# Final report

## Scoping the development of a best practice manual for managing pesticide use while maintaining healthy dung beetle populations


Project code: P.PSH.1270



Prepared by: Paul Meibusch, Majella Bathurst, Dr Amrit Kaur, Dr Penny Cain and Dr Bernard Doube
Colere Group Pty Ltd



Date published: 28 February 2021

PUBLISHED BY
Meat & Livestock Australia Limited
PO Box 1961
NORTH SYDNEY NSW 2059
This is an MLA Donor Company funded project.

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government and contributions from the Australian Meat Processor Corporation to support the research and development detailed in this publication.

# Abstract

Producers do not have a single source of reliable information to guide their choices about healthy dung beetle population management on their farms, whilst not compromising profitable decisions about key animal pests (for example worms, lice and ticks). They are interested in the production and ecological benefits of dung beetles on their farms, however learning that common pesticides can damage dung beetle populations.

Many animal health products showed significant effects on adult fertility and/or mortality and/or dung beetle offspring, while various models have been proposed to reduce the harmful effect on populations. Although some models described a rapid extinction of dung beetles after successive treatments of animals, the trans-generational and within-generational effects (delayed effects) of these compounds to dung beetles have not been considered. Producers need to manage pesticide usage whilst encouraging beetle populations which support their productivity.

This report provides a framework for industry funding agencies to make choices about investing in the development of the recommended Best Practice Manual (BPM), including additional supporting R&D, for cattle and sheep producers on pesticide use in livestock production. The aim is to provide producers with clear recommendations on how they can best integrate pesticides and dung beetles in their farming system in a sustainable and productive manner.

# Executive summary


## Background

There is no single source of reliable information for producers who seek to manage key pests and promote healthy dung beetle populations on their farms. Existing information in publications such as The Cattle Parasite Atlas[*] (MLA 2021) lists known chemicals used in parasite control and an indication of insecticidal activity in dung, however no clear guidance exists quantifying the impact of chemical use on beneficial soil-dwelling insects such as dung beetles.

This report maps out the research required to create a Best Practice Manual (BPM) for cattle and sheep producers on pesticide use in livestock production. The scope of this project included the use of oral drenches as well as all other methods of controlling parasites and insect pests in cattle and sheep production systems (dust bags, spraying insecticides, ear tags, pour-ons and oral methods) and how these impact dung beetle populations. The aim and subsequent BPM development will provide producers with clear recommendations on how they can best integrate pesticide use and dung beetles in their farming system in a sustainable and productive manner.

## Objectives

The objectives of the current project were to:

- Clearly define the research questions that will need to be answered in order to underpin future BPM guidelines through solid science.
- Determine what information producers would like to see in relation to the project findings and how to best communicate to enable adoption (i.e., consider best practice manual, fact sheets, newspaper articles, videos, industry forums, etc.)
- Begin a process of developing protocols for the independent assessment of new pesticides and their formulations and uses to assess their impact on dung beetles, in order to ensure the industry can safely incorporate new products into their farming practices.

All the objectives in this project were successfully completed.

## Methodology

The project began with an extensive literature review which was initially undertaken to identify and understand the interactions between dung beetles and the main groups of chemicals being used on farm for parasite management, before a proposed structure and template for the BPM guidelines was developed. Finally, R&D requirements were mapped based on prioritised gaps from the review process.

## Results/key findings

The literature review identified a number of key findings that will be important in the planning and conducting of research on the impact of pesticides on dung beetles.

1. Commonly used veterinary pesticides can have impact on dung beetles. The severity of this impact, which might include death, depends on the class of chemical and level of residue in


[*] https://www.mla.com.au/research-and-development/animal-health-welfare-and-biosecurity/parasites/cattle-parasite-atlas/

dung, and the timing of chemical exposure in the beetle life cycle. Beetle species is significantly less important.

2. Eco-toxicological information on the effect of the key active ingredients and the excretion curve in dung is not available. This severely limits accurate evaluation of the toxic effect of these products on dung beetles specifically and on ecosystem functions more broadly.

3. Published field evidence has shown that moderate levels of dung burial by beetles can achieve a degree of biological control of the infective stages of gut parasites. Substantially greater levels of dung burial occurs when soil is damp (a key time for gut parasites). The impact of such substantial dung burial on field populations of intestinal parasites needs to be studied in more detail, especially in sheep. The impacts of this service need to be assessed in the context of management of parasites on farm.

4. Information about pesticides effect on dung beetles is highly dispersed and difficult to find. Without a central point to access such information, it is difficult for producers to make informed decisions.

## Benefits to industry

This project has the potential to benefit Australian producers and the industry through a number of direct and indirect channels:

- Identifying and understanding the research questions that will need to be answered in order to underpin new best practice guidelines with solid science and thereby enable producers to make informed decision around safe and appropriate use of pesticides.

- Helping to develop protocols for the consistent and objective assessment of new pesticides and their formulations and uses through specific assessment of their impact on dung beetles, in order to ensure the industry is able to safely incorporate new products into their farming practices.

- Providing producers with clear guidelines via a BPM on how to balance responsible chemical pesticide use with healthy dung beetle populations, for long-term benefits and sustainability.

- Actively reducing the reliance on chemical treatments to manage parasites, protecting valuable effective agents against the development of pesticide resistance, and reducing input costs by providing regionally specific and timely advice on pesticide usage.

- Assisting producers to take greater advantage of the multiple ecosystem benefits provided by having a full cohort of dung beetle species operating on farm throughout the year.

## Future research and recommendations

The project has recommended five areas for future research. These are the highest ranked projects from a longer list of identified knowledge gaps, prioritised based on need, cost effectiveness and technical feasibility. 1. Predicting the potential amount of chemical active in dung and the margins of safety for dung beetles, 2. Develop dung beetle information packages for current key providers of pesticide recommendations.3. Develop guidelines to test the off-target effects of new actives on dung beetles.4. Determine the impact of buffalo fly ear tags on dung beetle populations. 5. Research the role of dung beetles in controlling helminth populations.

# Table of contents

# 1. Background

## 1.1 The issue

There is no single source of reliable information for producers who seek to manage key pests and promote healthy dung beetle populations on their farms. Existing information in publications such as The Cattle Parasite Atlas[†] (MLA 2021) lists known chemicals used in parasite control and an indication of insecticidal activity in dung, however no clear guidance exists quantifying the impact of chemical use on beneficial soil-dwelling insects such as dung beetles.

Parasites are a significant issue for the Australian sheep and cattle industries with an estimated cost of mitigation and lost productivity in excess of $675 million annually (Lane et al. 2015). Tolerance (immunological resistance) is a key element in the control of internal and external parasites in livestock: many production systems tolerate (without chemical treatment) a low level of parasitism which stimulates and maintains immunological resistance to the parasites. Selective breeding for greater internal parasite resistance in sheep is currently under way within the industry but progress is slow. Pasture management by spelling and animal treatments with anthelmintics (‘drenching'), acaricides (dipping) and use of fly control products (ear tags, jetting and spray-ons) are the main current day-to-day management practices for reducing the impact of these parasites. However, chemical treatments can also come with a cost in the form of reduced insect activity in dung of treated animals (Floate 2006, Jacobs and Scholtz 2015).

Dung beetles are increasingly being recognised as a vital part of profitable extensive grazing systems. They provide a range of important ecosystem services, many of which are critical to the environment as well as to livestock farming systems. An established population of dung beetles has been shown to increase pasture production and carbon storage in soil, reduce nutrient runoff, as well as increasing water infiltration and decrease animal parasite populations by limiting the opportunities for flies and other pests to breed in dung (Sands and Wall 2017). For example, it has been shown that dung beetle impact on plant-growth enhancement was equal to that of using chemical fertilisers (Fincher et al. 1981, Nichols et al. 2008). Separate modelling has calculated that dung beetles save the US cattle industry an estimated $380 million annually through efficiently incorporating nutrient rich organic matter into the soil (Losey and Vaughan 2006).

Despite the benefits that dung beetles provide, populations are impacted by common drench and dip residues present in animal dung post treatment (Manning et al. 2017). Most producers are aware of this problem but have neither the knowledge nor the tools to make informed decisions that balance animal health and dung beetle mortality for profitable benefit. In fact, the recommended strategies for better parasite management usually include approaches designed to reduce the likelihood of parasite resistance forming through product rotation, further complicating the stewardship of dung beetle populations.

To address these issues, this report forms the basis for future investment in the development of BPM guidelines. It brings together our understanding of the interactions between dung beetles and the main groups of chemicals being used on farm for parasite management. It also identifies what we could currently consider to be best practice as well as the key knowledge gaps that require

[†] https://www.mla.com.au/research-and-development/animal-health-welfare-and-biosecurity/parasites/cattle-parasite-atlas/

further R&D. It is the first step in building a comprehensive resource for producers managing both their parasites and dung beetle populations.

The core issue facing producers is how to evaluate the balance that must be struck between treating cattle and sheep for pests and parasites, using systems and approaches to minimise development of parasite resistance, and minimising harm on dung beetles in the pasture.

There is no simple answer to this question and each producer will need to apply their own values to the importance of protecting the beneficial services provided by dung beetles and the benefits that pesticides have in their management systems, and to do this they will require readily accessible information.

A recent change in registration guidelines from the APVMA includes a requirement to evaluate environmental contamination risk, potentially including product impact on dung beetles. If enforced, this would align with EU vet chemical guidelines. However, the EU based guideline provided is not directly relevant to Australian dung beetles and the environment they operate in. Furthermore, while this seems a positive outcome for an Australian industry seeking to protect their beetle population whilst keeping their animals healthy, it may also impose another barrier to entry for new anti-parasitic products in a market with already limited options. Any such change will not apply to existing registered pesticides, so creates a knowledge gap between older (widely used) and upcoming pesticides, potentially further confusing end users and increasing the cost of new actives.

## 1.2 Scope

This project maps out the research investment required through Meat & Livestock Australia/industry funding to create a Best Practice Manual (BPM) with clear recommendations for cattle and sheep producers on how they can best integrate pesticides and dung beetles within sustainable livestock production systems. The scope of this project extends beyond the use of oral drenches to all methods for control of parasites and insect pests in cattle and sheep production systems (dust bags, spraying insecticides, ear tags, pour-ons and oral methods) and how these impact dung beetle populations.

By looking at the key parasites of importance to the red meat industry, and the products used to treat or manage these pests, the literature review ascertained known impacts associated with the use of these products on dung beetle populations as identified through the published literature. The review considered a broad range of conventional methods for control of internal parasites and insect pests in cattle and sheep production systems (dust bags, spraying insecticides, ear tags, pour-ons and oral methods) and how these impact dung beetle populations. Key gaps in knowledge that the reviewers identified as being crucial for producers and industry to make informed decisions on chemical use are mapped and presented.

Internal parasites and other insect pests are a significant issue for the Australian red meat industry with an estimated cost of $916M annually in treatment, prevention, and production losses (Table 1, MLA 2015). Strategic treatment with anthelmintics, pour-ons, tags and sprays are the current conventional management practice for internal and external parasites. As with most pesticide use in agriculture, this has led to widespread and prevalent pesticide resistance particularly in internal parasites of sheep and cattle, creating an endless “arms race” to develop new and effective treatments.

**Table 1: Economic cost of internal parasites and insect pest on Australian industry (MLA 2015)**

| | Pest | Economic Cost Annually |
|---|---|---|
| *Cattle* | Cattle tick | $156 M |
| | Tick fever | $4.3M |
| | Theileria (tick related) | $19.6M |
| | Buffalo fly | $98.7M |
| | Internal parasites | $ 93.6M |
| *Sheep* | Internal parasites | $435.9M |
| | Lice | $81.1M |
| | Liver fluke | $24.7M |
| *Goat* | Internal parasites | $2.5M |
| | Lice | $0.3M |
| | Liver fluke | $0.1M |
| *TOTAL* | | **$916 M** |

The role of dung beetles is somewhat lost in this parasite control arms race. While the ecosystem benefits brought by dung beetles are well understood in terms of soil, nutrient and water, what is not well understood is their role in reducing the impact of many parasites and flies (via dung burial). Dung beetles can also be detrimentally impacted by the use of the common chemicals being used to manage these animal parasites.

Despite current practice, there is considerable potential to reduce reliance on pesticides in many extensive systems by promoting dung beetles as a component of integrated parasite control. This can be achieved by modifying grazing management and treatment practices. However, the Australian livestock industry must make active decisions:

- Dung beetles can play a role in the integrated management of parasites, providing an effective means to reduce internal parasite eggs in grazing areas (Bergstrom et al. 1976); and
- Dung beetle activity reduces the opportunity for fly pupae to develop by physically removing dung from the soil surface (Doube and Marshall 2014).

However:

- Dung beetles are killed by the residues in dung of many common drenches (Manning et al. 2017) and the effects of a number of new animal health treatments on beetles are unknown; and
- There is no single source of reliable information for producers who seek to manage key pests and promote a healthy dung beetle population on their farm.
- While the effect of the actives are similar across the beetle species the timing of beetle activity for each species in each region may leave windows suited to treatment applications.

# 2. Objectives

The objectives of the project:

1. **Clearly define the research questions that will need to be answered in order to underpin best practice guidelines with solid science.**

   A literature review was undertaken as part of this process. In the review we identified where there are gaps in the science around the impact of pesticides on dung beetle species, particularly in field situations rather than laboratory experiments, which is more relevant for producers.

2. **Determine what information producers would like to see in relation to the project findings and how to work with them to best enable their adoption of BPM recommendations (i.e. consider best practice manual, fact sheets, newspaper articles, videos, industry forums, etc.)**

   Producers would like to see that the industry is working on providing clear recommendations. This project has been working towards providing the framework for a best practice manual for cattle and sheep producers to provide a consolidated source of information on managing pesticide use and maintaining dung beetle populations. When MLAs decides to proceed in the development of BPM guidelines, the team will work with a small group of growers to codesign published recommendations that are made with specific framing to on farm operational processes and system improvements.

3. **Develop protocols for the independent assessment of new pesticides and their formulations and uses to assess their impact on dung beetles, in order to ensure the industry is able to safely incorporate new products into their farming practices.**

   The literature review provides recommendations on how the industry can ensure the gaps in practical knowledge on the safe utilisation of pesticides to minimise dung beetle impact can be bridged by using supplementary studies or assessments. A path forward is recommended on developing new guidelines that would replace the current OECD document being used by the APVMA. This then covers both the APVMA's need for the approach to registration of new products in this sector and the chemical company's response in the form of labelled recommendations. The APVMA has avoided engaging in this area of registration and this has provided an opportunity for potentially confusing marketing statements about product safety to dung beetles. An improved guideline, developed by Australian experts should satisfy both needs.

# 3. Methodology

An extensive review which was initially undertaken to identify and understand the interactions between dung beetles and the main groups of chemicals being used on farm for parasite management, before a proposed structure and template for the BPM guidelines was developed. Finally, R&D requirements were mapped based on prioritised gaps from the review process.

The stages of the project were as follows:

1. A broad and in-depth literature review (journals and grey literature) was undertaken covering the interaction between dung beetles and all pesticides, not just internal drenches (i.e., including pour-ons, ear tags and pesticides used for pasture sprays). All searches used the keyword topic ('dung beetle' OR scarabaeinae OR geotrupidae OR aphodiinae). We identified literature considering dung beetle–pesticide associations using the search term (pesticide* OR parasiticide* OR specific active for example ivermectin*). Additional papers were identified by following publications cited in these articles.

2. The papers were then compiled according to sectional relevance in the review and summarised.

3. A logical and deductive process was undertaken to find key gaps in information that would be critical to underpinning practical recommendations in a prospective guide.

4. Knowledge gaps were elucidated, listed and prioritised based on critical need for the knowledge, technical feasibility of undertaking R&D to answer the research question and industry contextual need.

5. A structure and template for a best practice manual with an option to provide regional addendums and case studies. A framework has been developed, based on both the existing scientific literature and industry guides, for the best practice manual to manage pesticide use while maintaining healthy dung beetle populations. The framework highlights where there are current unknowns in the research and provides recommendations for future research investment by the industry.

6. A roadmap, including costs, to address R&D gaps has been developed (with trials across lab, pen and field environments) to underpinning scientific data requirements for the BPM.

# 4. Results

As expected, in the literature review we found issues with both inconclusive and contradictory information in terms of the impact of chemical pesticides (parasiticides) on dung beetles. This contrary research, along with the significant gaps in knowledge have resulted in the current inability to provide clear recommendations for producers and industry advisors in managing dung beetle populations and their livestock health with parasiticides.

Practical and anecdotal evidence from producers highlights the conflicting management recommendations being provided by commercial companies (via labels) and dung beetle experts. While it would be hoped that independent industry sources (for example ParaBoss or WormBoss) would provide a balance between the two, or indeed a definitive answer, we find that they are largely silent when it relates specifically to use of chemicals, timing of application and appropriate chemical selection and subsequent perspectives about dung beetle impact.

There are two main issues:

1. Industry needs definitive R&D investment that fills the knowledge gaps and works out the contradictory evidence.
2. Producers need clear advice that enables them to understand and value the co-contribution of the two different technologies: (1) chemical parasite control and (2) biological activity.

In regard to issue 2, it is important that producers understand how chemicals are used, their impact on the ecosystem, and the economic value they provide to the farming enterprise. On the other hand, they also need to understand and value the benefits brought by dung beetles as a biological control agent within farming ecosystems. By fully understanding the two, there is an opportunity for producers to fit these two potentially opposing elements together successfully in a localised parasite management plan. This will also provide them with an integrated pest control program for livestock as is critical for long term sustainability.

## 4.1 Key knowledge gaps

The literature review identified key gaps in the current knowledge that (ideally) need to be answered before a comprehensive best practice manual can be produced and/or accurate and relevant recommendations can be made to producers on how to best manage chemical usage safely for dung beetles.

The following specific gaps were identified in the literature and should be considered as potential areas of future research:

1. **Do insecticide impregnated ear tags affect dung beetle populations?**

There is no data on potential dung residues from ear tags, which are widely used for fly control. This could be studied via a field study using the most commonly used tags with faecal collection and laboratory larval challenge study. There is no information on the transfer of insecticides (Organophosphate (OP)s, Synthetic pyrethroids (SP)s and macrocyclic lactone (ML)s) from impregnated ear tags or dust bags to dung and how that might affect dung beetle populations.

Experimental approach:

**Ear tags:** Use feedlot cattle with and without ear tags. Collect dung over three weeks and test dung for the presence of the chemical. If positive results are produced, then test the

toxicity of impregnated dung to beetles common in the buffalo fly regions of Australia. For example *Onthophagus gazella* and *Euoniticellus intermedius*.

**Dust bags:** Perform parallel studies on commonly used dust bags but in an open range environment. The extent to which the use of toxic MLs generate a local/regional decline in dung beetle abundance is unknown. Some agvet companies appear to believe that the absence of evidence is evidence of absence in that they claim that their products are 'dung beetle friendly' in that there is no evidence for a regional decline in dung beetle abundance following the use of chemicals that in laboratory tests have been shown to be toxic to dung beetles.

**2. Do back rubs and sprays for cattle impact on non-target insects for example dung beetle?**

There is limited information on these administration routes. This could be studied via a field study using the most commonly used rubs and sprays with faecal collection and laboratory larval challenge study.

Experimental approach:

Treat cattle in a standard manner and collect and assay dung.

**3. Does autumn or spring application of MLs affect populations of summer active beetles?**

There is no data on this. MLs are the most toxic class of parasiticides and autumn and spring use of MLs is widespread. There is no information about whether autumn or spring application of MLs affects populations of summer active beetles in southern Australia. The summer-active beetles provide biological control of the bush fly and so the loss of summer beetle activity could have important consequences. Summer beetles depend upon spring and autumn breeding to produce the summer generation.

Experimental approach:

Field experiments that assess the impact of spring and autumn mortality of the summer populations of *Onthophagus taurus* and *Euoniticellys fulvus*.

**4. What is the curve of parasiticide excretion in dung over time across chemical classes?**

Depending on formulation, application route and species, data on chemical excretion curves is variable. This is critical to evaluate effect of different classes and routes of administration on dung beetles, and pasture level ecosystem more widely. A between class study evaluating pasture level residues after treatment of the most common sheep and cattle parasitises is a valuable starting point for such a data set. Some of this data overlaps with question 1 and 2. In addition, the decay of the chemicals in dung on the ground (i.e. post production) and the decay in the concentrations of chemicals in dung produced over time following treatment of the host animal both need to be examined for a range of chemical classes.

Experimental approach:

Use the established protocols in the literature.

**5. To what extent does the use of pour-on toxic MLs generate local/regional decline in dung beetle abundance. How quickly do the reduced populations recover?**

This is a wider-focus question and would be best approached with regional/ state research partners.

**6. What is the long-term impact of parasiticide use on beetle diversity and changes to dung living insect fauna?**

This is a wider-focus question and would be best approached with university/ regional/ state research partners.

7. **To what extent does dung burial during winter (*B. bison* activity) reduce the populations of helminths in sheep and cattle?**

While there has been significant research around the impact of dung beetles on helminths, there is still a need for specific information in this area that can be used directly to inform producers on how the benefits can be better leveraged in practical situations.

8. **In managing pesticide use, it is critical that resistance levels are assessed regularly. How many drench resistance tests are currently being conducted and is there a goal for the industry in order to provide current advice on pesticide use?** There is minimal effective regulation and communication around emerging chemical resistance. Producers/end users are often left to research this themselves with mixed results and potentially increased mismanagement of products and the subsequent resistance that develops in parasites.

This is a question for AHA and MLA to consider addressing and is outside the scope of this project.

9. **Within specific actives there is no literature on their impact on dung beetle populations:**
    a. **CNS Inhibitor: Amitraz**: There are no reports available for any data regarding the use of amitraz in livestock showing non-target effects on dung beetles.
    b. **Imidazothiazoles: Closantel & Nitroxynil***:* no reports available for any data regarding their non-target effects on dung beetles.
    c. **Salicylanilides (oxyclozanide):** no data available for any data regarding their non-target effects on dung beetles.
    d. **Insect growth regulators (IGR): Cyromazine, Dicyclanil:** no information available for any data regarding their non-target effects on dung beetles.
    e. **Organophosphates: Diazinon, Chlorfenvinphos:** no record of any non-target effect on dung beetles after using diazinon or chlorfenvinphos on livestock is available.
    f. **Tetrahydropyrimidines - Morantel citrate**: no data showing any assessment of non-target effects of morantel citrate against dung beetles is available so far.

## 4.2 Drivers for change

There are several strong drivers for change in the red meat industry that include components around reduced pesticide use, lower environmental impact and better stewardship of the land. While in the past they could be separated into market led and producer led drivers there is also now a more coordinated industry led driver in the form of initiatives (including MLAs flagship CN2030 program).

**Organic agriculture** is a critical part of growth markets and products. The demand for organic beef and lamb has been greater than available supply (both in export and domestic markets) for more than a decade according to MLA reports. The 2015 MLA funded report "Increasing organic beef production on Australian farms" outlined the complexity of producers moving to and maintaining organic producer status. A significant portion of this challenge is around the management of animal health issues without pesticides. The role of dung beetles in parasite management in the organic farming system is not specifically articulated in any reports we found, but is none the less critical.

**Regenerative agriculture** has at its core the intention to improve the health of soil or to restore highly degraded soil, which symbiotically enhances the quality of water, vegetation and land-productivity. For examples, Rhodes (2017) sets out a case for why regenerative agriculture methods make it possible to increase the amount of soil organic carbon (SOC) in existing soils. He puts this down to biological sequestration (bio-sequestration). More generally, bio-sequestration is about the direct removal of carbon dioxide from the atmosphere through land-use change, reforestation, carbon storage in landfills and practices that enhance soil carbon in agriculture. Dung beetle populations obviously have a key role to play in this nutrient cycling through their tunnelling and dung burying behaviour.

While productive system R&D is on-going, it is known that land management changes can lead to agricultural soils sequestering and storing carbon primarily through inputs and microbial activity (see Gupta and Sharma 2021). These changes can also lead to changes in structure, stability, resistance to erosion and ultimately biodiversity, while some people also suggest improved productivity and profitability. By improving ground cover and building soil structure, it is well established that producers can significantly reduce the impact of dryland salinity, reduce sedimentation rates in rivers and streams and improve water quality. Many of these attributes work alongside healthy dung beetle populations and the ecosystem benefits they provide.

# 5. Conclusion

Dung beetles have the opportunity to provide an increasingly important role in the management of key gastrointestinal parasites for the livestock industry. As identified through the literature review, the ecosystem services offered by dung beetles, can be negatively impacted through lethal and sublethal effects of pesticide residues in dung. However, the impacts vary between actives, modes of application and the timing of exposure in the beetle's lifecycle.

There is no silver bullet in terms of pesticide use and maintaining dung beetle populations. Supporting healthy dung beetle populations on rangeland comes down to management and incorporating regenerative agriculture practices. In terms of grazing management, certain grazing practices can help promote dung beetles. Rotational grazing has been shown to favour dung beetle abundance as well as species diversity. Grazing cattle at higher stocking densities increases the concentration and dispersal of dung piles, which is very influential for attracting dung beetles.

## 5.1 Key findings

**The following key findings were made through this literature review:**

1. All scarabaeid dung beetle species represented in research appear to be similarly susceptible to the toxic and non-toxic anthelmintics tested. However, there is limited evidence that one species of geotrupine dung beetle is damaged by the ML moxidectin, which is considered to be a 'beetle-friendly' chemical for the scarabaeids. This suggests that future research to develop protocols for assessing the impact of pesticides on beetles needs to be tested against a limited range of scarabaeid species and at least one geotrupine beetle.
2. The nature of the chemical used and the timing of application (in relation to the beetle's lifecycle) are key factors to consider when assessing the impact of chemicals on dung beetle populations.
3. There can be significant difference in chemical toxicity to dung beetles, between and within classes of parasiticides, depending on the chemical, formulation and route of administration, route of excretion and curve of excretion. It is difficult to reduce the data to a simple list of chemicals and treatment program because of the matrix of variables, however the following general points were noted from the literature review:

    a. In general, chemicals that are excreted through the urine are less toxic to dung beetles compared to chemicals excreted through the faeces.

    b. In many cases endectocides for nematode treatment are excreted primarily in the faeces of the treated animal, whereas topical ectoparasiticides are mainly excreted in the urine of treated animal.

    c. In general, Benzimidazoles have limited adverse effect on dung beetles. This is to some degree because they are extensively metabolised within the animal and residue excretion is primarily via urine, rather than faeces.

    d. Imidazothiazoles, i.e. Levamisole/morantel/closantel groups, appear to have limited adverse effect on dung beetles.

e. IGRs such as cycromazine, dicyclanil, diflubenzuron and flurazon are not highly toxic to dung beetles but can potentially reduce egg laying and hatching rate, and reduce faecal consumption by adults, the effect varying between each chemical. Fluazon appears to be the least toxic to dung beetles.

f. Macrocytic lactone effect varies depending on the chemical and route of administration, but in general they have some toxicity to dung beetles. Moxidectin and Doramectin appear to be the least toxic MLs. Ivermectin and eprinomectin are significantly more toxic and Abamectin appears to be the most toxic, being excreted in dung for up to 42 days after treatment. There are data gaps between drenches versus pour-on formulations so more information between administration routes would benefit producers in decision making.

g. OP chemical effect on dung beetles is not well studied and there is limit information available. Chlorfenvinphos and diazinon are primarily excreted in the urine, so unlikely to be harmful.

h. Synthetic pyrethroids (SP) are generally applied externally, with formulation variations between products. The impact on dung beetles varies between individual chemicals formulations, which may impact on duration and peak of faecal excretion of chemical. SP chemicals can impact sub-lethally and lethally on adult dung beetles and potentially impact intergenerational on beetle fertility. There are data gaps for some routes of use. The impact of pyrethroids on local depression of dung beetles at sublethal levels is a concern for its effect on wider pasture level ecosystems.

i. There is very limited data about faecal residues from ear tag use. Newer tags combine OP and SPs. This data gap is of concern because of the widespread use of ear tags in areas depending on dung beetles to assist in reducing fly pressure. The use of oversprays, backrubbers, dust bags and ear tags result in less chemical contamination of the dung, however it there is insufficient data to indicate how this use patter could impact on dung beetles.

j. There is insufficient data on Neonicotinoids (Imidacloprid, Thiacloprid), Spinosad, and monepantel amongst others to determine impact on dung beetles. This data gap should be addressed for commonly used chemicals and routes of administration. Data for less commonly used chemicals such as praziquantel, morantel and others is less important, unless registrations and use patterns change.

4. There is no meaningful difference in the impact of pesticides between beetle species. The chemical used and timing in the beetle lifecycle was more crucial than the species being exposed. This means that future research and protocols for assessing the impact of pesticides on beetles do not need to test against a range of species but do need to consider species active at the time of pesticide application.
5. Across the studies there is patchy information about excretion/ residue curves for parasiticides for the different routes of administration and formulations, in dung. More information would be valuable to producers in evaluating treatment time against dung beetle survival.

6. The dung community contains many beneficial species (for example predators and parasites of pest flies), in addition to dung beetles. A limited body of somewhat contradictory literature, and the use of contrasting experimental approaches, makes comparisons of the impact of various key chemicals on dung fauna (including dung beetles) difficult. The possibility that prolonged use of parasiticides will cause loss of beetle diversity (i.e. local extinctions) and changes to dung fauna in general has not been studied in depth. These factors have contributed to the varied and at times conflicting recommendations provided to producers/vets/advisors.
7. The long-term regional impact of parasiticide use on dung beetle populations has not been defined using field-scale studies. This is essential information if we are to develop industry wide strategies and if individual producers are to take into account the effects of neighbour's strategies.
8. The long-term impact of parasiticide use on dung beetle populations is unclear as is the loss of beetle diversity and changes to dung living insect's fauna with prolonged use of parasiticides.

## 5.2 Benefits to Industry

This project has the potential to benefit Australian producers and the industry through a number of direct and indirect channels:

- Identifying and understanding the research questions that will need to be answered in order to underpin new best practice guidelines with solid science and thereby enable producers to make informed decision around safe and appropriate use of pesticides.
- Helping to develop protocols for the consistent and objective assessment of new pesticides and their formulations and uses through specific assessment of their impact on dung beetles, in order to ensure the industry is able to safely incorporate new products into their farming practices.
- Providing producers with clear guidelines via a BPM on how to balance responsible chemical pesticide use with healthy dung beetle populations, for long-term benefits and sustainability.
- Actively reducing the reliance on chemical treatments to manage parasites, protecting valuable effective agents against the development of pesticide resistance, and reducing input costs by providing regionally specific and timely advice on pesticide usage.
- Assisting producers to take greater advantage of the multiple ecosystem benefits provided by having a full cohort of dung beetle species operating on farm throughout the year.

# 6. Future research and recommendations

The team makes the following recommendations:

1. Significant promotion of the ecosystem services and value of dung beetles to livestock producers is still required via a comprehensive extension program. There continues to be regions and producers who do not understand the benefits that dung beetles can play in pest management and the value they bring to a grazing system. There is a polarisation between those that do know and those that don't, and this is reflected in the parasite management decisions made on farm (as shown both from the literature and anecdotal evidence). The responsibility for this work begins with the DBEE, however since some of the economic valuing of beetle services will only be available at the end of the DBEE program, a new plan for extension beyond the life of the project is needed.

2. Dung beetle management advice must be included on ParaBoss (and affiliate websites) to provide produces with wholistic information to guide their animal treatment decisions. Advice would most likely focus on the timing of livestock treatments so as to minimise impact at critical beetle lifecycle stages. For example, the right application in early spring, as a new population of beetles' species emerge, may only impact winter active species who are nearing the end of their lifecycle. The lower parasite burden after this treatment may be then supported by the new dung beetles emerging and eliminating an additional number of parasite eggs.

3. ParaBoss is good for producers that have a good understanding of their farming system and need to select the right chemicals, but is not as helpful to producers wanting to build a strategy for parasite management. New Paraboss workshops are required to support advisor and consultant advice to producers. These need to include dung beetle sessions and management. Participants should include vets in sheep areas, both private and government; sheep health consultants; sheep extension staff and facilitators; rural merchandise staff with an animal health focus; pharmaceutical company sales staff and their technical managers; leading producers and farm managers; and veterinary and animal health lecturers, researchers and, students. Participants should learn a process that captures a farmer's current practices, relevant objectives, and their particular farm situation, and combines it with ParaBoss recommendations. This would then allow the participant to develop simple, but effective, annual farm management and treatment calendars for control of worms, flies and lice.

4. MLA should take ownership of the anthelmintic resistance (AR) issue across the industry to help producer address this issue. It is not the responsibility of APVMA to report or manage AR. Chemical companies have a vested interested and do not seem to be taking responsibility for AR. However, the information gap is a major factor in the mismanagement of products and the subsequent resistance that develops by parasites – producers simply do not know **their** anthelmintic resistance situation and if they do, seem to be addressing it in ways that may well increase resistance.

The project has recommended five area for future research. These are the highest ranked projects from a longer list of identified knowledge gaps, prioritised based on need, cost effectiveness and technical feasibility.

Project 1: Predicting the potential amount of chemical active in dung and the margins of safety for dung beetles.

Project 2: Develop dung beetle information packages for current key providers of pesticide recommendations.

Project 3: Develop guidelines to test the off-target effects of new actives on dung beetles.

Project 4: Determine the impact of buffalo fly ear tags on dung beetle populations.

Project 5: Research the role of dung beetles in controlling helminth populations.

# 7. References

Bergstrom, B.C.., Maki, L.R and Wehner B .A. 1976. Small dung beetles as biological control agents: laboratory studies of beetle action on trichostrongylid eggs in sheep and cattle feces. In Proceedings. *Proceedings of the Helminthological Society of Washington*, 43:2, pp. 171-174.

Doube, B., and Marshall, T. (2014). Dung down under: Dung beetles for Australia. Adelaide: Dung Beetle Solutions Australia.

Floate, K. D. 2006. Endectocide use in cattle and fecal residues: environmental effects in Canada. *The Canadian Journal of Veterinary Research*. 70, pp. 1-10.

Fincher, G., Monson, W., and Burton, G. 1981. Effects of cattle feces rapidly buried by dung beetles on yield and quality of coastal Bermuda grass. *Agronomy Journal*, 73, pp. 775-779.

Gupta, V.V., Sharma, A. K.(Eds) 2021. Rhisosphere Biology: Interactions Between Microbes and Plants. Springer. ISBN: 978-981-15-6125-2

Jacobs, C.T. and Scholtz, C.H., 2015. A review on the effect of macrocyclic lactones on dung-dwelling insects: Toxicity of macrocyclic lactones to dung beetles. *Onderstepoort Journal of Veterinary Research*, *82*(1), pp.01-08.

Losey, J.E. and Vaughan, M., 2006. The economic value of ecological services provided by insects. *Bioscience*, *56*(4), pp.311-323.

Manning, P., Slade, E.M., Beynon, S.A. and Lewis, O.T., 2017. Effect of dung beetle species richness and chemical perturbation on multiple ecosystem functions. *Ecological Entomology*, *42*(5), pp.577-586.

Meat & Livestock Australia, 2015. *B.AHE.0010 Meat & Livestock Australia Final Report: Priority list of endemic diseases for the red meat industries.* *https://www.mla.com.au/contentassets/5c4a6eb332a94448b15602249c9fa6f1/b.ahe.0010_final_report.pdf* accessed 14 May 2021.

Meat & Livestock Australia 2021. *The Cattle Parasite Atlas.* https://www.mla.com.au/research-and-development/animal-health-welfare-and-biosecurity/parasites/cattle-parasite-atlas/ accessed 14 May 2021.

Nichols, E., Spector, S., Louzada, J., Larsen, T., Amezquita, S., Favila, M.E. and The Scarbaeinae Research Network, 2008. Ecological functions and ecosystem services provided by Scarabaeinae dung beetles. *Biological conservation*, *141*(6), pp.1461-1474.

Rhodes, C.J., 2017. The imperative for regenerative agriculture. *Science progress*, *100*(1), pp.80-129. https://doi.org/10.3184/003685017X14876775256165.

Sands, B. and Wall, R., 2018. Sustained parasiticide use in cattle farming affects dung beetle functional assemblages. *Agriculture, Ecosystems & Environment*, *265*, pp.226-235.