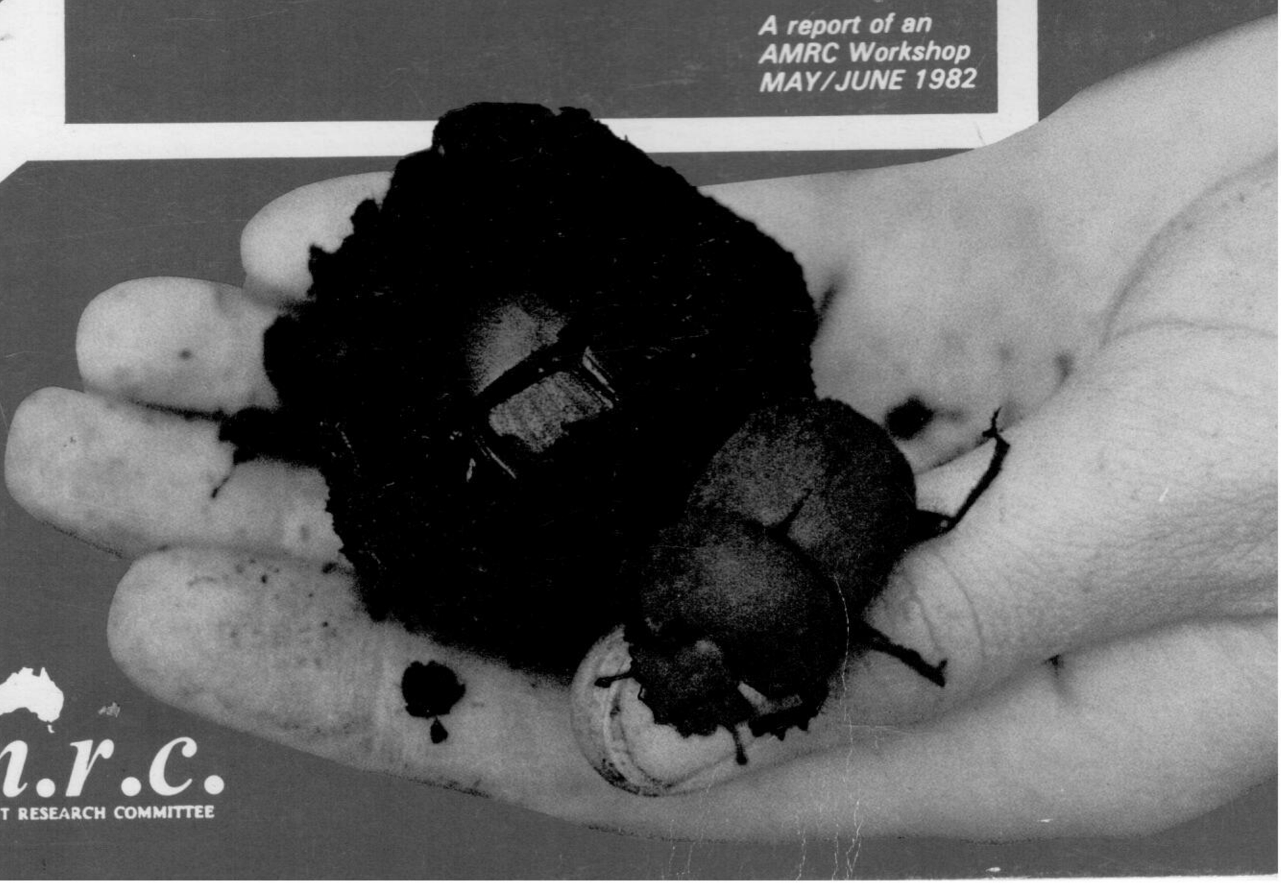
THE BIOLOGICAL CONTROL OF DUNG IN AUSTRALIA

A report of an AMRC Workshop MAY/JUNE 1982



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AUSTRALIAN MEAT RESEARCH COMMITTEE

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BIOLOGICAL CONTROL OF DUNG

A REPORT OF AN A.M.R.C. WORKSHOP

HELD AT CANBERRA MAY 26TH TO JUNE 4TH, 1982

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I. INTRODUCTION

The decision by the Australian Meat Research Committee to fund a research programme on the 'Biological Control of Dung' was based largely upon the potential benefit of achieving reductions in the abundance of the dung-breeding buffalo fly, Haematobia irritans exigua and the bush fly, Musca vetustissima. It was acknowledged also that any increase in the rate of dispersal and burial of dung would yield benefits in terms of nutrients, soil structure, run-off and pasture contamination. An additional reason for supporting this research was the fact that the lesions caused by the buffalo fly would provide ideal sites for oviposition by the screw-worm fly should that pest ever become established in Australia.

As a consequence, A.M.R.C. has supported the program since 1964, expending $3.4M. up to June 30th 1981 and allocating a further $504,000 in 1982/83.

The program has two broad aims:

1. The removal of dung from the surface of pastures to increase nutrient recycling and decrease pasture contamination; and

2. To determine the major factors influencing the abundance of buffalo fly and bush fly with the objective of reducing adult population of both species by biological or other means.

The possibility of using dung beetles to destroy the breeding sites of the horn fly, a close relative of the buffalo fly, was first proposed in the early 1900's and implemented in Hawaii in 1923. However, the effectiveness of the dung beetles remained largely unexamined until Bornemissza (1976) carried out exclusion experiments showing that the beetles reduced horn fly emergence by about 95%.

In similar fashion the effects of introduced dung beetles on the survival of the Australian bush fly in dung pads has been measured in laboratory and field experiments with conclusive results: in general, bush fly survival decreases with increasing numbers of dung beetle (Hughes et al 1978, Ridsdill Smith 1981, Wallace & Tyndale-Biscoe 1982). However, it has not been possible to demonstrate any significant reduction on the actual abundance of adult bush fly in the field except for an isolated instance at Narrabri in the 1975-76 season when an unusually low level of bush fly abundance was associated with massive activity by the introduced dung beetles Euoniticellus intermedius (Reiche), and E. africanus (Harold). Clearly large-scale movement of bush flies may sometimes obscure regional differences caused by the activities of dung beetles and other dung-inhabiting fauna including predacious beetles and mites.

The diverse nature of the project, both in terms of geography and scientific endeavour, makes it essential that communication between researchers and industry be as free and spontaneous as possible, bearing in mind the cost. For this reason, AMRC holds regular workshops to review progress, to identify specific gaps in our knowledge and, on the basis of new knowledge, to assist CSIRO in re-directing its research into areas of greatest potential benefit with respect to achieving practical results.

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IV. PAPERS OF THE FORMAL SEMINAR

AN OVERVIEW OF THE AIMS AND ACHIEVEMENTS

OF THE

AUSTRALIAN DUNG BEETLE PROGRAMME

by

M.M.H. Wallace

The purpose of this introductory talk is to give a broad outline of the dung beetle programme so that the individual contributions which follow over the next two days may be better appreciated and understood within the total dung beetle project.

Firstly, let me re-cap on the broad aims of the programme as outlined by George Bornemissza in his publication of 1960 entitled "Could dung eating insects improve our pastures?". In that publication he outlined the likely benefits of the introduction of dung beetles into Australia as (1) the rapid incorporation of dung into the soil, with a resulting retention of volatile nitrogenous constituents and a contribution to soil structure, (2) a reduction in susceptibility to cattle and sheep of parasitic worms and (3) a reduction in breeding habitats for dung breeding flies such as the bush fly and buffalo fly.

All of these aims are now incorporated in the single title by which he programme has become known viz. "The biological control of dung".

The development of the programme was based essentially on two broad reservations and assumptions.

(a) that Australian dung beetles were essentially adapted to marsupial pelleted dung and were mostly unsuccessful in large dung pads (cow, horse, etc.);

(b) that the apparent absence or lower density level of dung-breeding flies in Africa was due principally to the rapid dispersal of dung there by dung beetles with some assistance from predatory beetles.

I think it would be useful here to examine briefly the achievements of the programme as they relate to these two assumptions.

Firstly then the observation that Australian dung beetles were adapted to marsupial pelleted dung and were mostly unsuccessful in large cow dung pads.

That observation has been shown to be essentially true although it is now known that many species of native dung beetles are attracted to and can breed successfully in cattle dung.

No doubt the adaptation of many of the beetles to marsupial pellets is one good reason why they have not transferred their activities to the dung of the larger herbivores. However, perhaps, an even more important reason has been the inability of the beetles to tolerate the change from the forest and woodland habitat to the open pasture habitat. Studies throughout the world have illustrated how closely linked many beetles are to a particular habitat, and we will be hearing more about that later from the South African scene.

Despite the successful transfer to the pasture habitat of a number of Australian species, there is no doubt that, taking Australia as a whole, there is by no means adequate dispersal of cattle dung pads by the native beetles. Nevertheless, there are areas where very large quantities of dung are regularly dispersed every year.

In a large part of south-eastern Australia there are several species of beetles which must be classified as very effective dung dispersers and/or buriers. Top of the list would come Onthophagus granulatus (up to about 8000 have been recorded in one pad). This beetle is helped in many situations by O. australis. Species with more limited distribution would include O. pentacanthus and O. mniszechi, and there are a number of others.

Their total impact is substantial but limited by intrinsic activity patterns, weather, soil type, vegetation cover and so on.

In south-western Australia there is really only one native Australian dung beetle, O. ferox, which has any significant impact on dispersal of cattle pads. Similarly, in northern Australia probably the only effective species is O. consentaneus and that may well be an accidental introduction from countries to the north.

As far as I am aware there has been only one study done in which measurements were made of the amount of dung removed by native beetles. That is described in the paper by Hughes (1975) working in south-eastern Australia and specifically at Canberra, Jugiong and Bombala, areas where native dung beetles are possibly more active than anywhere else in Australia. He concluded that "the droppings of cattle are utilised extensively by dung beetles native to the southern highlands of Australia, and in spring and autumn these insects (particularly O. granulatus) bury or disturb a significant proportion of the dung." He estimated that at the Canberra site, for five weeks in spring, an average of 78% of the dung was buried. At other times of the year, between beetle generations, much lower levels of burial and disturbance were observed.

Obviously the Australian dung beetles need some help. I am glad to say they are now getting a great deal of it.

What, then, are our achievements?

To date, some 52 species of dung beetles from overseas have been introduced into Australia. Of these, 40 were successfully bred in the insectaries and subsequently released in the field, and of those 40, 21 are now known to be established. Of the 18 still to be recovered, five were released 10 or more years ago and seem unlikely to be recovered now; and six have been released within the last three years and should be recovered in the near future.

So far, the north of the continent is much better catered for than the south. Of the 21 established beetles, 16 are basically northern species (i.e. adapted to summer rainfall patterns) and only 5 are southern or winter rainfall species. However, two of the northern species are able to penetrate into some of the southern regions specially where summer moisture is available either through natural soakage or through artificial irrigation.

General observations throughout Australia and actual measurements by Gus Macqueen at Rockhampton have shown clearly that enormous quantities of dung are now being either buried or dispersed by the introduced beetles.

The most spectacular areas would cover most of northern Australia, including northern NSW and northern SA but also particular areas of south western Australia and coastal NSW.

Thus the beetle introduction programme has already been an outstanding success and the amount of dung buried and the number of areas in which that takes place will increase as more species become established.

However, it must not be thought that massive dung dispersal will occur every year at the same level. There are indications that in northern Australia, soon after the introduced beetles (mainly O. gazella and E. intermedius) became established over most of the area around 1974/75, they were particularly abundant during the subsequent 3-4 years of above average rainfall, but became quite scarce during the following 2-3 dry years. Similar variations in abundance from site to site are known to occur even in southern Africa or Europe whence the beetles came.

There will always be a gap in winter and no doubt spatial and temporal variations in dispersal will occur throughout the period of major beetle activity.

Gus Macqueen, Bernard Doube and James Ridsdill-Smith will all be discussing these aspects of the programme for their respective areas of study.

Another question relating to dung burial and disturbance is its influence on soil fertility and pasture productivity. Some attempts to determine these effects have been made. However, experimental work has been limited to pot or plot experiments and anybody who has attempted to extrapolate from such experiments to the broad-acre farm or grazing situation will tell you how difficult or even impossible it is to do that. Probably all that can be said at this stage is that some benefit is likely, depending largely on cattle density.

Obviously dung dispersal is needed specially where cattle density is high for example in the dairy situation. Excellent dung dispersal has been achieved in some of those areas in WA by O. binodis, but indications elsewhere seem to suggest that such areas are, in fact, the most difficult places in which to achieve good beetle activity. That is a question receiving attention at the present time and it may be that particular species of beetles are needed in those situations. In fact O. nigriventris, from the Kikuyu grass areas of Kenya, and which is now doing an excellent job on Norfolk Island, seems as if it may fill that niche very satisfactorily at least in some areas.

It is now clear that we must learn about activity patterns and behaviour in much greater detail in order to be able to select beetles for the more specific time and space niches yet to be filled.

Underlying all these factors is, of course, the overriding importance of climate in determining the distributions of the beetles. I won't go into that here but Keith Houston will be describing some of his findings later. Amongst the many criteria used in selecting beetles climate remains, as always, the first to be considered.

One problem that presents itself when one begins dealing with beetles with highly specialised activity patterns is that of insectary breeding. These beetles often have distinct developmental or reproductive dormancy periods incorporated into their life-cycles and it is not easy to manipulate those periods in the insectary. This has meant in the past that some beetle species, both from Africa and from Europe, have never emerged from the breeding rooms in Pretoria or, having successfully produced eggs there, have not completed their life-cycles in the Canberra quarantine rooms. Those problems are slowly being overcome and some of the methods will be described by Penny Edwards, Hartmut Aschenborn and Marina Tyndale-Biscoe in their papers later today.

So much then for the first aim of the programme. A highly successful venture by any standards.

I come now to the second part of the programme and that is in relation to control of dung breeding flies and in particular the bush fly and the buffalo fly. Not, I might add, including the blow flies, which are all too often mentioned in radio and T.V. programmes about the dung beetle project.

There are two aspects of fly control that need to be mentioned. Firstly, the control of fly breeding in the dung pad and secondly the abundance of the adult flies in the field. Unfortunately, the relationship between the two seems far from a simple one.

As far as breeding of the bush fly in the dung pad is concerned there is now ample experimental evidence that dung beetles are capable of achieving very substantial control even to the extent of total mortality if the numbers of beetles reach a certain level. That precise level depends upon the species of beetle concerned, as well as on many other factors, but broadly the larger the beetle the lower the numbers needed to achieve an equivalent level of control.

Dung beetles seem also capable of a certain level of control of buffalo fly breeding in the dung pad but for the same beetle density the control achieved is considerably less than that achieved against the bush fly. Whereas in the bush fly, control can be directly related to beetle numbers infesting the pad, no such clear relationship has been demonstrated for the buffalo fly.

One of the chief reasons for the observed differences in response of the two fly species to beetle infestation is the susceptibility of the eggs of the flies to inundation in dung fluid. Experiments at Rockhampton and in Canberra have shown that the eggs of the bush fly are considerably more susceptible than those of the buffalo fly, although the very young eggs (less than a hour or two old) of both flies may be killed by early inundation.

It appears likely that control of the buffalo fly in the dung pad will be brought about more by desiccation than by inundation of the eggs and to achieve complete desiccation of the dung pad requires a high level of beetle activity.

Turning to the field, what then has been the result of the very considerable beetle activity and dung dispersal now observable in different parts of the country.

As far as the bush fly is concerned, there has, over recent years, been a good deal of circumstantial evidence that dung beetle activity has, in fact, resulted in a lower abundance of flies in the field. For example, for some years after O. gazella and E. intermedius became established and widely dispersed in northern Australia, we received reports of a marked reduction in bush flies. That was from about 1975 and for the subsequent 3-4 years. Reports then began to come in that the flies had returned to those areas and were once again in great abundance. At the same time dung beetle activity was much reduced. The years 1974-1977 were, in fact, exceptionally wet years in much of the north and the following years were very dry. Department of Agriculture personnel then advised that those sorts of fluctuations in fly abundance were regularly experienced during periods of high and low rainfall, with high rainfall reducing numbers of flies and low rainfall favouring the build up of numbers.

Dick Hughes had indeed shown experimentally that rainfall had a marked effect on survival of the immature stages of the bush fly in the dung pad and recent studies at Uriarra seem to indicate that those effects may be carried over to the adult fly population in the field. Thus the rainfall that enhances dung beetle activity at the same time directly affects the breeding of the fly in the dung pad. That is one reason why in the wetter areas of the Northern Territory or of the north-eastern coast of Queensland the bush fly is never a problem and rarely reaches high numbers.

Unfortunately no systematic sampling of fly abundance has been done in those northern areas so that it is not possible, at this stage, to say exactly what has been happening during the period in question. The individual contributions of rainfall and dung beetles cannot be separated easily.

The only site where regular bush fly sampling has been undertaken is here in Canberra at Uriarra where eleven years of weekly samplings are now available. More recently regular monitoring has begun in south western W.A., at Alice Springs and at several sites in NSW.

At Uriarra, despite massive dung beetle activity (by O. granulatus) during one of those years, viz. 1976/77, there was no detectable influence on bush fly numbers. There may be good reasons for this, of course, and one of these, to be described in more detail by James Ridsdill-Smith and John Matthiessen, is the probable poor timing of beetle activity in relation to fly breeding cycles. The major burst of beetle activity in fact occurred too late in the season to be able to influence fly breeding when it was at its peak. Perhaps this can be rectified by the further introduction of beetles selected specially for this early spring activity.

Another possible reason for the apparent lack of substantial effect of beetle activity on fly abundance may be that there is already in the dung pad a very high level of mortality of flies brought about by the combined effect of all the existing, mostly native, fauna occupying the pad. In fact, we know that mortalities are already very high (90%).

In the face of all these interacting biological control agents it may be very difficult to insert an additional agent which will add significantly to that mortality. What may well happen is that the newly inserted organism may simply substitute its mortality for a mortality already present with little or no change in the overall survival of the fly. That probability is being studied here in Canberra and some early results will be described by Marina Tyndale-Biscoe.

Another complicating factor is illustrated by the observation that even at times of massive dung beetle activity when a very high proportion of the dung pads of an area are completly dispersed, or at times when dung quality is so poor that it could not support any fly breeding, there are still many flies to be caught in that area.

Recent studies now show that individual dung pads, even from a single herd of cattle, may vary enormously in quality for fly breeding. In addition, the site where the pad is dropped may determine very largely the fauna that is attracted to it. Thus neither the pads themselves, nor the fauna of those pads, are evenly distributed in space and it is quite likely that the flies are highly selective in choosing the pads most favourable for their breeding. This may enable them to circumvent the activities of some of the mortality agents.

It is clear then that control of bush fly abundance though an influence on their breeding success in dung pads is a far more complex operation that was at first thought.

Perhaps in Western Australia we have a better chance of improving the fly situation than in eastern Australia. In the west the flies are on average more abundant than they are in the east. The consistently dry summers of the west no doubt contribute largely to that situation. In the west the existing dung fauna is simpler than it is in eastern Australia (few native dung beetles and no effective predatory mite) so that it may be possible to increase mortality there by inserting new agents into the system.

We plan, therefore, to make a special effort to build up the dung beetle complex in south Western Australia but at the same time we will continue to introduce new beetles into south eastern Australia.

Much of northern Australia also has a relatively more simple fauna and that may allow the dung beetles to achieve additional control there as has already been reported.

A moment ago I mentioned the predatory mites for the first time and I think here may be an appropriate point to say something about them. They now, after all, occupy a substantial part of our overall effort.

The mites are, in fact, very effective predators upon fly eggs and larvae in the dung pad as shown by many field and laboratory experiments. They are almost totally reliant on dung beetles for transportation.

One effective species already occurs in south eastern Australia, either as a native species or as an accidentally introduced European species at some time in the past. Experiments have shown that that mite is a major contributor to overall fly mortality in the dung pad and is very important at times of relatively low beetle numbers. Such a mite does not occur in south west Western Australia or in South Australia and we are looking into the possibility of introducing a species for those regions. Bruce Halliday has been working on this taxonomically difficult group of mites in the USA for the past year and will tell you more about them tomorrow.

In relation to the Western Australian scene, there is a point which will need to be decided in the near future, and that is whether to introduce a predatory mite now or whether to delay it until such time as we have information on the influence of the dung beetles themselves on fly abundance. If we introduce the mite now and there is a measurable reduction in the fly numbers in the near future we will never know whether that result was achieved by the dung beetles alone or only after they were helped by the mites.

Some may ask "Does it matter if we don't know the answer to that question?"

Personally I think it does matter, because it is the only place left in Australia where the dung beetle influence per se can now be measured.

I should like now to dwell briefly on the buffalo fly and relate this back to the second observation or assumption noted at the beginning of my talk.

You will remember that the observation was that the buffalo fly is a relatively scarce and unimportant fly in South Africa and the assumption was that this was due principally to the destruction of the dung pads there by dung beetles.

The group in Pretoria has now been looking into this situation specially in the eastern low veld areas and in particular in Hluhluwe Game Park. Highlights of this work will be given by Bernard Doube and Harry Fay tomorrow. For my purposes this morning I will simply relate one or two pertinent facts.

The first is the discovery that the buffalo fly in the Game Park is, in fact, an abundant fly on the buffalo herds there. It is not scarce in that environment. The second is that the fly is indeed scarce and unimportant on domestic cattle outside the Game reserve.

Now it is known that the dung fauna in the woodland and forest of the Game Reserve is generally more abundant both in species and in individuals than in open grassland areas. Similarly, it is clear that species' abundance at least is much lower outside the Park in the open farming areas. It is difficult then to sustain the view that it is the dung beetle fauna of the farmland that is responsible for the low numbers of flies there. Unless, of course, fewer species can achieve more for fly control than many competing species.

There must be other reasons for the lack of flies on domestic cattle and those reasons need to be closely examined. Perhaps the buffalo fly in South Africa in indeed just that - a buffalo fly, with little or no adaptation to domestic cattle. Perhaps the intensive tick dipping procedures carried out in the area are partly responsible for the low fly numbers. Perhaps other management practices are important. Whatever the reason we obviously cannot assume that it is solely due to dung destruction.

Coming back to Australia and the work to be described by Gus Macqueen, we find that despite the establishment now of six species of dung beetles in the Rockhampton area over the past 6-7 years, accompanied by extensive dung dispersal, there has been no sustained reduction in buffalo fly numbers as measured on the Craighoyle herd. In fact fly numbers have actually increased during that period.

That is an observation which we cannot ignore and we must now examine the situation carefully to try and find the reasons.

Rob Sutherst will indicate tomorrow that subtle climate change may have played a part, at least in the southern movement of the buffalo fly, into NSW, if not also in its apparent increase in numbers.

Changes in tick dipping procedures and chemicals could conceivably have been responsible although there are differences of opinion on that score and that situation is not at all clear.

A somewhat unpalatable possibility which must be examined, is that the dung beetle itself has in fact made a contribution to an increase in fly abundance.

Whilst this seems improbable it needs to be examined closely specially in the light of some recent observations e.g. (1) that some buffalo flies may breed and emerge from dung that is either buried or carried away by dung beetles and (2) an American experiment showing that the activities of some dung beetles (in this case O. gazella) may adversely affect the performance of some predatory beetles (in this case Staphylinidae).

We know that the predatory fauna at Rockhampton plays a very significant role in the mortality of the buffalo fly in the dung pad, so that any interference with its influence needs to be examined and understood.

Recently a new predator, the mite M. peregrinus, was introduced into the north. That mite is a proven performer in fly control in the dung pad. It is now thoroughly established, widespread and abundant, but so far it is not possible to determine whether it has had any influence on fly numbers on the Craighoyle herd of cattle. However, more time is needed to sort that question out.

Once again then it is clear that, as in the case of the bush fly, control of the numbers of adult buffalo flies on the cattle through interference with their breeding in the dung pad is no simple operation. We are again dealing with a situation in which there is a very high level of mortality already existing in dung pads (up to 99 or even 100%), and it may be quite difficult to insert new agents of mortality that will be additive rather than substitutional.

Like all complex ecological situations where there are large assemblages of interacting organisms, the addition of a new organism is not likely to affect only the single target organisms we are interested in (in our case, bush fly or buffalo fly) but all the other organisms present. We understand that situation and must now study it in detail so that we select for introduction only those organisms which have the greatest chance of benefiting out programme.

My purpose in presenting this paper has been to leave you with some sort of impression in your mind of what the dung beetle programme is all about. I hope I have succeeded and I also hope you will agree with me that it has now some considerable achievements to its credit.

It also clearly has some major challenges to face up to. I believe within our group we have not only the expertise necessary but also the enormous enthusiasm of dedicated scientists and support staff to meet those challenges.

SUMMARY

1. Description of research progress in Australia

Australia has 250 species of native dung beetles and 21 introduced ones that have become established. The activities of these beetles results in the dispersal and burial of large quantities of dung each year.

Initially, it was thought that Australian dung beetles were essentially adapted to marsupial pelleted dung and were less attracted to large dung pads of cattle. This adaptation to marsupial dung by Australian dung beetles has been shown to be largely true, although a few species of the genus Onthophagus have a substantial impact on cattle dung under favourable conditions of weather, soil type and vegetation cover. The limited nature of the native beetle activity has been described for one area in the Southern Highlands where 78 per cent of dung was disturbed for a period of 5 weeks with activity being on a low level at other times of the year. Such gaps in the process of dung dispersal allows ample time for pest flies to breed and thus maintain their populations.

In contrast, the activities of the 16 introduced beetles that are established in Northern Australia have been clearly shown to result in rapid dispersal of large amounts of dung. There are seasonal and species variations in the activities of the introduced beetles with dry years substantially reducing their numbers and hence activity. Similar variation in abundance from site to site and season to season has been recorded in Africa and Europe.

Selection of beetles for importation to Australia requires an understanding of how climate, vegetation and soil type determine their distribution and dung dispersal activities. Work has therefore been continuing in Africa, Europe and Australia on the biology of beetles. The detail to which it will be necessary to investigate any one beetle species/environment relationship will vary and be largely a matter of judgement.

2. <u>Examination of the effectiveness of beetle and mite introductions in the reduction of pest fly population</u>

A. <u>Buffalo Fly</u>

There is adequate direct experimental evidence to demonstrate that dung beetles can control buffalo fly breeding in the dung pad to continue the project. Such evidence is based on laboratory and field experiments in Australia and South Africa. It seems that the buffalo fly eggs are more resistant to inundation in dung fluid than bush fly eggs and their tougher outer coats protect them from the predatory activities of the phoretic mites. However, buffalo fly larvae are successfully attacked by phoretic mites. Buffalo fly control in the dung pad is more likely to occur through dessication and as such requires a high level of beetle activity to produce shredding rather than burial of the pad.

At Rockhampton, Hluhluwe and Moloto difficulty is being experienced in relating the numbers of beetles and their activities to the abundance of buffalo flies in the field, an inverse relationship that subjectively appeared very well founded in the early years of this project. The development of an accurate means to determine the size of buffalo fly populations means that additional information on fluctuations will be possible.

B. <u>Bush Fly</u>

There is now ample evidence to show that dung beetles and predatory phoretic mites can achieve substantial reduction in the survival of bush flies in dung. However, there has been no consistent or widespread reduction in bush fly numbers throughout Australia and it must be concluded that the activities of the introduced fauna are not yet sufficient to reduce survival in dung to a level that prevents bush fly increase, especially in spring when weather and dung quality are so favourable. In future, the research will concentrate on searching for dung beetles and other beneficial dung fauna (including predators) that are active during the period of rapid bush fly increase in spring.

3. Description of research progress in South Africa

The work in South Africa is studying the factors that control dung breeding pest flies especially, the impact of dung fauna. The field biology of selected species is examined in sufficient detail to assess its potential for pest fly control before attempting transplantation of the beetle to Australia. Next the life cycle of the beetle or mite needs to be understood so that breeding can be undertaken in the laboratory.

In order to satisfy the demands of the above, a large number of field surveys have been conducted. Initially, such surveys were to describe the dung fauna and in particular the dung beetles. Earlier, it was possible to select dung beetles that by their widespread distribution appeared to be able to cope with variable environmental conditions. Subsequently, it became apparent that the dung fauna/environment/pest fly interactions were much more complex and field surveys and experiments have had to become more definitive in their objectives.

Dung beetle distribution has been shown to be a function of climate, soil type, vegetation, dung type, weather and seasonal biology, in order of decreasing dominance. Some beetle species are very specific to one environment while others are ubiquitous. The outcome of these diverse habits is a dung beetle fauna whose members occupy a wide diversity of complementary niches. In each locality it seems likely that a small number of dung beetle species will constitute the majority of individuals within a community, the structure of which is largely determined by competition between species in environments where beetles are abundant and by their ability to reproduce successfully where beetles are scarce.

The present programme in Africa is aimed at describing the abundance of dung beetles in a community as a function of the interaction of the fecundity of the adults, their ability to compete for dung and survival of the immatures. Superimposed upon the above programme and the single criterion by which the relevance of information is judged is the impact that dung fauna or other physical factors have on dung breeding pest fly populations.

Consequently, some research effort has been devoted to studies on the interactions between Haematobia and other fauna of bovine dung at both Hluhluwe Game Reserve and Moloto. Results so far have confirmed the correctness of the early assumption that populations of dung breeding pest flies are controlled by biological means but that other dung fauna besides dung beetles and their mites may be important.

Complementary and essential to the whole programme is the study of dung beetle and mite biology. Such studies have been proceeding at two different but inter-related levels. The first is the field study of the selected dung beetles' life cycles followed by empirical attempts to breed them in the mass rearing unit for the production of eggs for shipment to Australia. The second is a detailed in depth study of the factors controlling the progression of the life cycle to establish overall principles that can be used for many species.

CONCLUSIONS

1. It is clear from the results obtained so far that the original idea to reduce dung contamination of the environment using dung beetles and other dung fauna and hence bush and buffalo fly populations is sound. However, the same results now indicate that the task of dung dispersal and reduction of pest fly populations is much more complex than was originally conceived in 1964.

2. Since the last AMRC review, some conflicting evidence has emerged from the laboratory and field experiments which, with actual field observations concerning the percentage of flies emerging from dung pads under attack by beetles, indicate an apparent lack of impact of beetle activity on populations of bush and buffalo flies. Such observations do not support the hypothesis that is central to this project and make it imperative that validity of the above observations be established urgently.

3. In order to achieve a clearer understanding of the impact of both native and introduced dung beetles on bush and buffalo fly populations it is essential that a method of measuring the size and age of both populations be developed as soon as possible. Once an adequate method of measuring the bush and buffalo fly populations has been achieved then an understanding of the factors that control them will be possible and construction of computer simulation models will be a natural and proper extension of this work. It is likely that similar population studies will be necessary for dung beetle and phoretic mite populations later in the life of the project.

4. Since the populations of pest flies, dung beetles and mites depend entirely on dung for their survival then dung supply and quality is central to the dynamics of their population sizes. It follows that a more precise understanding of the term 'dung quality' is needed, especially with reference to the environment where it is produced in terms of soil moisture, temperature, pasture type, particle size, nitrogen content and microbial status.

5. Simultaneously, studies on the field biology of dung beetles and mites (both in Australia and overseas) relative to habitat and ecology of the target flies needs to be continued. Although the emphasis placed on field biology of dung beetles will of necessity fluctuate with time and requirements, at present there is insufficient fundamental data concerning almost all species for there to be any reduction in efforts in this area.

6. A substantial part of this deficiency of data concerning the field biology of beetles stems from a failure to evolve less labour intensive experimental techniques and to develop equipment capable of collecting information on beetle numbers and activities over a wide area simultaneously. Attention must be given to designing and testing equipment suitable for this purpose if progress with the field biology of beetles is going to be achieved at a rate commensurate with the needs of the whole project. A start has been made in this direction by the examination of the biomass of beetles as a function of their impact on pest fly numbers. Examination of trapping methods for their accuracy and relevance to the whole population is likewise an urgent requirement. Definitive experiments to investigate the efficiency of trapping and the impact of whole fauna on fly populations have already commenced in both Africa and Australia.

7. Once the information has been collected and evaluated for the objective selection of beetles and mites for Australia then techniques for their breeding and rearing must be evolved. The initial stage is to describe the factors controlling the life cycles in sufficient detail to enable mass rearing to commence. Studies on beetle life cycles is the key to the success of the project and received inadequate attention prior to the 1979 review. Progress since that date has been largely restricted to one species of beetle that has been studied in detail to enable the principles surrounding dormancy to be understood. This work is now ready for expansion to more species with wider characteristics.

8. The specialist nature of the project and the scattered geographical distribution of the workers, some of whom have limited access to library facilities, requires that greater attention be paid to dissemination of information: a computer based information service is to be investigated.

M.A.S. JONES

SYDNEY

20/9/82

A P P E N D I X

THE BIOLOGICAL CONTROL OF DUNG

The origin and status of the Scarabaeidae (Scarabaeinae), Geotrupidae and Histeridae introduced into Australia. Updated May 1982.

Strains:
ER Even Rainfall
SR Summer Rainfall
WR Winter Rainfall
C Cold
GP Gene Pool
T Tropical
1 etc - see files

Climate types after Walter and Leith:
I Equatorial, humid
II Tropical, summer rains
III Subtropical, hot and arid
IV Mediterranean, winter rains
V Warm-temperate, humid
VI Humid with cold season

Status of each species/strain:
Ins. C. Currently in Canberra insectaries.
F. Failed in insectaries.
Rel. Date first released in Australia.
Rec. Date first recovered in Australia.

Species	Strain	Country of Origin	Climate	Status		
				Ins.	Rel.	Rec.
SCARABAEIDAE (SCARABAEINAE)						
Oniticellini						
Liatongus militaris (Castelnau)		S. Africa via Hawaii	II		Jan 68	Feb 75
Oniticellus cinctus (Fabricius)		Ceylon via Hawaii	I	F		
Euoniticellus africanus (Harold)		South Africa	II		Oct 71	Feb 75
E. fulvus (Goeze)	1	France	V(IV) & IV(V)	C	Mar 78	Jan 82
E. fulvus (Goeze)	2	Turkey	IV(V)		Nov 78	
E. fulvus (Goeze)	3	Turkey	IV	F		
E. fulvus (Goeze)	4	Turkey	V		Dec 78	Jan 81
E. fulvus (Goeze)	5	Turkey	V(IV)		Apr 78	
E. intermedius (Reiche)		South Africa	II		Nov 71	Nov 73
E. pallipes (Fabricius)	1	Iran	IV(V)		Mar 77	Nov 80
E. pallipes (Fabricius)	2	Turkey	IV		Feb 78	Jan 79
E. pallipes (Fabricius)	3	Turkey	IV	C	Feb 78	Dec 79
Onitini						
Chironitis sp. (nr *scabrosus* (F))		South Africa	II		Oct 72	
Onitis alexis Klug	C	South Africa	II		Aug 72	Mar 74
O. alexis Klug	T	South Africa, Malawi, Rhodesia & Mozambique	II		Sep 73	Apr 75
O. anthracinus Felsche		Kenya	I(II)	F		
O. aygulus Fabricius	SR	South Africa	II(III)		Jan 77	
O. aygulus Fabricius	WR	South Africa	IV		Mar 77	Oct 80
O. belial Fabricius		Morocco	IV & IV(III)	F		
O. belial Fabricius		Spain	IV	F		
O. belial Fabricius		Spain	III(IV)	F		
O. caffer Boheman	SR	South Africa	II		Oct 79	Apr 82
O. caffer Boheman	ER	South Africa	V(IV)	F		
O. caffer Boheman	WR	South Africa	IV	C		
O. crenatus Reiche		South Africa	II		Nov 76	
O. deceptor Péringuey		South Africa	II & II(III)		Dec 79	
O. pecuarius Lansberge	SR	South Africa	II		Nov 76	Mar 81
O. pecuarius Lansberge	ER	South Africa	IV(V)		Oct 77	Feb 80
O. uncinatus Klug		South Africa	II & II(III)		Dec 79	
O. vanderkelleni Lansberge		Kenya	I(II)		Oct 74	Apr 80
O. viridulus Boheman		South Africa	II		Sep 76	May 78
O. westermanni Lansberge		Rhodesia	II		Jan 77	
Bubas bison (Linnaeus)	1	Morocco/Spain	IV	F		
B. bison (Linnaeus)	2	France	IV	C		
B. bison (Linnaeus)	3	Spain	IV	C		

Species	Strain	Country of Origin	Climate	Status		
				Ins.	Rel.	Rec.
Onthophagini						
Onthophagus alcyon Klug		Kenya	I(III)	F		
O. andalusicus Walte		Morocco	IV & IV(III)	F		
O. binodis Thunberg	SR	South Africa	II		Oct 71	Dec 72
O. binodis Thunberg	WR	South Africa	IV & IV(V)		Jan 72	Oct 75
O. bubalus Harold		South Africa	II		Oct 72	
O. cameloides d'Orbigny	1	South Africa	IV	C	Dec 80	
O. foliaceus Lansberge		Angola	II		Sep 75	
O. gazella (Fabricius)	T	Africa via Hawaii	II		Jan 68	Jan 69
O. gazella (Fabricius)	C	South Africa	II		Jul 72	Nov 73
O. gazella (Fabricius)	GP	South Africa	II		Sep 73	Jun 74
O. gazella (Fabricius)	ER	South Africa	IV(V)		Dec 77	Mar 79
O. incensus Say		Mexico	?	F		
O. nigriventris d'Orbigny		Kenya	I(II)		Sep 74	Apr 76
O. obliquus (Olivier)		Nigeria	I(II) & II		Jan 76	Apr 80
O. opacicollis d'Orbigny		Greece	IV	C	Apr 82	
O. sagittarius (Fabricius)		Ceylon via Hawaii	I		Jan 68	Jun 69
O. taurus (Schreber)	1	Spain & Italy	IV & V		Feb 75	Oct 79
O. taurus (Schreber)	2	Greece	IV(III)		Nov 77	Jan 79
O. taurus (Schreber)	3	Turkey	IV	C	Dec 77	Dec 79
O. taurus (Schreber)	4	Turkey	V(IV)	C	Mar 78	
O. taurus (Schreber)	5	Turkey	IV(V)		Feb 78	Oct 80
O. taurus (Schreber)	6	Turkey	V		Feb 78	Mar 80
O. vacca (Linnaeus)	1	Spain	IV & V(VI)	F		
O. vacca (Linnaeus)	2	Morocco	IV	F		
O. vacca (Linnaeus)	3	France	IV	C		
O. vacca (Linnaeus)	4	France	IV(V)	C	Sep 80	
O. vacca (Linnaeus)	5	Spain	IV	C		
Coprini						
Heliocopris andersoni Bates		South Africa	II	F		
H. faunus Boheman		South West Africa	II & III	F		
Copris bornemisszai Ferreira		Rhodesia	II		Jan 77	
C. diversus Waterhouse		Kenya	I(III) & II(I)		Oct 76	
C. elphenor Klug	1	Southern Africa	II & II(III)	C	Jan 77	
C. fallaciosus Gillet		Kenya	I(III)		Jan 77	Oct 78
C. hispanus Linnaeus	1	Morocco/Spain/Italy	IV	F		
C. hispanus Linnaeus	2	Spain	IV	C		
C. incertus Say		Mexico	?		Apr 69	
C. lunaris (Linnaeus)	1	Italy	IV	F		
C. lunaris (Linnaeus)	2	France	IV(V)	C		
Scarabaeini						
Sisyphus fortuitus Péringuey		South Africa	II		Dec 76	
S. infuscatus Klug		South Africa	II		Mar 76	Feb 82
S. mirabilis Arrow		South Africa	II		Apr 72	
S. rubrus Paschalidis		South Africa	II		Mar 73	Dec 75
S. spinipes Thunberg		South Africa	II		Mar 72	Apr 74
Garreta nitens Oliver		South Africa	II	F		
Allogymnopleurus thalassinus (Klug)	1	South Africa	II		Mar 79	
Canthon humectus Say		Mexico via Hawaii	?		Apr 69	

Species	Strain	Country of Origin	Climate	Status		
				Ins.	Rel.	Rec.
GEOTRUPIDAE						
Geotrupes spiniger Marsham	1	France	V(IV)		Apr 79	Mar 82
G. spiniger Marsham	2	France	IV		May 79	
G. spiniger Marsham	3	Greece	IV	C		
HISTERIDAE						
Hister caffer Erichson		Africa via Hawaii	?		May 68	
H. calidus Erichson		South Africa	?		Dec 71	Dec 76
H. chinensis Quensel		Java via Fiji	?		Apr 67	Dec 69
H. cruentus Erichson		South Africa	?		Apr 70	
H. nomas Erichson		Africa via Hawaii	?		Dec 67	Mar 72

No. of species	Scarabaeinae	Geotrupidae	Histeridae	Total
Introduced	51	1	5	57
Currently in insectaries	11	1	0	12
Released	39	1	5	45
Recovered	21	1	3	25