Integrated Project- Dung beetle activity in the Northern Rivers region of New South Wales

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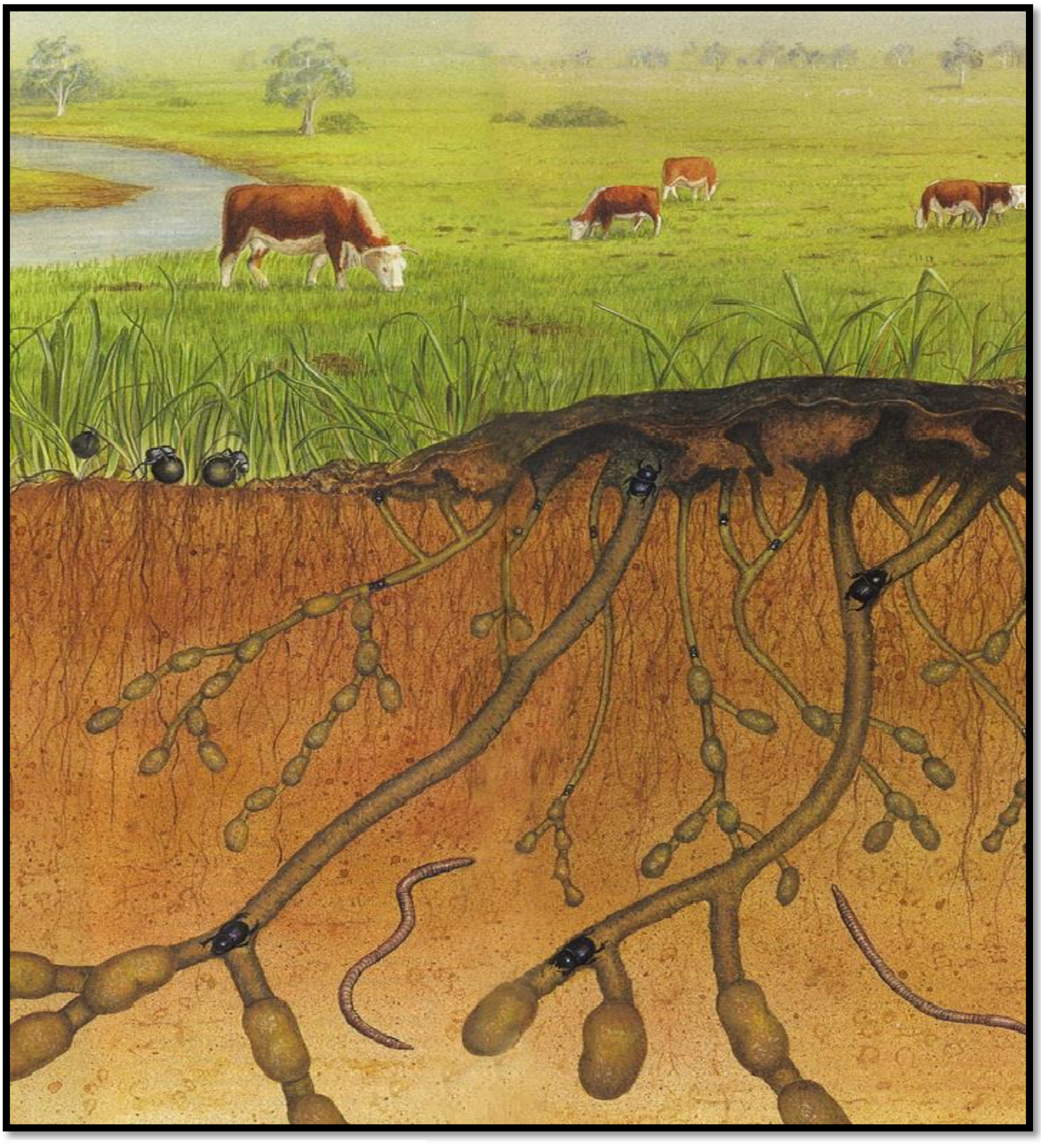

Source: Australian Geographic, (1994).

This document is the result of an Undergraduate Integrated Project at Southern Cross University. It contains information derived from samples collected during September 2016 to December 2017 and has been prepared for the landholders and other parties involved in the project.

Acknowledgements

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- *Tweed Shire Council Natural Resource Management Unit:* **Eli Szandala** (*Sustainable Agriculture- program leader*) and **Aiden Sloman** (*Biodiversity- project officer*)
- *Whian Whian Landcare*: **Emma Stone** (*Landcare coordinator*)
- **John Grant** (*Academic supervisor*)

Abstract

Dung beetles provide the biological control of dung by burying and dispersing it for their nutritional and reproductive needs. This has numerous benefits for graziers and the environment including reduced pest and parasite incidence, enhanced soil structure and fertility, increased pasture production and decreased pollution of waterways. The Northern Rivers region of New South Wales currently experiences a gap in dung beetle activity during the cooler months in winter and early spring. This represents a lost opportunity for nutrients to be buried underground and stabilised via dung beetles. Little is known about the identity and distribution of species occurring in the area, or of the impact of farmer's management regimes. The aims of the present study were to 1) assess the suitability of introduced species *Bubas bison* to fill the areas current winter gap in activity by conducting field trials at two different locations 2) identify spring active dung beetle species and their emergence periods in a number of locations throughout the region with different site characteristics 3) survey a number of sites with different pest control regimes in order to investigate what effects this might be having on beetle species, and 4) prepare a technical report, a brochure and contribute to community field days to convey the findings of the study; and to promote the role of dung beetles in enhancing farm productivity and environmental sustainability. Adult *B. bison* were released into soil core traps at Whian Whian and Koonorigan on the 4th June 2016 and assessed nearly 4 months later on the 26th September. Results revealed 5 brood balls, 3 of which contained eggs; and a total 10 brood balls, 5 of which contained eggs and one containing a larva, at the first and second site respectively. A total of 7 survey sites were established in the Tweed Shire and surveys were conducted from September 2016 to December 2017. During these surveys a total of 16 different species were observed including 14 introduced and 2 native species. Species richness generally increased at the sites throughout surveys. A survey of landholders' management practices showed a heavy reliance on parasiticides for pest control. The effect of parasitices on dung beetles and their different methods of application were considered. The project engaged with the community through contributing to field days and by preparing a brochure about how dung beetles promote productive and sustainable agriculture.

Keywords: Dung beetles, *Bubas bison*, soil core traps, dung burial, sustainable agriculture, Northern Rivers

Contents

1. Introduction

1.1 Background

There are around 26 million cattle in Australia (ABS, 2005). Each individual produces around 18kg of dung each day resulting in over half a billion tonnes of dung being deposited onto Australian soils and pasture, or in feedlots or dairy sheds every day (Doube, 2008). On the land surface this dung reduces pasture palatability, serves as a breeding ground for pests and parasites, has the potential to release greenhouse gases such as methane and nitrous oxide and has the potential to contaminate groundwater and surface water bodies with a range of nutrients and organic matter (Bornemissza, 1960; Doube, 2008; Nichols *et al.*, 2008). If the nutrients could be stabilised and the dung placed below ground, there would be major benefits to productivity, soil, water resources and in the reduction of greenhouse gases (Bang *et al.*, 2005; Doube, 2008).

Dung beetles provide ecosystem services that benefit the economy, agricultural productivity and environmental sustainability. Tunnelling, burial and dispersal of dung by dung beetles reduces pasture fouling (Bang *et al.*, 2005; Bornemissza, 1970; Doube & Marshall, 2014) and nutrient runoff into water ways (Bornemissza, 1960; Doube, Dalton & Ford, 2003; Doube & Dalton, 2003; Fincher, 1981), decreases pest fly and parasite breeding habitat (Doube, 2004; Ryan, Yang, Gordon, & Doube, 2011; Waterhouse, 1974) and augments nutrient cycling, soil fertility, water infiltration and aeration of soil (Bornemissza, 1976; Doube, 2008; Doube & Marshall, 2014; Fincher, 1981; Nichols *et al.*, 2008). In doing so, dung beetles are considered to have the potential to transform the otherwise pollutant dung into a multi-million dollar production benefit (Bornemissza, 1970; Doube & Dalton., 2003; Waterhouse, 1974).

Summer and winter active dung beetle species have been previously released by government funded projects and other private operators in winter and even-rainfall regions of Australia over past decades (Doube, 2008). However, because the beetles are relatively slow to disperse and colonise new areas most regions still lack a fauna capable of achieving effective, year round disposal of cattle dung. The lack of dung beetles in late winter and early spring represents an annual loss of 17- 25% of that benefit in the main grazing areas of temperate Australia (Wright *et al.*, 2015). In order to rectify the lack in dung beetles in these regions it is first necessary to determine the current and potential distributions of species to identify where there are significant gaps in activity (Doube, 2008). In addition to this, it is necessary to trial candidate species to assess their capacity to establish in these areas, and effectively provide a blanket of year round activity (Doube, 2008). Lastly, once the appropriate candidate species have been selected, they should be subject to widespread introductions in areas where they are absent (Doube, 2008).

The ecosystem services provided by dung beetles undoubtedly have a significant monetary value to the Australian economy by reducing expenditure on farming inputs, pest and parasite control and costs associated with the negative externalities suffered from land degradation. One could assume that the reduction in pest fly numbers resulting from dung burial by dung beetles would be worth millions of dollars to the likes of food, cafe, livestock, tourism and other effected industries. Studies in the U.S. suggest that estimated economic losses averted annually as a result of accelerated burial of livestock faces by dung beetles to be worth $122 million due to reduced pasture fouling, $58 million for reduced nitrogen loss and $200 million saved by reducing pests and parasite incidence (Losey & Vaughan, 2006). Further to this, in Australia it is estimated that cattle dung could be worth over $7 billion per annum if it was all converted into organic fertiliser (Doube, 2008).

A recently developed method involves the feeding of biochar to cattle. This reduces methane production from the rumen and also binds some of the otherwise highly mobile nutrients in the dung. If the dung, with incorporated biochar, is then buried by dung beetles there are further benefits to be had (Joseph *et al*., 2015). The International Panel on Climate Change and the FAO have identified cattle production as one of the major contributors to greenhouse gases (Gerber *et al*., 2013). This technology has potential to mitigate some of those emissions and provide an advantage for Australian producers.

Australia is host to a rich dung fauna including around four-hundred indigenous species of dung beetles (Edwards, 2002). Some of these species can be observed in cattle dung, however the majority occur exclusively in woodlands and forests where they have coevolved with marsupials and feed primarily on their dry fibrous dung (Bornemissza, 1960, 1976; Doube, Macqueen, Ridsdill-Smith, & Weir, 1991; Edwards, 2002). When cattle were introduced in 1788 the large, moist dung they produced proved beyond the capacity of indigenous dung beetles (ABS, 2005). This resulted in vast amounts of dung lying undispersed on grazing land for extended periods of time (Bornemissza, 1960, 1976; Doube & Marshall, 2014; Nichols *et al*., 2008).

1.2 History of dung beetle introductions into Australia

Dr George Bornemissza from the CSIRO division of Entomology knew that in his native Hungary it was common to observe dung beetles effectively dispersing cattle dung, and he became the first to propose that exotic dung beetles be introduced into Australia to address the production and environmental issues associated with the excessive amounts of manure (Bornemissza, 1960, 1976). In 1968, he initiated and developed the 'Australian Dung Beetle Project' which involved considerable investment in importing, testing and distributing exotic dung beetle species, mostly from Africa and Mediterranean Europe where they coevolved with dung from large ruminants (Bornemissza, 1976; Wright, Gleeson, & Robinson, 2015). The main project was terminated in 1986 when industry funding was withdrawn, by which time over 50 species of the Scarabaeid dung beetles had been released into the country (Edwards, 2002; Wright *et al*., 2015). In all, 23 introduced dung beetle species have become established in Australia as a result of the project including twenty-one tunnellers and two ball rollers (Doube & Marshall, 2014). They can now be observed burying significant volumes of dung in many locations where they have become well established (Doube, 2008; Losey & Vaughan, 2006). This is well demonstrated in parts of South Australia, where as many as five-thousand beetles can be found in a single pad, resulting in its complete disintegration in as little as one day (Doube, pers. comm., 2016).

1.3 Dung beetle biology

Adult dung beetles feed on the fluid portion of dung, whereas the beetle larvae feed on both the fluid and solid portions. In both cases, they feed exclusively on the dung from vertebrates. Dung beetles are strong fliers and can travel several kilometres during a single dung searching event, guided by an excellent sense of smell. Different beetle species may either fly during the daylight hours or at dusk or dawn. Adults may nest in tunnels beneath dung pads or in dung balls rolled some distance away. Tunnelling beetles carry dung underground and mould it into balls ('brood balls') to lay eggs in. Larvae hatch from the eggs and feed on the dung in the brood ball. Once the larval growth is complete, the larva pupates, before emerging as an adult and digging up to the soil surface. The number of generations per season varies depending on the species of dung beetle and environmental variables. Factors influencing the seasonal patterns of dung beetle breeding are dung quality, temperature and soil moisture and the length of time between generations depends the species (Ridsdill-Smith, 1993).

1.4 Pest control regimes and toxic dung

Agvet chemicals include the various pesticides, parasiticides and veterinary medicines that are used to control pests, diseases and parasites that are detrimental to animal husbandry and agricultural productivity. In the Australian cattle industry, parasiticides are commonly used to control both internal parasites (e.g. gastrointestinal worms) as well as external parasites such as ticks, lice and buffalo fly. The results of laboratory studies have led to the growing realisation that the active ingredients of many parasiticides or their breakdown products have serious potential to harm dung beetles. In addition to this, the risk of such harmful effects from chemical treatments used for pest control, coupled with a general lack in accessible information has generated confusion among some farmers who believe it is in their best interest to minimise toxicity to dung beetles. Synthetic Pyrethroids (SP's) are a group of parasiticides that were once used extensively for controlling cattle ticks, and are now mainly employed to control buffalo fly (Wardhaugh, 2000). It is now recognised that the fly fly has developed a high level of resistance to SP's in areas (Wardhaugh, 2000). Macrocyclic Lactones (ML's) are another group of parasiticides that have been used for years in cattle to control worms and ticks, with the added bonus of buffalo fly and louse control (Benz & Cox, 1989). ML's have the broadest spectrum out of all parasiticides, as is the case for avermectins (a type of ML) which are toxic to a very wide range of insects and arthropods (Strong and Brown, 1987). Ridsdill-Smith (1993) details how scarabaeine dung beetles feeding on dung from cattle treated with an injection of avermectin exhibited larval mortality, mortality of immature adults, reduced egg production and inhibited ovariole development for periods of 1- 4 weeks following treatment. Although there was no evidence suggesting that avermectin had any detrimental effects to the adult dung beetles, populations would certainly be adversely affected should treatment coincide with peak breeding season (Wardhaugh, 2000). Fortunately, there are some alternatives to treating cattle with beetle toxic chemicals. Moxidectin, another ML, claims to have no known effect on dung beetles (Wardhaugh, 2000: Wardhaugh, Longstaff & Morton, 2001). Only a relatively small number of studies have investigated the toxicity of moxidectin to beetles, and the numbers of different species that have been tested are also limited. However, the claim does seem to be true, making the substance a valuable agricultural resource that needs careful management in order to avoid the development of resistance among pests. There is still a suite of agvet chemicals (including parasiticides) that are yet to be tested for their toxicity to dung beetles, and the majority of those that have been tested are done so under laboratory conditions, highlighting the need for further and more extensive testing in the field in order to fill the current lack of information and its level of accessibility.

1.5 Justification for current research

The Northern Rivers region in New South Wales supports healthy populations of summer active dung beetles but lacks those that remain active throughout the winter and early spring periods (Doube & Marshall, 2014; Wright *et al*., 2015).This gap in activity results in excess unburied dung and a lost opportunity to further improve soil and pasture, minimise pests and parasites, reduce nutrient runoff into waterways and reduce greenhouse gas emissions by optimising dung beetle activity. Little is known about the current activity of dung beetle species in the area and the effects of different management regimes on those species. In 2015, following advice from dung beetle experts, a batch of the introduced species *Bubas bison* was released in one trial location by Whian Whian Landcare in an attempt to canvas the potential for this species to fill the winter gap. However, they failed to establish, probably due to the limited number of beetles used. A more recent attempt in 2016 saw the release of greater numbers of *B. bison* involving multiple landholders with a range of site characteristics. This release presently requires monitoring and additional research is necessary to determine what species are active during the spring period in the region, the first emergence period of these species, as well as to understand the effect particular farm management practices have on those species.

1.6 Aims and Objectives

This project aims to contribute to optimising dung beetle activity in the Northern Rivers region, through the following objectives:

- To assess the potential of introduced species *Bubas bison* in filling the current winter gap in dung beetle activity
- To identify spring active dung beetle species in the region and determine the first emergence period of these species in a number of locations with different site characteristics
- To survey sites with different pesticide regimes and determine what effect this might be having on these species
- To prepare a technical report, an information brochure and participate in community events to present the findings of the study and provide strategies for graziers to optimise their dung beetle populations and inform them about how they benefit agricultural productivity, economy and environmental sustainability

2. Methods

2.1 Details of the study area

The study was located in the Northern Rivers region on the far north coast of New South Wales, Australia (Figure 1).

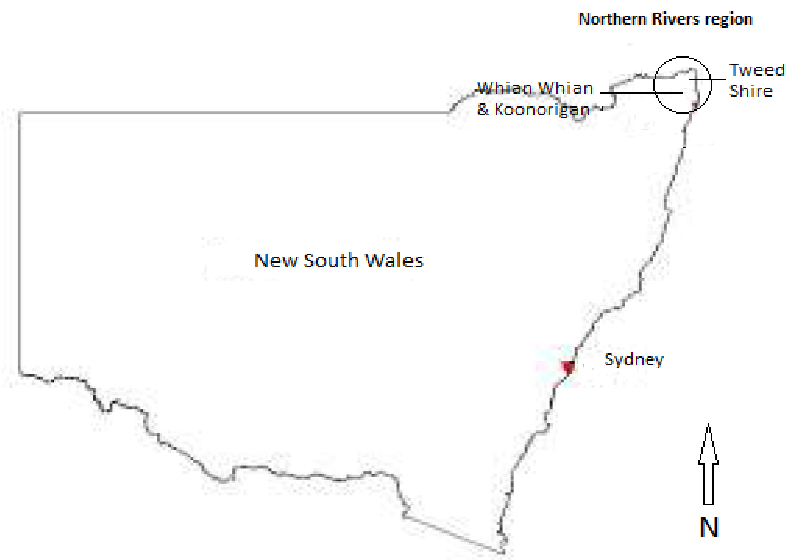

Figure 1: Location of the Northern Rivers dung beetle study in north east New South Wales

The regions subtropical to temperate climate is associated with relatively mild temperatures throughout the year and distinct late-summer to early-autumn maximum rainfall and mostly dry winters (Figure 2).

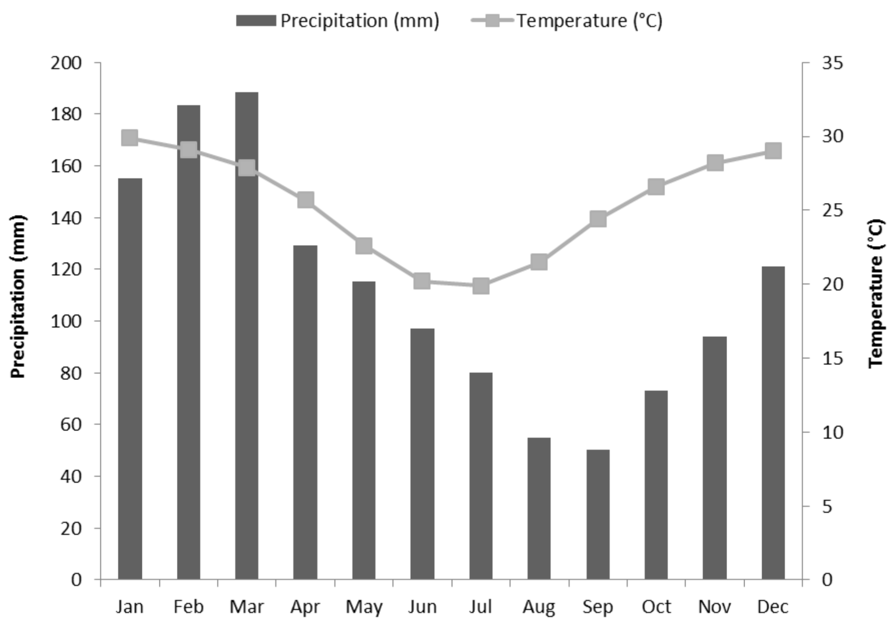

Figure 2: Climograph showing mean monthly precipitation and temperature in the Northern Rivers

The region is situated within the Mesozoic Clarence-Moreton Basin, a structure comprising siltstones, shales, lithic and quartz sandstones and conglomerates. The Northern rivers section of the basin are dominated by Tertiary volcanics originating from the Tweed Shield Volcano in the middle of the Tweed Valley, and the Focal Peak Volcano located in south east Queensland. The lavas are mostly basalts with some areas of rhyolite. Quaternary alluvium occurs throughout large areas of the region and extensive Quaternary sand bodies flank the coast. Palaeozoic metasediments form most of the landscape on the eastern side of the catchment (Morand, 2010).

Brown, Yellow, Red and Grey Kurosols generally form on sedimentary rocks and metasediment areas in the Clarence-Moreton Basin. Red Ferrosols and Brown Dermosols can be found on the basaltic slopes and Vertosols on basaltic foot slopes and drainage depressions. Soils formed on alluvium are variable however Vertosols are dominant where basalt is the main source of sediment. Otherwise, Grey Kurosols, Dermosols, Kandosols, Vertosols and Hydrosols occur in varying combinations. Podosols have mainly formed on the coastal sand bodies along with Organosols. The estuarine areas are generally occupied by Sulfidic or Sulfuric Hydrosols (Morand, 2010).

2.2 Bubas bison trials

Field trials were conducted at Whian Whian and Koonorigan to assess the site suitability for *B. bison* to tunnel, bury dung, and breed and for the young to develop into adults and emerge. The area was once dominated by a closed forest vegetation type known as the 'big scrub' recognised for being the longest continual stretch of lowland subtropical rainforest to ever exist in Australia. Extensive logging and clearing associated with European settlement has resulted in only 1 % of the original vegetation existing today. The major types of land use now include urban development, intensive horticultural crops and grazing land. Both trial sites were dominated by a Ferrosol soil type which is generally well-structured and free-draining with a high clay content throughout the profile (Australian Soil classification). At each site three soil cores (15 cm diameter x 45 cm depth) were extracted from the soil profile before being lined with beetle-proof onion bags and the soil returned with care to ensure that mixing of soil horizons was avoided. The top of the bags protruded above the soil surface such that it could be tied up, leaving enough space for a dung pad and adult beetles to be added. The onion bag material allowed water, soil organisms and plant roots to move freely between the core trap and surrounding soil but does not allow adult beetles to escape. On the 4th June 2016, fresh dung and 20 adult *B. bison* were placed into each trap and the bags tied. Sites were visited on the 23rd of September (almost 4 months later) and traps were assessed. This was done by carefully excavating around the soil cores lined with onion bags before removing and placing them onto a tarp to be cut open. The number of brood balls, eggs, pupae and larvae and depth of burial was recorded.

2.3 Identifying spring active dung beetle species in the region- Tweed Shire

A landholder survey was carried out to obtain information about potential participant's geographical location, site characteristics and management regimes. This was done in order to stratify survey sites according to dung beetle species with environmental preferences. A total of seven sites were established, five of which were surveyed twice; in early spring and again in late spring/ early summer. The purpose of surveying on two occasions was to examine if there was any chance in species richness as the season progressed.

Surveying commenced in September and finished in early December. Ten replicate samples were collected at each site which involved recovering dung beetles from pads using the flotation method. The method involved selecting dung pads that are about 2 days old to give both night and day-time flying species a chance of being attracted and represented in the sample. Using a shovel, dung pads were scooped up along with about 5-10 cm of soil from underneath and placed into a 10 L bucket of water and the contents stirred to break up any aggregates of dung. A total of about five minutes was allowed for the beetles to float to the surface where they were collected for identification (Feehan, 1999). Species were identified in the field where possible with reference to- *Introduced Dung Beetles in Australia. A Pocket Field guide* (Wright *et al*., 2015). Species that were unable to identified using rapid survey methods were collected and preserved for later identification including seeking advice from technical experts where needed. Some other ancillary data collected in the field included estimated percent of dung burial and the number of soil casts and brood balls observed in samples.

2.4 Survey sites in the Tweed

Pumpenbill

Site details: Located beneath the 'pinnacle' of the Border Ranges in the western area of Tweed Shire (Figure 3), this area formerly comprised of rainforest and sclerophyll vegetation types. Extensive clearing has occurred and the major land use is now for improved pasture.

Soil description: Moderately well drained, brownish black fine sandy clay loam, with a weak grade of pedality and very weak consistence. Depth 2 m+. (Morand, 2017).

Industry type: Beef cattle Pest management: Diazinon and coumaphos (ear tags)

Uki

Site details: This site is situated just south of the Tweed Volcano (Figure 3). The former rainforest vegetation has been extensively cleared and the area is now dominated by camphor laurel (Cinnommonium camphor).

Soil description: Moderately well drained, dark brown coarse light sandy clay loam, moderate pedality and a very weak consistence. Depth to 1.5 m. (Morand, 2017).

Industry type: Beef cattle	Pest management: Moxidectin Pour-on – buffalo fly and tick season. Own mix – vegetable oil, Dettol, methylated spirits and Eucalyptus oil

Murwillumbah

Site details: Located in the centre of the Tweed Shire, this site lays to the east of the Tweed Volcano (Figure 3). The historic rainforest vegetation has been cleared with only a few isolated remnant species remaining. The main land uses surrounding the site include improved pasture and urban development.

Soils: Well drained, dark brown light clay with strong to moderate pedality, moderately plastic and very weak consistence. Depth to 1.5 m +. (Morand, 2017).

Industry type: Dairy	Pest management: N/A

Burringbar

Site details: Located in the east and in close proximity to Tweed coast line (Figure 3), this site has been extensively cleared and is now used for timber/ scrub/ unused, with improved pasture occurring in the general area.

Soils: Moderately well drained, brown yellow medium clay with strong pedality and a sticky, moderately weak consistence. Depth 1.5 m +. (Morand, 2017).

Industry type: Dairy	Pest management: Moxidectin- September, eprinomectin- October, ivermectin- June

Mount Burrell

Site details: Located in the south west of the Shire (Figure 3), the site has been extensively cleared with existing vegetation on steep slopes to the south towards 'Sphinx Rock'. Land is used for scrub/ unused and some areas of pasture.

Soils: Well drained, reddish brown light clay, pedality strong and consistence moderately weak. Depth 2 m +. (Morand, 2017).

Industry type: Alpaca hobby farm	Pest management: Q drench and Zolvix

Eungella

Site details: Located to the north of the Tweed Volcano (Figure 3) on a hillslope, the previous rainforest and wet sclerophyll vegetation has been completely cleared, and the area is now used for pasture, banana plantations and other restricted agricultural crops.

Soils: Well drained, dark brown light medium silty clay with weak pedality and moderately firm consistence. Depth to 1 m +. (Morand, 2017).

Industry type: Hobby beef cattle	Pest management: Moxidectin ear tags. Pyrethroid ear tags before last round of sampling

Sleepy Hollow

Site description: This was furthest east and most coastal survey site (Figure 3) with tall undulating hills and steep slopes comprising existing rainforest and sclerophyll vegetation from down into narrow foothills and deep gullies which have been cleared and are used for improved pasture.

Soils: Well to moderately drained dark greyish yellow brown silty clay loam with moderate pedality and weak to moderate consistence. Depth to 3 m. (Morand, 2017).

Industry type: Beef cattle   Pest management: N/A

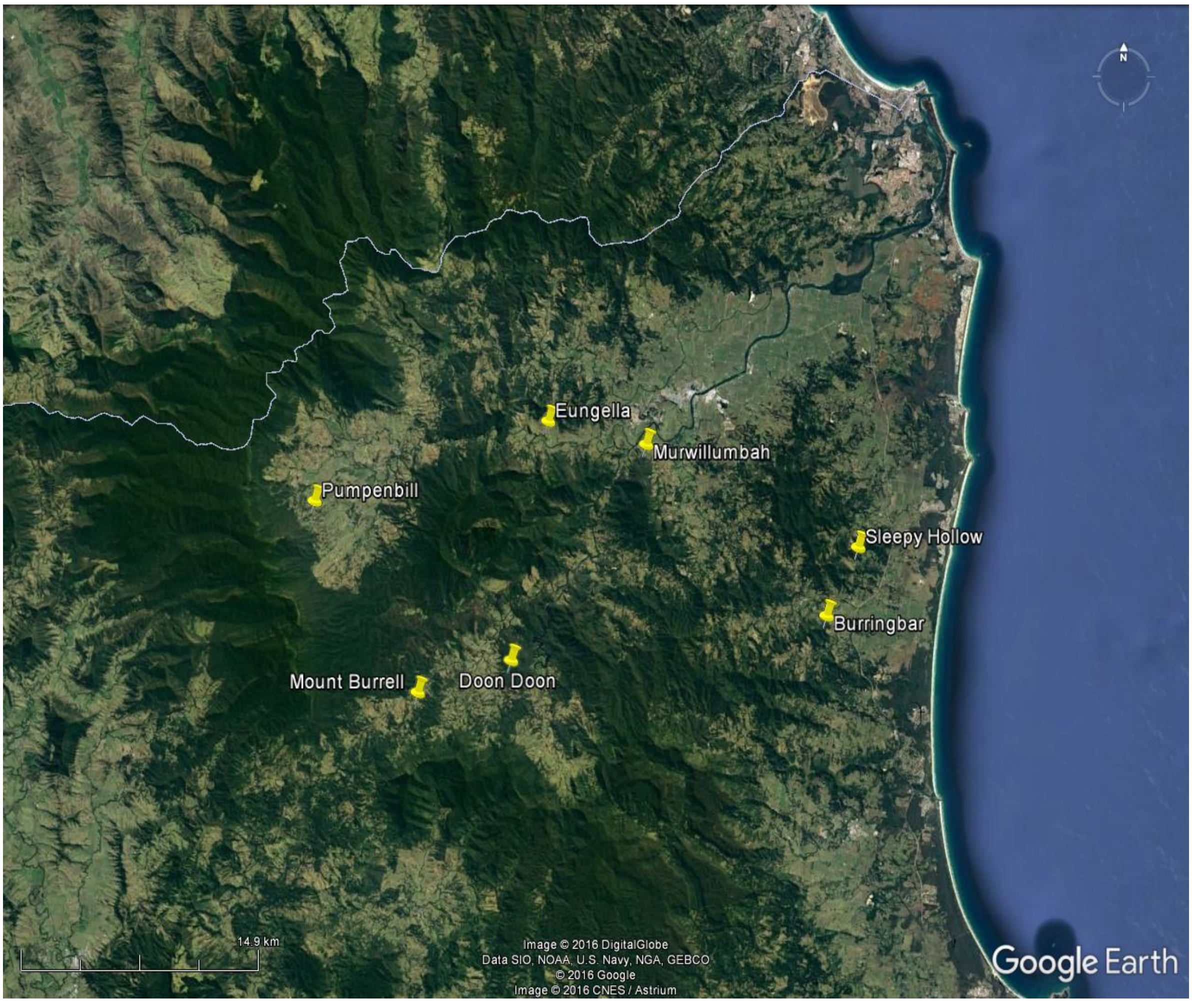

Figure 3: Geographical location of the seven survey sites located in the Tweed Shire (Google Earth, 2017).

3. Results

3.1 Landholder surveys

The landholders represented 3 different livestock industries including 4 beef farmers, 2 dairy farmers, and 1 alpaca hobby farmer (Figure 4).

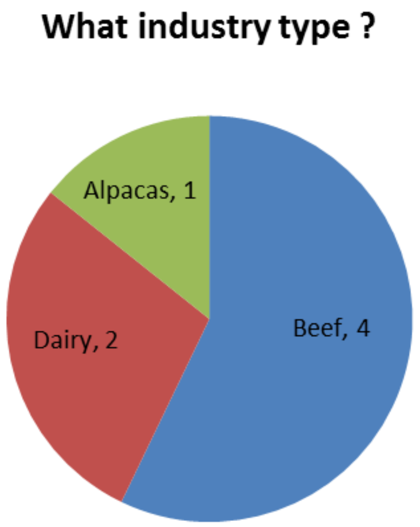

Figure 4: Number of landholders representing different livestock industries where dung beetle surveys were conducted

When landholders were asked if they currently monitored dung beetles on their property, most responded no (67%). Seventeen percent indicated that they conducted informal monitoring only. Only 16% of respondents actively monitored dung beetles (Figure 5).

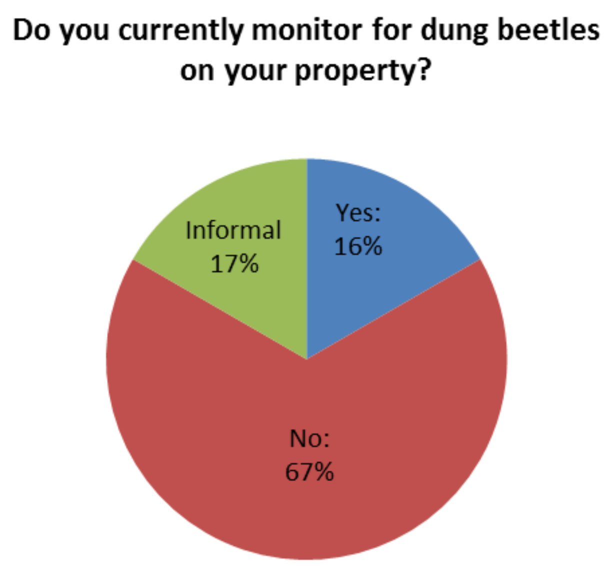

Figure 5: Percentage of respondents who actively monitored dung beetles on their property

Half of the respondents said that they had not ever previously observed dung beetles on their property (Figure 6).

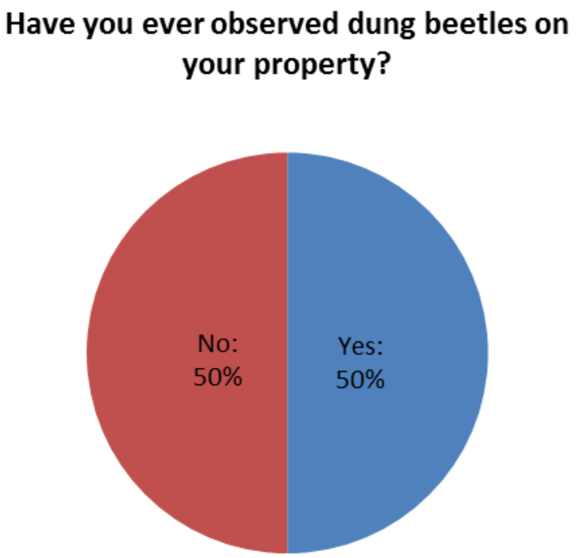

Figure 6: Percent of respondents who had previously observed dung beetles on their property

The vast majority of respondents had not previously released dung beetles on their property 83%. Murwillumbah and Burringbar landholders represented the landholders who had (17%), (Figure 7).

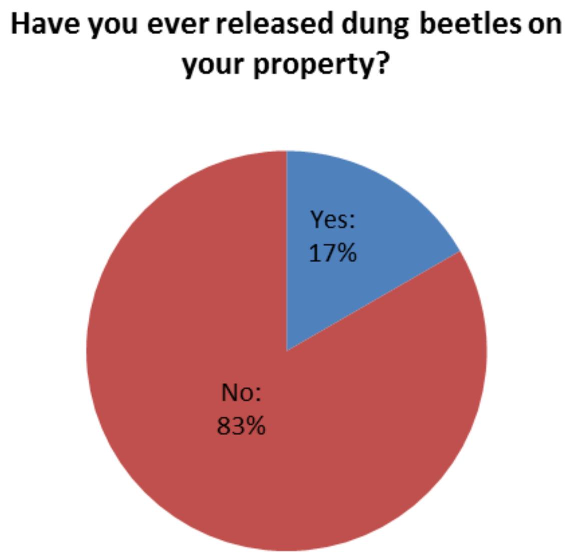

Figure 7: Percent of respondents who had previously released dung beetles

The most popular chemical used by landholders for pest and parasite control was Cydectin (Moxidectin) (67%), with half applying the product as pour-ons and the other half using ear-tags. Other respondents indicated that they used Eprinomectin pour-ons and ear-tags containing Diazinon and Coumaphos (Figure 8).

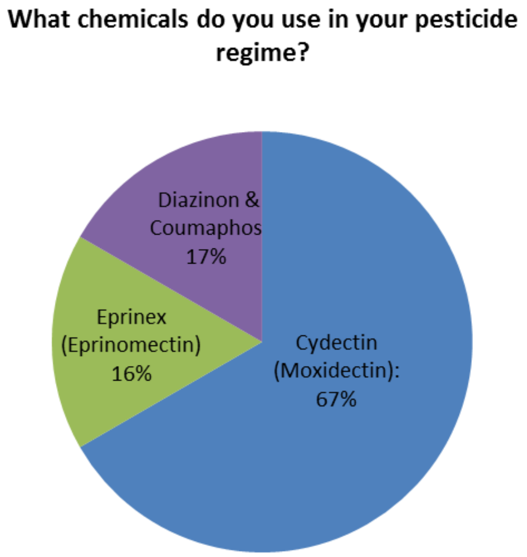

Figure 8: Percentage of landholders using certain chemicals to control pests and parasites

When asked how important they perceive the benefits of dung beetle to be farm productivity and environmental sustainability on a scale of 1 to 5, half of the respondents gave a rating of 5. Thirty-three percent contributed to the lowest rating of 3 out of 5 (Figure 9).

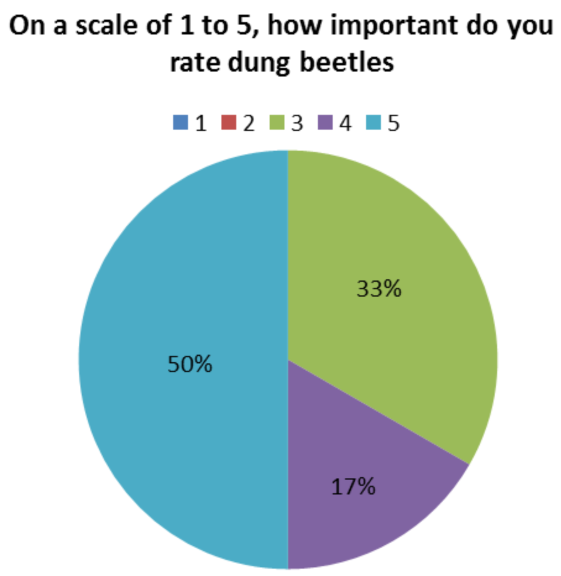

Figure 9: Landholders rating of the importance of dung beetles for productivity and sustainability

The majority of respondents (67%) indicated that they would be interested in taking part in dung beetle surveys on their properties to help them gain the skills to do so themselves in the future (Figure 10).

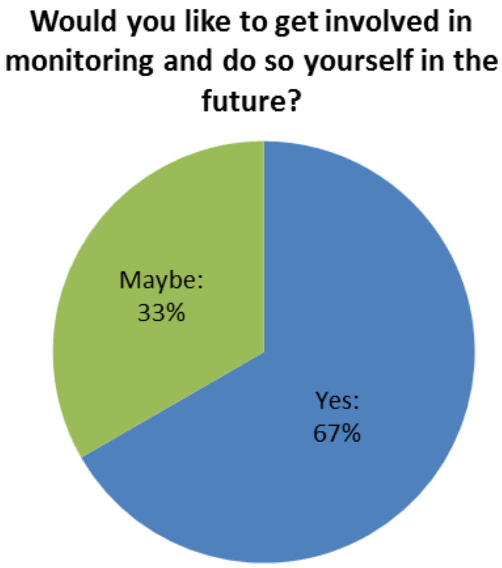

Figure 10: Percentage of landholders interested in taking part in dung beetle surveys on their property

When landholders were asked if they would be interested in participating in a future community field day to present and discuss the project findings, the vast majority said yes (83%) and the remainder said maybe (Figure 11).

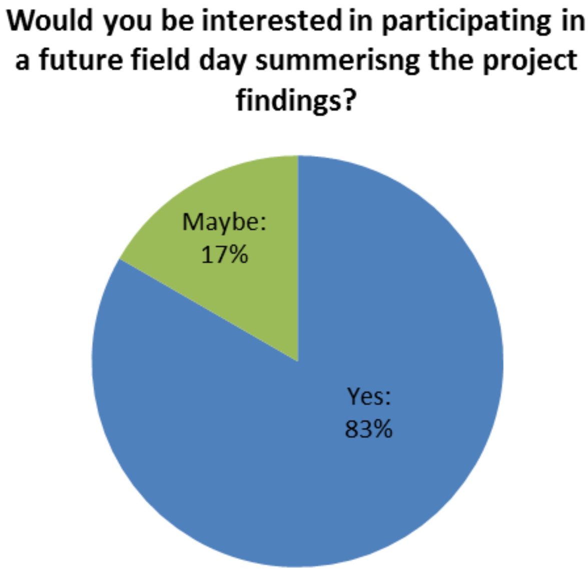

Figure 11: Percentage of respondents interested in attending a community field day at project completion

3.2 Bubas bison trials

Monthly rainfall figures for The Shannon (located and in close proximity between Whian Whian and Koonorigan) are shown in Figure 12. Mean monthly rainfall values ranged from 112.3 mm in June to 46.2 mm in September. Total monthly rainfall values ranged from 311.4 mm in June when *B. bison* where released into traps, to 36.9 mm in September when traps were assessed.

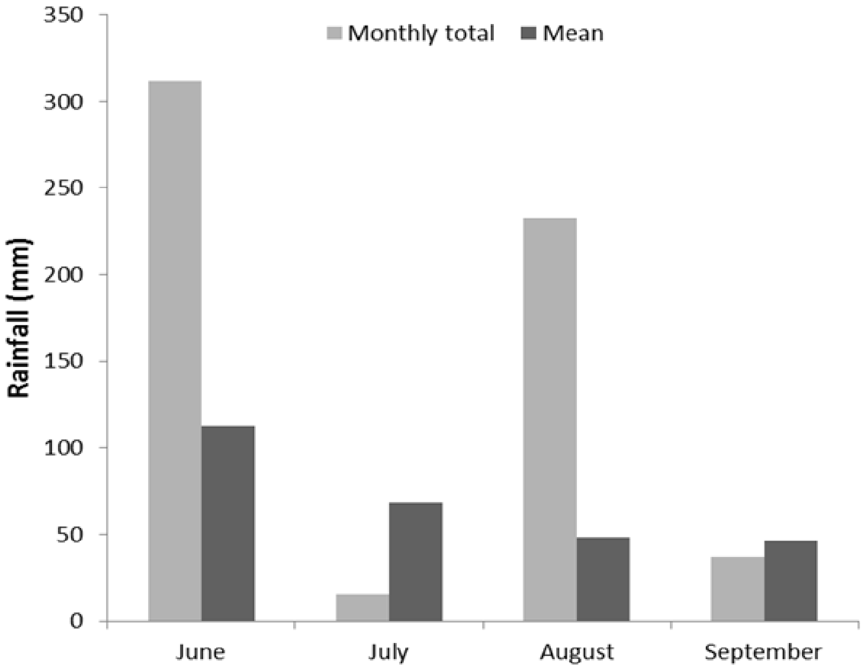

Figure 12: Mean and total monthly rainfall at sites for the period of the B. bison trial in 2016 (BOM, 2017).

A total of five brood balls were found buried in the soil core at Whian Whian, three of which contained a single *B. bison* egg (Table 1).

Table 1: Results from *Bubas bison* trial at Whian Whian

Date assessed	Property name	Locality	Findings
23-09-2016	Nathan Kesteven	Whian Whian	5 x brood balls >40cm 3 x eggs

Figure 13: Onion bag with soil core inside being removed from the ground at the Whian Whian trial site

Figure 14: Tunnels and buried dung found at the bottom of the soil core profile at Whian Whian

Figure 15: A single *Bubas bison* egg found inside a brood ball at Whian Whian

Ten brood balls were found buried to the bottom of the soil core at Koonorigan, with five each containing a single *B. bison* egg and one containing a live larvae (Table 2).

Table 2: Results from *Bubas bison* trial at Koonorigan

Date assessed	Property name	Locality	Findings
23-09- 2016	Stephanie Alt	Koonorigan	10 x brood balls >45cm 5 x eggs 1x larvae

Figure 16: The onion bag with soil core inside being cut open at Koonorigan

Figure 17: Evidence of tunnelling and dung burial by *B. bison* down to the bottom of the soil profile at Koonorigan

Figure 18: A *B. bison* egg inside brood ball at Koonorigan

Figure 19: *Bubas bison* larvae found inside a brood ball at Koonorigan

3.3 Dung beetle surveys in the Tweed Shire

Mean and total monthly rainfall figures for the period that dung beetle surveys were conducted in the Tweed are shown in Figure 20.

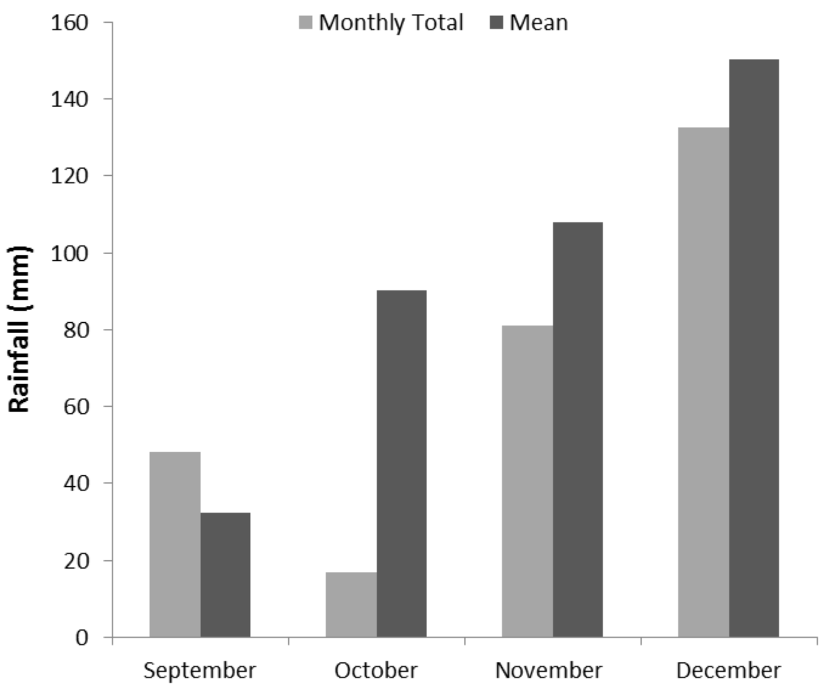

Figure 20: Mean and total monthly rainfall at sites for the period of dung beetle surveys in the Tweed Shire in 2016 (BOM, 2017).

Table 3: The species of Scarabaeoidea found during surveys, their taxonomical affiliations and geographical range within the Tweed Shire

Species name	Family	Subfamily	Tribe	Sites observed
## Aphodius fimetarius	Scarabaeidae	Aphodiinae	Aphodiini	Pumpenbill, Doon Doon, Murwillumbah, Burringbar, Mount Burrell, Eungella and Sleepy Hollow
## Aphodius lividus	Scarabaeidae	Aphodiinae	Aphodiini	Pumpenbill, Doon Doon, Murwillumbah, Burringbar, Mount Burrell, Eungella and Sleepy Hollow
# Euoniticellus intermedius	Scarabaeidae	Scarabaeinae	Oniticellini	Burringbar and Eungella
#^ Hister nomas	Histeridae	Histerinae	Histerini	Pumpenbill, Murwillumbah, Burringbar, Eungella and Doon Doon,
# Liatongus militaris	Scarabaeidae	Scarabaeinae	Oniticellini	Pumpenbill, Doon Doon, Sleepy Hollow, Burringbar, Murwillumbah and Eungella
# Onitis alexis	Scarabaeidae	Scarabaeinae	Oniticellini	Murwillumbah, Pumpenbill, Doon Doon and Eungella
# Onitis pecuaris	Scarabaeidae	Scarabaeinae	Oniticellini	Burringbar and Eungella
# Onitis viridulus	Scarabaeidae	Scarabaeinae	Oniticellini	Eungella and Sleepy Hollow
** Onthophagus australis*	Scarabaeidae	Scarabaeinae	Onthophagini	Pumpenbill and Doon Doon
# Onthophagus binodis	Scarabaeidae	Scarabaeinae	Onthophagini	Pumpenbill
** Onthophagus capella*	Scarabaeidae	Scarabaeinae	Onthophagini	Pumpenbill
# Onthophagus gazella	Scarabaeidae	Scarabaeinae	Onthophagini	Doon Doon, Murwillumbah, Mount Burrell, Eungella, Pumpenbill, Sleepy Hollow and Burringbar
# Onthophagus nigriventris	Scarabaeidae	Scarabaeinae	Onthophagini	Eungella
# Onthophagus sagittarius	Scarabaeidae	Scarabaeinae	Onthophagini	Pumpenbill, Doon Doon, Murwillumbah, Burringbar, Eungella and Sleepy Hollow
# Sisyphus rubrus	Scarabaeidae	Scarabaeinae	Sisyphini	Eungella
#^ Sphaeridium discolor	Hydrophilidae	Sphaeridiinae	Sphaeridiini	Doon Doon, Murwillumbah and Eungella

Names of species prefaced by # are introduced, ## accidentally introduced, * native and ^ predatory

Table 4: Summary of results from dung beetle surveys in the Tweed Shire

Total number of species observed in surveys:	16
Number of introduced species observed during surveys:	14
Number of native species observed during the surveys:	2
Number of tunnelling species observed:	12
Number of ball rolling species observed:	1
Most introduced species observed at one site:	12 at Eungella in December
Most native species observed at one site:	2 at Pumpenbill in November
Most beetles (introduced and native) at one site:	414 at Burringbar in November
Most introduced dung beetles found in one pad:	400 *Aphodius lividus* at Burringbar in November
Most native dung beetles found in one pad:	3 *Onthophagus capella* at Pumpenbill and 3 *O. australis* at Doon Doon in November

A total of 137 individuals and 8 introduced dung beetle species were identified at survey sites in September. The number of individuals collected ranged from 41 *A. fimetarius* at Pumpenbill to 1 *A. lividus* at Doon Doon and 1 *O. taurus* at Murwillumbah (Table 5).

Table 5: Dung beetle observations at survey sites in September 2016.

	Species	**Number of individuals**	**Number of pads found in**	**Mean per pad**
Pumpenbill	*Aphodius fimetarius*	41	9	4.56
	Hister nomas	8	3	2.67
	Onthophagus sagittarius	6	5	1.20
	Aphodius lividus	5	2	2.50
Doon Doon	*Onthophagus sagittarius*	33	9	3.67
	Onthophagus gazella	4	3	1.33
	Aphodius fimetarius	4	2	2.00
	Liatongus miltaris	3	2	1.50
	Aphodius lividus	1	1	1.00
Murwillumbah	*Aphodius fimetarius*	15	4	3.75
	Aphodius lividus	7	3	2.33
	Onitis alexis	3	2	1.50
	Onthophagus sagittarius	2	2	1.00
	Hister nomas	2	1	2.00
	Onthophagus gazella	2	1	2.00
	Onthophagus taurus	1	1	1.00

Collated results for surveys conducted in September showed that *A. fimetarius* exhibited 44% relative abundance, followed by *O. sagittarius* (30%), *A. lividus* (9%) and *O. taurus* (1%), (Figure 21).

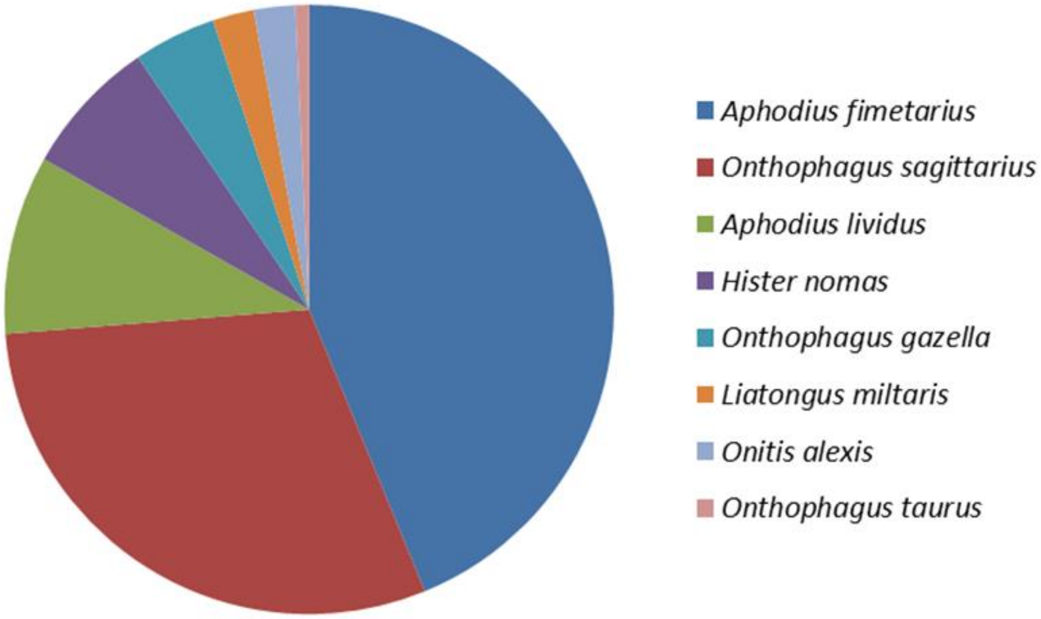

Figure 21: Relative abundance of observed species at survey sites in September 2016

A total of 512 individuals including 7 introduced dung beetles species were identified at the three survey sites in October. *Aphodius fimetarius* recorded a mean 32.89 individuals per pad at Burringbar, 11 individuals at Mount Burrell and 15.44 at Eungella. *Onthophagus gazella* was frequently observed (4 replicates) in the Mount Burrell alpaca middens. Single *Onitis pecuaris, Aphodius lividus* and *Onitis viridulus* individuals were also observed during this month (Table 6).

Table 6: Dung beetle observations at survey sites in October 2016.

	Species	Number of individuals	Number of pads found in	Mean per pad
Burringbar	*Aphodius fimetarius*	296	9	32.89
	Onthophagus sagittarius	17	4	4.25
	Hister nomas	1	1	1.00
	Onitis pecuaris	1	1	1.00
Mount Burrell	*Aphodius fimetarius*	11	1	11.00
	Onthophagus gazella	11	4	2.75
	Aphodius lividus	1	1	1.00
Eungella	*Aphodius fimetarius*	139	9	15.44
	Onthophagus sagittarius	27	5	5.40
	Hister nomas	4	1	4.00
	Onthophagus gazella	3	3	1.00
	Onitis viridulus	1	1	1.00

The collated results for October show that *A. fimetarius* accounted for 83% relative abundance, followed by *O. sagittarius* (8%), *O. gazella* (5%), *A. lividus* and *O. viridulus* (0.02%), (Figure 22).

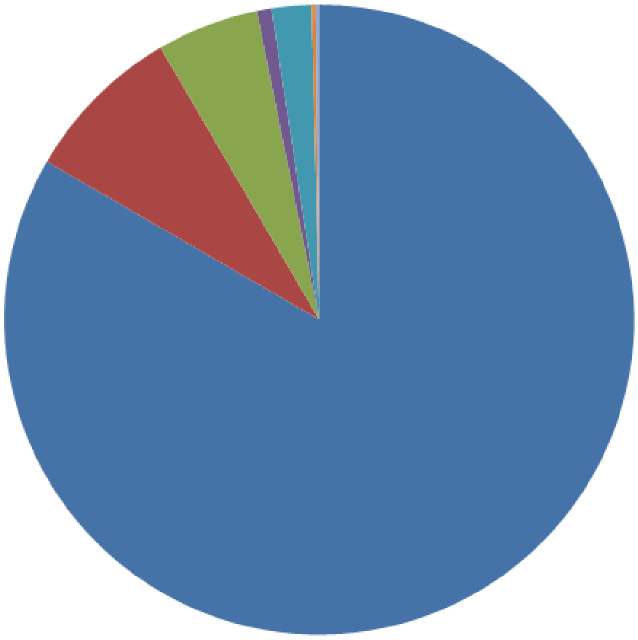

Figure 22: Combined relative abundance for species observed at survey sites in October

A total 815 individuals including 12 introduced and 2 indigenous species (*) were identified at the five survey sites in November. *Aphodius lividus* recorded a mean of 66.67 individuals per pad at Burringbar and a mean of 10 at Pumpenbill. A mean 7.13 *Onthophagus sagittarius* individuals were recorded in pads at Sleepy Hollow in November (Table 7).

Table 7: Dung beetle observations at survey sites in November 2016.

	Species	Number of individuals	Number of pads found in	Mean per pad
Pumpenbill	*Liatongus militaris*	25	7	3.57
	Onthophagus sagittarius	19	5	3.80
	Onthopgagus gazella	13	7	1.86
	Aphodius lividus	10	1	10.00
	*Onthophagus capella**	3	1	3.00
	Onitis alexis	3	1	3.00
	Aphodius fimetarius	3	3	1.00
	*Onthophagus autralis**	1	1	1.00
	Onthophagus binodis	1	1	1.00
Sleepy Hollow	*Onthophagus sagittarius*	57	8	7.13
	Onthophagus gazella	16	4	4.00
	Onitis viridulus	9	4	2.25
	Aphodius lividus	5	1	5.00
	Liatongus militaris	3	2	1.50

	Aphodius fimetarius	3	2	1.50
Burringbar	*Aphodius lividus*	400	6	66.67
	Onthophagus sagittarius	5	1	5.00
	Onitis pecuaris	4	2	2.00
	Onthophagus gazella	2	2	1.00
	Liatongus militaris	2	1	2.00
	Euoniticellus intermedius	1	1	1.00
Doon Doon	*Onthophagus sagittarius*	15	4	3.75
	Liatongus militaris	13	4	3.25
	Onthophagus gazella	10	3	3.33
	Onitis alexis	5	2	2.50
	*Onthophagus australis**	3	1	3.00
	Hister nomas	2	2	1.00
	Sphaeridium discolor	1	1	1.00
Murwillumbah	*Sphaeridium discolor*	164	9	18.22
	Aphodius lividus	28	9	3.11
	Onthophagus sagittarius	18	6	3.00
	Liatongus militaris	3	3	1.00
	Onthophagus gazella	2	2	1.00
	Hister nomas	1	1	1.00

Collated results from November indicate that *Aphodius lividus* contributed to 52 % relative abundance of species, followed by *Sphaeridium discolor* (19%), *O. sagittarius* (13%), and *O. bindosis* and *E. intermedius* (1%). Native species *Onthophagus capella* and *O. australis* contributed to 0.04% relative abundance (Figure 23).

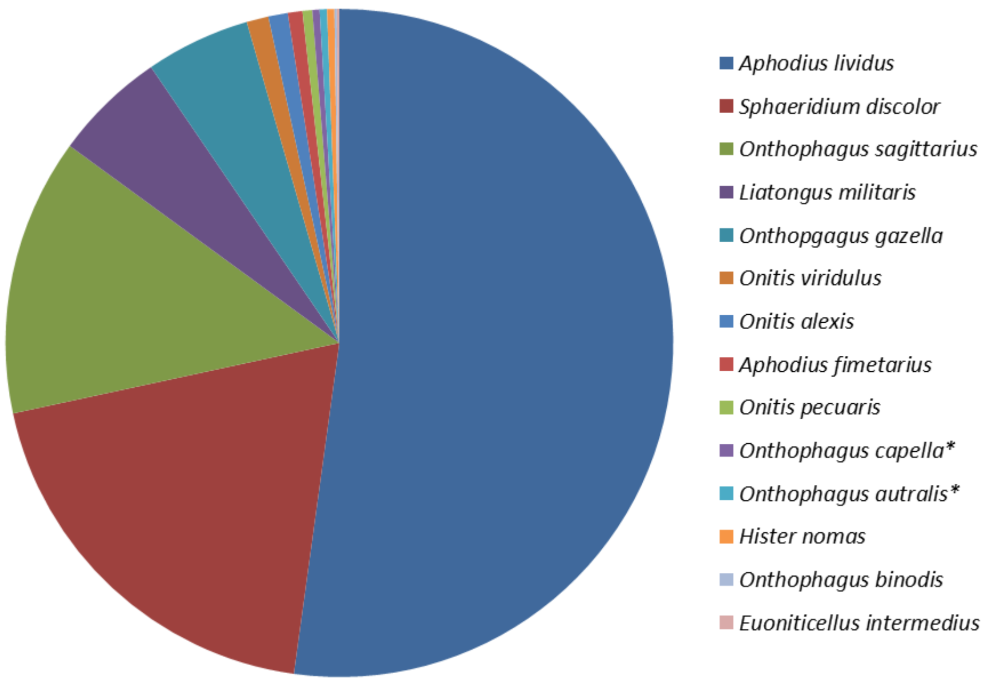

Figure 23: Combined relative abundance for species observed at survey sites in November

A total 161 individuals and 12 introduced species were recovered from pads at Eungella in December. *Onthophagus sagittarius*, *H. nomas* and *L. militaris* were frequently observed and relatively abundant in pads (Table 8). Two individual *Sisyphus rubrus*^ (ball rolling) species were found here. A single *Onthophagus nigriventris* individual was also observed on this occasion (Table 8).

Table 8: Dung beetle observations at survey sites in December 2016

	Species	Number of individuals	Number of pads found in	Mean per pad
Eungella	*Onthophagus sagittarius*	81	8	10.1
	Hister nomas	32	7	4.6
	Liatongus militaris	26	6	4.3
	Aphodius lividus	6	2	3.0
	Onitis viridulus	4	3	1.3
	Euoniticellus intermedius	3	2	1.5
	Aphodius fimetarius	2	2	1.0
	Onitis alexis	2	2	1.0
	Sisyphus rubrus^	2	2	1.0
	Onitis pecuaris	1	1	1.0
	Sphaeridium discolor	1	1	1.0
	Onthophagus nigriventris	1	1	1.0

Records from December indicated that *O. sagittarius* contributed to 50% relative abundance, followed by *H. nomas* (20%), *L. militaris* (26%) and *O. viridulus* and *E. intermedius* (4%). *Onitis alexis*, *S. rubrus*, *O. pecuaris*, *S. discolor* and *O. nigriventris* accounted for 1% relative abundance (Figure 24).

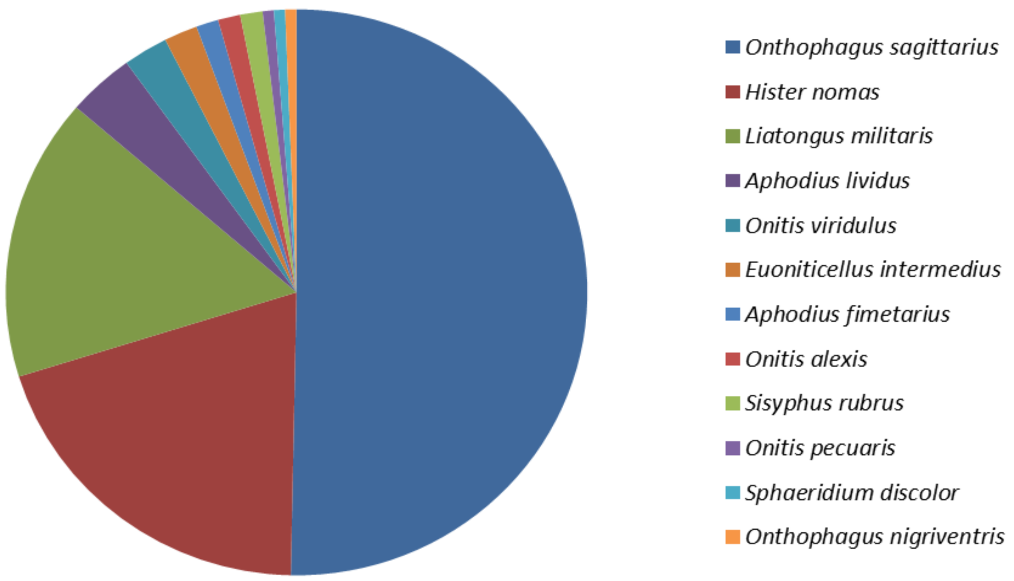

Figure 24: Relative abundance for species observed at Eungella in December

Figure 25: Species of *Onitis* and *Onthophagus* were common in the Tweed Shire

Figure 26: Inspecting a pad exhibiting evidence of shredding and disposal by dung beetles in the Tweed Shire

Figure 27: Clay soil casts on a pad indicating dung beetle activity

The number of different dung beetle species found at each site during the survey is shown in Figure 28. In September, the number of different species ranged from 4 to 7. Mount Burrell had the least number of different species (3) in October, and Eungella had the most (5). The number of species in November ranged from 6 at Sleepy Hollow, Burringbar and Murwillumbah, to 9 at Pumpenbill. In December, Eungella recorded a total 12 different species being in early December.

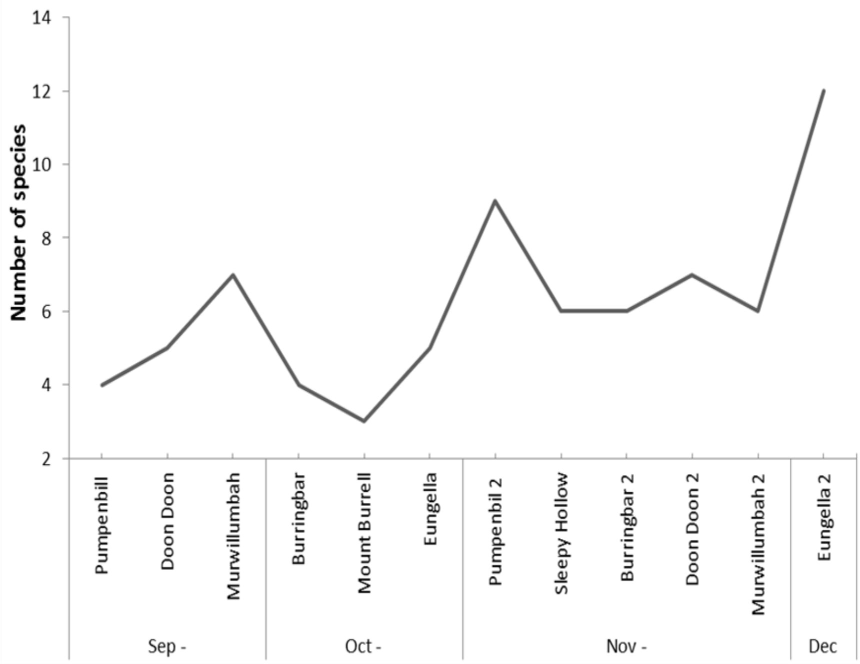

Figure 28: Species richness at sites during surveys

Species richness at sites with different pest control regimes during surveys in early and late spring is illustrated in Figure 29. The number of species in early spring ranged from 4 at Pumpenbill and Burringbar to 7 at Murwillumbah. In late spring, the Murwillumbah sites recorded one less species compared to the previous survey in early spring. Eungella recorded 7 extra species in early December that were not recorded during the previous survey at the beginning of spring (Figure 29).

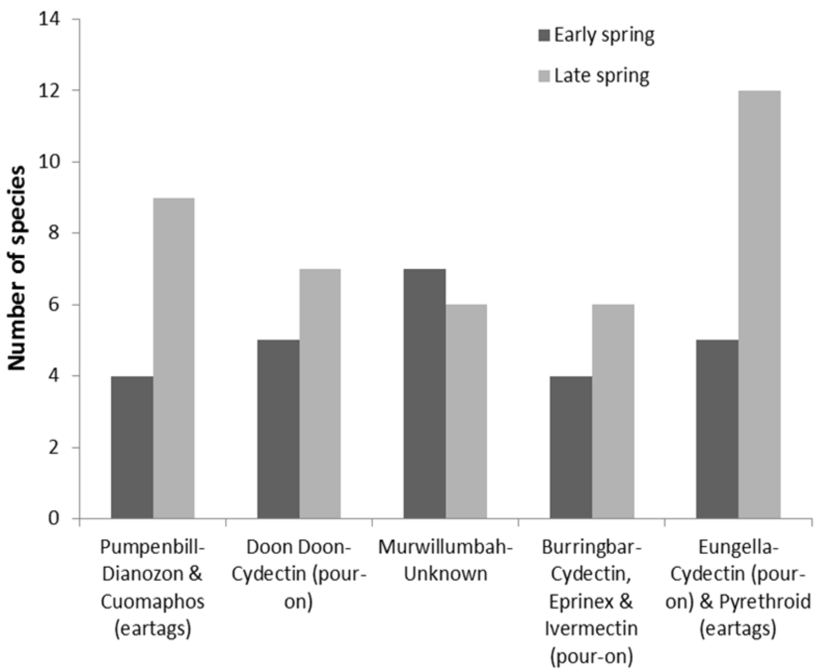

Figure 29: Species richness at sites with different pest control regimes

4. Discussion

4.1 Landholder surveys

Survey respondents composed landholders that are active participants in a local sustainable graziers group, an initiative of Tweed Shire Council's Sustainable Agriculture programme. They represented a mix of commercial and hobby farmers practicing in three different industry types including 4 beef, 2 dairy and 1 alpaca farms. Both dairies were commercially operated. Half of the beef farms were commercially operated, while the other half, along with the alpaca farm, were considered hobby farms. The survey revealed that not all of the respondents were aware of local dung beetle activity, or of the role that they play in promoting productive and sustainable agriculture.

Seventeen percent of respondents made anecdotal observations of dung beetle activity, while only 16% formally monitored dung beetles on their property. Half of the landholders had never observed dung beetles on their properties at all. The present surveys revealed that there were indeed dung beetles present on all of their properties, at least, during the spring and early summer period. Both dairy farmers had previously released species on their properties in attempt to optimise year-round dung beetle activity. The Murwillumbah dairy farmer indicated that multiple introduced species had been released on site around 20 years ago. Unfortunately the identity of these could not be confirmed. For this reason it is impossible to determine if any of the species observed at present had resulted from the previous releases. The Burringbar landholder indicated that a grant application was made to Landcare in order to obtain and release a winter-active species. It was again unfortunate that the identity of the species released could not be confirmed. No such winter-active species was recorded during the present survey. This may have been because surveys commenced to late in the cold season for it to be active. However, the landholder also indicated that conditions were unseasonably hot and dry the day that beetles were released in winter and that they were rapidly preyed upon by birds.

All landholder's pest management regimes relied heavily on the use of parasiticides. Cydectin was the most commonly used. Moxidectin, the active constituent in cydectin, is advertised as "dung beetle friendly" with some research support (Ridsdill-Smith, 1988; Wardhaugh et al., 2001). Other parasiticides used by landholders included eprinex (active constituent eprinomectin) pour-ons, ear tags containing diazinon and coumaphos and home remedies. Ear tags are considered the preferable method of applying parasiticides because generally less of the chemical is delivered to the tissues of treated animals resulting in reduced chemical contamination of dung meaning it is less harmful to dung beetles (Wardhaugh, 2000). The survey revealed that half of the landholders used ear tags to apply parasiticides, whereas the other half used a pour-on method of application.

Half of the respondents gave the importance of dung beetles for farm productivity and sustainability a rating of 5 out of 5. This is presumably because they are advocates for sustainable agriculture, although some indicated that were not sure and that their response was more of a guess. Most landholders (67%) indicated that they were willing to get involved in dung beetle surveys on their property to enable them to do so themselves in the future. This was encouraging and proved very helpful upon visiting the sites to conduct surveys. Eighty-three percent of respondents said that they are interested in participating in a future field day to summarise the findings of the project. It is anticipated that the involved landholders will have a greater appreciation of the ecosystem services provided by dung beetles as a result of the project, and that the number conducting their own surveys will increase after attending the future planned field day where they will receive a free copy of- Wright, Edwards, & Wilson, (2015) a pocket field guide to introduced dung beetles in Australia.

4.2 Bubas bison trials

Results from the trials demonstrated that the released *B. bison* were able to tunnel, bury dung and mould brood balls in which to lay eggs at both the Whian Whian and Koonorigan sites. The species is known to construct dung-filled tunnels 20- 60 cm in the subsoil beneath the site of the pad (Doube, 2008). This was evident in the present trials as dung and brood balls were buried to a considerable depth, particularly at Koonorigan where brood balls had been buried to the depth of the soil core (> 45 cm). This suggests that the Ferrosol soil type at the sites were, to an extent, suitable for the beetles to breed in. *Bubas bison* are known to breed successfully in duplex soils, loams and clays but not in deep sand (Doube, 2003; Doube & Marshall, 2014). Doube (2008) details how *B. bison* commonly produce 5 to 10 (up to 20) larvae per litre of dung. In light of this the number of brood balls and eggs observed at the trial sites is encouraging, as is the larvae found at Koonorigan, that other eggs will also further develop under such conditions.

The observed eggs and larvae where assumedly the offspring of adults that were previously released into the traps in early winter (June). Other studies (Doube, 2008) support this by detailing similar patterns of seasonal activity in Southern Australia where adults emerge in autumn to breed and mate in shallow tunnels beneath pads before when ready to reproduce, working in pairs to construct a dung-lined tunnel below the surface, followed by the female packing the tunnels with dung and laying a single egg inside a series of brood balls. Eggs laid during winter hatch in spring and larvae consume all the dung in tunnels over the following months, leaving behind loosely packed faecal material before forming a protective faecal shell (Doube, 2008). Indeed the breeding patterns observed in the current trials seem similar to those in Southern Australia where the species have become well established.

There have been other promising results from landholders who collaborated on the *B. bison* trials throughout the region using the same methodology. One trial in Old Bonalbo saw the release of adult beetles on the 29th May 2016 and when assessed four months later revealed that a total ten brood balls had been buried, mostly at 30 to 40 cm depth in the upper clay layer (pers. comm. Lindsay Johnston, 2016). Subsequent assessment of soil core traps at these sites is planned for the following autumn- at the end of April 2017, at which stage it is anticipated that results from the trials will give a good indication of the suitability of *B. bison* to successfully establish and fill the region's current winter gap in activity.

4.3 Identifying spring active dung beetle species in the region- Tweed Shire area

The area experienced below average monthly rainfall during dung beetle surveys, with September being the exception. This would have assumedly caused a decrease in soil moisture which is considered a critical factor affecting the seasonal activity of dung beetles (Ridsdill-Smith, 1993). Comparisons of dung beetle fauna in naturally dropped pads are inherently confounded by the differences in dung type, size and composition that normally exist in grazing landscapes (Finn & Giller, 2002). Variation in dung composition may arise from seasonal differences as well as variation in pasture quality and cattle diets (Finn & Giller, 2002). Such differences in dung composition are known to have considerable effects on dung beetle ecology (Ridsdill-Smith, 1986; MacQueen et al., 1986; Edwards, 1991). Gittings and Giller (1998) acknowledged that among different types of dung pads with varying age and composition, there are at least 3 factors of potential importance for processes involving dung beetle colonisation and reproduction. The first factor included what was termed as the 'findability' of the dung, regardless of the suitability of that dung type as microhabitat. The second factor is the suitability of the pad as microhabitat for dung beetles (in any stage of their lifecycle). Lastly, the chemical and physical qualities of the dung may affect its nutritional quality as a food source for adult and larvae dung beetles. Other important variables include soil type- which inherently affects the breeding capacity of dung beetle species; as well as time of day that surveys were conducted at each site. All of the above factors need to be carefully considered when interpreting the results of the present study.

Of the twenty-three species previously introduced into Australia by the CSIRO project, fourteen were recorded dung during the present surveys in the Tweed Shire. Introduced species *Aphodius fimetarius* was very abundant at the majority of sites and dominated during September and October. Another species of *Aphodius- A. lividus,* recorded the highest relative abundance at sites surveyed in November. *Aphodius* species are typically endocoprid (larvae that live and feed within the pad) and the adults are relatively small, with the elytral length generally being less than 15 mm. Such small size means they are typically required in very large numbers in order to bury enough dung to effectively provide its biological control (pers. comm. Doube, 2016). This was further supported by anecdotal observations made in the field which suggested that dung burial was minimal in pads where *Aphodius* species were abundant.

Onthophagus sagittarius (tribe Onthophagini) was observed during every survey event and was no less than the third-most abundant beetle recorded at sites. It was the dominant species at Eungella in December. Although this species was abundant and frequently observed during the project, anecdotal observations suggested that dung burial was limited in pads where the species was abundant, again perhaps due to their relatively small size.

Other species of Onthophagini included *Onthophagus gazella* which were also recorded at all survey sites except for at Eungella in December. The species was particularly dominant amongst the alpaca dung at Mount Burrell. In contrast to cattle, alpacas produce rather dry pellet-like dung which is confined to small patches in the paddock termed "middens".

Remarkably, adult *O. gazella* were observed burying the alpaca dung underground in what appeared to be a network of permanent tunnels. The landholder at this particular site was removing the dung from the paddocks and stockpiling it to be used as garden fertiliser. Having said this *O. gazella* were assumedly acquiring their share of the dung before it was removed, and water infiltration and soil organic matter in areas of these middens would undoubtedly contrast that of the surrounding soil.

Liatongus militaris was not very abundant at sites in the beginning of spring and was not recorded in October. However the species became more abundant throughout surveys. It was the fourth-most abundant in November and third-most abundant species in December at Eungella.

Onitis alexis is a large robust beetle that followed a similar pattern of distribution and abundance to *L. militaris*. It was only recorded at Murwillumbah in September and was seventh most abundant during this month. The species was not observed at any sites in October but remerged at Pumpenbill and Doon Doon in November and was also present at Eungella in December. Anecdotal observations suggested a relatively considerable amount of dung burial in pads where *O. alexis* was abundant.

Hister nomas is a predatory beetle that feeds on fly larvae in dung (Wright *et al*., 2015). It was recorded during every survey event. It was the fourth most abundant species at sites in September and October, twelfth most in November, and was second most abundant in December at Eungella. There was no noticeable relationship between numbers of this species in dung pads and dung burial observed in the field. Only a single *Onthophagus taurus* individual was recorded during the entire project at Murwillumbah in September.

Aphodius fimetarius, O. sagittarius and *O. gazella* were again frequently observed at sites in October and recorded the highest relative abundance respectively. Two introduced species were observed in October that had not been previously recorded at sites - *Onitis pecuaris* and *O. viridulus* were found at Burringbar and Eungella respectively. Belonging to the *Oniticellini* tribe, *Onitis* species are large robust beetles and anecdotal observations suggest that they are efficient dung buriers.

Five dung beetle species that had not been previously recorded during surveys were identified at sites in November. These included three introduced species- *S. discolor, Onthophagus binodis* and *Euoniticellus intermedius*; and the first 2 indigenous species recorded so far- *Onthophagus australis* and *Onthophagus capella*. *Aphodius lividus, S. discolor. O. sagittarius* and *L. militaris* exhibited the highest relative abundance respectively. At Pumpenbill where both native species were observed, there was a considerable amount of native vegetation bordering the fence line. Although recording their presence does not necessarily point to their success in breeding in cattle dung, it would be interesting to know to what extent such native beetles have adapted to living, feeding and breeding in dung from large ruminants.

Eungella was the final site and was surveyed in early December. Although this summer survey was not stated in the project plan, it was due to the field work being more time consuming then initially anticipated and at the least gave a good indication of the change in species composition and abundance as temperature further increased. *Onthophagus sagittarius* recorded the highest relative abundance on this occasion, followed by *H. nomas* and *L. militaris*. In addition to this, two introduced species were found here that were not previously recorded in surveys. This included a single *Onthophagus. nigriventris* individual and two *Sisyphus rubrus* individuals. *Sisyphus rubrus* found here represented the only ball rolling species recorded throughout the entire project.

The lack of native dung beetles observed in the present surveys highlights the view that such species have a high level of specificity towards marsupial dung (Coggan, 2012) and a preference for forest habitat types (Bornemissza, 1976). Edwards (2002) survey of dung beetles throughout Queensland collected 73 species of native dung beetle using pitfall traps and suggested there may be some native species that now process both cattle and marsupial dung.

Variations in soil type, local climatic conditions, seasonal beetle activity and the actual established distribution of species are possible explanations of why some were not recorded in locations where they theoretically could occur. These included:

Copris elphenor- a native to southern and eastern Africa, in Australia is active from spring to autumn, occurs in parts of eastern Australia and is suitable for much of eastern Queensland and possibly northern parts of New South Wales (Wright *et al*., 2015).

Euoniticellus africanus- is native to south Africa, in Australia is active from late spring to autumn and has become established in eastern NSW and south-east QLD (Wright *et al*., 2015).

Geotrupes springer- is native to Europe, in Australia is active from early spring to early winter and is known to be established in northern NSW (Wright *et al*., 2015).

Onitis aygulus- is native to cool dry areas of South Africa and Namibia, while in Australia is active from autumn to winter and is established in NSW although its actual distribution may be limited to more central areas on the state (Wright *et al*., 2015).

Onitis caffer- is native to South Africa, while in Australia introduced summer- and winter-rainfall strains have become established in NSW and south-east QLD and are active from autumn to early/ mid-winter (Wright *et al*., 2015). Although the winter rainfall strain of this species is known to become active again in spring (Wright *et al*., 2015), it is reasonable to assume its lack of seasonal activity in spring is the reason why it was not encountered in the present surveys.

Onitis vanderkelleni- is native to the wet tropical highlands of Africa, where in Australia is active from November to May and is established in the Atherton Tablelands and the Gold Coast hinterland (Wright *et al*., 2015). Being active in spring and in such close proximity to the present survey sites, one could anticipate that *O. vanderkelleni* would more likely than not be observed. This species would certainly be a worthy candidate for introduction into the Northern Rivers; as such species of *Onitis* are considerably large and efficient dung-buriers.

Sisyphus spinipes- is native to Africa, while in Australia is active from spring to autumn where it is established in QLD and north-east NSW (Wright *et al*., 2015). This is another species one would have anticipated finding during spring surveys in the Tweed Shire.

Overall, results from surveys indicate that there is a need to increase dung beetle species richness and abundance throughout the spring period in the Tweed Shire if biological control of dung is to be achieved. Along with a mixture of day and night-time flying species, a good mixture of both tunnelling and ball rolling species is known to improve levels of dung burial through minimising competition between species by minimising the period of time that their activity overlaps (Feehan, 1999). This may be done by releasing new introduced species that are active over the cooler months and also by redistributing species that already occur in the area but are in insufficient numbers. The lack of native species also needs to be further investigated.

4.4 Pest control regimes at survey sites

All sites exhibited an increase in species richness in the second round of surveys in late spring compared to the first round in early spring, with the Murwillumbah site being the only exception recording 1 less species in the late spring. Unfortunately, details on the pest control regimes for the Murwillumbah site were not confirmed. Cydectin was the most commonly used parasiticide with ear-tags and pour-ons being equally the most common method of application. Moxidectin, the active ingredient in Cydectin, is advertised as "dung beetle friendly" with some research support (Ridsdill-Smith, 1988; Wardhaugh *et al*., 2001). Ear tags are considered to be the preferable method of application for pesticides as less of the chemical is absorbed by the animal and excreted in the dung (Wardhaugh *et al*., 2001). There was however no clear difference in species richness between sites where moxidectin was applied using these different methods. At the Burringbar site, moxidectin pour-on was used previous to the first round of surveys in early spring, followed by the application of Eprinex pour-on (active ingredient Eprinomectin) previous to the second round later in spring. Although not quantified, there was no noticeable negative impact on species richness between such occasions, with the number of species slightly increasing as was the case with most other survey sites. It should be noted that because this chemical affects the breeding capacity of female beetles, it would have likely inhibited population numbers in the following generation. Also worthy of mention is the unprecedented numbers of *A. lividus* were observed during the second survey in Burringbar. The reason behind this is uncertain. It may have been because conditions were very hot and dry during the survey. Also, if the timing of eprinomectin application coincided with the emergence period of other dung beetle species, it would likely have negative impacts and effectively limit their numbers. Eprinomectin constitutes a group of chemicals called endectocides, which are known to adversely affect dung beetles, causing mortality of young adults, breeding females and their eggs and larvae (Wardhaugh, 2000). This could possibly explain the dominance of *Aphodius* species (subfamily Aphodiinae) at the site as they are known to be more prolific and even-season breeders in contrast to other "true" dung beetle (subfamily Scarabaeinae) who usually have a more pronounced seasonal emergence period (Ridsdill-Smith, 1993; Wardhaugh *et al*., 2001).

Pumpenbill exhibited the second highest increase in species richness from late to early spring with an increase of 5 species. The chemicals used here were organophosphates belonging to the ectocide group of parasiticides. Although yet to be tested on dung beetles, diazinon and coumaphos are known to be mainly excreted through the urine of cattle (Wardhaugh, 2000). Such chemicals are therefore generally not considered to cause dung to be toxic to beetles, particularly when practicing the ear-tag method of application.

The Eungella site recorded the greatest increase in species richness (> 7 species) between surveys in early and early summer. Moxidectin ear tags were used previous to the first survey, which notably changed to pyrethroid based ear tags as landholders responded to increased buffalo fly incidence previous to the second survey in early December. Belonging to a group of chemicals known as ectocides- synthetic pyrethroids are known to cause mortality in mature and young adult beetles as well as breeding females and their eggs and larvae (Wardhaugh, 2000). However, such detrimental effects were not reflected by either the richness or abundance of species in comparison to earlier surveys at the site when moxidectin was used. Perhaps the ear tag method of application is a contributing factor. Or perhaps the next generation of beetle populations would be effected as the chemical can reduce the breeding capacity of female beetles. Without taking quantitative measures one cannot be certain on what effect they are having on dung beetles, highlighting the need for further quantitative field based research on the topic of parasiticides.

5. Conclusions

5.1 Assessing the potential of introduced species Bubas bison in filling the current winter gap in dung beetle activity

Field trials were conducted at Whian Whian and Koonorigan to assess the site suitability for *B. bison* to tunnel, bury dung, and breed and for the young to develop into adults and emerge. This was done using 'traps' consisting of soil cores lined with onion bag material to which dung and adult *B. bison* were added on the 4th June 2016. Sites were visited on the 23rd September 2016 (almost 4 months later) and traps were assessed. At the Whian Whian site, 5 brood balls, 3 of which contained a single *B. bison* egg, were found buried to a depth of 40 cm. Ten brood balls, 5 containing eggs and 1 containing a larvae, were found buried to the bottom of the soil core (45 cm) at Koonorigan. Results indicated that *B. bison* were indeed able to tunnel, bury dung and create brood balls in which to lay eggs subject to the different site characteristics and their dominant Ferrosol soil type. Further to this, the larvae observed at the Koonorigan site is promising evidence that the species will be able to successfully reproduce in the area. These results will contribute to a wider study composing numerous identical trials in the area which require further monitoring, at which stage it is anticipated that results from the trials will give a good indication of the feasibility of *B. bison* to successfully establish and fill the region's current winter gap in activity.

5.2 Identifying spring active dung beetle species in the region and determining the first emergence period of these species in a number of locations with different site characteristics

A survey was conducted in order to obtain information about the locality, type of livestock in practice and management regimes of different landholders. In consideration of this, seven sites were established and stratified according to environmental preferences of dung beetle species. Dung beetles were recovered from 10 replicate dung pads at each site using the flotation method. Three sites were surveyed in September and October, followed by 4 in November and 1 in early December. A total 14 introduced and 2 native species were identified during surveys including 12 tunnelling and a single ball rolling species. *Aphodius fimetarius*, *Onthophagus sagittarius* and *O. gazella* were among dominant species in September and October. Sites surveyed in November where dominated by *A. lividus*, *S. discolor*, *O. sagittarius* and *L. militaris*. The final site was surveyed in December where *O. sagittarius*, *H. nomas* and *L. militaris* exhibited the highest relative abundance respectively. Species richness increased at sites throughout spring and into early summer, with values ranging from just 3 species at Mount Burrell in October to 12 species at Eungella in early December.

Results on the current distribution and abundance of dung beetle species throughout the Shire suggest that there is a gap in spring-time dung beetle activity. Field observations further indicated that the biological control of cattle dung during this period is very limited. In order to rectify this gap in activity, firstly, it is necessary to trial candidate species to assess their capacity to establish in locations throughout the Shire with different site characteristics. Once the desired candidate species have been selected they should then be subject to widespread introductions and reinforced by local distribution programs.

5.3 Surveying sites with different pesticide regimes and determining what effect this might be having on such species

The landholder survey also enabled information about landholders' different pest control regimes to be obtained. All 7 respondents relied heavily on the use of parasiticides to control pests and parasites. Cydectin (active ingredient moxidectin) was the most commonly used (67%) and applied using both ear tags and pour-ons. Others included eprinex (Eprinomectin) pour-on and pyrethrum, diazinon and coumaphos ear tags. All sites exhibited an increase in species richness in the second round of surveys conducted in late spring compared to the first round conducted in early spring, with the Murwillumbah site being the exception. Although the ear tag method of application is preferable over pour-on's in regards to reducing beetle toxic residues being produced in the dung, there was no noticeable difference in species richness between sites using the different methods. However the complexity of this equation (site variables vs species response) would suggest that only a very large survey would produce significant differences. *Aphodius lividus* was extremely abundant relative to other species at the Burringbar site where eprinex was used indicating that the parasiticide may have inhibited other species with a more pronounced emergence period. At Eungella, cydectin (dung beetle friendly) was substituted for pyrethroid based ear tags previous to the second survey event in late spring as landholders responded to an increase in pest fly incidence. Interestingly, although pyrethroids are known to cause mortality of immature beetles, breeding females and their eggs and larvae, there was no noticeable negative impact between such occasions as indicated by species richness. However it should be noted that in the case of parasiticides known to affect the breeding capacity of females, there is likely to be detrimental impacts on future generations. Quantitative measurements need to be taken to determine the effects of parasiticides on dung beetle species with any level of certainty, highlighting the need for further such field based experiments particularly where there are gaps in current knowledge.

5.4 Preparing a technical report, an informative brochure and participating in community events to present the findings of the study and provide strategies for graziers to optimise their dung beetle populations and inform them about how they benefit agricultural productivity, economy and environmental sustainability

It is anticipated that the current technical report will provide land managers with useful information about the different dung beetle species occurring in the region, the emergence period of species throughout the spring and early summer period, and the potential of introduced species *Bubas bison* to fill the regions current winter gap in activity. It may serve as a case study for landholders and others interested in conducting their own dung beetle surveys, allowing them to determine when populations are present in sufficient numbers to provide the biological control of dung, and therefore plan their pest control regimes in consideration of this. To date, other outputs from the project have included the preparation of a dung beetle flyer and contribution to a Landcare field day at Mumbulgum. In the Tweed Shire, further community engagement is planned by preparing another informative brochure, content adapted to Councils website, and by contributing to the design, management and implementation of a field day that will present the findings of this study to the involved landholders and the wider community and showcase expertise and advice from a range of industry experts.

7. References

ABS. (2005). Yearbook Australia: agricultural commodities, Australia. Retrieved from <http://www.abs.gov.au/ausstats/abs@.nsf/lookup

Bang, H. S., Lee, J.-H., Kwon, O. S., Na, Y. E., Jang, Y. S., & Kim, W. H. (2005). Effects of paracoprid dung beetles (Coleoptera: Scarabaeidae) on the growth of pasture herbage and on the underlying soil. *Applied Soil Ecology, 29*(2), 165-171. doi:http://dx.doi.org/10.1016/j.apsoil.2004.11.001

Benz, G.W., and Cox, J.L., (1989). *Use of abamectin in cattle.* In: W.C. Campell (Editor), Ivermectin and Abamectin . Springer, New York, pp. 230- 233.

Bornemissza, G. F. (1960). Could dung eating insects improve our pastures. *Journal of Australian Institute of Agricultural Science, 26,* 54-56.

Bornemissza, G. F. (1970). An effect of dung beetle activity on plant yield. *Pedobiologia, 10*, 1-7.

Bornemissza, G. F. (1976). The Australian dung beetle project 1965- 1975. *Australian Meat Research Committee Review, 30*, 1-30.

Doube. B. (2008). The pasture growth and environment benefits of dung beetles to the southern Australian cattle industry. *Meat & Livestock Australia*.

Doube, B. (2004). Dung beetle- Cryptosporidium research: review and a pilot study on the recovery of C. parvum ocysts from dung buried by the dung beetle Bubas bison. *Dung Beetle Solutions Australia*.

Doube, B., Dalton, G., and Ford, R. (2003). The potential of dung beetles to improve the quality of catchment water in Australia. *MLA Super PIRD S2005/NO3 Final Report*, 26-27.

Doube, B. and Dalton, G. (2003). Dung beetles: transform a pollutant into an environmental and agricultural benefit. *Fleurieu Beef Group Inc.*

Doube, B. M., Macqueen, A., Ridsdill-Smith, T. J., & Weir, T. A. (1991). Native and introduced dung beetles in Australia 167- 2007. *Landcare Australia*, 63pp.

Doube, B. M., and Marshall, T. (2014). *Dung Down Under: Dung Beetles for Australia*: Dung Beetle Solutions Australia.

Edwards, P.B. (1991). Seasonal variation in the dung of African grazing mammals, and its consequences for coprophagus insects, and its consequences for coprophagus insects. Funct. Ecol. 5, 617–628.

Edwards, P. B. (2002). Improving sustainable land management systems in Queensland using dung beetles.

Feehan, J., (1999). Dung beetle survey of South east Queensland. Final Report for Meat & Livestock Australia Limited.

Fincher, G. T., (1981). The potential value of dung beetles in pasture ecosystems. *J Georgia Entomol Soc*, 316- 333.

Finn, J. A., & Giller, P. S., (2002). Experimental investigations of colonisation by north temperate dung beetles of different tyes of domestic herbivore dung. *Applied Soil Ecology, 20(1), 1- 13.*

Gerber, P. J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A. and Tempio, G. (2013). *Tackling Climate Change Through Livestock - A global assessment of emissions and mitigation opportunities.*Food and Agriculture Organization of the United Nations (FAO), Rome, 115 pp.

Gittings, T., Giller, P.S., (1998). Resource quality and the colonisation and succession of coprophagous dung beetles. Ecography 21, 581–592.

Joseph, S., Pow, D., *et al.* (2015). Feeding Biochar to Cows: An Innovative Solution for Improving Soil Fertility and Farm Productivity. *Pedosphere* **25**, 666-679.

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

MacQueen, A., Wallace, M.M.H., Doube, B.M., (1986). Seasonal changes in favourability of cattle dung in central Queensland for three species of dung-breeding insects. J. Aust. Entomol. Soc. 25, 23–29.

Morand D. T., (2017). Soil Essentials Report. NSW Soil and Land Information System. Office of Environment and Heritage (OEH) 9489

Morand, D. T., (2010). The World Reference Base for Soils (WRB) and Soil Taxonomy: an initial appraisal of their application to the soils of the Northern Rivers of New South Wales. World Congress of Soil Science. Soil Solutions for a Changing World. 1- 6 August 2010, Brisbane, Australia.

Nichols, E., Spector, S., Louzada, J., Larsen, T., Amezquita, S., & Favila, M. E. (2008). Ecological functions and ecosystem services provided by Scarabaeinae dung beetles. *Biological conservation, 141*(6), 1461-1474. doi:10.1016/j.biocon.2008.04.011

Ridsdill-Smith, T. (1993). Effects of avermectin residues in cattle dung on dung beetle (Coleoptera: Scarabaeidae) reproduction and survival. *Veterinary parasitology*, *48*(1), 127-137.

Ridsdill-Smith, T. (1988). Survival and reproduction of Musca vetustissima Walker (Diptera: Muscidae) and a scarabaeine dung beetle in dung of cattle treated with avermectin B1. *Australian Journal of Entomology*, *27*(3), 175-178.

Ridsill-Smith, T. J., (1986). The effect of seasonal changes in cattle dung on egg production by two different species of dung beetles (Coleoptera: Scarabaeidae) in southwestern Australia. Bull. Entomol. Res. 76, 63-68.

Ryan, U., Yang, R., Gordon, C., & Doube, B. (2011). Effect of dung burial by the dung beetle Bubas bison on numbers and viability of Cryptosporidium oocysts in cattle dung. *Experimental Parasitology, 129*(1), 1-4. doi:http://dx.doi.org/10.1016/j.exppara.2011.06.009

Strong, L., and Brown, T.A., (1987). *Avermectins in insect control and biology*: a review. Bull Entomol. Rez., 77: 357- 389.

Wardhaugh, K. G. (2000). Parasiticides registered for use in cattle in Australia- *an evaluated bibliography and literature guide CSIRO Publishing, 56*.

Wardhaugh, K. G., Longstaff, B. C., & Morton, R. (2001). A comparison of the development and survival of the dung beetle, Onthophagus taurus (Schreb.) when fed on the faeces of cattle treated with pour-on formulations of eprinomectin or moxidectin. *Veterinary parasitology*, *99*(2), 155-168. doi:http://dx.doi.org/10.1016/S0304-4017(01)00451-4

Waterhouse, D. F. (1974). The biological control of dung. *Sci Amer*, *230*, 100-109.

Wright, J., Edwards, P., & Wilson, P. (2015). *Introduced Dung Beetles in Australia. A Pocket Field Guide.* (Vol. Third Edition): CSIRO Publishing.

Wright, J., Gleeson, P., & Robinson, F. (2015). *Importation of 2 winter-active dung beetles for southern Australia*. (B.ERM.0213). Sydney: Meat & Livestock Australia Limited.

7. Appendix

7.1 *Dung beetle brochure*