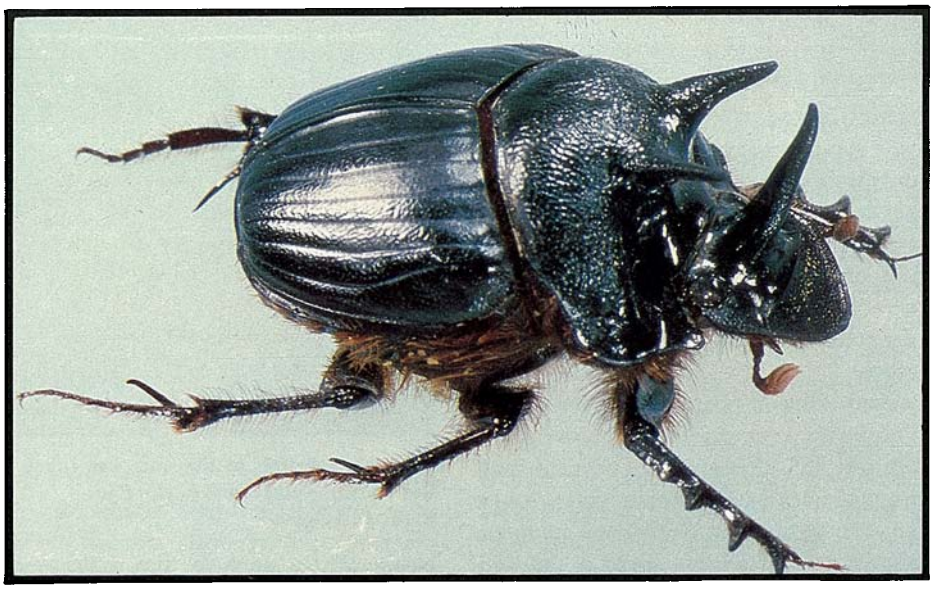


***Onthophagus ferox* is the commonest native dung beetle in the agricultural areas of Western Australia.**

Dung beetles get a little help from their friends

One hot day last February a message reached the CSIRO Division of Entomology's station at Rockhampton, Queensland. A farmer had found huge numbers of dung beetles on his property, about mid way between Springsure and Roma.

The entomologists greeted this news with hardly less enthusiasm than prospectors learning of a gold strike, and soon two vehicles were travelling through the heat to the property.

The beetles were certainly abundant. Within 3 days two field workers had collected 83 000, almost all belonging to the species *Sisyphus rubrus*. Packed in damp peat moss over ice in polystyrene containers, the beetles were kept alive for the few days needed to transport them to new homes.

Sisyphus rubrus is an immigrant from Africa, given assisted passage by CSIRO and released in Queensland 7 years ago, and the scientists were taking the opportunity to accelerate the beetle's natural colonization of its new land. They found 25 suitable release sites distributed over hundreds of kilometres, west to Barcaldine, north to Nebo, and as far south as Dalby, and at each site they tipped several thousand beetles onto their natural habitat, fresh cow dung.

The CSIRO dung beetle program has caught the public's imagination as much as any of the Organization's activities, but unfortunately interest has not always been matched by understanding. Only a few months ago, fully 13 years after the first beetles were released, one of Australia's more responsible newspapers credited dung beetles with the suppression of blowflies and and house-flies, and with declining sales of indoor insecticides. But this is impossible.

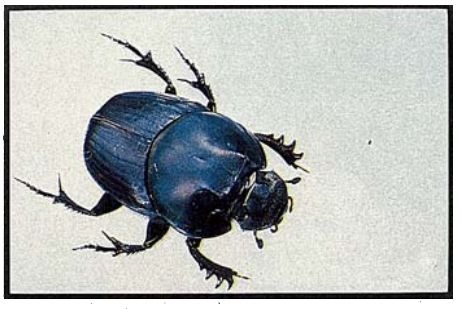
Dung beetles dispose of dung, and only flies that breed in dung can be affected. Blowflies lay their eggs in animal carcasses — hence the maggots in fly-blown meat. The ecological paths of dung beetles and blowflies do not cross.

House-flies generally breed in domestic refuse; they sometimes lay eggs in dung, but mostly in farmyard heaps rather than the fresh pads where dung beetles go to work. In any case, house-flies rarely stray far from houses, so they too are unlikely to be influenced by dung beetles.

Bushflies, which do breed in fresh dung

***Onthophagus binodis* go to work on a fresh cowpad.**

All that's left of a cowpad after *O. binodis* has shredded it.



The African species *Onthophagus binodis* is efficient at destroying cowpads in summer in south-western Western Australia.

and can be suppressed by the beetles, are virtually restricted to rural areas and do not come into homes, so their disappearance, if it ever comes about, will not be reflected in sales of indoor fly sprays.

Dropping into trouble

Scientists recruited dung beetles to combat one enemy in particular: dung. In Australia, unlike countries in which cattle and similar large herbivores evolved, cowpads used to lie about, drying and hardening, for a long time, even many months.

A persistent pad upsets farmers for several reasons. First of all, it smothers the pasture. Because each beast drops about 12 pads a day, a significant proportion of a paddock may become temporarily unproductive. Moreover, some of the dung's nutrients, including much of the nitrogen, are lost to the atmosphere instead of being recycled to the soil, and immediately around the pad the grass grows so rank that cattle eat it only if they can find no better alternative.

It is difficult to estimate the total economic loss caused by persistent pads, but the sums must be large. Traditionally farmers have broken up large accumulations of dung by harrowing, but the natural world offers a more efficient choice.

In many countries dung disappears rapidly, especially in warm, wet conditions, thanks to the activities of specialist beetles that both feed and breed in animal droppings.

Female dung beetles lay their eggs in balls of fresh dung. In due course the eggs hatch and larvae emerge. These pale, soft-bodied grubs have chewing mouthparts. For them, dung is an ample, balanced diet. It is also their whole world; they never leave it and are not equipped to cope with other types of food.

Like all insects, the larvae shed their skins as they grow, and after three stages, called instars, they pupate, still inside the dung. Finally the pupal case splits and out crawls an adult beetle, even more specialized than its junior stages, because its mouth-parts are adapted exclusively for sucking dung juices through a fine filter of hairs.

The adults have a keen sense of smell, and quickly find any freshly fallen dung in which to feed or reproduce in their turn. For a beetle this speed is important; other dung beetles are competing for the same droppings, and in any case the pad will soon dry out.

Depending on the species and the temperature, the complete life-cycle may take less than a month or up to a whole year.

Three types of home

A dung pad that receives the vigorous attentions of these busy beetles soon disintegrates. Some beetles tunnel into the pad, excavating chambers in which they deposit their brood balls. These species, the endocoprids ('inside-dung beetles'), produce broods under adverse conditions, such as dry spells, when other beetles are less active.

In many countries dung disappears rapidly, thanks to the activities of specialist beetles.

Beetles belonging to another group bury their brood balls underground. The males pass dung to the females, which tunnel into the soil beneath the pad and shape the dung into balls or sausages, each with a chamber in which an egg is laid. A female may leave as many as 15 brood balls beneath one cowpad.

Because they operate beneath the surface of the dung, these paracoprids ('near-dung beetles') are inconspicuous to us, but they do more to disperse dung than any other beetles. Freshly excavated soil around a cowpad is a sign that the females are at work, both enriching the soil with organic matter and physically improving it by tunnelling. The agricultural merits of paracoprid beetles are much like those of earthworms, with the bonus of dung disposal.

To man, the most noticeable dung beetles are the ball-rollers, familiar to the inhabitants of ancient Egypt and exemplified in Australia by *Sisyphus rubrus*, the beetle collected in large numbers in Queensland last February. These beetles make brood balls that are larger than themselves and in some cases almost as big as a tennis ball. Called telecoprids ('distant-dung beetles'), they push the ball away from the pad, then either bury it in the soil or place it in a grass tussock.

In a country with a rich native fauna of dung beetles, droppings attract large numbers of a wide variety of species. One enterprising scientist in Kenya collected 22 746 beetles from a particularly well-populated 7-kg lump of dung 12 hours after it was dropped by a passing elephant.

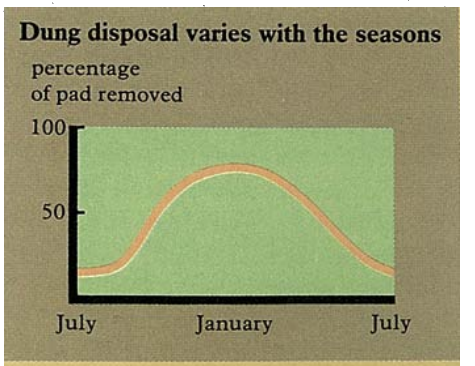
A cowpad often disappears in only 3–4 hours. In Africa and India, ball-rollers alone, when they are really numerous, can reduce a cowpad to a stain on the ground inside an hour.

These are outstanding performances; usually beetles in such countries take a day or two to eliminate a cowpad, and this is speed enough to improve the nutrient content and physical condition of the soil, while avoiding the agricultural ills that attend long-lived pads.

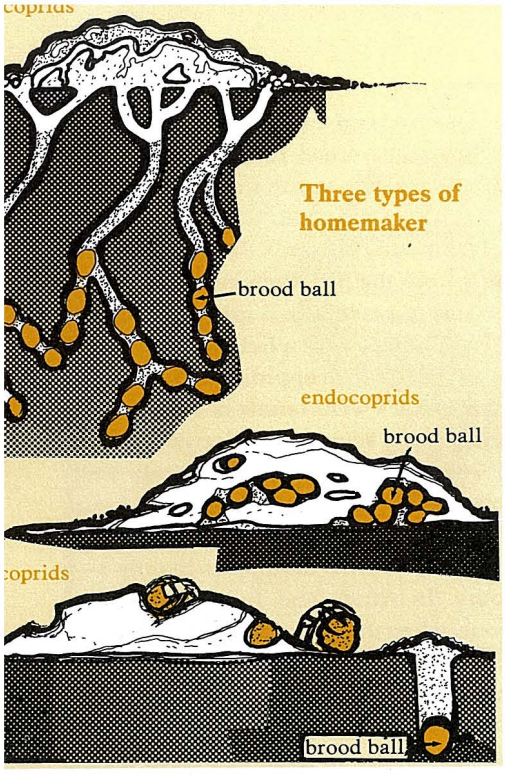
Immigrant labour

Until about 13 years ago these benefits were hardly available to Australian farmers. Most of the native species of dung

Around old cowpads grows rank grass that cattle find relatively unpalatable.



At Rockhampton dung beetles are most active during the warm, wet conditions of summer.



All dung beetles deposit their eggs in brood balls of dung: paracoprids below the cowpad, endocoprids within it, and telecoprids at a distance from the pad.

beetle are adapted to forests and do not thrive in cleared agricultural land. The idea of importing migrant dung beetle labour to Australia, first proposed by Dr George Bornemissza of the Division of Entomology in 1960, had immediate appeal, and not only as a way of burying dung.

Among the many insects attracted to fresh droppings are two that trouble man. The bushfly, *Musca vetustissima,* a relative of the house-fly, pesters people out of doors but without hurting their wallets.

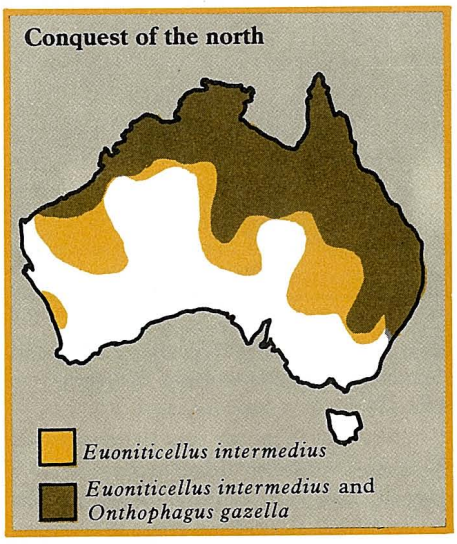
The buffalo fly, *Haematobia irritans exigua,* poses more serious problems. Up to 1000 flies may take up positions on a cow, biting the skin many times a day for meals of blood. The beast is severely disturbed, developing sores as it rubs its body in an attempt to relieve the irritation. Beef animals may feed less well and put on less meat, and cows produce less milk.

The bushfly is native to Australia. By contrast the buffalo fly, a tropical species, was introduced with buffaloes to Melville Island, N.T., from Timor in 1825. For more than 80 years it spread no farther than the Cobourg Peninsula region, until in 1910 it appeared in the Kimberleys, W.A., and in 1928 was first seen in Queensland.

At intervals of many years, the fly has expanded its range rapidly. By 1946 it had apparently halted its advance at Bundaberg, but 30 years later it reached the Brisbane Valley, and it is now near Grafton, N.S.W.

Both kinds of fly lay their eggs in dung, buffalo flies almost as soon as a pad hits the ground, and bushflies at any time up to a few hours later. When dung beetles are active, they disrupt the flies' larval home in two ways. If they are breeding, the beetles remove some of the dung in the form of brood balls, but usually leave a number of small lumps of dung in which some fly eggs can develop.

At other times the adult beetles are intent on feeding and they plough through the dung extracting nutrient-rich liquid.



The present distributions of Australia's two most widespread introduced dung beetles.

In the process the beetles reduce the cowpad to shreds, and many bushfly eggs become submerged in the soggy dung, where they drown. Unfortunately, buffalo-fly eggs survive submergence.

The proposal to introduce dung beetles was therefore a proposal to try to correct an ecological imbalance. In other countries cattle had their humble insect attendants, burying dung and apparently keeping pest flies in check. Australia lacked suitable dung beetles. Perhaps some of the overseas species could help?

Any side-effects?

The deliberate importation of organisms from other lands cannot be undertaken lightly. Is there a danger that dung beetles

Keeping out illegal immigrants

From the start of the dung beetle project, entomologists have been well aware that the importation of foreign species can be a two-edged sword; with the beneficial beetles may come undesirable pest or disease organisms.

The very first dung beetles brought to Canberra in 1966 were found to be sheltering tiny unwanted mites under their wing-cases, survivors of a dose of acaricide powder applied specifically to destroy them before they left Hawaii. For this reason neither those beetles nor any collected overseas since have been released in Australia. Instead, stocks are bred in quarantine.

Nowadays all beetles are imported as eggs. Members of the CSIRO team in South Africa breed beetles in the laboratory at Pretoria. They collect the eggs and immerse them for a few minutes in 3% formalin to sterilize the surfaces. The eggs are then packed in sterilized peat moss from Australia and flown to Canberra, where they hatch in the quarantine laboratory.

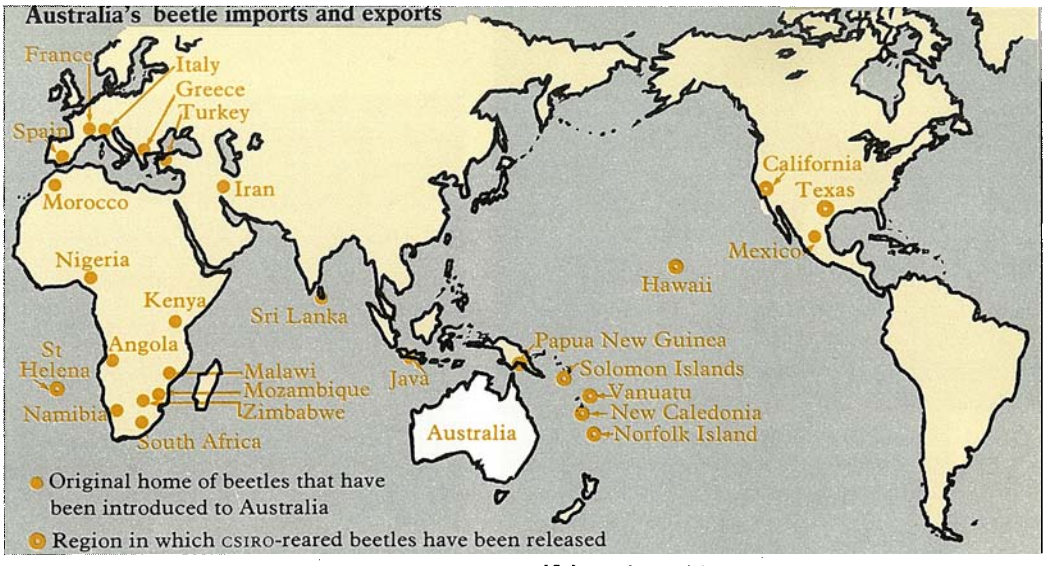
Each larva is then carefully transferred into a brood ball of dung, either hand-rolled by dedicated entomologists or fashioned by a work force of beetles kept especially for the purpose. When the adults emerge, at least some are retained in Canberra for further breeding.

These strict precautions have enabled Australia to import 56 species (in all, 79 strains) without side-effects.

The scientists are learning new tricks all the time. For example, one species in the Canberra laboratory increased its brood production several-fold when the beetles were fed on prime-quality dung out of the freezer. The best dung is generated by the best pasture, usually in late spring in southern Australia, and the entomologists now collect large quantities when it is 'in season' and keep it on ice.

When the stocks of beetles have grown sufficiently large, batches are released in the field, and eventually the most successful species may well be 'cropped', as *Sisyphus rubrus* was in Queensland last February, for wider dispersal.

All State and Territory Departments of Agriculture liaise closely with the Division in selecting suitable release sites and monitoring the beetles' progress. So far, more than a million beetles, belonging to 61 strains of 42 species, have been released at well over 1000 sites, and already 25 strains of 19 species are known to have become satisfactorily established.



could damage crops, for instance, or proliferate undesirably like the rabbit?

Ecologically, the beetles are such specialists that the question is easily answered. Their mouth-parts and behaviour patterns commit them to total dependence on dung.

All dung beetles belong to the family Scarabaeidae but, unlike some other scarabs, dung beetle larvae cannot chew grasses, damaging suburban lawns or rural pastures. Indeed, if they are removed from their brood balls, they die. The adult beetles obtain all their nourishment from liquid and very fine particles in recently deposited dung, and are not equipped to feed on any other diet. What's more, dung beetle populations are self-regulating: no dung, no beetles.

The beetles' mouth-parts and behaviour commit them to total dependence on dung.

So there is no danger of dung beetles becoming pest or plague insects. Moreover, as most of the native dung beetles are forest species, they are unlikely to be threatened by ecological competition with species introduced from savannah and open plains.

One serious risk remains. Immigrant animals could bring diseases from which Australia is at present thankfully free, such as foot-and-mouth. To eliminate this danger, rigorous quarantine is vital (see the box).

First release

The stage was thus set in the 1960s for the introduction of foreign beetles to Australia. Curiously, one South African beetle anticipated the CSIRO program by several decades, becoming established in Australia before 1900, probably by accident, but the first deliberate imports of beetles were from Hawaii, where Mexican, African, and Asian species had been introduced from as early as 1906 to combat the horn fly, a close relative of our buffalo fly.

Looking back, we can see that January 30, 1968, was one of the most significant days in the project. On that date an African beetle, *Onthophagus gazella*, bred under quarantine in Canberra from Hawaiian stocks, was released in Australia for the first time. Over the next few years more than 200 000 further specimens of this beetle were released, every one bred from eggs laid in captivity.

The beetle expanded its range by 50 to 80 km a season from the original release sites in northern Queensland, and is now one of the two most widespread introduced beetles (see the map).

Six other dung beetle species were introduced from Hawaii in the late 1960s, and many more species came directly from Africa as eggs, starting in 1970. Meanwhile CSIRO entomologists at field stations in South Africa, France, and Greece continue to collect and study local species, assessing their potential as new Australians.

As with all biological control projects, it is impossible to predict which species will thrive best after release in their new home. Some have not yet been seen since their release. On the other hand the ranges of two African species, *O. gazella* and *Euoniticellus intermedius*, are expanding well: they spread so fast soon after their release that their populations were described as exploding.

Between these extremes are the many species that have been recovered, sometimes several years after their release, in numbers and places that suggest they are variously spreading more or less rapidly or, in some instances, taking time to become established.

However successful some species turn out to be, their numbers will usually fluctuate. We cannot expect any beetle to be exceedingly abundant every year; natural insect populations generally have marked ups and downs. One of the aims of the program is to establish a sufficient variety of species to ensure that, as far as possible, a significant amount of dung is always being disposed of.

Dung does disappear

The beetles have already made a major impact, especially in the northern half of Australia. Experiments by CSIRO are quantifying the widespread observation that dung is disappearing. Dr Gus Macqueen and his colleagues at the Division's Craighoyle field station near Rockhampton have for 4 years been putting out standard-sized pads of cow dung every week and retrieving the remains after 7 days for measurement.

At their most active, the five locally established beetle species generally destroy 60–70% of a pad within 2 days, but in the drier winter months and during dry spells in summer a much higher proportion of the pad persists.

When the program began, the first priority was to find beetles for northern Australia, but now the CSIRO team, under the leadership of Mr Murray Wallace in Canberra, is also looking for suitable species to colonize the south-east and south-west. The entire project is awesomely ambitious, attempting as it does to establish active groups of dung beetles in each of the wide variety of climates into which man has introduced cattle.

At their most active the beetles destroy 60–70% of a pad within 2 days.

Every species of beetle has its unique way of life, requiring detailed study if scientists are to understand where it fits in the ecological jigsaw. Some beetles are more active early in the year, some later; each has its particular time of day for flight; there are those that need cool temperatures and those that prefer the heat; some beetles are more widespread than others; and they all have their individual environmental requirements — such as amount of rain, and particular factors needed to provoke the larvae to pupate and continue their development.

Experiments with screens are helping to clarify the roles of dung beetles and other invertebrates in the suppression of buffalo flies. This screen denies dung beetles access to the pad, but lets smaller animals through.

As the world contains more than 4000 species of dung beetle, the choice is enormous, but so is the amount of work needed to assess them all.

Match-making

The entomologists at Rockhampton and the team led by Dr James Ridsdill Smith at the Division's Perth station are busily collecting and studying, in an attempt to define the ecological gaps in their respective dung beetle faunas. Meanwhile field workers overseas, such as the Pretoria team under Dr Bernard Doube, are characterizing their most promising species and trying to identify the beetles most likely to plug those gaps.

An important part of the exercise is climate-matching — that is, finding areas in other countries with similar climates to those in the different parts of Australia where beetles are needed, exemplified by the Division's three stations: at Rockhampton (tropical with summer rain), Perth (winter rain), and Canberra (year-round rainfall).

In Canberra Dr Keith Houston analyses the distributions of beetles in their native habitats and predicts their potential range if they are introduced here. This kind of information is also used in the selection of species to be exported from Australia to other countries with a dung beetle program, such as Papua New Guinea and parts of the United States of America.

Buffalo flies suck blood from cattle and breed in cow dung.

If need be, investigators may one day extend their studies to Indonesia, the Indian sub-continent, and South and Central America in their search for effective beetles.

Tackling flies

Dung beetles have proved their competence against cattle pads. How good are they at suppressing flies?

This is harder to assess. In the laboratory they perform well: 100 *Onthophagus gazella* will reduce the number of adult bushflies emerging from a pad by 97%, and beetle concentrations of 200 or more totally eradicate the fly. Buffalo flies survive such assaults rather better; beetles reduce the number of emerging adult flies by a little more than 40% regardless of whether the pad has 100 beetles or 400.

But it is a giant leap from an isolated dung pad to the complex community of flies and their enemies in the wild. Australia's only regular counts of buffalo flies on cattle are carried out at Craighoyle and at Amberley, near Brisbane. So far the results have been unclear. At times, few flies emerge from the experimental pads; there are also times when relatively few flies infest cattle. Unfortunately these times do not necessarily coincide. Much more research is needed into this complex matter.

As the world contains more than 4000 species of dung beetle, the choice is enormous.

It seems probable that, without dung beetles, fly numbers would be higher, yet this is a tricky suggestion to test. What we really need is something we can never now have: accurate statistics for the numbers of flies at several sites before dung beetles arrived, ideally spanning at least two decades, so that we can see the natural fluctuations in fly populations.

As it is, one way we can measure the impact of beetles on flies is to compare pads to which beetles have access with those from which they are excluded. The Rockhampton team has been carrying out such an investigation.

Female buffalo flies are quick to settle on a fresh pad and lay their eggs. The scientists rapidly enclose the chosen pad in a net, and collect and count all the flies taking off after laying. From sample dissections, they know how many eggs the average fly lays, and can estimate how many have been deposited on the pad being investigated.

They then remove the net and place over the pad one of three frames: a fine-meshed one to exclude all insects, a medium one that excludes all but the few smallest dung beetles but admits smaller insects, or a coarse one serving only to keep cattle off. After comparing many experimental pads, the scientists have concluded that small insects can destroy up to about 90% of the flies that would otherwise emerge.

Although this leaves only a small percentage of the original potential fly population, that percentage amounts to a large number of buffalo flies. When dung beetles have access to the pad, their efforts, combined with those of the other insects, can achieve more than 95% mortality at times. Clearly the beetles are capable of reducing the number of flies that emerge to pester cattle, but more research must be done before their precise significance becomes clear.

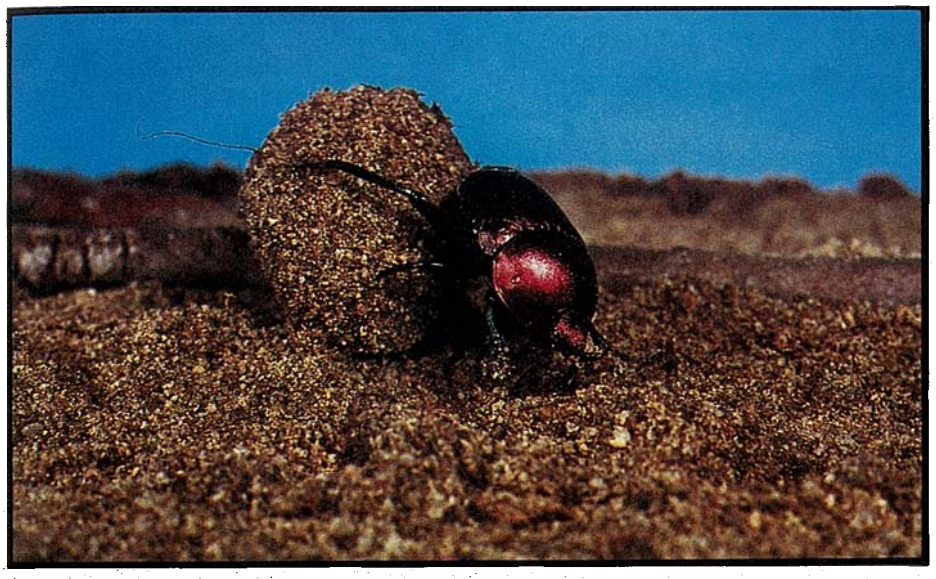
We see from such experiments that dung beetles are by no means the only destroyers of buffalo flies. Similar investigations near Canberra have revealed a high mortality of bushflies, too, at certain times when dung beetles are scarce. The most effective suppression of pest flies will be by a whole community of organisms, in which dung beetles complement the activities of a variety of other animals.

The cowpad community

The cowpad, then, is a miniature ecosystem: excitingly rich but challengingly complex. What are these other predators, that so effectively reduce fly survival?

They include histerid beetles, whose potential has been recognized for some time; the earliest imports from Hawaii included two species in this group. They have biting mouth-parts and prey directly on fly larvae. Those released in Australia did not at first seem particularly effective, but *Hister nomas* is now abundant on the coast of New South Wales, and perhaps beginning to 'bite'. In the laboratory this beetle destroys large numbers of bushfly eggs, but more research is needed to find out how big an impact it is making in the field.

Members of two other beetle families, the hydrophilids and staphylinids, also prey on fly larvae, as do the larvae of some predatory flies. The larvae of hydrophilids, which are apparently all native



Some dung beetles roll their brood balls away from the pad.

Australian species, seem to be responsible at times for almost total suppression of bushflies.

Important elements in the food webs of overseas cowpads are mites — tiny, eight-legged relatives of spiders. Some dung mites are real specialists, hunting exclusively in animal droppings for their diet of fly eggs and larvae, topped off with nematode worms. Australia has several kinds of dung mite, but their taxonomic relations are obscure and scientists do not know whether some are native or all were introduced accidentally, probably in the early days of settlement. Unfortunately only one of these mites, provisionally named *Machrocheles glaber*, seems to take a toll of the flies that annoy us.

Would introduced mites enrich the Australian cowpad community and help keep pest flies in check?

Would introduced mites enrich the Australian cowpad community and help keep pest flies in check? It is too early to say, but the scientists at Canberra are studying three species, *M. glaber* and two still under quarantine from South Africa.

The early results look promising, but there is one problem: unlike bushfly eggs, those of the buffalo fly are apparently too tough for the mites, which have to wait for the fly larvae to emerge before they can begin their cull. There will always be some larvae that hatch and burrow to safety below the surface of the pad.

A rather different problem is that of putting names to these creatures. This year CSIRO appointed an acarologist to tackle the neglected field of dung mite taxonomy, which is, as Mr Wallace remarks, 'a bit of a headache at the moment'. The grouping of convenience, '*Machrocheles glaber*', possibly includes dozens of species.

If suitable mites are released their populations could explode: one of the South African species being studied completes a generation in only 3 days.

However effective mites may turn out to be, dung beetles will never be out of a job. Not only are they the only insects that bury dung, but the mites totally depend on them for dispersal. The mites leave pads, either as nymphs or as adult females, by hitching a ride on a dung beetle. Clinging to beetles' bodies, mites rapidly colonize fresh pads.

In old Egyptian mythology the sun-god Khepri was a mighty dung beetle, rolling the sun across the heavens. As it perpetuated the daily cycle of renewed life, the scarab came to represent the eternal human soul. In another cycle of human culture, the ancient Egyptian symbol of resurrection has become a modern Australian instrument of revitalized land.

John Seymour

More about the topic

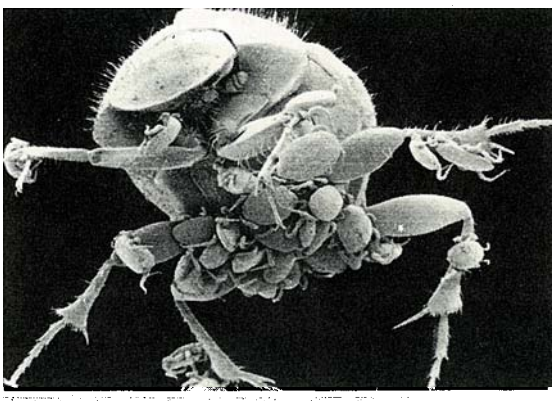
The biological control of dung. D.F. Waterhouse. *Scientific American*, 1974, **230**, 101–8.

Dung beetles dig in. *Rural Research* No. 98, 1978, 13–20.

The influence of *Machrocheles glaber* on the breeding of the Australian bushfly *Musca vetustissima* in cow dung. M.M.H. Wallace, M. Tyndale-Biscoe, and E. Holm. *Recent Advances in Acarology*, 1979, **2**, 217–22.

A French dung beetle, *Geotrupes spiniger*, is released on a fresh cowpad near Canberra. This beetle is adapted to a relativly cool climate.

Mites eat the eggs and larvae of pest flies, and are dispersed by dung beetles. This scanning electron micrograph shows mites on the underside of *Onthophagus granulatus*.



Apart from dung beetles, some other insects help suppress flies that breed in dung. Here a histerid beetle, *Hister caffer*, gets its mandibles into a juicy fly larva.

The introduced dung mite *Macrocheles glaber* is well established in south-eastern Australia.