SECTION 2

Introduced Dung Beetles Established in Australia

1. *Bubas bison*

FIG 1A

(A) ORIGIN

Bubas bison (Fig 1A) is native to Europe. The strains introduced into Australia originated from Spain and France.

(B) RELEASE AND REDISTRIBUTION

Release. A total of 527 *Bubas bison* (origin France/Spain) was released near Dardanup WA in 1983. Later in the same year several hundred larvae and pupae in their faecal shells (cocoons) were buried at the same site. A further 586 beetles were released near Kojonup in 1985/6 (origin France). A third release of 500 beetles was made near Toodyay in 1996 (origin Spain) (Fig 1B, solid circles).

Redistribution. Between 1992 and 1995 approximately 33,000 beetles were redistributed at 58 sites in southwestern WA and one in Vic (Fig 1B, open circles). In the last six years approximately 400,000 *B. bison* have been redistributed to SA, Vic and NSW (sites not shown).

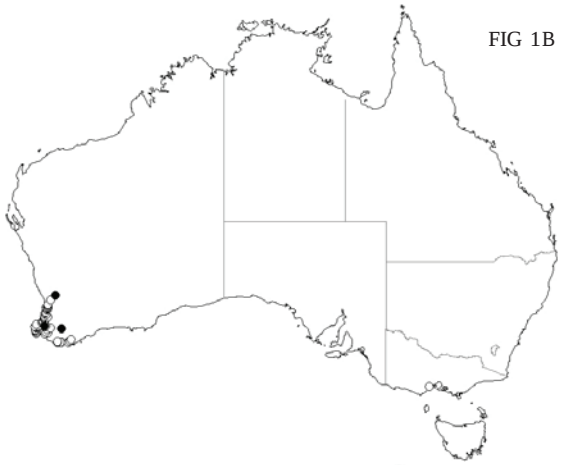


FIG 1B

(C) RECOVERIES

Bubas bison has been recovered in the vicinity of Dardanup, Kojonup, Dandaragan and Gingin WA, also in SA (Fleurieu Peninsula and Kangaroo Island), in Vic (Goulburn River Catchment) and in southern NSW). In June 2007, *B. bison* was recorded in Canberra ACT (J. Feehan pers. comm.) (Fig 1C, solid circles). A single specimen was found at Tenterfield NSW in 2005, two years after a colony was released. It is too early to confirm if the species has established at this site (Fig 1C, open circle).

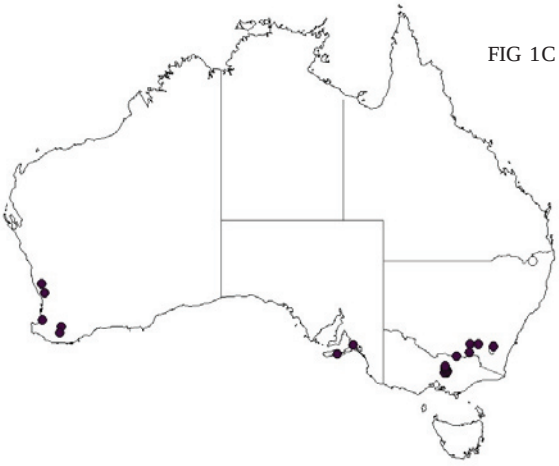


FIG 1C

(D) POTENTIAL DISTRIBUTION

The potential distribution of *Bubas bison* in Australia was modeled in BIOCLIM using distribution data from Spain, Portugal, France, Tunisia, Morocco, Algeria and Croatia (Fig 1D). A conservative model (not shown) including all 19 climate parameters provided no matching areas in Australia. A less restrictive model using four climate parameters (10, 11, 18, 19) is shown on the right.

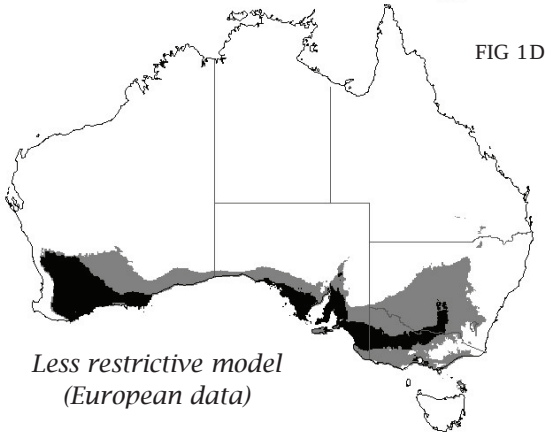


FIG 1D

Less restrictive model (European data)

(E) COMMENT

In Spain, *Bubas bison* is one of the two dominant dung beetle species in spring (the other is *Copris hispanus*). It has one generation a year, with adults emerging in autumn and breeding mainly in spring. It has a Mediterranean distribution pattern, and is thus likely to be suited to similar climate zones in Australia. The species clearly has potential for further redistribution within Australia, and efforts should be concentrated in regions shown in black in the map above, particularly where there is a Mediterranean climate.

2. *Copris elphenor*

FIG 2A

(A) ORIGIN

Copris elphenor (Fig 2A) is native to southern and east Africa. Stocks were introduced to Australia from South Africa.

FIG 2B

(B) RELEASE AND REDISTRIBUTION

Release. *Copris elphenor* was released at two sites in Qld (Fig 2B, solid circles). Six releases totaling 2,105 beetles were made near Jambin between 1978 and 1983, and one release of 182 beetles was made near Roma in 1977.

Redistribution. *Copris elphenor* was redistributed to 10 sites in Qld between 2001 and 2006 (Fig 2B, open circles). The total number of beetles redistributed was 8,940, with release sizes ranging from 600 to 1,200 beetles.

FIG 2C

(C) RECOVERIES

Copris elphenor has been recovered from three sites near Jambin in Qld, including the original release site (Fig 2C, solid circles).

(D) POTENTIAL DISTRIBUTION

The potential distribution of *Copris elphenor* in Australia was modeled in BIOCLIM using distribution data from Africa (Fig 2D). A conservative model (left) included all 19 climate parameters, and a less restrictive model (right) included four temperature and rainfall parameters (10, 11, 18, 19).

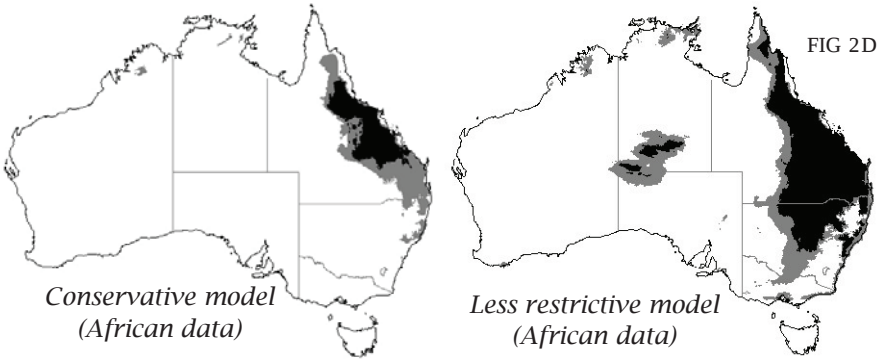


FIG 2D

(E) COMMENT

Copris elphenor is a large, brood-caring dung beetle. It buries large amounts of dung very rapidly to provision its nest. It thus has great potential for control of dung-breeding pest flies. Since it spreads very slowly, there is considerable scope for further redistribution of this species. Both models indicate that central and northern Qld are highly suitable for this species. Southern Qld, northern inland NSW and Central Australia may also be well suited.

3. *Copris hispanus*

FIG 3A

(A) ORIGIN

Copris hispanus (Fig 3A) is native to Europe. The strain introduced into Australia originated from Spain.

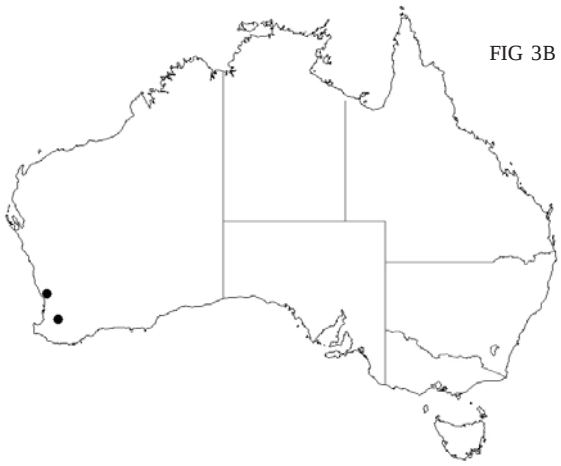


FIG 3B

(B) RELEASE AND REDISTRIBUTION

Release. A total of 264 *Copris hispanus* was released near Williams WA in 1983. In 1994, 30 *C. hispanus* were released near Gingin WA (Fig 3B, solid circles).

Redistribution. No redistribution of *C. hispanus* has been undertaken.

FIG 3C

(C) RECOVERIES

Copris hispanus has been recovered at the original release site near Williams WA (Fig 3C, solid circle).

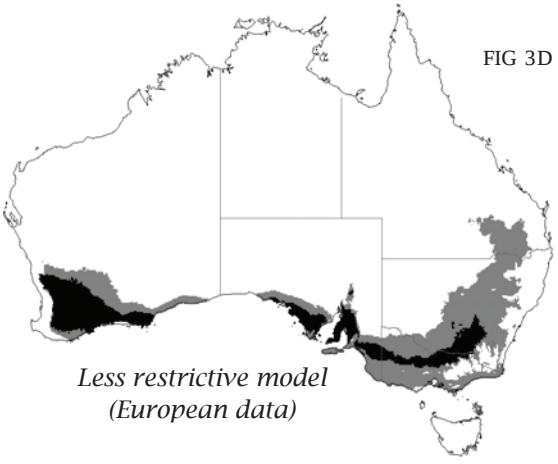


FIG 3D

Less restrictive model (European data)

(D) POTENTIAL DISTRIBUTION

The potential distribution of *Copris hispanus* in Australia was modeled in BIOCLIM, using distribution data from Spain, Portugal, France, Greece, Morocco and Majorca (Fig 3D). A conservative model (not shown) using all 19 climate parameters provided no matches in Australia, apart from a tiny area near Wangaratta Vic. A less restrictive model (right) was based on four temperature and rainfall parameters (10, 11, 18, 19).

(E) COMMENT

Copris hispanus is a large, brood-caring dung beetle, with a Mediterranean distribution in Europe. In Spain it is one of the most abundant species in spring, and was selected to contribute to bush fly suppression in WA. Although it is known to be established, its current abundance in WA needs to be assessed, to determine if it is possible to commence redistribution of this species. The model indicates it should be suitable for much of the winter-rainfall regions of southwest WA, southern SA, Vic and inland NSW. The model is very similar to that for *Bubas bison*, another Mediterranean species.

4. *Euoniticellus africanus*

FIG 4A

(A) ORIGIN

Euoniticellus africanus (Fig 4A) is native to South Africa.

(B) RELEASE AND REDISTRIBUTION

Release. *Euoniticellus africanus* was released between 1971 and 1984 in all states except NT (Fig 4B, solid circles). A total of 49,009 beetles was released at 56 property sites and at 115 road release sites. Numbers released per site (including road releases) ranged from 50 to 732 beetles.

Redistribution. A small number (100) was redistributed near Braidwood NSW in 1987 (Fig 4B, open circle). Approximately 10,000 beetles have been redistributed each year from 2000 to 2007 into southern NSW and western Vic (not shown on map).

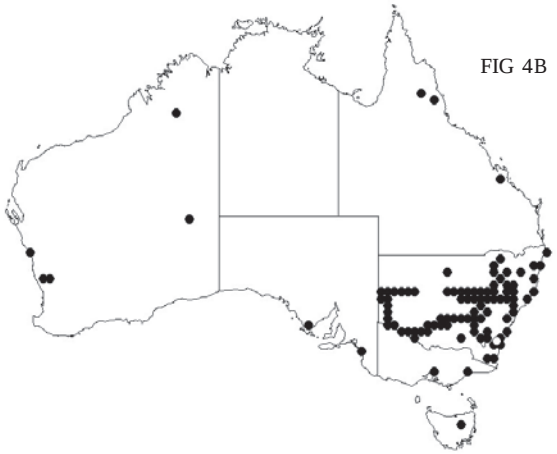


FIG 4B

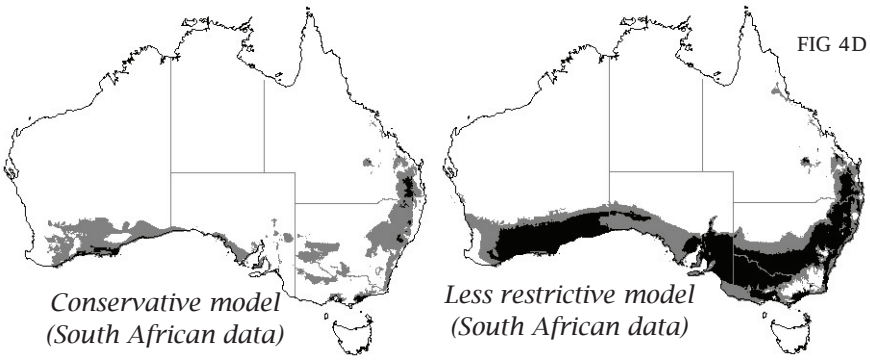
(C) RECOVERIES

Euoniticellus africanus has been recovered in inland southeast Qld, and in central and northeast NSW (Fig 4C, solid circles). It is more abundant in the southern part of its range than in the north.

FIG 4C

(D) POTENTIAL DISTRIBUTION

The potential distribution of *E. africanus* in Australia was modeled in BIOCLIM using the South African distribution of the species (Fig 4D). A conservative model (left) included all 19 climate parameters, and a less restrictive model (right) included four temperature and rainfall parameters (10, 11, 18, 19).



Conservative model (South African data)

Less restrictive model (South African data)

FIG 4D

(E) COMMENT

The native range of *Euoniticellus africanus* is restricted to South Africa. Since its release into Australia, *E. africanus* has extended its distribution into southern Qld, and has probably reached its northern limit. The conservative model provides an excellent fit to the distribution of *E. africanus* in eastern Australia. However both models indicate southern areas of WA, SA, Vic and NSW to be suitable for *E. africanus*. In South Africa *E. africanus* occurs in winter-rainfall and even-rainfall areas, in addition to the summer rainfall area. It is possible that separate strains exist, and that the summer-rainfall strain currently in Australia may not be suitable for other parts of Australia. The identity of specimens collected in southern Australia should be carefully checked as it can be difficult to distinguish *E. africanus* from *E. pallipes.*

5. *Euoniticellus fulvus*

FIG 5A

(A) ORIGIN

Euoniticellus fulvus (Fig 5A) is native to western and central Europe, the Middle East and north Africa. It is known from many countries, including Iran, Spain, Greece, France, Austria and Morocco. Introductions were made from Turkey and France.

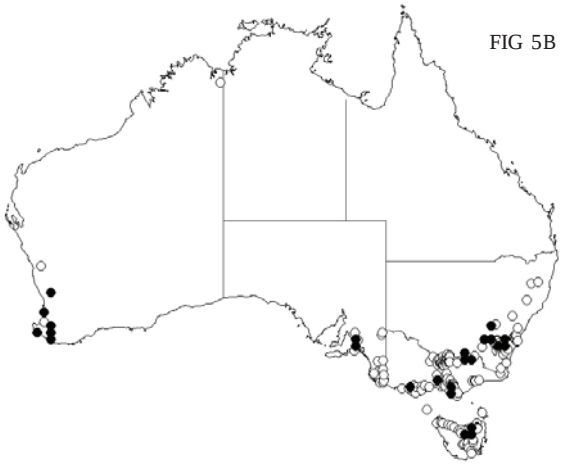


FIG 5B

(B) RELEASE AND REDISTRIBUTION

Release. *Euoniticellus fulvus* was released between 1978 and 1983 in WA, NSW, Vic, Tas and SA (Fig 5B, solid circles). A total of 76,944 beetles was released at 34 sites. Numbers released per site ranged from 200 to 7,950 beetles.

Redistribution. 2.3 million *E. fulvus* were redistributed in southeast Australia between 1987 and 1992, and 10,699 in WA in 1993/4 (Fig 5B, open circles). Further redistribution continued up until 2005 (not shown on map).

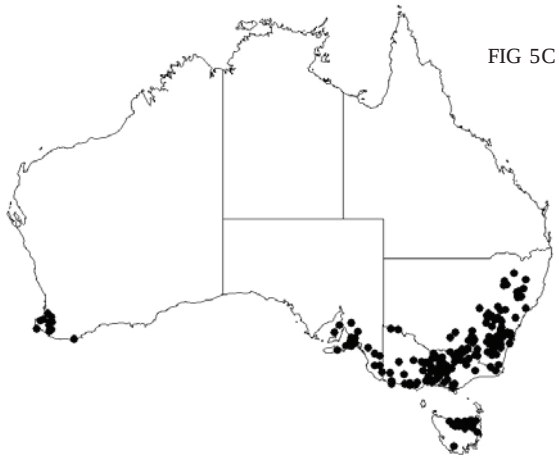


FIG 5C

(C) RECOVERIES

Euoniticellus fulvus has been recovered in eastern NSW, through most of Vic, northern Tas, southeast SA and the southwest tip of WA (Fig 5C, solid circles).

(D) POTENTIAL DISTRIBUTION

The potential distribution of *E. fulvus* in Australia was modeled in BIOCLIM using distribution data from Austria, France, Iran, Spain, Morocco, Greece, Turkey and Portugal (Fig 5D). A conservative model (left) included all 19 climate parameters, and a less restrictive model (right) included four temperature and rainfall parameters (10, 11, 18, 19).

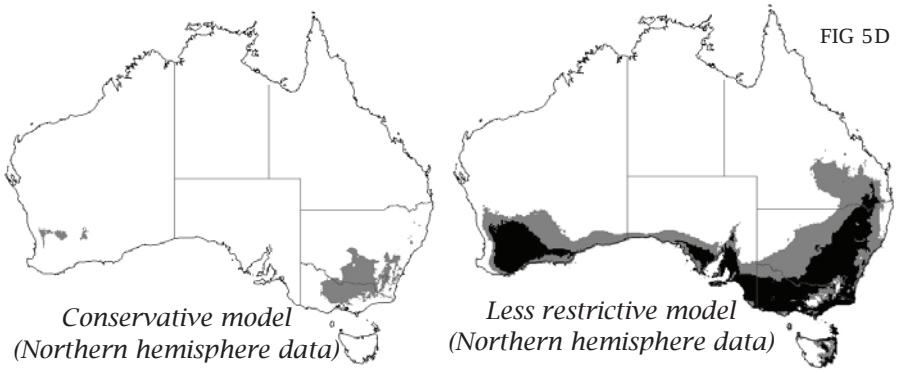


FIG 5D

Conservative model (Northern hemisphere data)

Less restrictive model (Northern hemisphere data)

(E) COMMENT

Euoniticellus fulvus occurs in a predominantly Mediterranean to even-rainfall climate in its native range. It now occupies a similar climate range in Australia. The less restrictive model provides a good prediction of the observed distribution in Australia. There is little scope for further redistribution of *E. fulvus* in Australia, except possibly in inland southwest WA and in the Eyre Peninsula region of SA.

6. *Euoniticellus intermedius*

FIG 6A

(A) ORIGIN

Euoniticellus intermedius (Fig 6A) has a wide distribution throughout Africa south of the Sahara. Beetles were introduced into Australia from South Africa.

(B) RELEASE AND REDISTRIBUTION

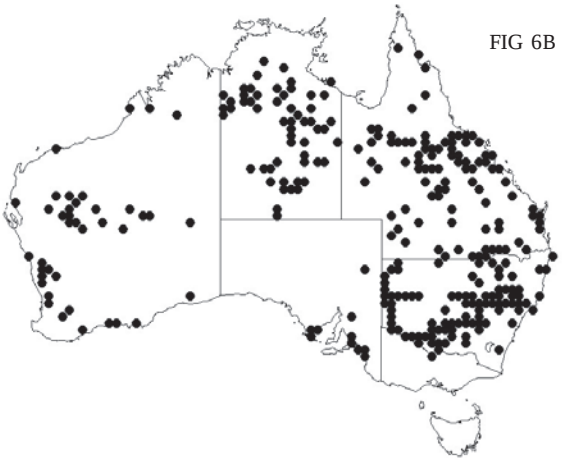


FIG 6B

Release. *Euoniticellus intermedius* was released between 1971 and 1984 in all states except Tas (Fig 6B, solid circles). A total of 248,737 beetles was released, of which about 100,00 were road releases. Releases of between 125 and 2,900 beetles were made at 262 properties (excludes road releases).

Redistribution. Due to the rapid establishment and spread of this species, it was not included in the redistribution program of the late 1980s and early 1990s. From 2000 to 2007 approximately 50,000 beetles per year were redistributed into southern NSW and northern Vic (not shown on map).

(C) RECOVERIES

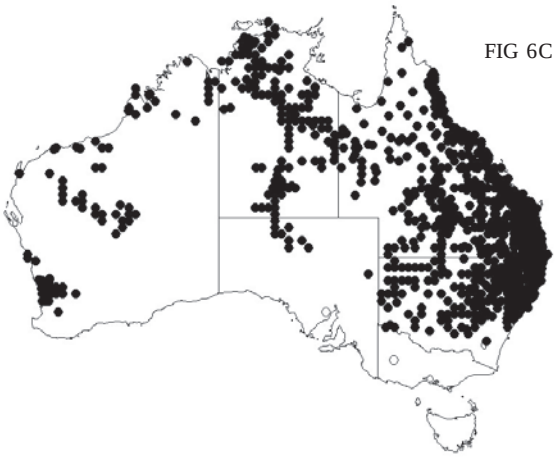


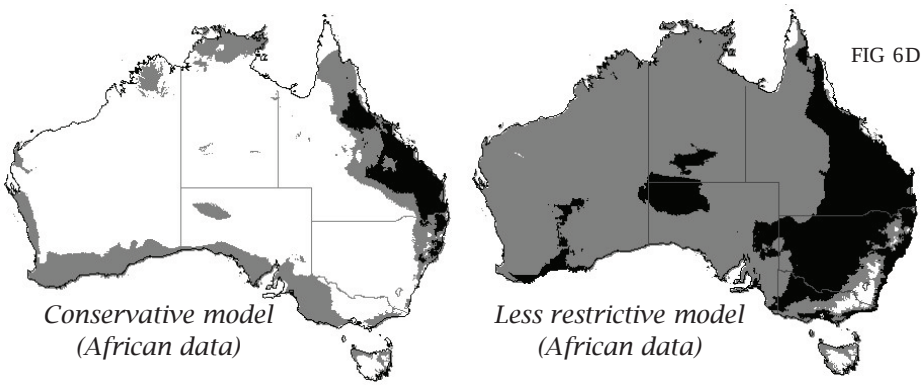
FIG 6C

Euoniticellus intermedius has been recovered from most of Australia (Fig 6C, solid circles). It is only absent from the southern coastal regions.

Two unconfirmed records are indicated by open circles.

(D) POTENTIAL DISTRIBUTION

The potential distribution of *E. intermedius* in Australia was modeled in BIOCLIM using the African distribution of the species (Fig 6D). A conservative model (left) included all 19 climate parameters, and a less restrictive model (right) included four temperature and rainfall parameters (10, 11, 18, 19).



Conservative model (African data)

Less restrictive model (African data)

FIG 6D

(E) COMMENT

Euoniticellus intermedius has a wide distribution in Africa, over a range of climate types. It also occupies a wide range of climate zones in Australia. Both models predict *E. intermedius* to be suitable for the southern coastal zone of Australia, in an area where it does not currently occur. It was released in this region but did not establish. Furthermore it has had ample opportunity to move into the area over the last 30 years. Thus this southern coastal zone appears to be unsuitable for the strain of *E. intermedius* that occurs in Australia.

7. *Euoniticellus pallipes*

FIG 7A

(A) ORIGIN

Euoniticellus pallipes (Fig 7A) originates from southern Europe through to India. Beetles were introduced to Australia from Iran and Turkey.

(B) RELEASE AND REDISTRIBUTION

Release. *Euoniticellus pallipes* was released between 1977 and 1982 in southern NSW, southeast SA and southwest WA. A total of 46,642 beetles was released at 25 sites (Fig 7B, solid circles). The number released per site ranged from 550 to 2,800 beetles.

Redistribution. A total of 1,906 *E. pallipes* was redistributed in Vic and Tas in 1990/2, and 959 in WA in 1993/4 (Fig 7B, open circles). In 1996/7 10,000 beetles were harvested at Esperance WA and released in central NSW and northern Vic (not shown on map).

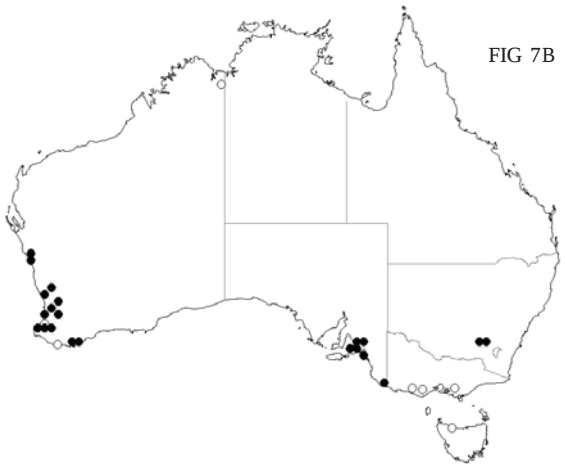


FIG 7B

(C) RECOVERIES

Euoniticellus pallipes has been recovered from southern NSW, Vic and southeast SA, and from southwest WA (Fig 7C, solid circles). Five unconfirmed records from northern NSW have been excluded from the map.

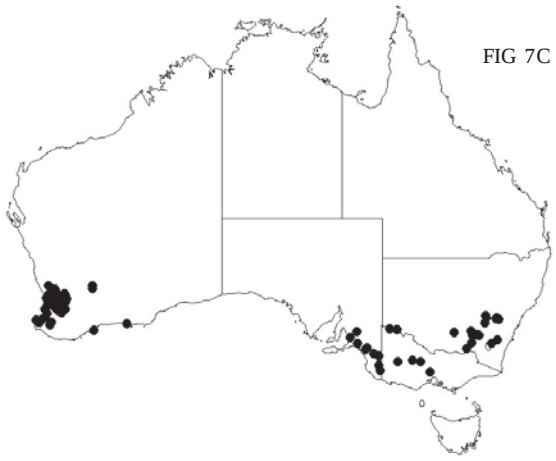


FIG 7C

(D) POTENTIAL DISTRIBUTION

The potential distribution of *E. pallipes* in Australia was modeled in BIOCLIM using the available world distribution data (from Portugal to Iran, and Pakistan to southern India) (Fig 7D). A conservative model (not shown) predicted much of Australia to be suitable, due largely to the inclusion of southern India in the data set. A less restrictive model (Fig 7D, left) was fitted using only data from Iran and Turkey (the source of Australian material) based on four climate parameters (10, 11, 18, 19). This provided a reasonable prediction for southeast Australia, but failed to include WA as a suitable area. A less restrictive model (10, 11, 18, 19) based on the distribution from the Mediterranean and Middle East (Portugal, Spain, France, Greece, Turkey, Iran) resulted in WA being included in the predicted distribution (Fig 7D, right).

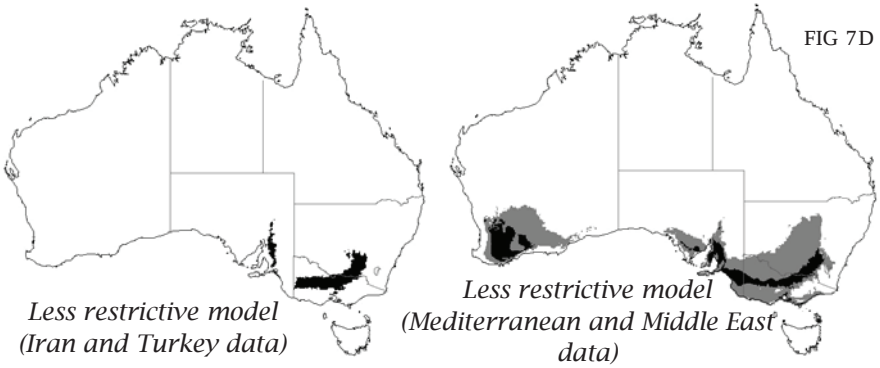


FIG 7D

Less restrictive model (Iran and Turkey data)

Less restrictive model (Mediterranean and Middle East data)

(E) COMMENT

It is likely that different strains of *E. pallipes* exist within its native range, and that the strain from the Mediterranean and Middle East region differs from that found in southern India. The species is probably close to its potential distribution in Australia.

8. *Geotrupes spiniger*

FIG 8A

(A) ORIGIN

Geotrupes spiniger (Fig 8A) occurs widely through Europe, including the British Isles. It occurs in the northern Mediterranean, in the Balkans, Ukraine and Middle East to the Pakistani border. Beetles introduced into Australia were collected in France.

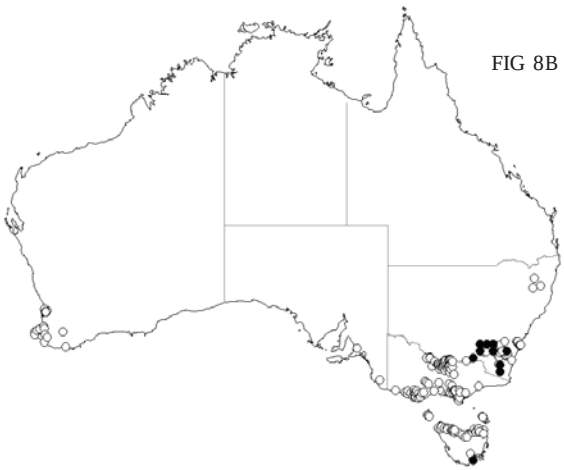


FIG 8B

(B) RELEASE AND REDISTRIBUTION

Release. *Geotrupes spiniger* was released between 1979 and 1982. A total of 12,082 beetles was released at 12 sites in southeast NSW and in southern Tas (Fig 8B, solid circles). Numbers released at each site ranged from 600 to 1,751 beetles.

Redistribution. 244,498 beetles were redistributed between 1989 and 1994 in NSW, Vic, Tas, SA and WA (Fig 8B, open circles). Colony size ranged from 27 to 6,000 beetles. Redistributions have continued over the last 10 years (not shown on map).

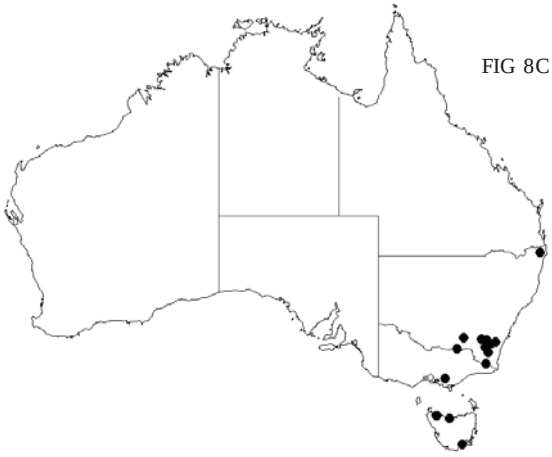


FIG 8C

(C) RECOVERIES

Geotrupes spiniger has been recovered in Tas, Vic and southeast NSW (Fig 8C, solid circles). There is one record for northern NSW (Wongavale).

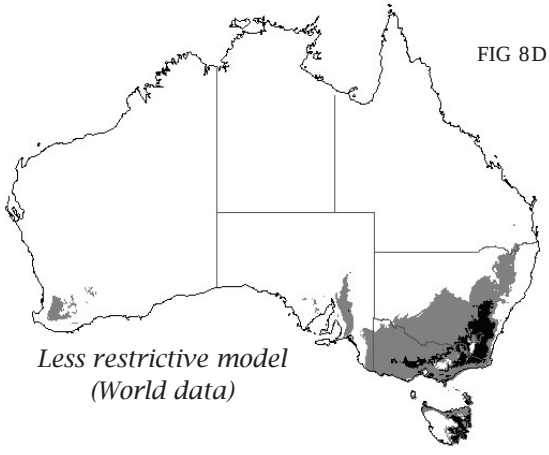


FIG 8D

(D) POTENTIAL DISTRIBUTION

The potential distribution of *G. spiniger* in Australia was modeled in BIOCLIM using the world distribution of the species (Fig 8D). A conservative model (not shown) included all 19 climate parameters, but provided no matching areas in Australia. A less restrictive model (right) included four temperature and rainfall parameters (10, 11, 18, 19).

Less restrictive model (World data)

(E) COMMENT

Geotrupes spiniger is a common beetle in France and in many cold and temperate regions of Europe. It occurs mainly at low to medium altitudes (below 800m) and predominantly in heavy soils. In Europe it breeds in late autumn and early winter, and can be found feeding in spring and occasionally in summer. It is thus a very useful beetle in cooler climates, burying dung at a time when most other activity has ceased. Continued redistribution within the area shown in the model above should be beneficial. Suitable areas include most of Victoria and much of southern NSW.

9. *Liatongus militaris*

FIG 9A

(A) ORIGIN

Liatongus militaris (Fig 9A) originates from southern and east Africa. Stocks were introduced into Australia from South Africa, via Hawaii.

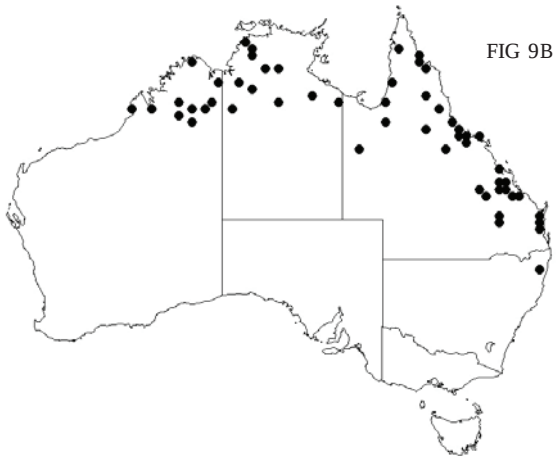


FIG 9B

(B) RELEASE AND REDISTRIBUTION

Release. *Liatongus militaris* was released in Qld, NT, WA and northern NSW between 1968 and 1979. A total of 70,450 beetles was released at 54 sites (Fig 9B, solid circles). Numbers released per site ranged from 54 to 11,737 beetles.

Redistribution. Beetles were harvested in southeast Qld and released into northeast NSW (not shown on map).

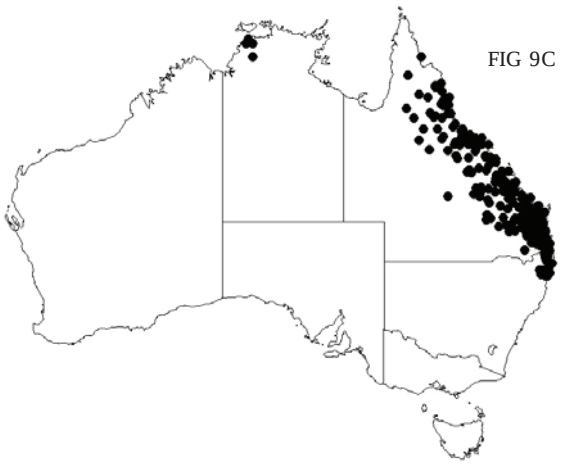


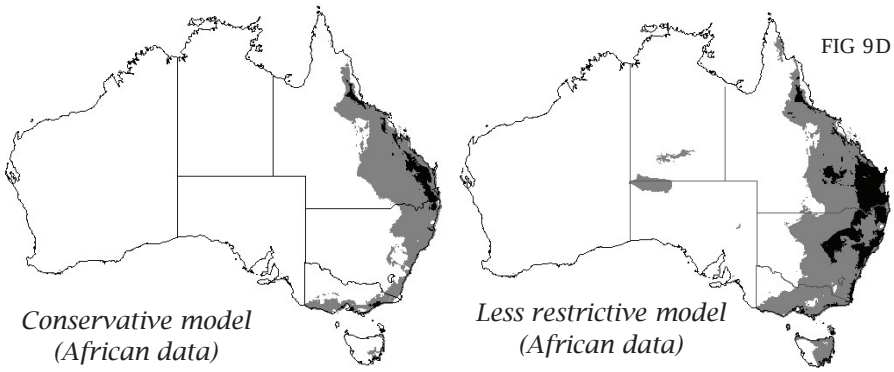
FIG 9C

(C) RECOVERIES

Liatongus militaris has been recovered in summer rainfall regions of northern NSW, Qld and northern NT (Fig 9C, solid circles). It occurs mainly where the average rainfall exceeds 600mm.

(D) POTENTIAL DISTRIBUTION

The potential distribution of *L. militaris* in Australia was modeled in BIOCLIM using the African distribution of the species (Fig 9D). A conservative model (left) included all 19 climate parameters, and a less restrictive model (right) included four temperature and rainfall parameters (10, 11, 18, 19).



Conservative model (African data)

Less restrictive model (African data)

FIG 9D

(E) COMMENT

Liatongus militaris is well established in eastern Qld. Both models indicate that eastern NSW may be suitable, and neither model predicts NT to be suitable. The species was introduced into Australia from Hawaii. It is possible that genetic selection may have occurred during this process, and that the population introduced from Hawaii differs in its climatic tolerances from the original South African population.

10. *Onitis alexis*

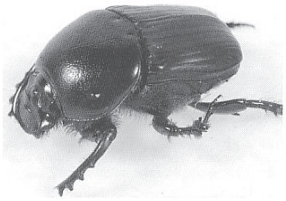


FIG 10A

(A) ORIGIN

Onitis alexis (Fig 10A) is widely distributed through warm dry parts of Africa, south of the Sahara, and in southern Europe.

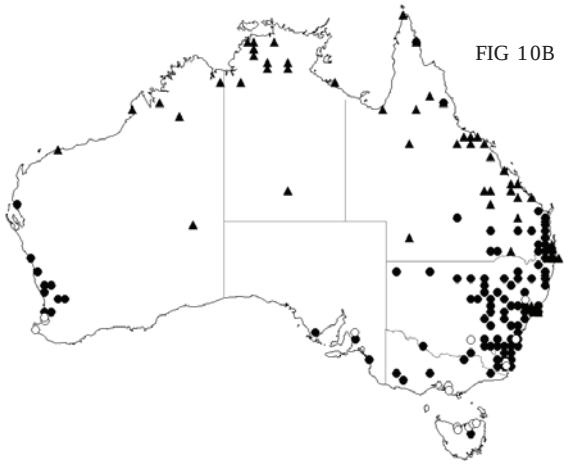


FIG 10B

(B) RELEASE AND REDISTRIBUTION

Release. *Onitis alexis* was released between 1972 and 1984 in all Australian states. A total of 186,441 beetles was released, of which 43,000 were roadside releases. The remaining beetles were released at 182 properties, with between 20 and 9,000 beetles released at each site. A 'cold strain' (Fig 10B, solid circles) and a 'tropical strain' (Fig 10B, solid triangles) was released.

Redistribution. A total of 1,084 *Onitis alexis* was redistributed in NSW, Vic, SA and Tas between 1985 and 1994, and 2,139 in WA in 1992/94 (Fig 10B, open circles).

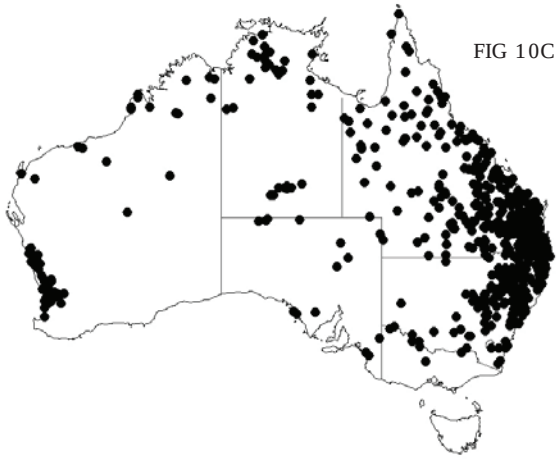


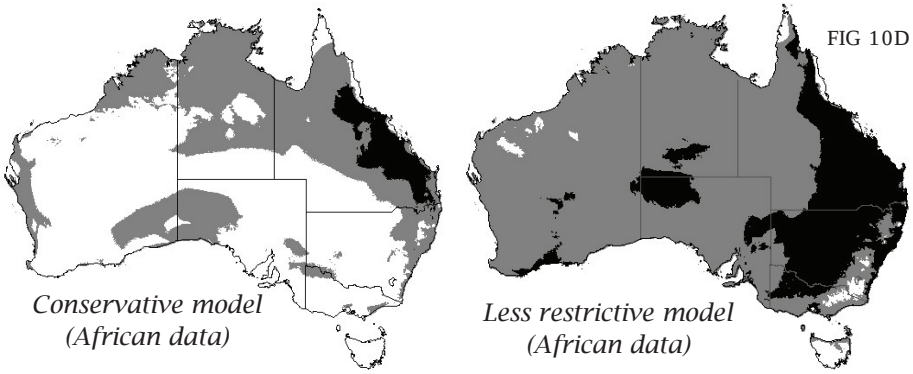
FIG 10C

(C) RECOVERIES

Onitis alexis has been recovered from all Australian states except Tas (Fig 10C, solid circles). In Vic it only occurs in the northern part of the state. It is abundant in many areas, particularly Qld and NSW. It is uncommon in southern SA.

(D) POTENTIAL DISTRIBUTION

The potential distribution of *O. alexis* in Australia was modeled in BIOCLIM using the African distribution of the species (Fig 10D). A conservative model (left) included all 19 climate parameters, and a less restrictive model (right) included four temperature and rainfall parameters (10, 11, 18, 19).



Conservative model (African data)

Less restrictive model (African data)

FIG 10D

(E) COMMENT

Onitis alexis is one of the most successful introduced dung beetle species in Australia, in terms of distribution and abundance. Two strains were introduced from South Africa, a 'cold strain' and a 'tropical strain'. The models predict a wide distribution in Australia, with much of eastern Australia being particularly suitable. There is little scope for further redistribution of this species.

11. *Onitis aygulus*

FIG 11A

(A) ORIGIN

Onitis aygulus (Fig 11A) occurs in the cooler drier parts of South Africa and Namibia.

(B) RELEASE AND REDISTRIBUTION

Release. *Onitis aygulus* was released in WA, SA and NSW between 1977 and 1982. A total of 8,738 beetles was released at 16 sites. Numbers released per site ranged from 470 to 1,712 beetles. A winter-rainfall strain was released in WA, SA and southern NSW (Fig 11B, solid circles). A summer-rainfall strain was released in central NSW (Fig 11B, solid triangles).

Redistribution. A total of 787 *Onitis aygulus* was redistributed in 1989/90 in NSW, Vic and Tas, and 5,667 in WA between 1992 and 1995 (Fig 11B, open circles). Further redistributions have been undertaken in the last 10 years. In Jan/Feb 2007 30,000 beetles were redistributed into southern NSW and Vic (not shown on map).

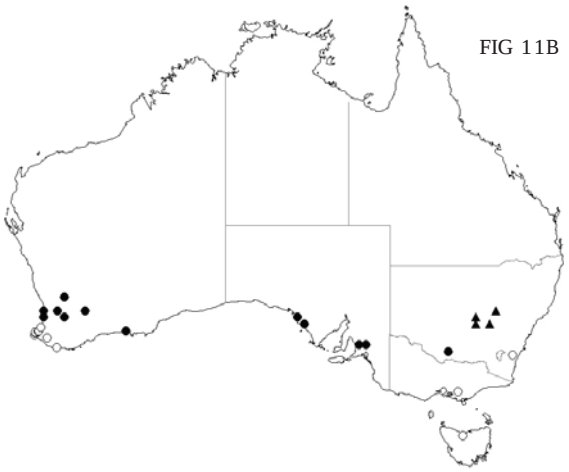


FIG 11B

(C) RECOVERIES

Onitis aygulus has been recovered in WA, SA, Vic and NSW (Fig 11C, solid circles). It has spread considerably from known release sites, with the most remote recoveries being in northern SA and Kalgoorlie WA.

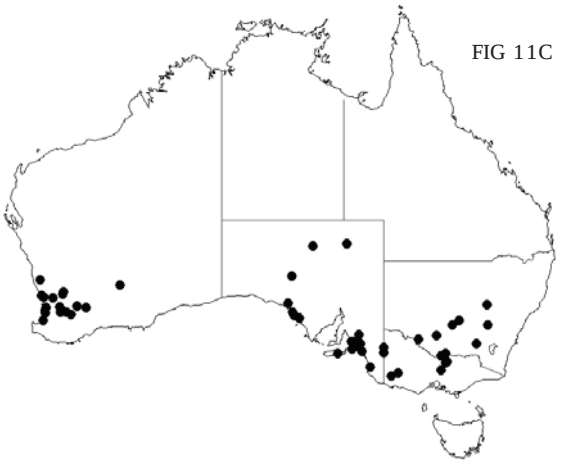


FIG 11C

(D) POTENTIAL DISTRIBUTION

The potential distribution of *O. aygulus* in Australia was modeled in BIOCLIM using the southern African distribution of the species (Fig 11D). A conservative model (left) included all 19 climate parameters, and a less restrictive model (right) included four temperature and rainfall parameters (10, 11, 18, 19).

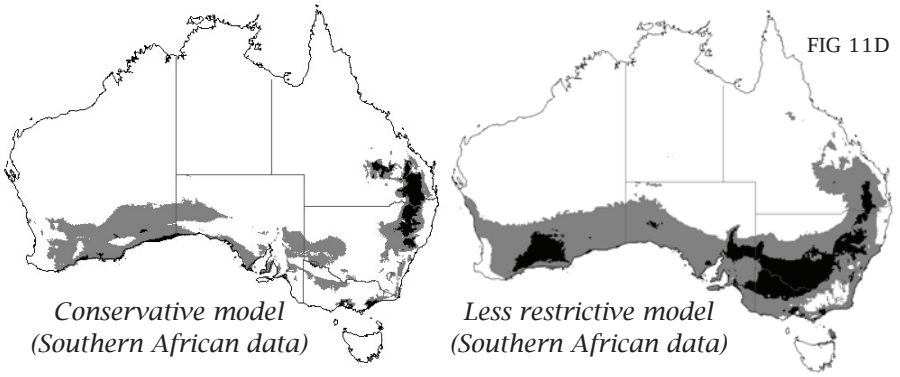


FIG 11D

Conservative model (Southern African data)

Less restrictive model (Southern African data)

(E) COMMENT

Onitis aygulus is now well established in several areas. The models indicate that much of southern Australia could be suitable for this species. While there is evidence of it moving large distances unaided, it would certainly benefit from further redistribution. Both models indicate that northeast NSW and southeast Qld, on the western side of the Dividing Range, could be suitable for *O. aygulus*. The summer-rainfall strain should be used for redistributions in this region. In southern Africa, *O. aygulus* occurs where rainfall is between 150 and 750 mm a year, and annual mean temperatures are between 13°C and 19.5°C. It is thus suited to cooler drier areas than *O. alexis*.

12. *Onitis caffer*

FIG 12A

(A) ORIGIN

Onitis caffer (Fig 12A) is native to South Africa.

(B) RELEASE AND REDISTRIBUTION

Release. *Onitis caffer* was released between 1979 and 1984 (Fig 12B, solid circles). Colony sizes ranged from 42 to 705 beetles. A winter-rainfall strain was released at 5 sites in WA and a summer-rainfall strain at one site in Qld (Highfields). It is not known which strain was released in NSW (Moruya). A total of 8,738 beetles was released (3,794 in WA; 2,467 in Qld; 2,477 in NSW).

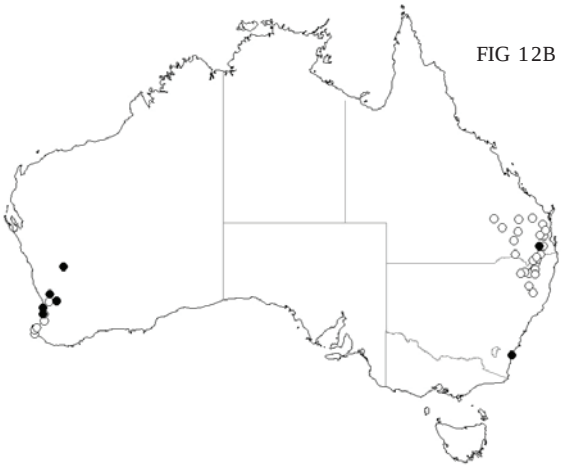


FIG 12B

Redistribution. A total of 27,638 beetles of the summer-rainfall strain was redistributed to 30 sites in southeast Qld and northeast NSW between 2002 and 2006. A total of 2,048 winter-rainfall strain beetles was redistributed in WA between 1992/3 (Fig 12B, open circles). Additional redistributions of the summer-rainfall strain have been made in the New England region and central NSW (not shown on map).

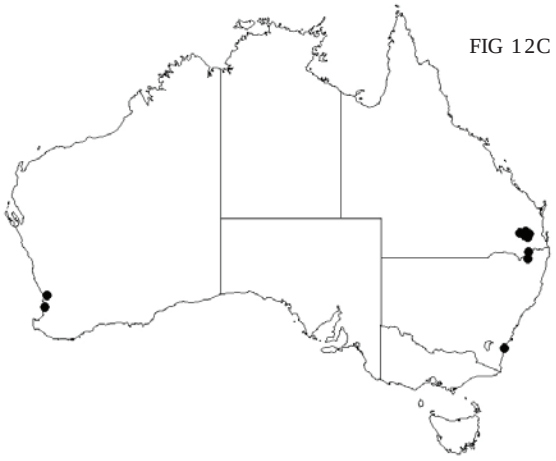


FIG 12C

(C) RECOVERIES

Onitis caffer has been recovered near the original release sites in NSW and southeast Qld, and at two sites in WA (Fig 12C, solid circles). Recoveries at two sites in northern NSW occurred after the redistribution of beetles to that region.

(D) POTENTIAL DISTRIBUTION

The potential distribution of *O. caffer* in Australia was modeled in BIOCLIM using the South African distribution of the species (Fig 12D). A conservative model (left) included all 19 climate parameters, and a less restrictive model (right) included four temperature and rainfall parameters (10, 11, 18, 19).

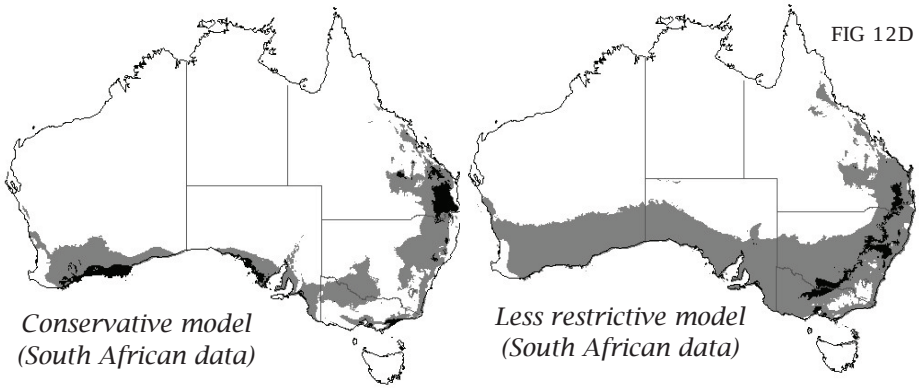


FIG 12D

Conservative model (South African data)

Less restrictive model (South African data)

(E) COMMENT

Onitis caffer is an important component of the introduced dung beetle fauna, as it is active in autumn and early winter, a time when activity of other species declines. Activity may also occur in spring in even-rainfall and winter-rainfall regions. The conservative model indicates that there are many areas in eastern and southern Australia that provide a good climate match with the South African distribution of *O. caffer*. Redistributions should be concentrated in the areas indicated by the conservative model. The break in the predicted distribution in NSW should be used as a guide to the limits for redistribution of the summer-rainfall and winter-rainfall strains.

13. *Onitis pecuarius*

FIG 13A

(A) ORIGIN

Onitis pecuarius (Fig 13A) is restricted to southern and eastern South Africa.

(B) RELEASE AND REDISTRIBUTION

Release. *Onitis pecuarius* was released between 1976 and 1979 in southern Qld and eastern NSW A total of 11,395 beetles was released, of which 5,480 were summer-rainfall strain (Fig 13B, 4 sites, solid triangles), and 5,915 were even-rainfall strain (Fig 13B, 6 sites, solid circles). Numbers of beetles released ranged from 500 to 2,000 per site.

Redistribution. A total of 43,409 *O. pecuarius* was redistributed between 1989 and 1994 in WA, SA, Vic, Tas and southern NSW (Fig 13B, open circles). The species has also been harvested in northeast NSW and from Milton NSW, and released along the NSW coast between Maitland and Coffs Harbour (not shown on map).

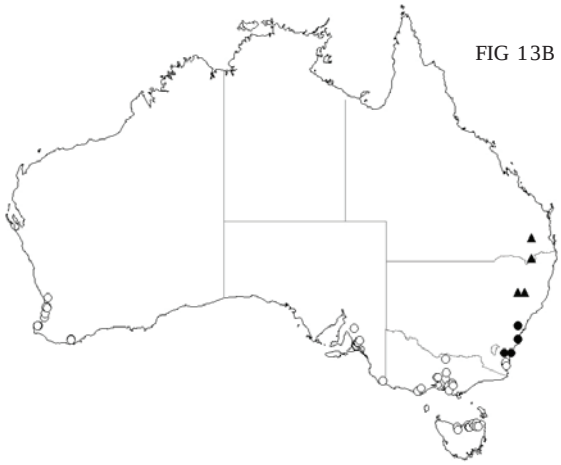


FIG 13B

(C) RECOVERIES

Onitis pecuarius has been recovered from southern Qld and eastern NSW (Fig 13C, solid circles).

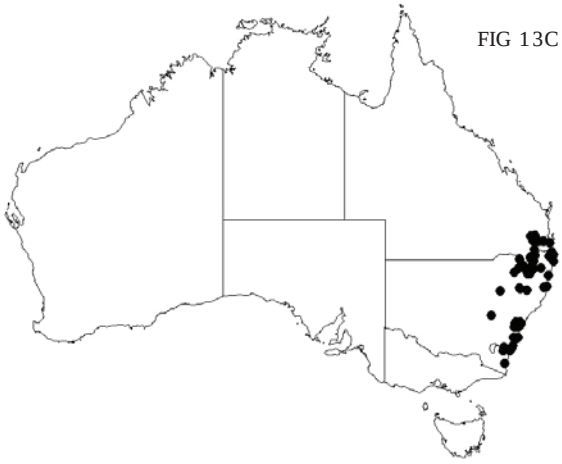


FIG 13C

(D) POTENTIAL DISTRIBUTION

The potential distribution of *O. pecuarius* in Australia was modeled in BIOCLIM using the South African distribution of the species (Fig 13D). [A single doubtful winter-rainfall record was omitted from the modeling]. A conservative model (left) included all 19 climate parameters. A small region of suitability in Vic is indicated with an arrow. A less restrictive model (right) included four temperature and rainfall parameters (10, 11, 18, 19).

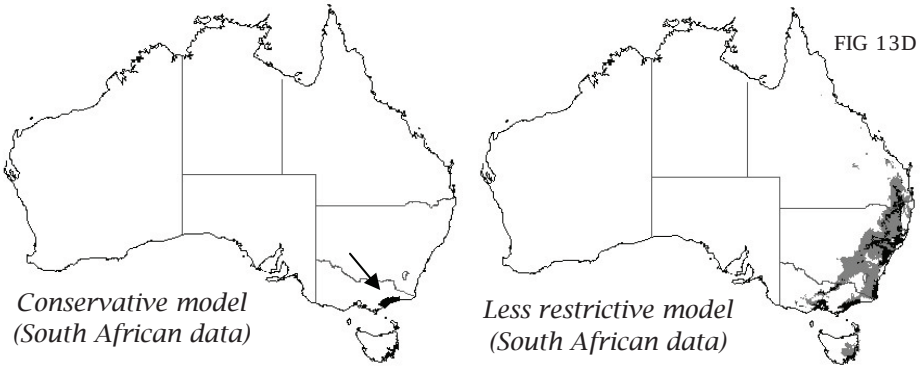


FIG 13D

(E) COMMENT

In Africa, *O. pecuarius* in the south complements the more northern species, *O. viridulus*. They have adopted the same pattern in Australia, with a small area of overlap in higher altitudes of southeast Qld. The less restrictive model provides a good prediction of the observed distribution in Australia. Both models indicate the eastern coast of Vic to be suitable, and this area should be considered for any further redistributions.

14. *Onitis vanderkelleni*

FIG 14A

(A) ORIGIN

Onitis vanderkelleni (Fig 14A) occurs in the moist tropical highlands of Africa, particularly Kenya, Rwanda and Zaire.

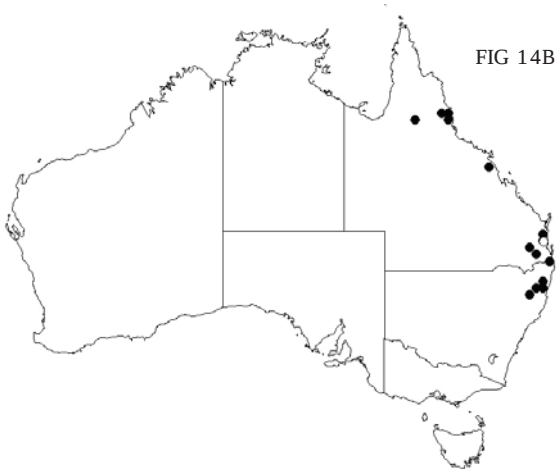


FIG 14B

(B) RELEASE AND REDISTRIBUTION

Release. *Onitis vanderkelleni* was released in Qld and northern NSW between 1974 and 1982 (Fig 14B, solid circles). A total of 10,852 beetles was released at 21 sites. Numbers released per site ranged from 342 to 765 beetles.

Redistribution. One colony of 450 beetles was redistributed to Maleny Qld in 2006 (Fig 14B, open circle).

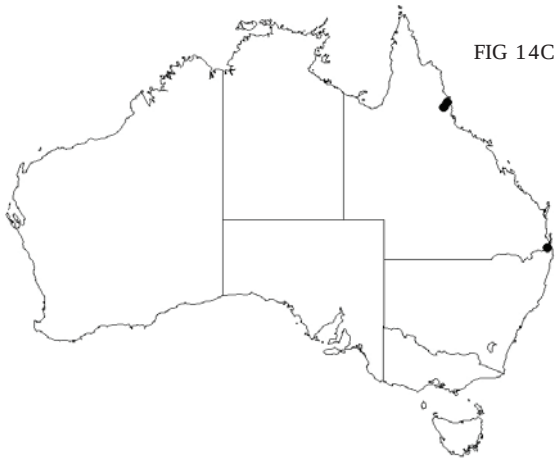


FIG 14C

(C) RECOVERIES

Onitis vanderkelleni has been recovered near Ravenshoe in north Qld and near Beechmont in southeast Qld (Fig 14C, solid circles).

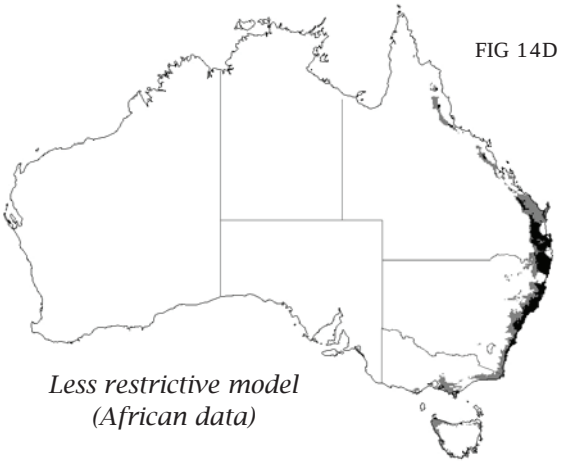


FIG 14D

Less restrictive model (African data)

(D) POTENTIAL DISTRIBUTION

The potential distribution of *O. vanderkelleni* in Australia was modeled in BIOCLIM using the African distribution of the species (Fig 14D). A conservative model (not shown) included all 19 climate parameters, but provided no matching areas in Australia. A less restrictive model (right) included four temperature and rainfall parameters (10, 11, 12, 18).

(E) COMMENT

Onitis vanderkelleni occurs in tropical Africa where the rainfall is between 800 and 2,000 mm a year. It mainly occurs at altitudes greater than 1,800 m. It is one of the few species suited to the very high rainfall areas of Australia, particularly in Qld. The less restrictive model indicates it may also be suitable for coastal NSW. It is worth attempting to redistribute it to areas where kikuyu pasture occurs, particularly on deep volcanic soils.

15. *Onitis viridulus*

FIG 15A

(A) ORIGIN

Onitis viridulus (Fig 15A) occurs in Africa, from Ethiopia to northern South Africa.

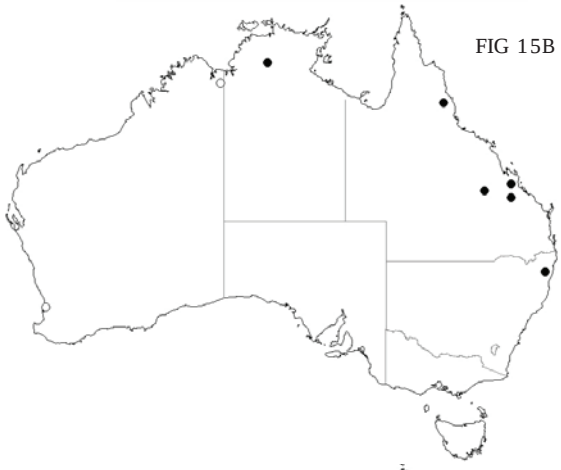


FIG 15B

(B) RELEASE AND REDISTRIBUTION

Release. *Onitis viridulus* was released at six sites in NT, Qld and NSW between 1976 and 1980 (Fig 15B, solid circles). A total of 8,008 beetles was released, with between 514 and 1,600 released per site.

Redistribution. A total of 1,733 *O. viridulus* was redistributed in WA in 1994/5 (Fig 15B, open circles).

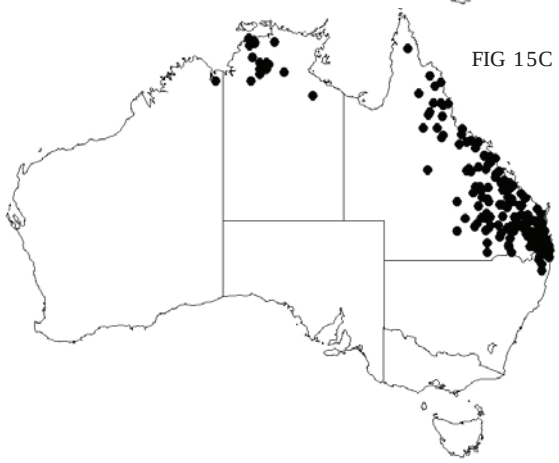


FIG 15C

(C) RECOVERIES

Onitis viridulus had been recovered through most of eastern Qld, in northern NT and northeast WA. It is also present in the far northeast of NSW (Fig 15C, solid circles). (Ten additional records from NSW have been omitted, as the specimens may have been confused with *O. pecuarius*).

(D) POTENTIAL DISTRIBUTION

The potential distribution of *O. viridulus* in Australia was modeled in BIOCLIM using the African distribution of the species (Fig 15D). A conservative model (left) included all 19 climate parameters, and a less restrictive model (right) included four temperature and rainfall parameters (10, 11, 18, 19).

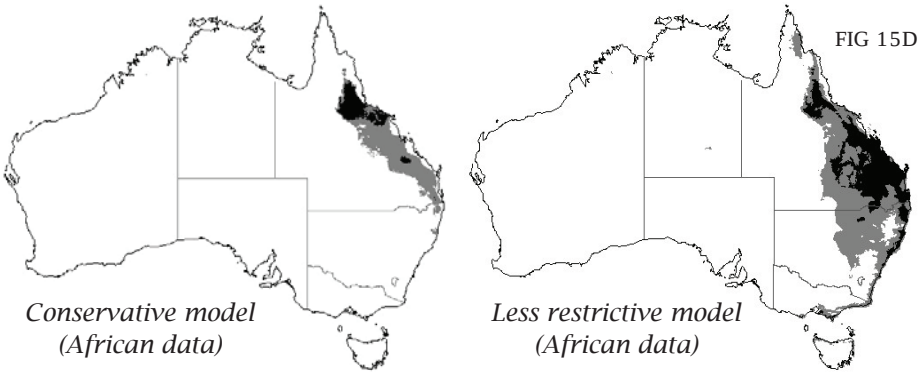


FIG 15D

Conservative model (African data)

Less restrictive model (African data)

(E) COMMENT

Onitis viridulus has established from a small number of releases and consolidated its distribution in Qld and NT. Both models indicate the climatic suitability of eastern Qld, but both models fail to predict the suitability of NT. This is possibly because the data used to construct the models did not include all African countries where it is likely to occur. In Africa, *O viridulus* to the north replaces *O. pecuarius,* which is restricted to South Africa. There is only a very small area of overlap of the two species in South Africa. This is similar to the situation that has developed in Australia. *Onitis viridulus* tends to bury older dung, and probably contributes little to fly control. Possibly its main role is 'mopping up' dung after other species have left. There is little scope for redistribution of this species, although it may be suitable for northern inland NSW.

16. *Onthophagus binodis*

FIG 16A

(A) ORIGIN

Onthophagus binodis (Fig 16A) is native to South Africa.

(B) RELEASE AND REDISTRIBUTION

Release. *Onthophagus binodis* was released in all Australian states between 1971 and 1983. A total of 173,018 beetles was released at 170 sites. Release sizes ranged from 250 to 5,000 beetles per site. A summer-rainfall strain (Fig 16B, solid circles) and a winter-rainfall strain (Fig 16B, solid triangles) were released.

Redistribution. A total of 231,205 *O. binodis* was redistributed in SA, Vic, Tas and NSW between 1987 and 1993. A further 15,615 beetles were redistributed in WA in 1993/4 (Fig 16B, open circles). Redistributions have continued over the last 10 years (not shown on map).

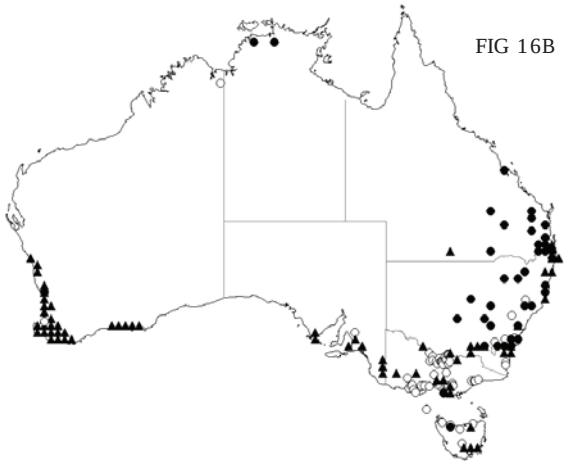


FIG 16B

(C) RECOVERIES

Onthophagus binodis has been recovered from southwest WA, southeast SA, southern Vic, Tas, eastern NSW and southeast Qld (Fig 16C, solid circles).

A recovery was made in 1975 at Injune Qld, 18 months after a colony was released there, and another at Wandoan Qld at much the same time (A. Macqueen, pers. comm.) (Fig 16C, open circles). There have been no further records from these areas, in spite of intensive trapping during 2001/2.

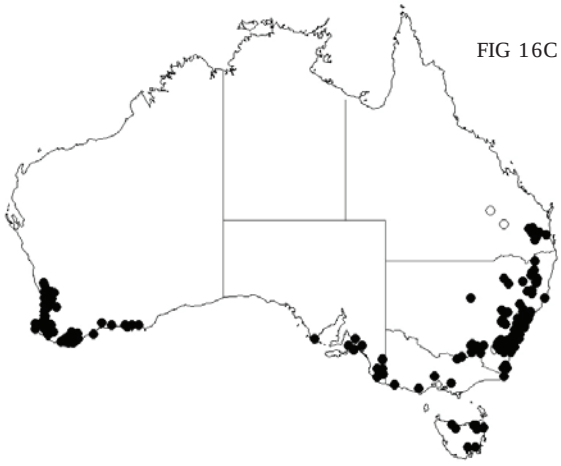
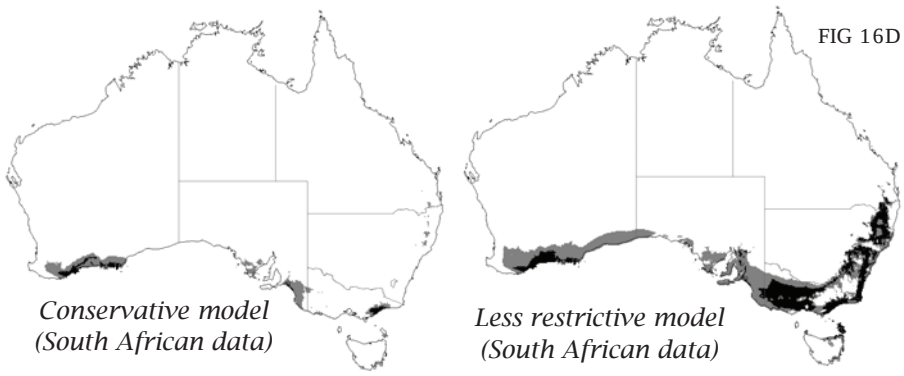


FIG 16C

(D) POTENTIAL DISTRIBUTION

The predicted distribution of *Onthophagus binodis* in Australia was modeled in BIOCLIM using distribution data from South Africa (Fig 16D). A conservative model (left) included all 19 climate parameters, and a less restrictive model (right) included four temperature and rainfall parameters (10, 11, 18, 19).



Conservative model (South African data)

Less restrictive model (South African data)

FIG 16D

(E) COMMENT

The similarity between the release map and recovery map indicates that the original release and redistribution sites were well selected. The less restrictive model of predicted distribution of *O. binodis* in Australia provides an extremely close fit to the observed distribution. Both models indicate the east coast of Vic to be highly suitable for *O. binodis*. Although no records from this area were found for this review, *O. binodis* is reported to be well established from Bairnsdale to the Cann River (J Feehan pers. comm.) There is thus little potential for redistribution of this species.

17. *Onthophagus gazella*

FIG 17A

(A) ORIGIN

Onthophagus gazella (Fig 17A) occurs through much of Africa, south of the Sahara.

(B) RELEASE AND REDISTRIBUTION

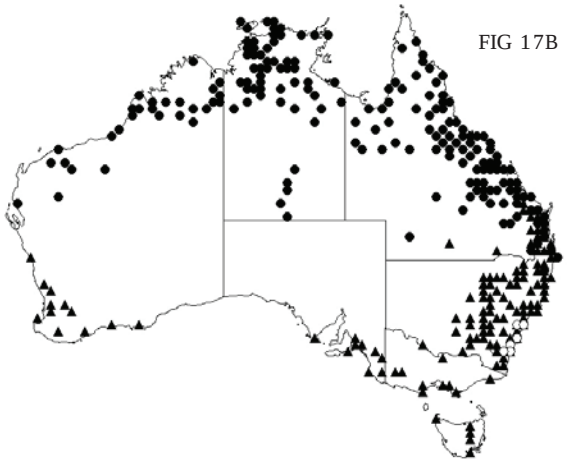


FIG 17B

Release. *Onthophagus gazella* was released between 1968 and 1984 in all Australian states. A total of 420,415 beetles was released at 372 properties and 50 road release sites. Numbers released per site ranged from 60 to 38,870 beetles. A "tropical strain" from South Africa (via Hawaii) and a "gene-pool strain" from South Africa were released in northern Australia (Fig 17B, solid circles). A "cold strain" from South Africa (Fig 17B, solid triangles) was released in southern Australia and an "even-rainfall strain" from South Africa (Fig 17B, open circles) was released in eastern NSW.

Redistribution. *O. gazella* has been redistributed into southern NSW and northern Vic (not shown on map).

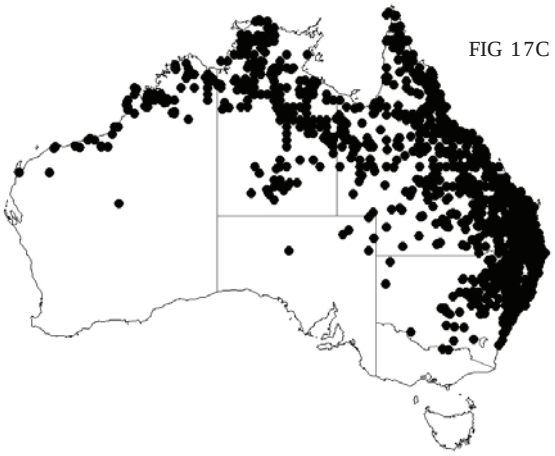


FIG 17C

(C) RECOVERIES

Onthophagus gazella has been recovered throughout northern and eastern Australia (Fig 17C, solid circles).

(D) POTENTIAL DISTRIBUTION

The potential distribution of *O. gazella* in Australia was modeled in BIOCLIM using the African distribution of the species (Fig 17D). A conservative model (left) included all 19 climate parameters, and a less restrictive model (right) included four temperature and rainfall parameters (10, 11, 18, 19).

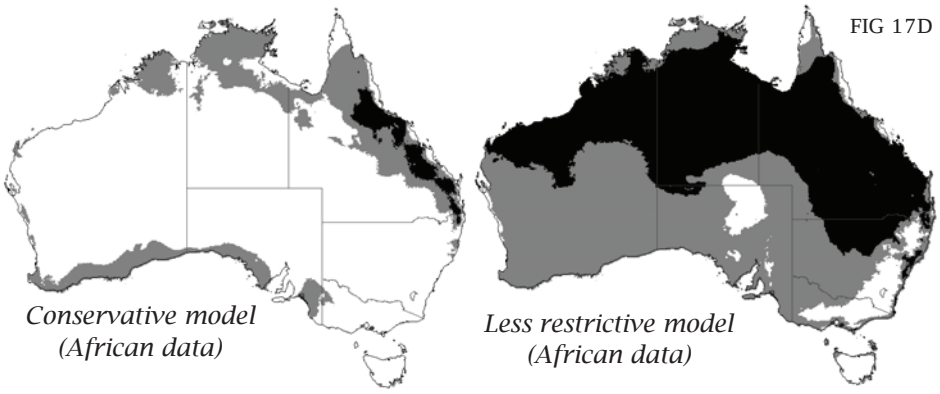


FIG 17D

Conservative model (African data)

Less restrictive model (African data)

(E) COMMENT

Onthophagus gazella is widespread across northern Australia, and is the dominant species in many subtropical areas. It occurs in some very low rainfall regions, where most other species have not established. Both models predict southern Australia to be suitable, however *O. gazella* has failed to establish here. Earlier modeling by CSIRO using CLIMEX also indicated these regions to be suitable. It is probable that a different strain would be required for this zone.

18. *Onthophagus nigriventris*

FIG 18A

(A) ORIGIN

Onthophagus nigriventris (Fig 18A) occurs in the tropical highlands of Africa, and is widespread in Kenya.

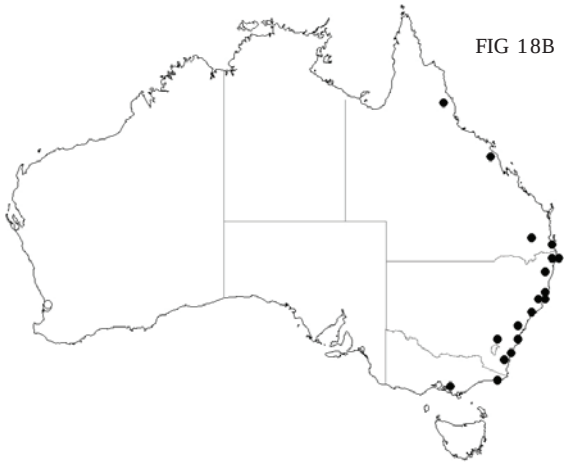


FIG 18B

(B) RELEASE AND REDISTRIBUTION

Release. *Onthophagus nigriventri*s was released in Qld, NSW and Vic between 1975 and 1983 (Fig 18B, solid circles). A total of 29,960 beetles was released at 24 sites. Numbers released per site ranged from 300 to 6,800 beetles.

Redistribution. A total of 833 *O. nigriventris* was redistributed in WA in 1993/95 (Fig 18B, open circle). Some redistribution has been undertaken on the NSW coast (not shown on map).

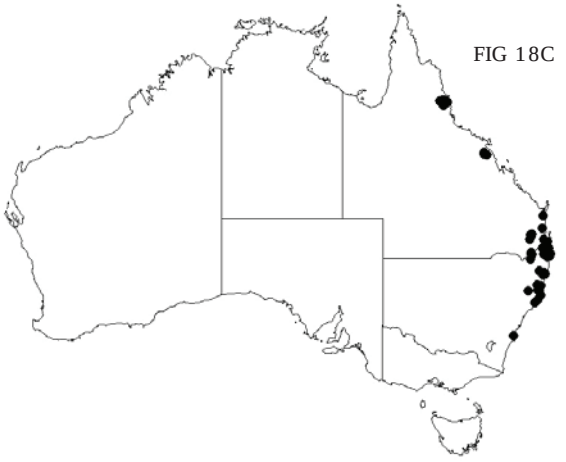


FIG 18C

(C) RECOVERIES

Onthophagus nigriventris has been recovered in coastal areas of NSW and southeast Qld, and in highland tropical areas of Qld, particularly Atherton Tablelands (Fig 18C, solid circles).

(D) POTENTIAL DISTRIBUTION

The potential distribution of *O. nigriventris* in Australia was modeled in BIOCLIM using African distribution data (Fig 18D). A conservative model (not shown) using all 19 climate parameters resulted in no matching areas in Australia. A less restrictive model (right) using four climate parameters (10 11 18 19) provided a match for most of the NSW east coast. Small regions of matching climate at higher altitudes in Qld (indicated with arrows) include the Atherton Tablelands (1) and Eungella region (2), both being areas where *O. nigriventris* has been recorded. The inland region (3) includes Carnarvon National Park.

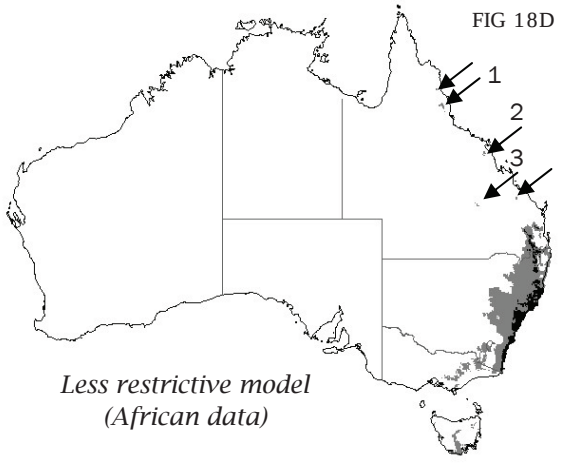


FIG 18D

Less restrictive model (African data)

(E) COMMENT

Onthophagus nigriventris was introduced from Kenya to assist in dung burial in the high rainfall tropical highland areas of northern Australia. It has established in these areas and also in coastal areas of southeast Qld and northeast NSW. The model indicates that most of the NSW coast and small parts of Vic and Tas may be suitable. The presence of kikuyu grass can be used as an indicator of areas suitable for release (J Feehan, pers. comm.).

19. *Onthophagus obliquus*

FIG 19A

(A) ORIGIN

Onthophagus obliquus (Fig 19A) is native to tropical Africa, including Nigeria, Senegal and Zaire.

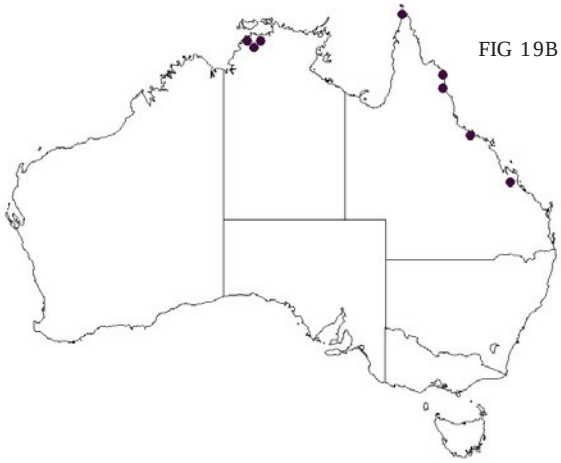


FIG 19B

(B) RELEASE AND REDISTRIBUTION

Release. *Onthophagus obliquus* was released between 1976 and 1977 in coastal Qld and north-west NT. A total of 9,300 beetles was released at 9 sites (Fig 19B, solid circles). Numbers released per site ranged from 500 to 2,200 beetles.

Redistribution. There are no records of this species having been redistributed.

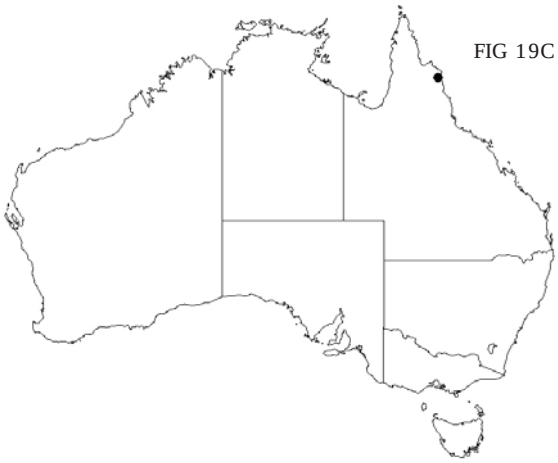


FIG 19C

(C) RECOVERIES

Onthophagus obliquus has been recovered from one site near Cooktown Qld (Fig 19C, solid circle).

(D) POTENTIAL DISTRIBUTION

The potential distribution of *O. obliquus* in Australia was modeled in BIOCLIM using the African distribution of the species (Fig 19D). A conservative model (left) included all 19 climate parameters, and a less restrictive model (right) included four temperature and rainfall parameters (10, 11, 12, 18).

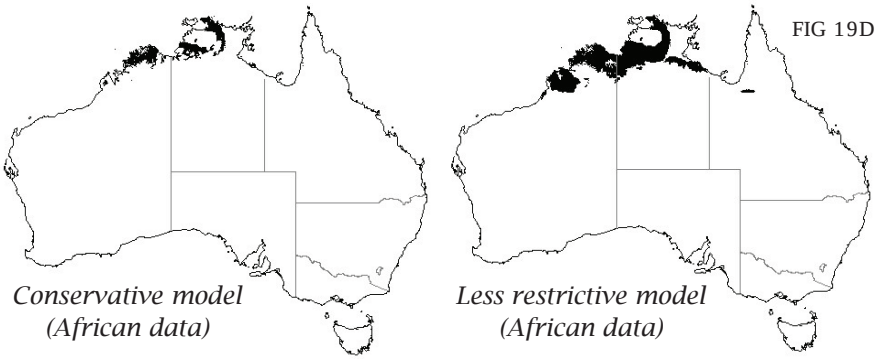


FIG 19D

Conservative model (African data)

Less restrictive model (African data)

(E) COMMENT

The current status of *Onthophagus obliquus* is uncertain. In the past it has been recorded as being quite abundant near Cooktown, but there are no recent records to confirm its current status. Both models indicate the Kimberley region of WA and parts of northern NT to be quite suitable. The species was not released in these areas, so redistribution here would be highly advisable, if sufficient beetles become available.

20. *Onthophagus sagittarius*

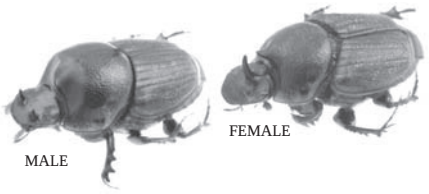


FIG 20A

(A) ORIGIN

Onthophagus sagittarius (Fig 20A) is native to southeast Asia. It was introduced from Sri Lanka into Hawaii, and from there to Australia.

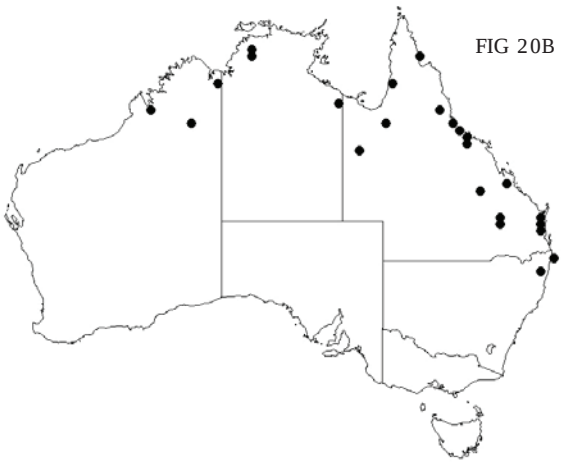


FIG 20B

(B) RELEASE AND REDISTRIBUTION

Release. *Onthophagus sagittarius* was released between 1968 and 1977 in northern WA, northern NT, Qld and northeast NSW (Fig 20B, solid circles). A total of 9,075 beetles was released at 22 sites (excluding road releases). Numbers released per site ranged from 22 to 1,483 beetles

Redistribution. The species was harvested in southeast Qld and redistributed southwest of Darwin NT (not shown on map).

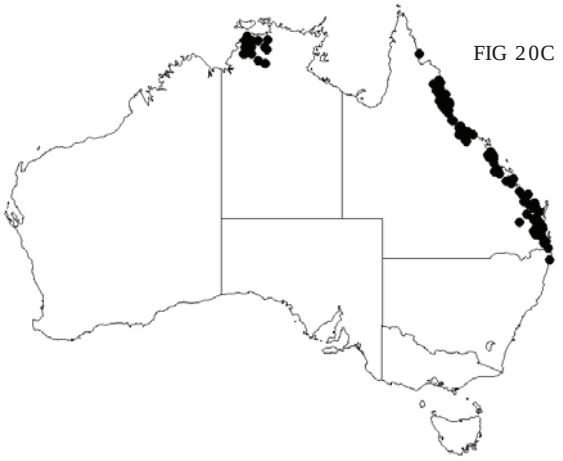


FIG 20C

(C) RECOVERIES

Onthophagus sagittarius has been recovered in northwest NT, coastal Qld and far northern coastal NSW (Fig 20C, solid circles).

(D) POTENTIAL DISTRIBUTION

Insufficient distribution data were available from the native range of *Onthophagus sagittarius* in Asia to use in a model. The potential distribution of *O. sagittarius* in Australia was modeled in BIOCLIM using climate data from 16 locations in Sri Lanka (not necessarily localities of *O. sagittarius*). Three parameters were used (10, 12, 18) to derive the model (Fig 20D). This indicates that high rainfall, particularly during the warmest months, adequately describes the observed distribution of *O. sagittarius.*

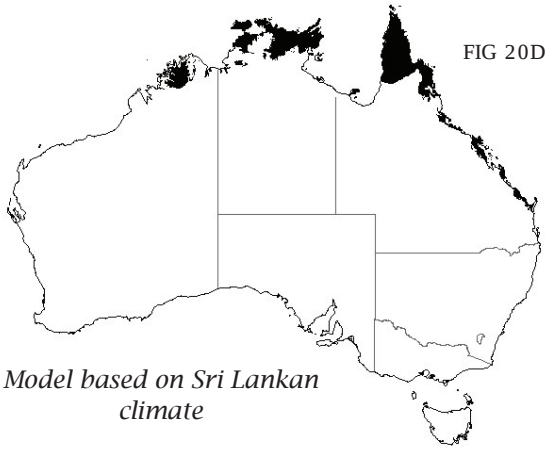


FIG 20D

Model based on Sri Lankan climate

(E) COMMENT

Onthophagus sagittarius is well established in warm regions with high summer rainfall. It has established and spread within a narrow band of suitable climate, predominantly in coastal Qld where the annual rainfall exceeds 800mm. The only scope for further redistribution of this species would be across northern Australia.

21. *Onthophagus taurus*

FIG 21A

(A) ORIGIN

Onthophagus taurus (Fig 21A) has a wide distribution in Europe, North Africa and the Middle East, including Spain, Portugal, France, Italy, Greece, Morocco and Turkey.

(B) RELEASE AND REDISTRIBUTION

Release. *Onthophagus taurus* was released in WA, SA, Tas, Vic and NSW between 1975 and 1984 (Fig 21B, solid circles). A total of 164,499 beetles was released at 97 sites. The number released per site ranged from 500 to 8,200 beetles.

Redistribution. A total of 663,497 *O. taurus* was redistributed in SA, Vic, Tas and NSW between 1987 and 1993, and 34,019 in WA in 1993/4 (Fig 21B, open circles). Further redistribution has taken place in the last 10 years (not shown), but since 2005 further redistribution has not been considered necessary. Beetles have also been redistributed around Lake Macquarie NSW and Brisbane Qld for burial of dog dung.

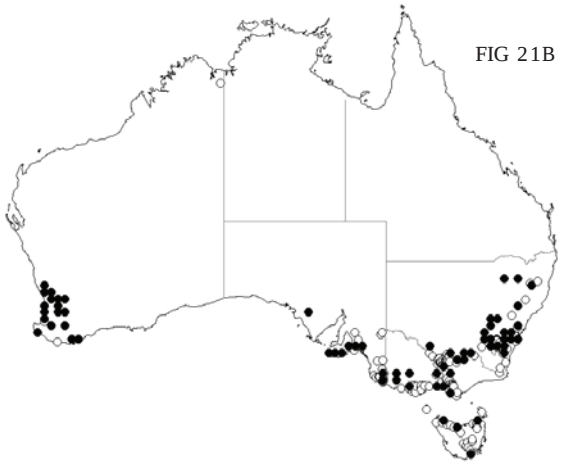


FIG 21B

(C) RECOVERIES

Onthophagus taurus has been recovered in WA, SA, Vic, Tas and NSW (Fig 21C, solid circles).

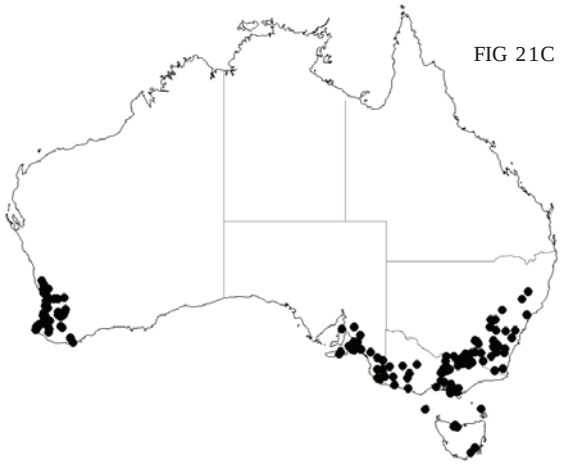


FIG 21C

(D) POTENTIAL DISTRIBUTION

The potential distribution of *O. taurus* in Australia was modeled in BIOCLIM using European and Middle East distribution data (Fig 21D). A less restrictive model using all available data (from Portugal, Spain, France, Italy, Austria, Greece, Morocco and Turkey) is shown on the left, and a less restrictive model using data from the four countries from which *O. taurus* was imported (Spain, Greece, Italy, Turkey) is shown on the right. Four climate parameters (10, 11, 18, 19) were used in both models.

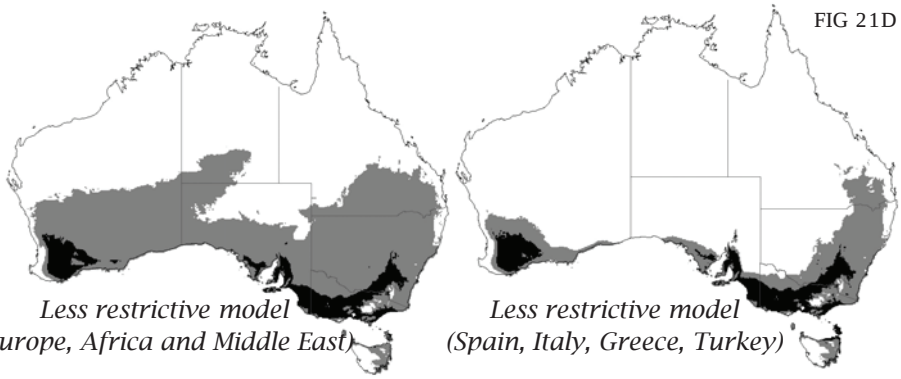


FIG 21D

Less restrictive model (Europe, Africa and Middle East)

Less restrictive model (Spain, Italy, Greece, Turkey)

E) COMMENT

Collections of *Onthophagus taurus* for introduction into Australia were made in Turkey, Spain, Greece and Italy. The distribution of *O. taurus* in Australia matches the predicted distribution based on the climate data from these four countries (above right). The model based on inclusion of all countries within the natural range of *O. taurus* (above left) gives a much wider predicted range than the observed distribution in Australia, suggesting that different strains of the species may exist. *O. taurus* is probably close to its potential distribution in Australia. Redistribution could be attempted along the southeast coast of Vic, Eyre Peninsula region of SA and inland southwest WA.

22. *Sisyphus rubrus*

FIG 22A

(A) ORIGIN

Sisyphus rubrus (Fig 22A) is native to southern Africa, and occurs in South Africa, Zimbabwe and Mozambique.

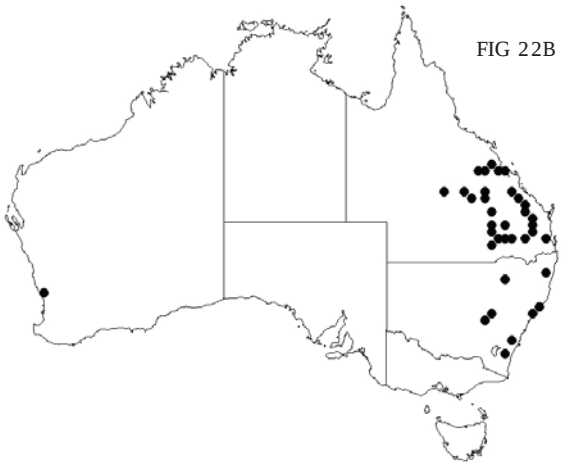


FIG 22B

(B) RELEASE AND REDISTRIBUTION

Release. *Sisyphus rubrus* was released in Qld, NSW and WA between 1973 and 1980 (Fig 22B, solid circles). A total of 85,933 beetles was released at 39 sites. Numbers released per site ranged from 300 to 4,000 beetles.

Redistribution. In about 1978 *Sisyphus rubrus* was redistributed north of a line between Rolleston and Rockhampton, with material collected from Rolleston (not shown on map). Some redistribution has occurred into northern NSW in recent years (not shown on map).

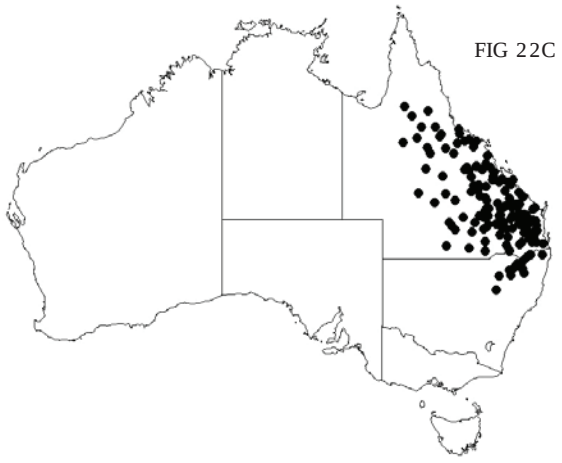


FIG 22C

(C) RECOVERIES

Sisyphus rubrus has been found through much of Qld and in northeast NSW, in areas where rainfall exceeds approximately 400 mm a year (Fig 22C, solid circles).

(D) POTENTIAL DISTRIBUTION

The potential distribution of *S. rubrus* in Australia was modeled in BIOCLIM using the African distribution of the species (Fig 22D). A conservative model (left) included all 19 climate parameters, and a less restrictive model (right) included four temperature and rainfall parameters (10, 11, 18, 19).

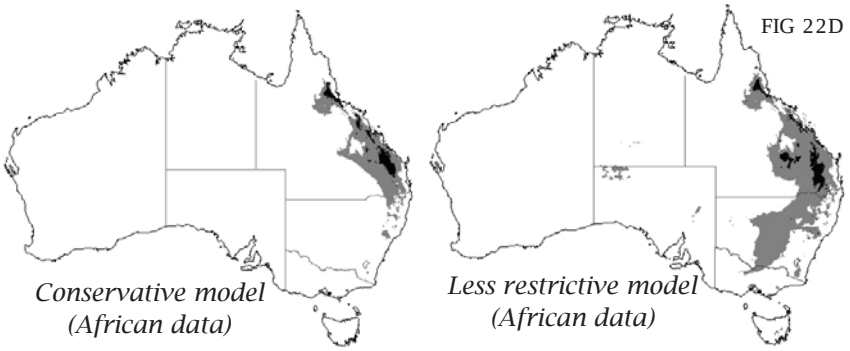


FIG 22D

Conservative model (African data)

Less restrictive model (African data)

(E) COMMENT

Sisyphus rubrus is a ball-roller that buries its brood balls (compare with *S. spinipes* which does not bury its brood balls). It occurs in Africa where rainfall exceeds 400 mm. This is slightly lower than for *S. spinipes* (500 mm), and is consistent with its range in Australia, which extends into drier regions than does that of *S. spinipes*. The models indicate that *S. rubrus* has probably reached its limit in Qld, but may extend further south into central NSW.

23. *Sisyphus spinipes*

FIG 23A

(A) ORIGIN

Sisyphus spinipes (Fig 23A) occurs in South Africa, Zimbabwe, Mozambique and Kenya.

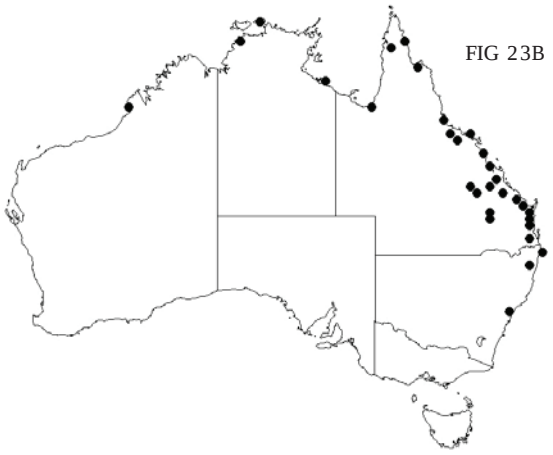


FIG 23B

(B) RELEASE AND REDISTRIBUTION

Release. *Sisyphus spinipes* was released in Qld, NT, WA and NSW between 1972 and 1978 (Fig 23B, solid circles). A total of 36,125 beetles was released at 35 sites. Numbers released per site ranged from 100 to 7,200 beetles.

Redistribution. Some redistribution of *S. spinipes* has occurred into northern NSW in recent years (not shown on map).

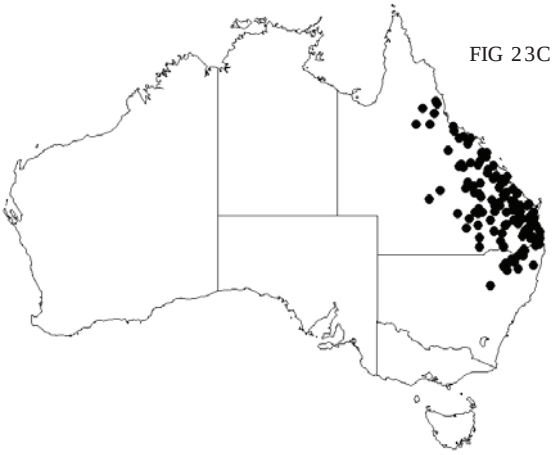


FIG 23C

(C) RECOVERIES

Sisyphus spinipes has been recovered from most of eastern Qld and from northeast NSW (Fig 23C, solid circles). It does not extend quite as far as *S. rubrus* into the drier areas of Qld.

(D) POTENTIAL DISTRIBUTION

The potential distribution of *S. spinipes* in Australia was modeled in BIOCLIM using the African distribution of the species (Fig 23D). A conservative model (left) included all 19 climate parameters, and a less restrictive model (right) included four temperature and rainfall parameters (10, 11, 18, 19).

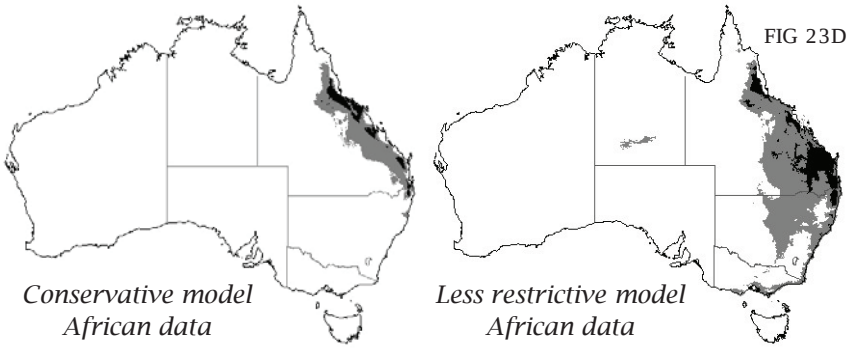


FIG 23D

(E) COMMENT

Sisyphus spinipes is a ball-rolling dung beetle which does not bury its brood balls, but attaches them to vegetation. It was thought that this habit might make it less dependent on rainfall for activity. However its seasonal activity pattern is very similar to that of *S. rubrus*, a species which does bury its brood balls. Both species are active in summer rainfall regions from about October until May. In Africa *S. spinipes* occurs where annual rainfall exceeds 500 mm. *Sisyphus spinipes* is most abundant in central Qld, but in general does not occur in such high numbers as *S. rubrus*. The models indicate that there is little potential for redistribution of this species, although its range could extend further south than at present.