INSECTARY STUDIES ON THE CONTROL OF DUNG BREEDING FLIES BY THE ACTIVITY OF THE DUNG BEETLE, *ONTHOPHAGUS GAZELLA* F. (COLEOPTERA: SCARABAEINAE)

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Abstract

The Afro-Asian dung beetle, *Onthophagus gazella* F., buries bovine dung as food for its larvae so rapidly that when beetle populations are of the order of 4 insects per 100 c.c. dung, entire cow pads are completely broken up and buried within 30 to 40 hours.

Insectary studies show that this rate of dung disposal caused 80 to 100 per cent. reduction in the numbers of the bushfly *Musca vetustissima* Walker emerging from the pads. Surviving maggots gave rise to small, stunted flies of low or nil reproductive capacity. Viable fly eggs or maggots were never found in brood balls, and it is presumed that they were destroyed in the course of the elaborate process by which the beetles convert lumps of dung into brood balls.

Speed of dung burial is the critical factor in fly control. If half of a cow pad is buried within the first 24 hours, few or no adult flies emerge. More rapid burial within this period resulting in the complete removal of the cow pad, produces complete fly control.

Introduction

Dung beetles of the subfamily Scarabaeinae have long been regarded as useful agents in the control of fly pests that breed in the dung of domestic animals. Hawaiian entomologists were probably the first to test the possibility that dung beetles could be used as biological control agents when they introduced a few into their islands for the control of the horn fly *Haematobia irritans* (L.) (Fullaway 1921). Later the present author also advocated the use of these beetles in Australia (Bornemissza 1960). The several potential benefits forecast (Bornemissza and Williams 1970) included the control of the bushfly, *Musca vetustissima* Walker, and of the blood sucking buffalo fly, *Haematobia exigua* (de Meijere), which is a serious pest of cattle in Australia.

However, the potential of dung beetles in fly control remained unproven until Bornemissza (unpublished data) carried out experiments in 1966 on the island of Hawaii, following the relatively recent introduction of beetles from Africa and Ceylon. By denying beetles access to some pads and trapping the flies that emerged from these and other pads attacked by beetles, it was found that pads with beetles produced some 95 per cent. fewer horn flies than those from which the beetles were excluded (unpublished data). However, it was not possible to study the mechanism of this phenomenon in detail in Hawaii, so the experiments described in the present paper were carried out in Canberra after the beetles had been introduced into Australia. The experiments were designed: (i) to check the results obtained in the field in Hawaii and to illustrate the role of dung beetles in fly control; (ii) to elucidate the mechanism involved in any such control; and (iii) to establish standards by which the fly control potential of other dung beetles could be measured.

Methods

The experiments were carried out in a temperature-controlled insectary (at 27°C), employing the Afro-Asian coprid, *Onthophagus gazella* F. (subfam. Scarabaeinae) and the Australian bushfly *Musca vetustissima.*

Two types of containers were used. The first consisted of 4 litre plastic buckets, 20 cm diameter at the top, 15 cm at the bottom, and 20 cm deep. These were firmly filled with a damp mixture of 2 volumes of red sand, 1 volume of loam and 1 volume of shredded peat moss to increase moisture retention. On the surface of each bucket 100 c.c. of fresh cow dung was placed, moulded into the shape of a small pad. Five gravid female bushflies were released into each of the 16 buckets and retained there

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by covering them with black nylon netting (Plate I E, F). After allowing two hours for oviposition, the flies were removed, and to each bucket either 1, 2 or 3 pairs of beetles were introduced to provide three treatments replicated four times. These densities per unit of dung were calculated on the basis of field counts in Hawaii, and represented the lower limits of the density classes of 'low', 'medium' and 'high', averaging 15, 25, and 40 pairs of beetles per 1,000 c.c. observed in Hawaii. The other four buckets which did not receive any beetles, served as controls. In another experiment the procedure was the same except that, instead of allowing the flies to lay, 50 first instar bushfly larvae (8 to 10 hours old) were added to each pad, and there were 5 replicates.

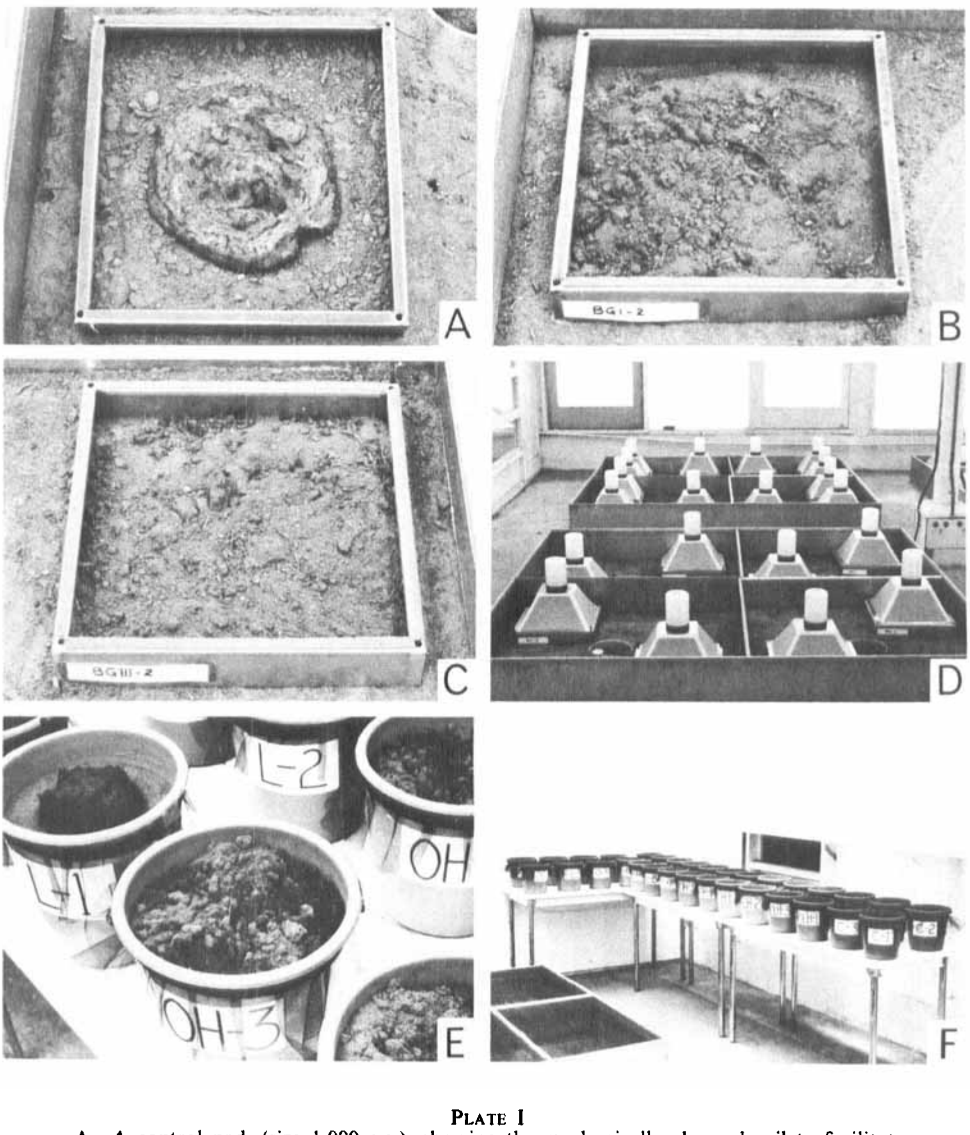

PLATE I

A—A control pad, (size 1,000 c.c.), showing the mechanically churned soil to facilitate pupation for the bushfly larvae.
B—The remains of an experimental pad buried by 10 pairs of *Onthophagus gazella* F.
C—As in B, a pad buried by 30 pairs of beetles.
D—View of part of the experiment, showing the trays with their covers on to capture the emerging bushflies.
E, F—General views of an experiment using plastic buckets similar to those described in the text.

The other type of container used was a steel barrier 30 × 30 cm, and 7.5 cm deep, pressed 3 cm into soil of the same composition as that used in the buckets, and forming part of the insectary floor (see Plate I A–D). The top 30 cm of the soil was electrically heated to a constant temperature of 27°C. A copper wire screen 20 cm below the soil surface prevented the beetles from penetrating down to the heating elements.

In each of these enclosures a 1,000 c.c. dung pad was placed, and 10 gravid female bushflies were introduced for 2 hours. Beetles were then released on the pads in batches of 10, 20 or 30 pairs per enclosure. Four enclosures were stocked at each rate and eight, designated as controls, did not receive any beetles.

In every control sample a steel rod was used to loosen the top 2.5 cm of soil around the dung pads, in order to make the soil texture and water loss rate comparable with that in the enclosures harbouring beetles (Plate I A–C). This was also essential to assist the wandering fly larvae to find suitable niches for pupation.

In all experiments, the progress of dung burial was estimated visually every six hours and expressed as a percentage of the initial volume. Previous measurements elsewhere had shown that such estimates had a maximum of error not exceeding 5 per cent. The emerging flies were left to die in the containers and then collected and photographed (Plate II).

THE NESTING HABITS OF *Onthophagus gazella*

This beetle is a dusk and night flying species which colonizes fresh pads of cattle dung in open pastures. It usually buries pads on sand or sandy soils rather

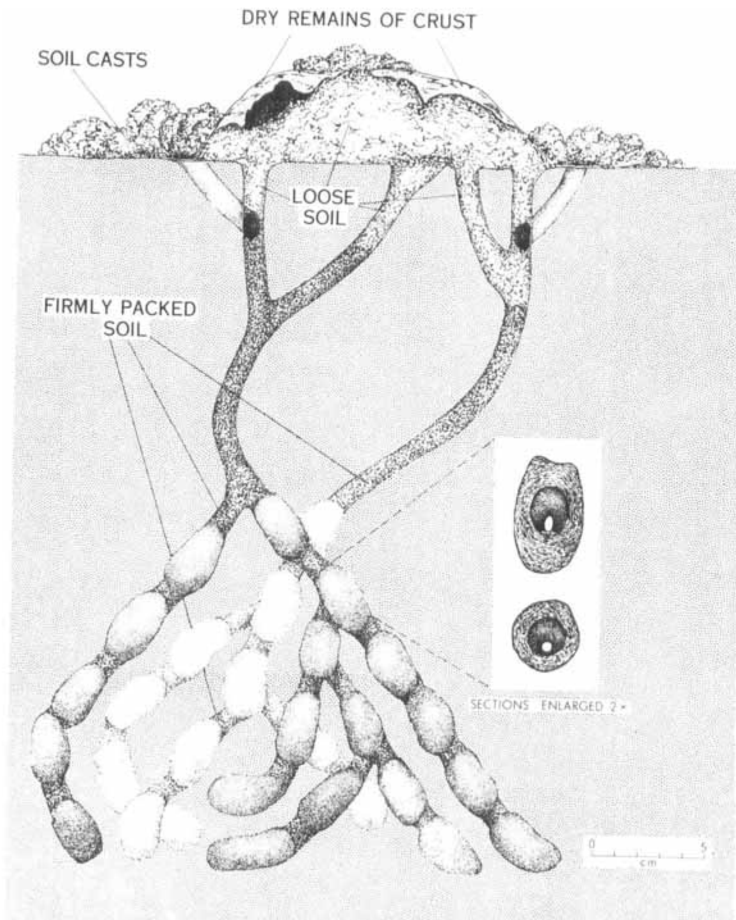

FIG. 1.—Vertical section of remains of a 200 c.c. dung pad, and the nest of one pair of ***Onthophagus gazella*** F. beneath it. Inset are enlarged vertical and cross sections of brood ball with egg *in situ* in cavity.

than on heavier soil types, and ignores pads in forested areas (Bornemissza, unpublished data).

At one site, on an irrigated pasture at Puako, South Kohala District of the island of Hawaii, *O. gazella* was so numerous that all pads, including those dropped 12 to 15 hours before the evening flight, were so heavily colonized that removal was complete within 40 to 48 hours. Pads dropped just prior to or during the flight were colonized even more heavily than the older ones, and were removed as early as 20 to 30 hours (Bornemissza, unpublished data).

The adult beetles ingest only the liquid or colloidal constituents of the dung, by 'lapping' them up with their highly specialized membranous mandibles. The larvae, however, ingest whole dung with their well developed biting-chewing mouth parts. Thus dung disposal is actually carried out by the adults when providing their larvae with food sufficient for their development.

The nest of *O. gazella* is of the *paracopric* type (Fig. 1), which is in the immediate vicinity of the dung pad and connected with it by tunnels (Bornemissza 1969). The beetles work in mated pairs, as typical of other *Onthophagus* species (Burmeister 1930, Bornemissza 1970), the female excavating the soil and building the brood balls from small pieces of dung that the male pushes into the opening of the shaft. In warm soil (25–30°C), *O. gazella* works extremely rapidly, and builds a brood ball about every two hours, providing each one with a single egg (Fig. 1). Each ball contains about 4–5 c.c. of dung material compressed into an ovoid shape of 2 c.c. size. Depending on the availability of dung, a single pair of beetles can construct up to 40 brood balls in one nest. In the field when beetle populations are high, the nests of each pair seldom contain more than 10 or 12 brood balls owing to the intense competition for dung. There may in fact be as many as 120 pairs of *O. gazella* in a 2,000 c.c. cow pad.

In view of the rapidity of the nesting, *O. gazella* ranks as a highly efficient, if not the most efficient paracoprid beetle known. It outperforms its very efficient European counterparts such as *O. vacca* L. and *O. taurus* Schreber, as observed by Burmeister (1930) in his laboratory studies in Germany, and by the author in field studies in southern Hungary (unpublished data).

Results

Exposure of dung with bushfly eggs

Beetles released into the buckets dug in quickly under the pad leaving small soil casts on the surface. As a rule, the volume of dung buried during the first six hour period was less than in later intervals (Figs. 2–4). The slow initial rate of dung disposal was probably due to time being occupied in feeding and, perhaps, mating, before nesting commenced. Once this was under way, progress in the disappearance of the dung was detectable at almost hourly intervals. At higher beetle densities, however, the rate of dung disappearance in the first six hours was comparable with that in later intervals.

As Figure 2 illustrates, dung disposal was so fast even at the lowest beetle density, that in almost all cases at least half of the dung was buried within 24 hours. In many samples, by then or even earlier, activity of bushfly larvae was discernible in the exposed parts of the pad where the *O. gazella* males were carving out pieces of dung. The increased movements of the maggots suggested disturbance by their unnaturally intensified concentration into the rapidly diminishing food supply. In samples subjected to high beetle density this became maximal 18 hours after the addition of beetles.

By the time the pad was reduced to a size of approximately 2 × 4 cm, few if any maggots were visible. The fate of the maggots is unknown, but in dung with low and medium beetle densities, the surviving bushfly larvae pupated prematurely in the soft soil casts thrown up by the beetles. In the high density treatment, the maggots were completely deprived of their food by the 24th hour and presumably died of starvation. Because of the rapidity of development and the low number of surviving larvae in the samples containing beetles, bushfly larvae were not observed in their wandering stage. In the controls, full-sized larvae were seen after 72–80 hours leaving the dung pads and crawling around for a few minutes before disappearing in the loose top soil.

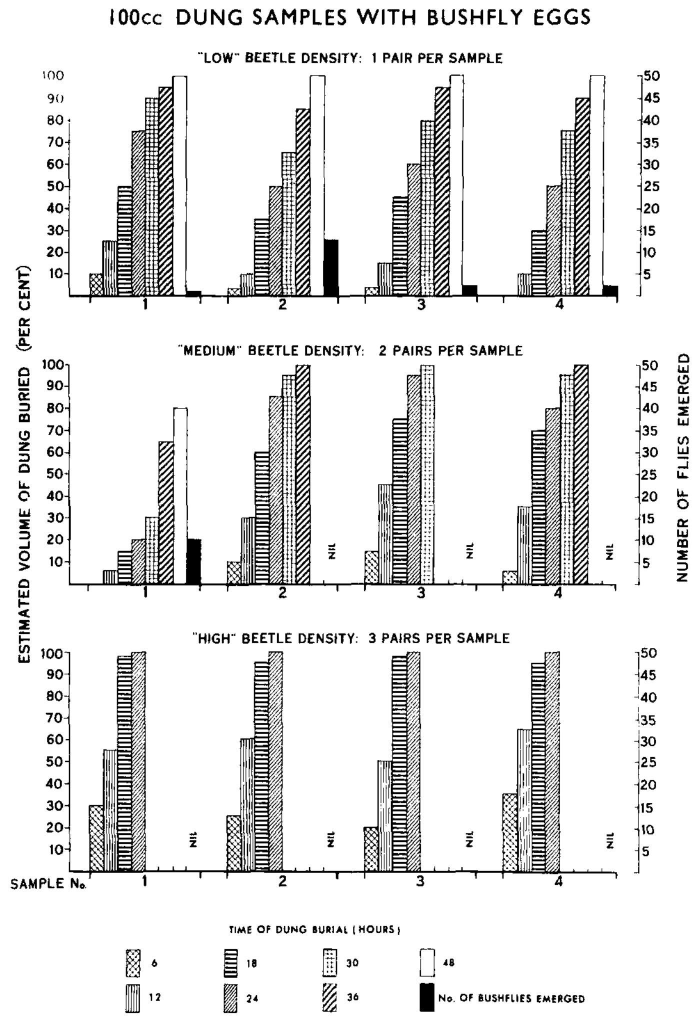

FIG. 2.—Estimated volume of dung removed by *Onthophagus gazella* F. in six hour periods after their introduction, and numbers of bushflies resulting from the eggs present when beetles were introduced. Flies from sample number 2 and 3 in 'low' beetle density and from 1 in 'medium' beetle density are shown in Plate II B–D respectively. For controls see data in Table 1.

Fly maggots were not found in the brood balls built by *O. gazella*. Accidental inclusion of fly eggs or small larvae in the fragments of dung taken underground cannot be ruled out, however, but it seems unlikely that any of them could have survived the processing of the dung in which the female beetle packs it down firmly, layer by layer, when converting it into a brood ball (see enlargement on Fig. 1). When the bushfly larvae run short of dung above the ground, they might follow the beetles down the shafts to their subterranean nests, but they would have only a remote chance of survival in the top part of the brood ball, or in its egg chamber. Should they manage to penetrate the brood balls, the survivors would have little chance of appearing at the surface as adult flies, for they would have to negotiate as callows through the firmly packed soil with which the beetles effectively seal off the access to each brood ball (Fig. 1). Beetles emerging from all treatments were of normal size and also number for the quantity of dung, so they had obviously faced no serious competition by the presence of bushfly maggots.

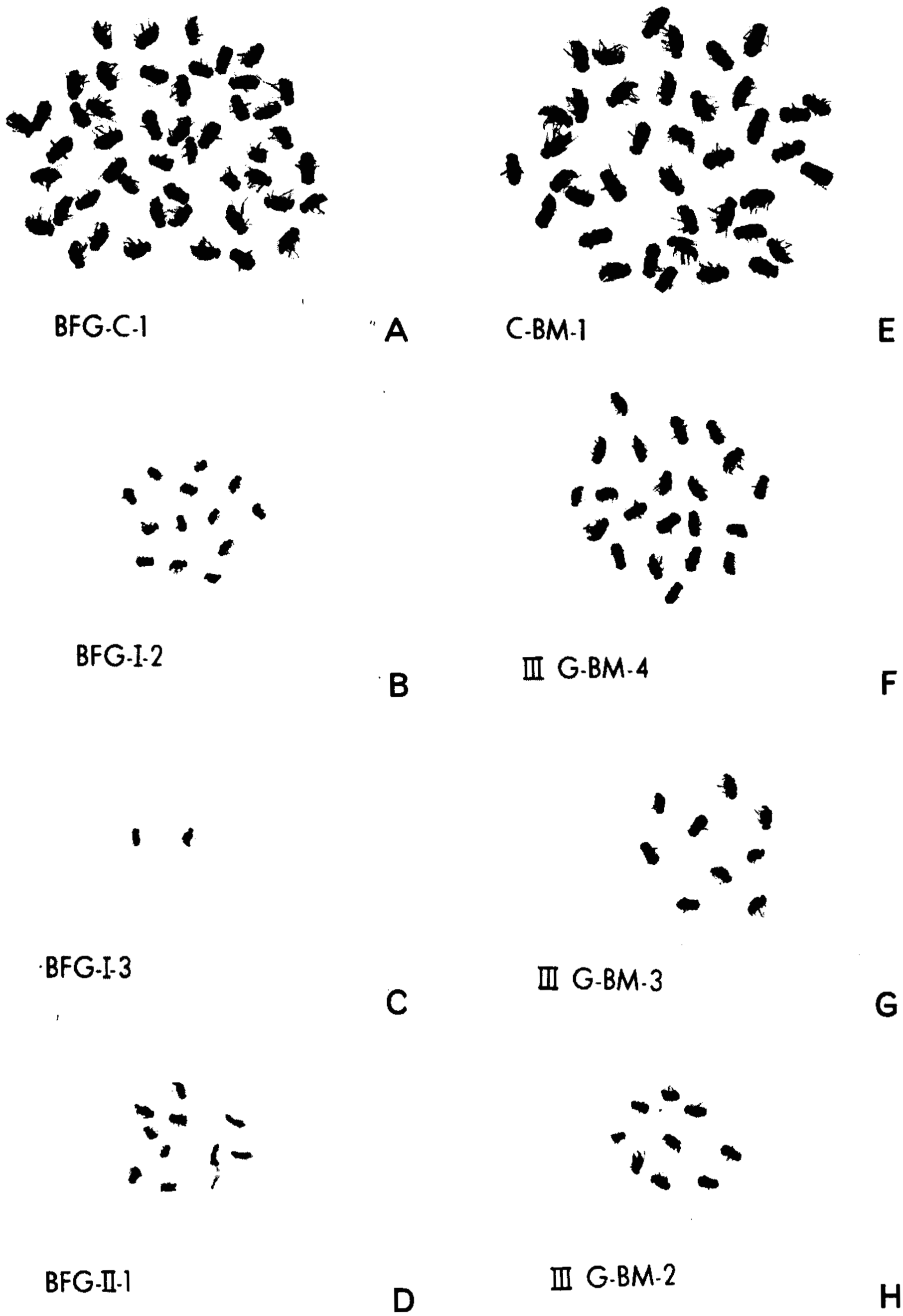

PLATE II

The photographs show the number and size of bushflies that emerged from 100 c.c. dung samples exposed during their egg stage to *Onthophagus gazella*. All pictures are reduced by half. See also legend to Figure 2.

A—Flies from a control sample devoid of dung beetles. B, C—Total fly production of two samples with only one pair of beetles present in each. D—The total emergence from a sample where 2 pairs of *O. gazella* were active. E-H—Total fly production from 100 c.c. dung samples which received 50 first instar bushfly larvae each. E shows the flies which emerged from a control sample as compared with those (F-H) which received 3 pairs of *O. gazella* each. See also legend to Figure 4.

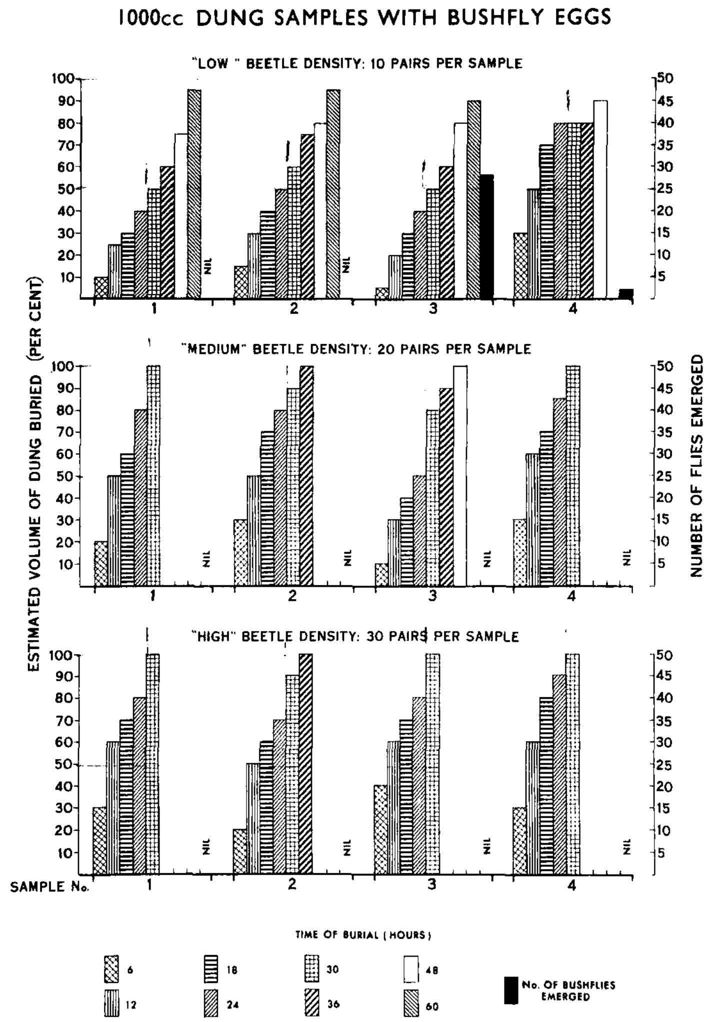

FIG. 3.—Estimated volume of dung removed by *Onthophagus gazella* F. in six hour periods after their introduction, and numbers of bushflies resulting from the eggs present when beetles were introduced. For controls see data in Table 1.

Flies that survived the activity of the beetles always emerged from the samples 24 to 30 hours earlier than those from the controls. As can be seen from Plate II B–D, the flies emerging from treated samples were substantially smaller than those emerging from the controls. In several instances stunting was so severe that the flies died soon after emergence, some even before they could expand their abdomens and wings. Several flies were also recovered which had died within the puparium.

Figures in Table 1 are consistent with the block diagrams of Figures 2 and 3 which illustrate the rate of dung burial. As can be seen from Figure 2, fast and regular dung disposal resulted in total fly mortality, if at least half the dung pad was buried within 24 hours and burial continued at the same rate. When burial was slower, some larvae managed to survive, but the emerging flies were invariably stunted.

TABLE 1

THE EFFECT OF THE ACTIVITY OF *Onthophagus gazella* AT VARIOUS POPULATION DENSITIES ON THE SURVIVAL OF BUSHFLY LARVAE

Data given are means for the number of flies that emerged.

10 Bushfly Females per 1000 c.c. Dung Pad			
Control	Number of Pairs of Beetles		
	10	20	30
90.7 (Range: 68-109)	7.5	Nil	Nil

5 Bushfly Females per 100 c.c. Dung Pad			
Control	Number of Pairs of Beetles		
	1	2	3
44 (Range: 27-51)	4.5	2.5	Nil

50 Bushfly Larvae per 100 c.c. Dung Pad			
Control	Number of Pairs of Beetles		
	1	2	3
39.5 (Range: 37-41)	22.5	11.8	8

Exposure of dung with bushfly larvae

In this experiment known numbers of fly larvae were employed, and it simulated to some extent the field situation in which colonization of the cow pad by dung beetles is delayed.

The advantage conferred on the larvae by being in the dung pad 12-15 hours earlier than the beetles, was reflected by the emergence of flies being significantly higher than in the former series (Fig. 4, Table 1). Nevertheless, the consistently lower emergences than in the controls and the stunting of the resulting adults, indicated quite clearly that the process of dung burial was detrimental to the bushfly (Plate II E–H).

DISCUSSION

The experiments described in this study were designed to establish parameters for rate of dung disposal and to measure the potential of an efficient bovine dung beetle in fly control. The geographical overlap between the tropical-subtropical *O. gazella* and the largely temperate zone fly pest, *M. vetustissima* used in these experiments will probably be marginal in Australia. The study has, nevertheless, achieved its aim of securing data that can be used as a standard to measure dung beetle efficiency in relation to fly control. The degree of control recorded in these experiments should be directly applicable to the buffalo fly *Haematobia exigua* in northern Australia where *O. gazella* has recently become established (Bornemissza

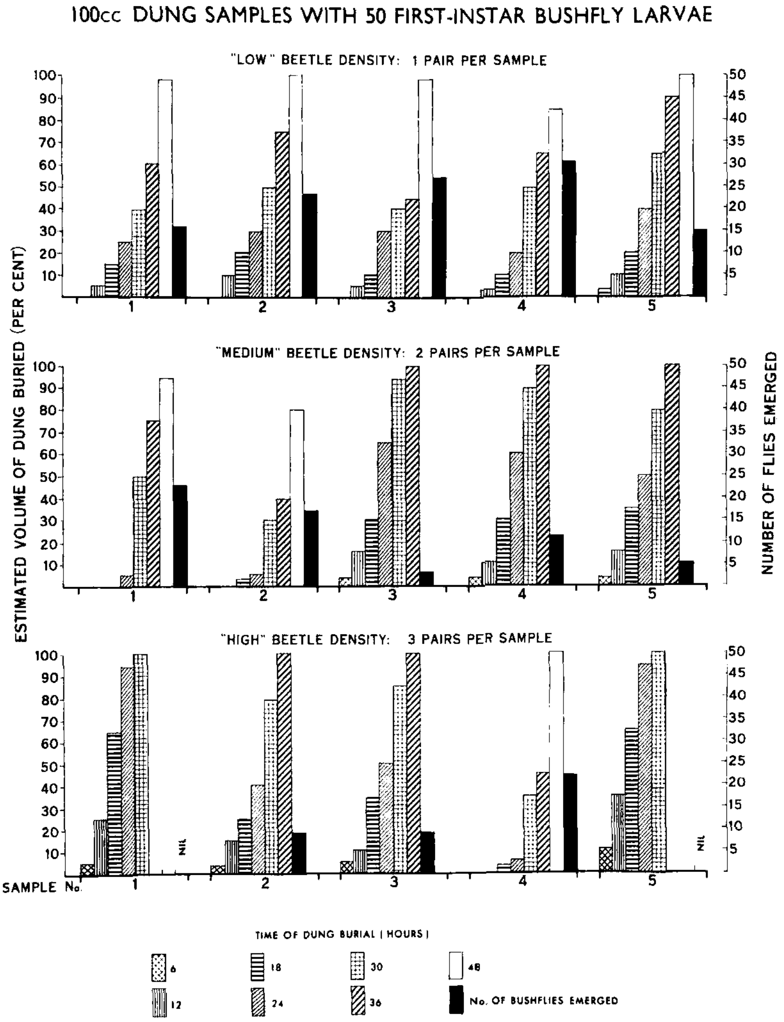

FIG. 4.—Estimated volume of dung buried by *Onthophagus gazella* F. in six hour periods after their introduction, and numbers of bushflies emerging from the larvae present when beetles were introduced. Flies from 2, 3 and 4 in 'high' beetle density are shown in Plate II F–H respectively. For controls see data in Table 1.

and Ferrar, unpublished data), since the buffalo fly has a life history very similar to that of the bushfly.

The present inquiry has highlighted three possible situations that can occur in the field. First of all, when no dung beetles are active, or those present are inefficient in the burial of cow dung, fly production of cow pads will be more or less comparable with that recorded in the controls, as these approximate the current conditions in most parts of Australia. Secondly, when the activity of the endemic or the introduced species is too slow, or they are hampered by adverse seasonal conditions, the situations could be similar to that observed in the larval series (Fig. 4, Plate II). Finally, when the introduced species realize their full potential, it is expected that results should be comparable with the experiments in which the beetles had access to the pads with only fly eggs present (Figs. 2, 3; Plate II).

The number of flies that emerged from pads varied with the rate of dung burial, which in turn is a reflection of beetle density. In all experiments the flies surviving in pads attacked by beetles were stunted. This results in reduced reproductive capacity as shown by Tyndale-Biscoe and Hughes (1969), who found fewer ovarioles

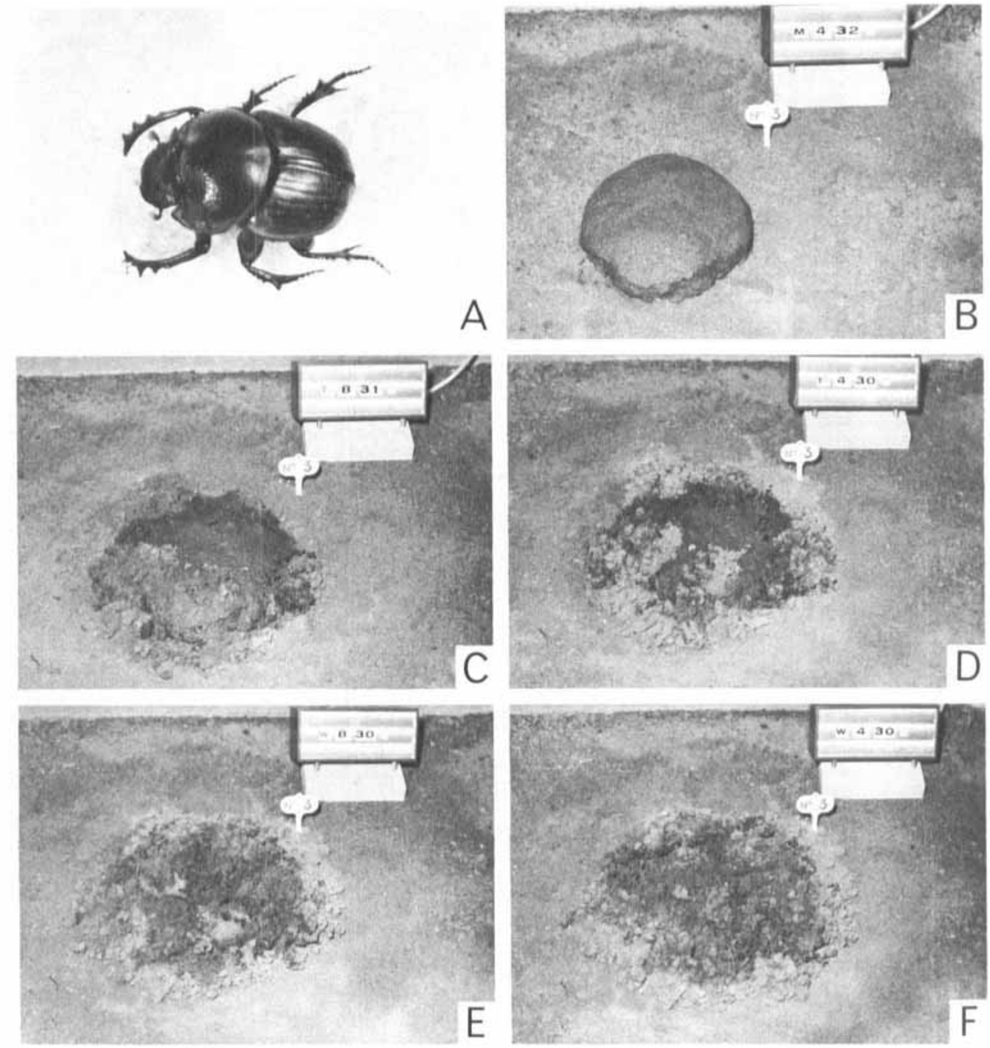

PLATE III
A—*Onthophagus gazella* F., male, × 2 enlarged.
B-F—Progress in the burial of a 1000 c.c. cow pad by 30 pairs of *O. gazella*. The beetles were released immediately after photograph (B) was taken at 16.30 hr and the succeeding photographs were taken at 8.30 and 16.30 hr on the following 2 days (see clock). By the 40th hr (E), 95 per cent. of the pad was buried. At this rate of dung burial, muscid larvae would not have survived.

in the bushflies derived from under-nourished and under-sized larvae. Thus, beetle activity affects the vital larval requisites: the quality and quantity of their food supply, currently the most critical factor in the regulation of bushfly densities in Australia (Hughes and Walker 1970).

In the next few years the CSIRO Division of Entomology plans to introduce to Australia many species of African dung beetles selected to obtain a well balanced complex of co-adapted species which will have specific adaptations to climatic, edaphic and botanic factors. Care will also be taken to ensure that this selection will include species with various nesting and diel flight habits, to ensure the rapid colonization of cow pads dropped any time during the day or night. In addition to dung beetles, some reliance will also be placed on maggot predators such as histerids, which seem to be less dependent than the coprids on soil moisture in dry periods (Bornemissza 1968).

It would be unrealistic to speak of 'total' control, for this would involve the actual extermination of the target species. The majority of coprids are excellent fliers and are very efficient in their food detection. Even so, a few pads, if for no other reason than the vagaries of weather, would be either missed or insufficiently exploited by the beetles, and so would give rise to enough flies to ensure the survival of the species. From the results presented in this study, and past experience in the laboratory and the field, it seems likely that both the bushfly and the buffalo fly could be greatly reduced in status in Australia within the foreseeable future.

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