbers [70 p74].

Adult beetles of some species have occasionally been recorded using other food sources: *G. stercorarius* [20; 33], *O. nuchicornis* [42], and *S. schaefferi* [119] have been reported from fungi, *O. nuchicornis* has been reported on decaying plant material [42], and *G. humanus* [110 p9], *O. nuchicornis* [42; 146], *S. sacer* [63; Fausek 1906 in 96 p18, Paulian 1938 in 96, p33] and *S. schaefferi* [Paulian 1938 and Panin 1937 in 96 p33] have all been found on carrion. However, these are generally not the primary food sources for coprophagous beetles [96 p33-34], and feeding on these sources do not pose a risk to either livestock or to commercial plants (see Section 8.3).

7.2 Ability to survive and adapt to climatic conditions

We used the Climate Match (Regional) model of CLIMEX [147] to compare the climates of known locations of each species to the climate in Australia. The underlying assumption in this analysis is that a species can establish in climatically similar locations in a novel area [147-151]. In such analyses, a climate match index (CMI) > 0.7 is accepted to be the minimum for the successful introduction of a species [151; 152]. Thus, for each of the species, we provide a map indicating the CMI to locations where it occurs, only showing regions that have a CMI > 0.7 (Table 14). We used a new, as yet publicly unavailable, 30' CliMond [153] climate grid for the world.

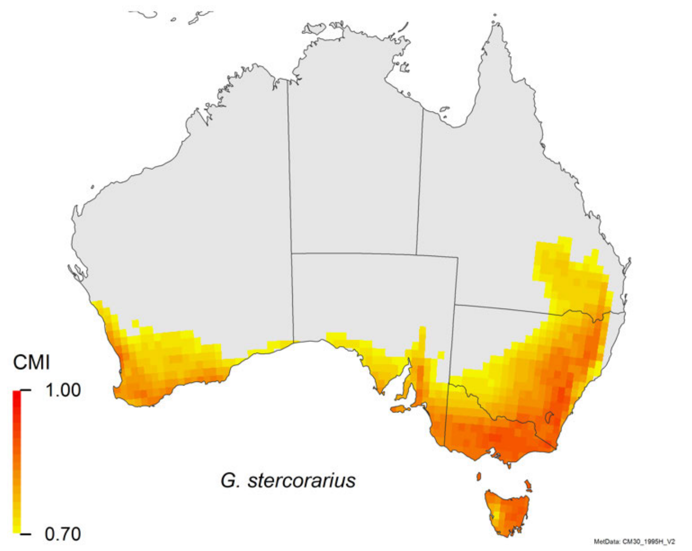
We have not run CLIMEX with any climate change scenarios. Whilst this is possible, all climate change scenarios are based on different emission scenarios, and these are all fraught with conjecture. Increases in temperatures will likely enable the more temperate species to expand their ranges further northwards; and species with a bimodal activity designed to avoid extreme summer temperatures may have more reduced activity peaks, or these peaks may extend further into the winter season if this also warms.

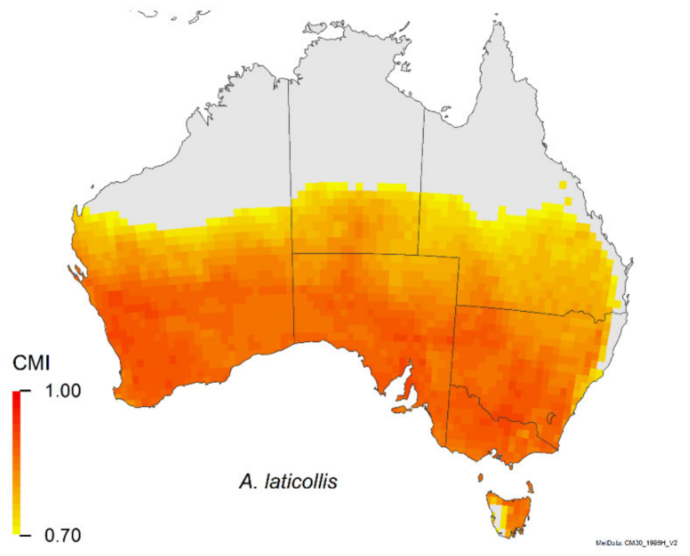
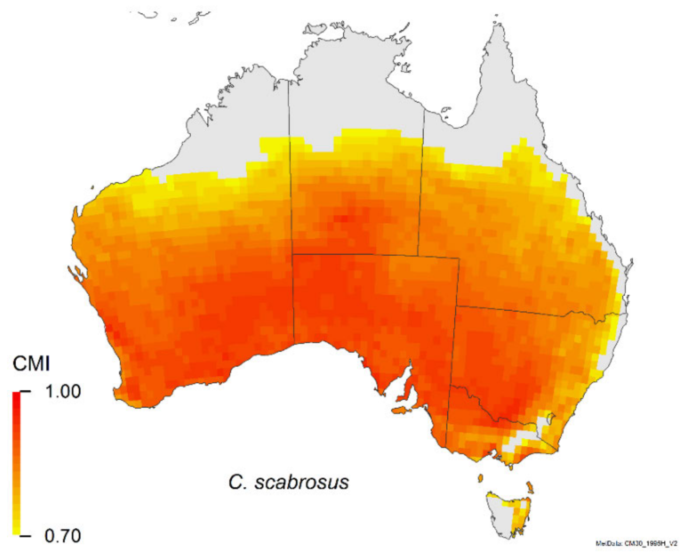
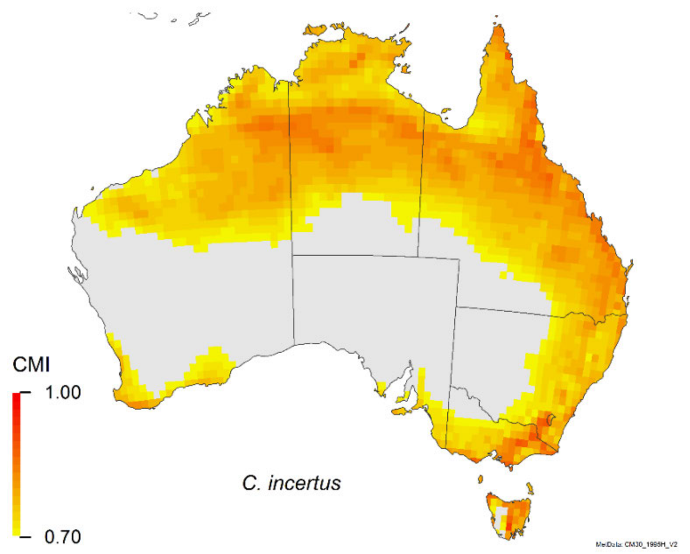
As shown earlier (Section 3.6, Table 8), many species have mechanisms by which to reduce activity in unfavourable climatic conditions. Some species have an obligate winter diapause (*O.*

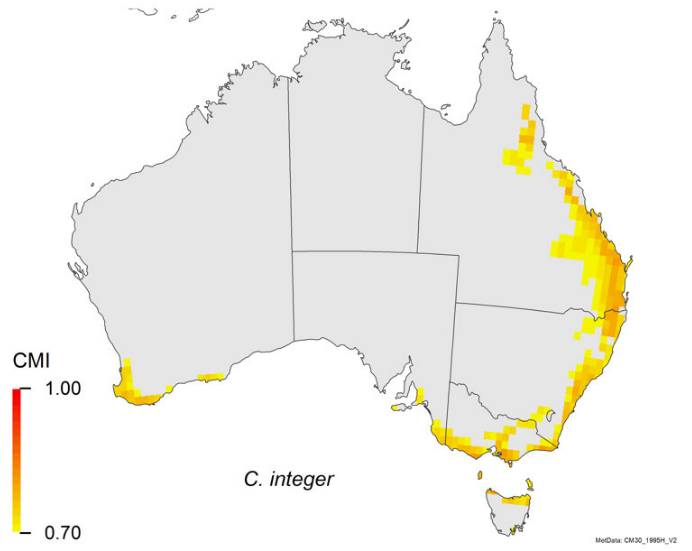
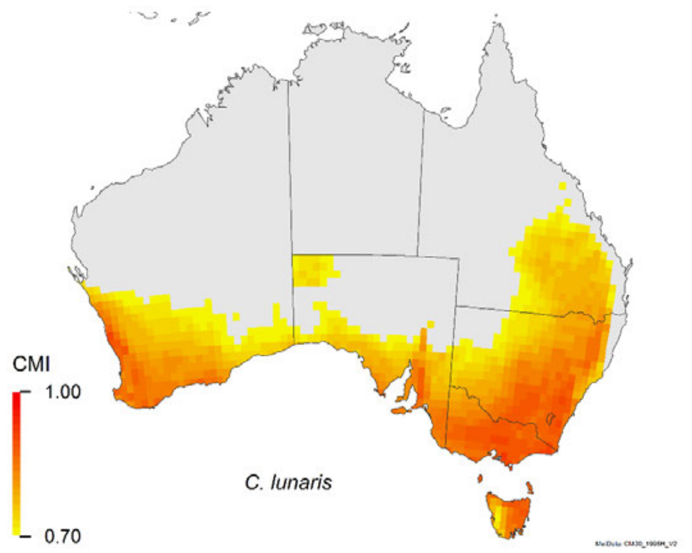
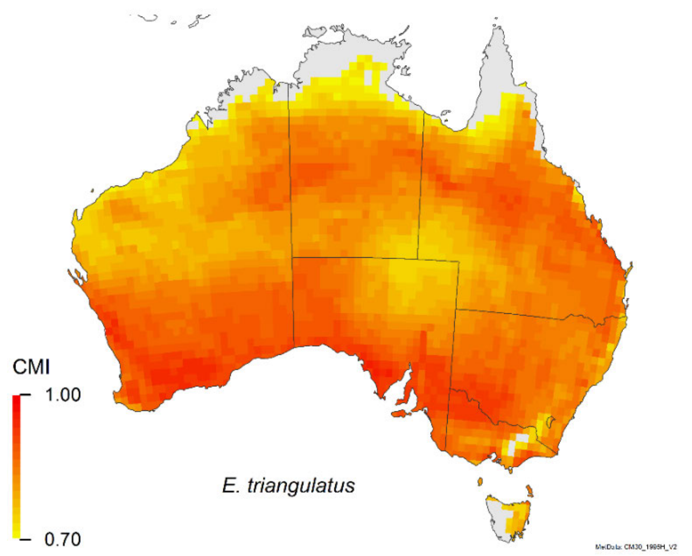
nuchicornis), whilst others appear to be able to reduce their activity in winter, but to capitalise on warm days to continue to feed (e.g., *C. incertus*, *C. lunaris, O. medius* and *O. opacicollis*). In addition, some species can reduce their activity if conditions become unfavourable (*C. scabrosus*, *C. incertus*, *E. triangulatus*, *O. opacicollis*, *S. schaefferi*). Thus, it is very likely that these species will all be able to adapt to Australian climatic conditions. If and when any of these species are imported to Australia, the CLIMEX Match Climates analysis can be repeated at a finer scale to identify and target the most likely places for successful establishment. CLIMEX Compare Locations models could also be built and used to target releases in the correct seasons, and to determine whether seasonal patterns in Australia will be similar to those in the native range. For example, some species (e.g., *C. incertus*, *C. lunaris, O. medius* and *O. opacicollis*) that generally overwinter when it is too cold may be able to be active over winter in parts of Australia where winter temperatures are not as severe.

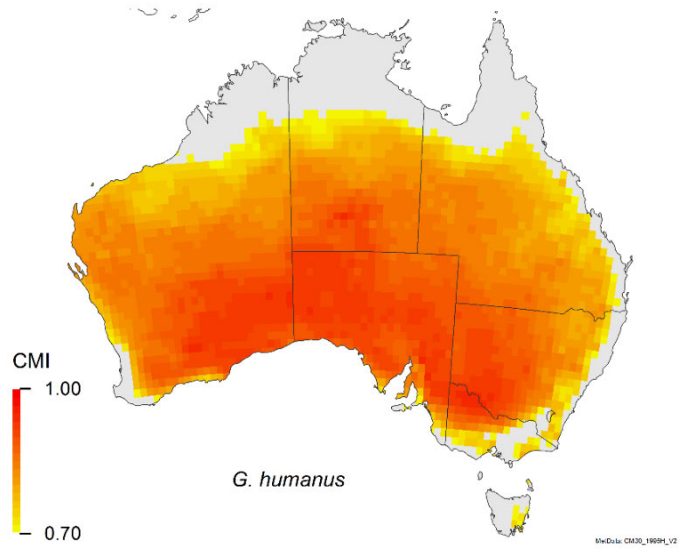
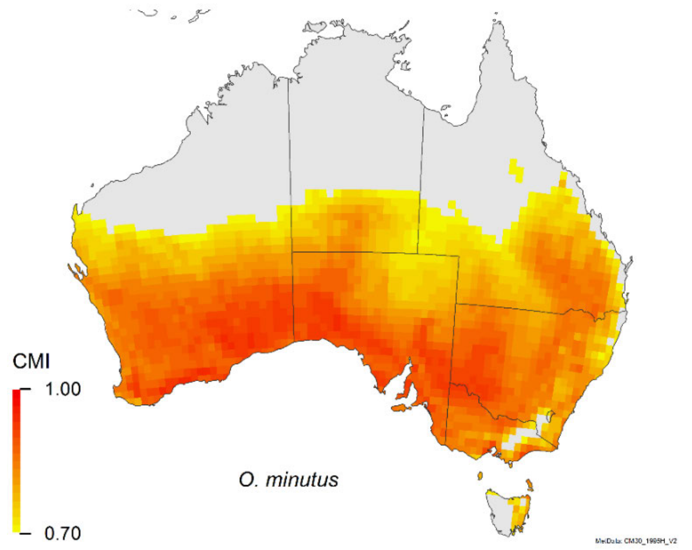
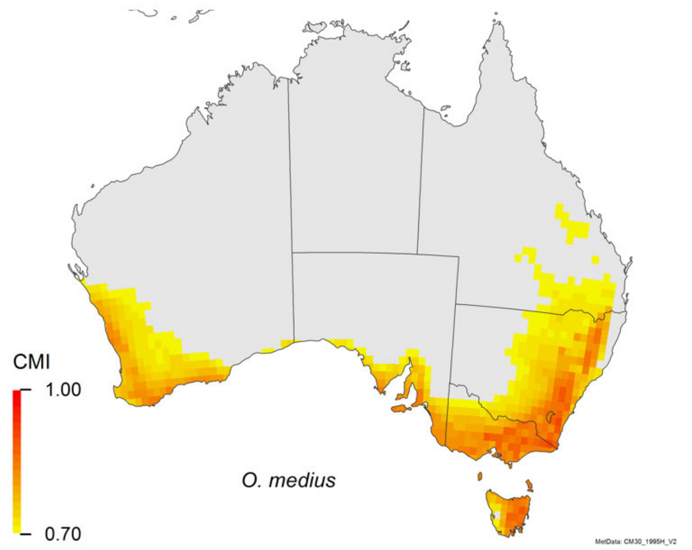
The CLIMEX analysis suggests that both the north and south of Australia have areas that match climates where *C. incertus* occurs. It is possible that this species has a wide climatic tolerance, as location records for Hawaii indicate that it is found at a range of altitudes (sea level to in excess of 1 000 m), and it is found in both relatively dry and moist environments (not all of Hawaii is tropical).

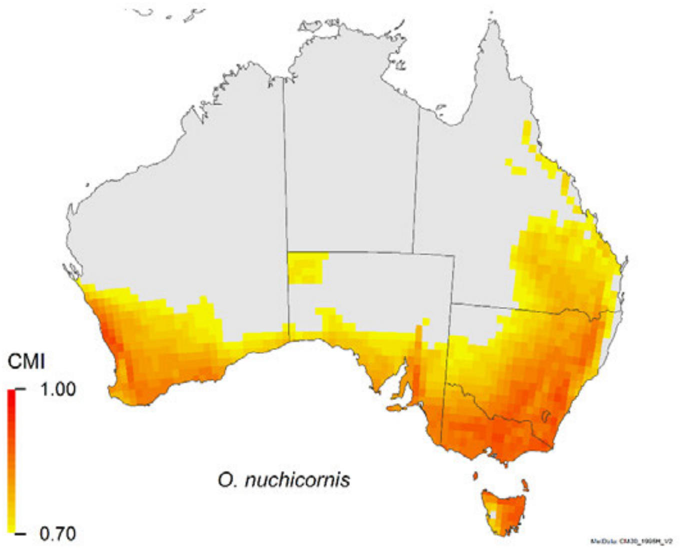
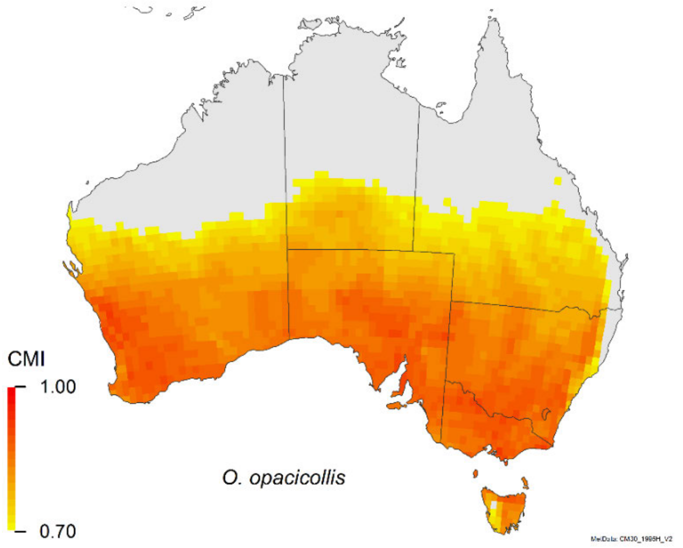
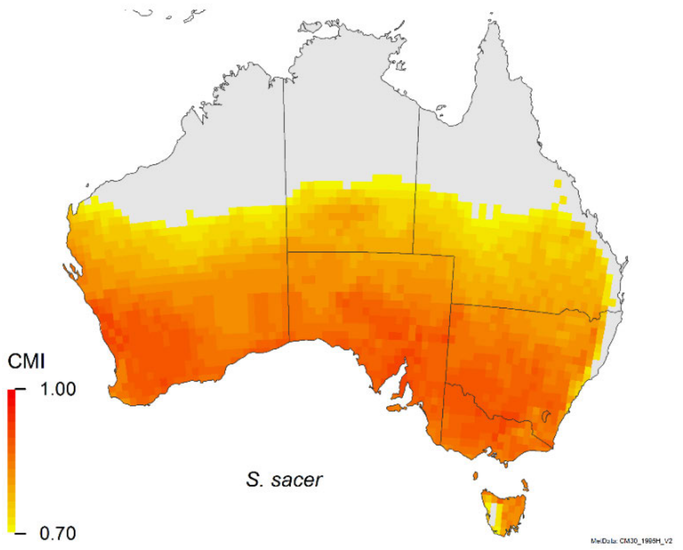
Table 14. Areas in Australia where each species is likely to be able to persist, based on a CLIMEX Match Climates (Regional), using a new CliMond meteorological dataset. Information is provided on the location records used for each species.

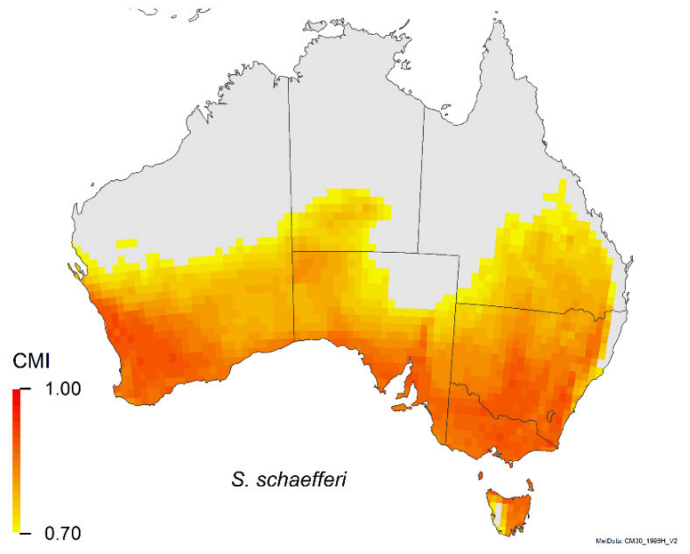
Regions of Australia matching the climate where the species is found. Climate Match Index (CMI) > 0.7	**Source of species' location records and additional notes on data used**
	GBIF.org (08 September 2021) GBIF Occurrence Download https://doi.org/10.15468/dl.yj2evn 1804 duplicate records removed, based on country, latitude, longitude and altitude

Regions of Australia matching the climate where the species is found. Climate Match Index (CMI) > 0.7	Source of species' location records and additional notes on data used
	GBIF.org (08 September 2021) GBIF Occurrence Download https://doi.org/10.15468/dl.9g2s33 601 duplicate records removed, based on country, latitude, longitude and altitude
	Adrian Davis; Pretoria, South Africa
	GBIF.org (08 September 2021) GBIF Occurrence Download https://doi.org/10.15468/dl.5fx98h 1009 duplicate records removed, based on country, latitude, longitude and altitude 82 records removed as likely mis-identifications (Colombia, Costa Rica, Ecuador, Guatemala, Honduras, Nicaragua, Panama and Peru) 3 records removed (Australia, Democratic Republic of Congo and Zaire) as unsuccessful introductions or the nature of establishment is unknown 28 records removed (Mexico) as not conforming to distribution in Darling and Génier [73] This analysis utilised location records from Hawaii, Mexico, New Zealand and Western Samoa

<table>
<tr><th>Regions of Australia matching the climate where the species is found. Climate Match Index (CMI) > 0.7</th><th>Source of species’ location records and additional notes on data used</th></tr>
<tr><td>
</td><td>GBIF.org (09 September 2021) GBIF Occurrence Download
https://doi.org/10.15468/dl.zabfqc
17 duplicate records removed, based on country, latitude, longitude and altitude</td></tr>
<tr><td>
</td><td>GBIF.org (08 September 2021) GBIF Occurrence Download
https://doi.org/10.15468/dl mve6nk
1643 duplicate records removed, based on country, latitude, longitude and altitude
36 records removed, as basis of record was invalid</td></tr>
<tr><td>
</td><td>Adrian Davis; Pretoria, South Africa</td></tr>
</table>

Regions of Australia matching the climate where the species is found. Climate Match Index (CMI) > 0.7	Source of species' location records and additional notes on data used
	Adrian Davis; Pretoria, South Africa
	Adrian Davis; Pretoria, South Africa
	GBIF.org (8 September 2021) GBIF Occurrence Download https://doi.org/10.15468/dl.uxcmed 432 duplicate records removed, based on country, latitude, longitude and altitude

Regions of Australia matching the climate where the species is found. Climate Match Index (CMI) > 0.7	Source of species' location records and additional notes on data used
	GBIF.org (08 September 2021) GBIF Occurrence Download https://doi.org/10.15468/dl.4gw8e2 732 duplicate records removed, based on country, latitude, longitude and altitude 39 records removed, as basis of record was invalid 3 records (southern India) removed, as outliers for known distribution
	GBIF.org (08 September 2021) GBIF Occurrence Download https://doi.org/10.15468/dl.j863n8 423 duplicate records removed, based on country, latitude, longitude and altitude
	GBIF.org (09 September 2021) GBIF Occurrence Download https://doi.org/10.15468/dl.vwrxug 232 duplicate records removed, based on country, latitude, longitude and altitude 3 records (Africa) removed as outliers of known distribution and/or because of record issues

Regions of Australia matching the climate where the species is found. Climate Match Index (CMI) > 0.7	Source of species' location records and additional notes on data used
	GBIF.org (09 September 2021) GBIF Occurrence Download https://doi.org/10.15468/dl.96tnsv 1030 duplicate records removed, based on country, latitude, longitude and altitude 38 records removed, as basis of record was invalid 3 records (South Africa, Morocco and Egypt) removed as outliers of known distribution and/or because of record issues

7.3 Ability to find shelter

All selected dung beetle species occur primarily in open habitats (grasslands, pastures), and only very rarely in wooded areas (Section 3.8.1, Table 9). They are dependent on dung for breeding and for food (Sections 4.1 and 7.1), and as discussed above (Section 7.1), these species generally prefer cattle, sheep and horse dung. As such, they will only occur in grazing areas where this resource is available. They will not be found in buildings, gardens, horticultural areas, broadacre farms, orchards or vineyards, as these will not have the requisite dung resources. Modified pastures or rangelands would be suitable, providing there is sufficient livestock to consistently produce enough dung for populations to establish.

7.4 Reproduction

The dung beetle species on this application have been selected to have high reproductive capacities. Most species have repeated nesting cycles in a season, with no brooding (parental care) of the young, and multiple eggs laid per season (Section 4, Tables 11 and 12). Three species (*C. incertus*, *C. integer* and *C. lunaris*) have compound nests (multiple eggs) with females caring for the brood balls until the new adults emerge, but *C. incertus* may have up to two nesting cycles in a year [38] and *C. lunaris* is capable of reproducing for two years [39; 40]. Information is lacking as to whether *C. integer* has repeated nesting cycles in a season and/or if females can nest over several seasons/years. However, parental care in these species is likely to improve breeding success, as nest care helps protect the brood balls and increases survival of offspring [90]. Studies in the CSIRO European Laboratory will determine likely rates of reproduction prior to release into the Australian environment.

Reproductive competition from other dung beetle species is not expected to be an issue, as discussed in Section 3.4.2. Dung beetles commonly occur in multi-species assemblages [47; 97-101], and avoid interspecific competition by having differences in feeding and breeding behaviours, patterns of activity (i.e., nocturnal, diurnal or crepuscular) and seasonal activity (i.e., when they are most active and breeding) [100].

7.5 Limiting influences on the species' distribution in Australia

Section 3.4 includes information on predation, competition and resource availability in the native range. As mentioned above, dung availability is key to dung beetle establishment as it is used both as a food source and for reproduction. Competition for dung or mates exists in dung beetles, but as the species in this application have been selected to fill gaps in dung beetle activity, interspecific competition should not be an issue.

7.6 Increased potential for population establishment if more individuals of the species were present in Australia

Introduced dung beetles seem to be less likely to establish in Australia when release numbers are lower. Of the 20 foreign species previously released by CSIRO that failed to establish, 19 had fewer than 8000 individuals released in total, whereas 20 of the 23 species that did establish had more than 8000 individuals released [144 p6]. The low numbers of beetles released for some species was generally due to the small number of eggs imported (for species bred from eggs) or due to difficulties in breeding in quarantine. All efforts will be made to breed as many individuals as possible for release in order to maximise the chances of establishment.

8. Assessment of the potential impact in Australia

8.1 Similar niche requirements to native species

Selected species are not likely to compete with native dung beetle species due to their different niche preferences. The non-native species generally utilise sheep and cattle dung in open habitats, while native dung beetles are adapted to marsupial dung in forest or woodland habitats. There are a number of native *Onthophagus* species that utilise domestic dung, and although the interactions between the native and introduced species are not well understood, populations of native species may have increased with increased dung availability rather than decreased as a result of competition with introduced species [70 p74]. Furthermore, as dung beetles occur in large assemblages with multiple species co-occurring [47; 97-101], and large numbers may be found on a single pad [70 p54, 65-66; 95 p5; 96 p67-68], it is unlikely that new species will exclude native species.

8.2 Transmission of pests and diseases

The importation process for adults of the selected species will mitigate the risk of transmitting exotic pests or diseases. Beetles collected in their native distributions will be starved and cleaned prior to shipping to Australia, and will be kept in an Approved Arrangements (quarantine) facility for the duration of the project. All eggs will be treated with a disinfecting agent (Virkon®) prior to being released from quarantine, reared to adulthood and released into the wild and/or used for the establishment of mass-rearing colonies.

Whilst dung beetles are able to disseminate pathogens that survive their digestive tract or attach to their bodies, it is not clear that dung beetle activity actually increases transmission rates of these infections [154; 155]. Dung beetles have been found to destroy pathogens in dung by altering the abiotic conditions within dung pads, by digesting and burying dung [155], and to reduce the number of infective pathogens on the soil surface as well as their survival [70 p92]. Pathogens that pose a risk to humans but are destroyed by dung beetles include *Cryptosporidium parvum* and *Escherichia coli* [154; 156; 157]. In any event, infected beetles should typically not come into contact with humans, and so their risk of transmitting parasites and diseases to humans is very small. And whilst ball rolling by dung beetles may possibly spread pathogens [158], this is unlikely to occur over a long distance as roller beetles do not bury their dung ball far from the original dung pad, and so again, the risk to humans is minimal.

8.3 Probable prey and food sources

Dung beetles require dung as a food source and for reproduction (see Sections 4 and 7.1), and hence do not attack or prey on wildlife, and neither do they pose any risk to domestic or commercial animals or plants. Some species will feed on carrion (*G. humanus* [110 p9]; *O. nuchicornis* [42; 146]; *S. sacer* [63; Fausek 1906 in 96 p18, Paulian 1938 in 96, p33]) and *S. schaefferi* [Paulian 1938 and Panin 1937 in 96 p33] but this does not pose a risk to live animals, and dung is nonetheless required for reproduction. Similarly, *G. stercorarius* has been reported from rotting fungi [20; 33], *O. nuchicornis* has been recorded to feed on fungi and decaying plant matter[42], and *S. schaefferi* to roll balls of fungal matter [119], but again, this does not pose a risk to any commercial plants and they only utilise dung for reproduction (Lumaret, pers. comm.).

8.4 Impacts on habitat and local environments

In general, dung beetles are considered to have beneficial impacts on habitats, not detrimental ones. Section 3.8.3 highlights evidence that they help prevent runoff of excessive nutrients that could lead to eutrophication of wetlands and aquatic environments [70 p23; 124], Section 5.2 indicates that dung beetles are beneficial to new environments, by removing dung and by improving soil health [22; 24; 70 p13-24; 143], and Section 8.2 highlights the benefits of beetles in reducing pests and diseases [70 p85-94; 155; 159].

Dung beetles can disperse seeds through the transport and burial of the dung of primary dispersers [160-162]. Seeds are dispersed both horizontally and vertically from where they are deposited [163]. Seeds can survive digestion by sheep and cattle, and although in some cases their viability may be reduced (Hogan and Phillips 2011), in some weeds it may be enhanced [164], so the selected dung beetles may be able to spread weeds within the original pasture. Dung beetle seed dispersal has been shown to have both positive and negative effects on germination success [160-162; 165]. It should be noted that weed dispersal by introduced dung beetles has not been reported in the literature, and if introduced dung beetles were highly effective dispersers of weeds, it is likely that property owners would have made CSIRO aware of this during the past 50 years of dung beetle work.

8.5 Potential control or eradication programs

The selected species are intended to be released as a biological control measure for bush flies and dung and they are not considered likely to become environmental pests; thus, no control or eradication programs are considered necessary.

8.6 Behaviours that cause environmental degradation

Dung beetles are not considered to contribute to environmental degradation. As discussed in Sections 3.8.3, 5.2, 8.2 and 8.4, dung beetles are seen to have positive impacts on the environment, not negative impacts.

8.7 Impacts on primary industries

Additional introductions of dung beetles to Australia are expected to improve productivity by incorporating dung nutrients into the soil and thereby increasing soil nutrients, aerating and mixing the soil to increase water permeability and reduce nutrient run-off, and increasing earthworm numbers. The presence of dung beetles was shown to markedly increase pasture production in experimental plots in South Australia, Victoria and Western Australia [70 p14]. Livestock will not generally graze around dung pads, and so dung burial by beetles not only removes the dung, but it also increases nutrient availability to enhance grass growth, thereby increasing pasture productivity [124; 163]. As discussed in previous sections, dung beetles do not pose a risk to humans or to native fauna, they are unlikely to become pests because they are only associated with dung (Section 3.11), they are not likely to transmit parasites and diseases that might negatively impact primary production (Section 8.2), and they have an overall positive impact on habitats and environments (Sections 8.4 and 8.6).

CSIRO is currently participating in a project under the Rural Research and Development for Profit program [166] to gain a more thorough understanding of the ways in which dung beetles can assist primary industry. Dung beetles have been shown to reduce the reproductive success of dung breeding flies, thereby contributing to fly control [70 p88; 159]. Beetle activity in Australia has also been shown to reduce the incidence of livestock intestinal worms (in the *Trichostrongylus* family) [70 p92-93].

8.8 Damage to property

Dung beetles are associated with livestock production in pastures and rangelands, and so do not pose a threat to property or equipment.

8.9 Status regarding social nuisance or danger

Dung beetles are only associated with dung and the species on this list are associated primarily with livestock dung. Therefore, they will not become a social nuisance in any built-up environments (e.g., cities, parks, public facilities).

8.10 Potentially harmful characteristics

As discussed in Section 3.11, dung beetles do not pose a bite or injury risk to other animals or humans. As indicated in Section 8.2, although they may carry pathogens, the risk to humans is minimal, and there is no evidence that they increase transmission of pests and diseases to animals [154; 155]. As discussed in Section 8.2, 9 and 11, appropriate quarantine measures will be taken to prevent disease or pest transmission by imported beetles.

9. Conditions and restrictions applied to reduce negative environmental impacts

Adult beetles of each species will be collected from various localities and air freighted to Australia. All species will be collected form sites where they are abundant. Following collection, adult beetles will be starved for three days to allow them to void any foreign parasites they may have eaten. They will be washed in clean water and any parasites on their bodies will be manually removed. The adults will be segregated by sex then placed in containers of moist vermiculite with breathing holes. These containers will be packed loosely to enhance their chances of survival. The containers will be placed in an insulated cooler box and air freighted to Australia at room temperature. After arrival in Australia, the imported adult beetles will be kept in an Approved Arrangements (AA) facility for the duration of the project. Any beetles that die in an AA facility will be stored in 100% ethanol or autoclaved before disposal, and all eggs released from an AA site will first be surface sterilised in Virkon®.

These importation and AA restrictions will follow Department of Agriculture, Water and the Environment conditions and reduce the risk of negative environmental impacts from parasites or the accidental release of imported beetles. Additional information on collection, importation, and AA practices can be found in Section 8.2, 9 and 11.

10. Rationale for importing dung beetles

10.1 History of the CSIRO dung beetle project

The objective of introducing new species of dung beetles to Australia is to enhance dung burial and reduce the negative impact dung accumulation has in both cattle and sheep farming areas. The use of exotic dung beetles for the biological control of bush flies was first proposed in the early 1960s by CSIRO Entomology. The first round of introductions imported adult beetles and surface-sterilised eggs from Hawaii, Africa, and Europe and ran until 1986 [144 p1]. A second round of introductions, which relied on the importation of adult beetles from Europe, was undertaken from 1990 to 1992 [144 p1]. These two rounds of introductions resulted in the field release of 43 species of Scarabaeine dung beetle, 23 of which are now regarded as being established [70 p50; 144 p6]. A third round of introductions, also relying on adult imports from Europe, was undertaken in 2011-2015 [108]. The fourth and current round of the project began in 2018, importing adult beetles of four additional species from northern Africa, to fill the spring gap in southern Australia.

The multiple benefits of dung beetles have been discussed in previous sections. They help prevent runoff of excessive nutrients that could lead to eutrophication of wetlands and aquatic environments (Section 3.8.4). They are considered to be of benefit in their new environments by removing dung, reducing negative impacts of other pests and improving soil health, and imported dung beetles are considered to be cost-effective, sustainable, and non-invasive (Section 5.2). They have been found to destroy pathogens and reduce the number and survival of infective pathogens on the soil surface, including some that pose a risk to humans (Section 8.2). And finally, they provide positive benefits to the primary industries sector as they increase pasture productivity (Section 8.7).

10.2 Benefits of dung burial

Previous dung beetle introductions have focused on cattle dung burial and bush fly reduction [144 p1; 167 p260], although bush flies can breed in sheep dung [168 p26] and other domesticated and feral animals such as pigs, horses and dogs [169]. Many of the species on this application utilise sheep, cattle and other animal dung, and so they may provide control for both livestock production systems and the environment. We discuss the specific impacts of dung burial in the following two sub-sections.

10.2.1 Soil improvement

The introduction of new dung beetle species is intended to reduce pasture fouling through dung burial, as unburied dung is a source of annoyance to farmers. Cattle dung may remain on the soil surface for between 1 - 16 months in New Zealand, depending on season and rainfall [170], and the annual loss of productive pasture from unburied dung voided by a single cow was estimated to be 0.08 hectare [171]. With the national herd running at 23.4 million [172], this potentially equates to an annual loss of pasture of 1.9 million hectares, although it has more recently been estimated that 200 000 hectares of pasture would be lost annually if cattle dung remained unburied [70 p13]. A Polish study [173] found that unburied sheep dung may cover around 20% of a pasture in a year, although no information was provided on stocking rate. Previous introductions of dung beetles have already helped mitigate this problem: whilst harrowing to disperse cattle and horse dung used to be common in southern Australia, it is now rare [70 p35].

Additional dung beetle introductions are expected to improve soil structure and nutrient levels, and to reduce nutrient runoff into waterways. In Australia, two introduced dung beetles were found to improve the soil and the surrounding landscape by incorporating nutrients, aerating and mixing the soil, increasing water permeability, and preventing nutrient runoff from unburied dung [70 p13-24] , and similar improvements in soil structure and nutrient levels have been observed outside Australia [163; 174]. Other studies have found an increase in plant productivity when dung beetles were present [70 p14-17; 163 p1464; 175; 176], suggesting that dung beetles may assist crop production (Section 8.7). CSIRO is currently participating in a project under the Rural Research and Development for Profit program to gain a more thorough understanding of the ways that dung beetles benefit the soil and improve crop productivity [166].

10.2.3 Control of pest flies

The Australian bush fly (*Musca vetustissima*) is widely known as a major nuisance pest of humans and livestock, although no formal assessments have been made of its economic impact. Bush flies have been implicated in the transmission of trachoma, a very serious problem in Australian Aboriginal communities [70 p34; 177]. The bush fly is present throughout the year in the northern half of the continent, but is unable to survive over winter in southern parts [178]. These areas are re-colonised during late-winter and spring by migrants from the north. The arrival of the bush fly in southern Australia in August-October commonly precedes the emergence of already established spring-active exotic beetles by 1-2 months (Section 10.3, Table 15). Dung is commonly available at this time of the year, enabling fly populations to build up rapidly; therefore, there is a need for winter- and spring-active beetle species.

Only a few native Australian dung beetles utilise the dung of cattle, sheep and horses: most indigenous species occur in forest and woodland habitats [70 p74; 167 p255], and preferentially utilise dung of native animals [70 p74; 167 p255]. Introduced dung beetles can supress this activity through their own use of dung for nesting and feeding. Not only do they disturb the dung pads and remove dung from the soil surface, but they also compete with bush flies by feeding on the dung juices, leaving fly larvae to die of dehydration [70 p85-88].

The introduction of exotic dung beetles for the biological control of dung and bush flies is widely regarded as being highly successful. For example, dairy farmers have benefitted from the absence of flies from milking sheds during summer [70 p34]. However, field control of flies has been difficult to document scientifically, despite laboratory studies demonstrating the effectiveness of dung beetles to reduce fly breeding [179; 180]. Field measurements with entire dung beetle assemblages are more complicated due to fly migration, seasonal weather, dung quality, and the changing seasonal abundance of dung beetle species [e.g., 181; 182] although some studies have demonstrated real reduction in flies emerging from dung pads due to dung beetle activity [183; 184]. In addition, the existence of the current outdoor dining culture in southern Australia has been credited to the activity of dung beetles in suppressing bush fly populations throughout Australia for much of the year [70].

10.3 Gaps in dung beetle activity

An analysis of dung beetle records in Australia has shown that most pastoral areas of Australia are now home to at least one or more species of introduced dung beetle. Whilst various areas may have between 6-10 introduced species, there are many regions where there are only 1-2 established species [144 p5]. Considering that these species have defined activity periods (Table 15), there are many remaining geographical and seasonal gaps in dung beetle activity. With climate change and major droughts that occurred in recent years, there is also a need for species that can withstand more arid conditions.

Table 15. Distribution and activity period of introduced dung beetles in Australia. Data from [144; 185; 186].

Species	Activity period	Distribution in Australia
Bubas bison	Autumn to spring	WA, SA, VIC, NSW
Copris elphanor	Spring to autumn	QLD: very localised
Copris hispanus	Autumn to spring	WA: very localised
Euoniticellus africanus	Spring to autumn	NSW, QLD
Euoniticellus fulvus	Spring to autumn	WA, SA, VIC, NSW, TAS
Euoniticellus intermedius	Spring to autumn	WA, SA, NT, NSW, QLD
Euoniticellus pallipes	Spring to autumn	WA, SA, VIC, NSW
Geotrupes spiniger	Spring to early winter	VIC, NSW, TAS
Liatongus militaris	Spring to autumn	QLD, NT, NSW (northeast corner)
Onitis alexis	Spring to autumn	WA, SA, NT, VIC, NSW, QLD
Onitis aygulus	Spring to autumn	WA, SA, VIC, NSW
Onitis caffer	Autumn/winter	WA, NSW, QLD
Onitis pecuarius	Late spring to autumn	NSW, QLD (southeast)
Onitis vanderkelleni	Spring/summer	QLD: very localised
Onitis viridulus	Spring to autumn	QLD, NT, WA (northeast corner)
Onthophagus binodis	Late spring to autumn	WA, SA, VIC, NSW, QLD, Tas
Onthophagus gazella	Spring to autumn	WA, NT, SA, NSW, QLD
Onthophagus nigriventris	Spring to autumn	NSW, QLD
Onthophagus obliquus	Beginning rain season	QLD: very localised
Onthophagus sagittarius	Summer	QLD (coastal), NSW (northeast corner), NT
Onthophagus taurus	Spring to autumn	WA, SA, VIC, NSW, TAS
Sisyphus rubrus	Spring to autumn	QLD, NSW (northeast)
Sisyphus spinipes	Spring to autumn	QLD, NSW (northeast)

A map of all dung species recovered and reported [144] was produced. This was compared to maps of cattle areas and densities [187] and sheep areas and densities [188] to identify regions with relatively low beetle activity for the livestock present. Areas were categorised by predominant Australian climate regions [144 p11]. The key seasonal gap identified by this analysis was winter: winter-active beetles are required in all the areas identified as needing additional dung beetle species to effectively deal with dung. There is also a need for species that can withstand both summer and winter in more arid conditions, as many of the currently established species cannot withstand prolonged hot and dry conditions: during the recent drought, dung beetle populations were observed to plummet. Five major seasonal/geographical gaps were identified:

Gap A: winter in wet summer, dry winter rainfall zone
Gap B: winter in wet summer, low winter rainfall zone
Gap C: winter in wet winter, low summer rainfall zone
Gap D: winter in arid rainfall zone
Gap E: summer in arid rainfall zone

It is important to note that other regional gaps exist, and these should also be filled where possible. This could be achieved with the species selected below, as most have different activity periods (Section 3.8.2, Table 10) and the climate match analyses indicate that broad regions of Australia have climates similar to those in the native ranges of the species (Section 7.2, Table 14).

10.4 Species selection

Dung beetle experts were consulted and the literature was reviewed to identify species suitable for these gaps, resulting in the species in this application.

By combining the five seasonal and geographical gaps identified (Section 10.3) with information on seasonality (Section 3.8.2, Table 10) and areas in Australia that match the climates where each species is found (Section 7.2, Table 14), we were able to identify the gaps for which each species could potentially be suited (Table 16).

Table 16. Selected species with targeted dung beetle activity gap.

Species	Gaps	Notes
Geotrupes stercorarius	B, C	Spring to autumn activity, but could be active earlier/later in a warmer climate
Ateuchetus laticollis	B, C, D	Spring to autumn activity, but could be active earlier/later in a warmer climate
Cheironitis scabrosus	B, C, D, E	Spring to autumn activity, but could be active earlier/later in a warmer climate
Copris incertus	A, B, C	Winter active in parts of New Zealand, could be active earlier/later or even over winter in a warmer climate
Copris integer	A, B, C	Active all year around
Copris lunaris	B, C	Spring to summer species, but remains active underground in winter
Euoniticellus triangulatus	A, B, C, D, E	Active all year around
Gymnopleurus humanus	B, C, D, E	Summer rainy season activity (but collected all year)
Onitis minutus	B, C, D	Active in May-June in South Africa
Onthophagus medius	B, C	Spring to autumn activity, but could be active earlier/later in a warmer climate
Onthophagus nuchicornis	B, C	Spring to autumn activity, but could be active earlier/later in a warmer climate
Onthophagus opacicollis	B, C, D	Spring to autumn activity, but could be active earlier/later in a warmer climate
Scarabaeus sacer	B, C, D, E	Spring to autumn activity, but could be active earlier/later in a warmer climate
Sisyphus schaefferi	B, C, D, E	Spring to autumn activity, but could be active earlier/later in a warmer climate

There are few dung beetle species that are active in winter; therefore, many of the species selected are spring-autumn active. However, we anticipate that these species could be active earlier in spring or later in autumn in a warmer Australian climate. Until beetles are imported and reared in Australia, we are unable to unequivocally identify the best winter-active beetles. However, potential species include *C. incertus* (gaps A-C), *C. integer* (gaps A-C), *C. lunaris* (gaps B,C), *E. triangulatus* (gaps A-D; E is a summer gap), and *O. minutus* (gaps B-D).

Although *C. incertus* failed to establish in previous introductions [144 p39], this may have been due to low numbers of beetles released at each site or because of an insufficient volume of high-quality dung (Section 5.3). In addition, the climate matching analysis (Section 7.2, Table 14) indicates that some of these release sites may also have been in marginally suitable areas. *Copris incertus* has been observed breeding in July (winter) in Auckland and further north in New Zealand in mild winters (SA Forgie, pers. comm.), and so it is likely to be able to feed and breed in warmer Australian winters.

Adults of *C. lunaris* feed on dung in feeding chambers or on soil surface during warm weather in winter [40], and winter temperatures in southern Australia are likely to be warmer than many regions where it occurs in in its native range. Even if it doesn't actually breed in winter, it may be able to extend its breeding activity to start earlier in spring and end later in autumn, and it could potentially still contribute to some dung removal by feeding in winter. As indicated previously, *C. lunaris* likely failed to establish when it was previously introduced due to the low number (96) of beetles released over a three-month period (Section 5.3). These data support the notion that locations for releases must be correctly identified, that the timing of these releases must be optimised, numbers of beetles released at any one time must be sufficiently large, and that sufficient volumes of quality dung resources are available when beetles are released.

Euoniticellus triangulatus is found throughout the year in Kenya and South Africa [53; 81] and *O. minutus* is active in May-June in South Africa [11 p372]. If climatic conditions where they are introduced in Australia are not as extreme as in their native ranges, these species may well be active throughout the Australian winter. Other species that may be suitable for Gaps A-D, but are unlikely to breed in winter, may nonetheless be able to extend their breeding season (earlier in spring, later in autumn), as discussed above for *C. lunaris*. These include *G. stercorarius*, *A. laticollis*, *O. medius*, *O. nuchicornis*, *O. opacicollis*, *S. sacer* and *S. schaefferi* (Table 16).

To fill the hot arid summer gap E, *C. scabrosus*, *E. triangulatus*, *G. humanus* and *S. sacer* appear to be good candidates, based on the climate matching analysis (Section 7.2, Table 14) and Table 16. These species may be able to better tolerate the arid climate than the species already introduced here. In addition, they should also thrive in several of the other regions, and in all areas be able to augment the diversity of the current beetle assemblages.

10.5 Numbers of beetles to be imported

We expect to import at least 500 male-female pairs of beetles of each species. They are to be collected from areas where they are locally abundant (Section 9). This number should be sufficient to establish a population in the AA site.

10.6 Male and female interactions

Male and female dung beetles only interact with one another when reproducing, with the level of interaction varying according to the species, as detailed in Section 4.

Adults will be segregated by sex for shipping (Section 9). For breeding purposes in Canberra, we will consider the breeding requirements of each species to determine the conditions that will optimise egg production.

10.7 Breeding: management and control

The purpose of importing these beetles is to breed them to better understand their biology and lifecycles, so as to enable mass-rearing for release. There will be no surplus of beetles from the breeding program, as all viable dung beetles will be required for release. Imported dung beetles that die in the AA facility will be kept in 100% ethanol or autoclaved before being disposed of, as per Department of Agriculture, Water and the Environment permit requirements. The number of beetles kept at any time on the premises is unknown as it will depend on the number of beetles imported and successfully reared.

Because we will be importing a large number (≥ 500) of beetles of each species, collected from different localities where they are abundant (Section 10.2), we will begin the breeding program with a relatively large population for each species. This will ensure that there is sufficient genetic diversity present.

10.8 Other potential uses

Separate from CSIRO, businesses have been set up to provide previously introduced dung beetle species such as *B. bison* to farmers looking for a way to manage dung. These businesses should not have a negative impact on the continuation of the dung beetle project. Rather, by establishing colonies of already introduced species to areas with appropriate climates and habitats, this commercial activity will assist the dung beetle project aims of livestock dung burial and bush fly suppression.

The Nagoya Protocol of the Convention on Biological Diversity is likely to affect the commercial sale of introduced dung beetles by enforcing the sharing of benefits from the utilisation of genetic resources. For example, businesses that sell introduced dung beetles to farmers may be required to share profits with the countries the beetles are native to. The Nagoya Protocol should not affect the dung beetle project as the aim is for public good. Consultation with each country will be made prior to importation through the official channels.

10.9 Collection of material

Beetles will be collected from areas where they are locally abundant (Section 9).

11. Guidelines on how species should be kept

11.1 Transport

Adult beetles of each species will be air freighted to Australia. After arrival in Australia, the imported adult beetles will be kept in an AA facility for the duration of the project.

11.2 Containment, management and release

Breeding containers in the dung beetle facilities in Canberra will contain male-female pairs, and will be provisioned with sufficient dung to minimise combat for resources, to prevent overcrowding, and to maximise egg production. Because each species will have different requirements for maximising egg production, the set up for each species might differ (size of container, number of pairs per container, substrate used, humidity, temperature and light regimes, etc.). The number of beetles that will be kept at any time on premises is unknown and will depend on the number of beetles imported and successfully reared.

There will be no excess progeny in the breeding program, as all viable dung beetles will be required for release. Any imported dung beetles that die in the AA facility will be kept in 100% ethanol or autoclaved before being disposed of, following Department of Agriculture, Water and the Environment guidelines.

Release sites will be chosen by selecting climatically optimal sites on properties where owners are committed to maximising beetle establishment, such as avoiding the use of parasiticides. Beetles will be released when they are sexually mature and physiologically synchronised with the local season. Release numbers will vary according to the numbers reared, but the aim will be to release a minimum of 500 male-female pairs of each species at any given site. Preference will be given to paddocks containing enough cattle to provide a sufficient quantity of high-quality dung, and in which there is a well-established cattle campsite.

12. State/Territory controls

None of the species on this application are prohibited by legislation or classed as a pest species by either the Commonwealth or any of the states and territories. Different websites required searching in different ways. In some cases, each species was individually searched for; in others, the family name Scarabaeidae was used; still others provided a list to scroll through. The following web sites were used to ascertain pest status of the species in the Commonwealth and in each state or territory:

- Commonwealth: http://www.environment.gov.au/biodiversity/threatened/key-threatening-processes/novel-biota-impact-on-biodiversity
- ACT: https://www.environment.act.gov.au/__data/assets/pdf_file/0008/575117/PAMS_WEB.pdf
- New South Wales: https://www.environment.nsw.gov.au/threatenedspeciesapp/
- Victoria: https://agriculture.vic.gov.au/biosecurity/pest-insects-and-mites
- South Australia: https://www.pir.sa.gov.au/biosecurity/introduced-pest-feral-animals
- Tasmania: https://dpipwe.tas.gov.au/invasive-species/invasive-animals/invasive-species-other-pests
- Western Australia: https://www.agric.wa.gov.au/pests-weeds-diseases/pests/pest-insects
- Northern Territory: http://pestinfo.nt.gov.au/
- Queensland: https://www.daf.qld.gov.au/business-priorities/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list

All species are proposed to be added to the Live Import List under the Biosecurity Act 2015. Import permits will need to be obtained from the Department of Agriculture, Water and the Environment.

AA facilities are already in place at CSIRO, as the importation of other dung beetles has been approved previously.

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