

Appendix 2. Additional information supporting an application to introduce exotic pastoral dung beetles into New Zealand

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1. Scope of the literature used in this appendix

A literature search of online journals and data bases yielded over 1,720 published articles and reports covering all aspects of dung beetle ecological research. Over 30 published and unpublished reports have also been sourced from colleagues. Only the key references are cited here.

2. Introduction: Native dung beetle diversity

There are approximately 7,000 recognised species of dung beetle in relatively well known taxonomic groups that occur on every continent except Antarctica, with the highest diversity in the tropics and in savannas (Hanski, 1991). All dung beetles belong to three subfamilies of Scarabaeidae: Scarabaeinae, Geotrupinae and Aphodiinae. Scarabaeinae are considered true dung beetles since

both adults and larvae of the majority of its members are obligate or facultative coprophages. This subfamily comprises more than 5000 species in 234 genera and 12 tribes. Diversification of the dung beetles is thought to coincide with the radiation of angiosperms and grasses (Eocene: ca 50mybp), mammalian herbivores, particularly artiodactyliforms (lower Oligocene: ca 35 mybp) and subsequent grass dominated savannah habitats (Scholtz and Chown, 1995). Fossil evidence from the upper Cretaceous suggests tunnelling, brood ball construction and nesting behaviour seen in modern dung beetles was established at least 65 million years ago (Krell, 2000).

Radiation of dung beetles marked a shift from humus (saprophagy) and fungi (mycetophagy) feeding to utilisation of dung (coprophagy) by adults and larvae, and while dung feeding is the predominant behaviour for feeding and breeding, several clades still retain or reverted back to saprophagy or mycetophagy. New Zealand's almost complete lack of mammals and therefore mammalian dung is thought to be the main factor which has restricted the evolutionary radiation of dung beetles and may explain their low diversity. Central Sulawesi, Indonesia and Mauritius are comparable regions as they prehistorically had low or complete lack of mammals, and accordingly have very low dung beetle diversity. This contrasts with mammal-rich regions such as Madagascar which has 215 endemic species in 19 genera (Davis and Scholtz, 2001) and Australia that has over 388 endemic species in 20 genera (Dr Geoff Monteith, Queensland Mus. Nat. Hist., pers. comm.).

2.2 Reproduction

Fecundity in dung beetles is low to very low compared to many other insects, with a range from 1 to 150 or more eggs laid per lifetime depending upon the species. Reduced fecundity is associated with the reduction of the female reproduction system to a single ovariole, which is a characteristic feature of the Scarabaeinae (Cambefort and Hanski, 1991). Parents invest a great deal of time and energy in nest building, collecting dung, and brood ball construction. Egg output becomes inversely proportional to complexity of nesting behaviour. Fast burying species that create brood chambers (e.g. *Copris hispanus*) tend to produce a small number of brood balls that are cleaned and protected by the female. This investment results in very low mortality of offspring (Cambefort, 1991).

The period of larval development is dependent on soil temperature and the number of growing degree days above the minimal temperature threshold for larval development for each species. For example, eggs laid in early spring by the native Australian dung beetle, *Onthophagus granulatus* in NZ pastures, did not complete development to adults until mid-late January. Whereas, it took 6-8 weeks to complete development of *O. granulatus* eggs laid in early February (Forgie, 2009). Newly emerged adults undergo a period of sexual maturation lasting several weeks during which they either feed at the food source or bury dung in tunnels to feed on unabated by completion before they breed and continue the cycle.

3. The effect of exotic species on native species: habitat and soil preference

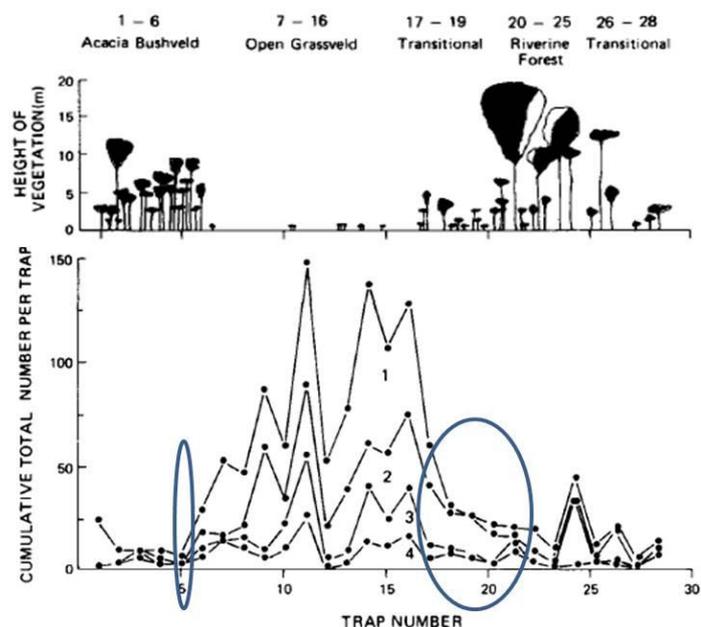
Forgie (In Preparation) is nearing completion of a systematic revision of New Zealand's native dung beetles. New Zealand has a depauperate dung beetle fauna with only 16 species in three genera *Saphobius* Sharp, 1873, *Saphobiamorpha* Brookes, 1944, and a new genus. All species lack wings and are therefore flightless. They are night active, ball-rollers and relatively small, ranging from 2 - 15 mm in size. All species are restricted to relatively undisturbed native forest habitat from sea level to 1100m altitude. At least one species (*Saphobiamorpha maoriana*) has been recovered from carcasses in South Island high country tussock habitat that adjoins forest. To our knowledge and those associated with scarab research in NZ (see Appendix 1), none have been found in un-natural (i.e., modified) environments (e.g. Seldon, 2002). Apart from dissertations by Seldon (2002) and Jones (In

preparation), very little research has been carried out that focuses specifically on our native dung beetles. This paucity of information should not prevent the opportunity to import and release exotic dung beetles that have evolved over 35million years to utilise mammalian dung in open grassland/modified pastoral habitats. We make up for what little we know about New Zealand’s native dung beetles by drawing comparisons from similar species and functional groups existing in similar forest-fringe-open habitats that have been extensively researched overseas. New Zealand’s dung beetles are not unique in terms of their specificity for undisturbed native habitat where they have evolved rather than anthropogenic- induced modified, broken cover or open habitats. Nor is their opportunistic feeding habits utilizing any food source available to them, in this case, carrion, humus and various faeces ranging from invertebrate (caterpillar, stick insect, weta, snail), reptilian (gecko), bird (kiwi, emu[moa]) and introduced mammalian dung from possums, rats, pigs, humans and livestock that invade native habitat (A. Jones, unpubl. data). Various studies utilising baited or non-baited pitfall traps find New Zealand dung beetles are often extremely abundant and constitute the majority of the biomass of the ground beetle decomposer fauna in many New Zealand forests which indicates their potential ecological value in terms of forest health.

3.1 Habitat specificity

Habitat specificity can be a fundamental determinant of the diversity and abundance of many species that are highly habitat specific in heterogeneous environments. Many studies have shown this with regard to spatial variance and assemblages in dung beetle communities along gradients transitioning shaded or semi-shaded undisturbed forest and scrub and open grassland or modified habitats (e.g., Seldon, 2002, Spector and Ayzama, 2003, Dureas *et al.*, 2005).

Evidence by Howden and Nealis (1975) indicates that species adapted to grassland, even if introduced from other continents, would not alter or compete with the forest adapted species. Spector and Ayzama (2003) revealed habitat specificity was extremely high for dung beetles in a Bolivian neotropical forest-savannah ecotone. Of the 50 most common species collected during their study, only 2 species were collected in both the forest and savannah habitats, indicating nearly complete community turnover in just a few meters. Strong edge effects were evidenced by the decline in abundance, total biomass, and species richness at the forest-savannah boundary. Duraes *et al.* (2005) after examining dung beetle assemblages across a natural forest-grassland ecotone in Brazil also concluded that the effect of the forest vs. grassland habitat has a much stronger effect on the assemblage, that is, dung beetles responded strongly to change in habitats. Density of individuals and species were higher in the forest than in the adjacent grassland, but overall richness was similar between habitats.

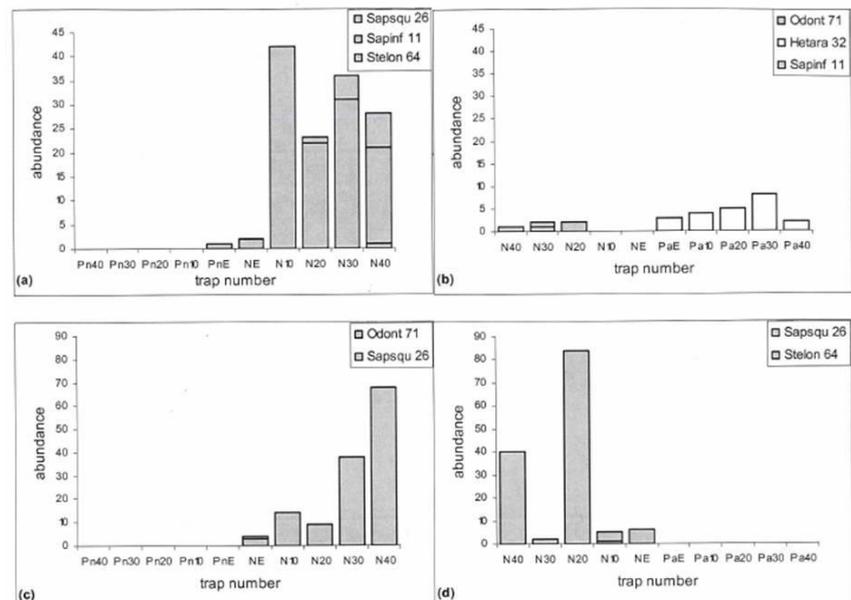


A—Vegetation profiles along the transect in Hluhluwe Game Reserve. Traps were placed at intervals of 20 m. B— Total numbers of each of four species of tunnelling grassland dung beetles caught at each trap site along the transect during a three-day period in January 1979. (1. *L. costatus*, n = 588; 2. *O. gazella*, n = 344; 3. *L. militaris*, n = 174; 4. *O. beiranius*, n = 181.). Compression of circles represent degree of recognition by grassland beetles of boundary distinctiveness between habitats. Recognition is largely influenced by density and shade effect of foliage. Modified from Doube (1983)

In contrast, some species can be less fussy in their habitat requirements. Duraes *et al.* (2005) note that species occurring in both forest and grassland habitat were consistently more abundant in one or another habitat but not both, indicating that while factors governing specificity for these species are less restrictive, there is still some preference for one or the other. In a study examining habitat preference of a variety of dung beetles utilising bovine dung in Hluhluwe Game Reserve in South Africa, Doube (1983), found considerable variability in the degree of habitat specificity between species. Four most abundant species from bush and grass habitat were chosen because the differences between their levels of abundance in the two habitats were substantial. An abrupt transition between grassland and thick bush existed between traps 6 and 7 which reflected clear distinction in habitat preference between the most abundant grass and bush species. However, all species occupied the transitional zone between traps 16-20 with a gradual yet significant shift in abundance of each species according to habitat preference. While a higher degree of restriction to the bush by the bush species was observed, Doube (1983) reported a number of grassland species occurred in all traps regardless of habitat. These findings may be attributed to degree of openness of shaded/semi-shaded habitat (particularly for day active species), preference for softer sandy loam soils in the riverine forest and the presence of bovine dung through all habitats (see comments regarding foliage density and soil type by Doube in Appendix 1). Studies assessing exotic versus native dung beetle preference and movement in relatively open natural habitat (mostly heath banksia woodland and some eucalypts in the gullies) and adjoining pasture were summarised by Ridsdall-Smith and Edwards (In press). Trapping was carried in three National Parks in the northern sand plains (Badjingarra, Watheroo and Moore River NPs) of the south of SW Australia. Ten dung baited traps were set per month in each park (30 traps) over 28 months (840 traps). A total of 4175 native scarabaeine beetles were trapped and 25 introduced beetles (0.6%); these were 17 *Onthophagus binodis* and 8 *Euoniticellus intermedius*. In the pasture adjacent to the Badjingarra National Park beetles were caught in 56 dung baited traps left open for seven days over 28 months. Three hundred and ninety-eight beetles were collected of which 70 were the native *O. ferox*, that has adapted to open habitat, 145 the introduced *Onitis alexis* and 183 the introduced *E. intermedius*.

Further evidence is provided by Klein (1989) in studying habitat specificity on dung beetle

communities showed clear differentiation in species preference to contiguous forest, forest patches and adjoining clear-cut areas developed for pastoral livestock farming. Fifty-five species in 15 genera were collected. Of these only 4 species in the genus *Glaphyrocanthon* out of 8 species not associated with contiguous forest or forest patches constituted 97% of the individuals captured that were largely unique to the clear-cut areas. The other 3% of individuals were found in a clear cut area containing secondary growth. No *Glaphyrocanthon* beetles were trapped in continuous forest



Habitat preference of indigenous Scarabaeidae species combined (shaded: *Saphobius squamulosus* (Sapsqu), *S. inflatipes* (Sapinf), *Odontria* sp. (Odont), *Stethaspis lingicornis* (Stelion)) and exotic Scarabaeidae species (White: *Heteronychus arator* (Hetara)) sampled from site 1- Pine (Pn) vs. native bush/forest (N) and their edges (E), (a); site 1- native bush/forest vs. pasture (Pa) and their edges, (b); Site 2- Pine vs. native bush/forest and their edges, (c), and site 2- native bush/forest vs. pasture (Pa) and their edges, (d). Sites 1(b) and 2(d) were grazed and un-grazed pastures respectively (Seldon 2002).

or larger 10ha forest patches but 3 individuals were obtained from traps within a 1ha forest fragment. Less than 40 *Glaphyrocanton* beetles were trapped in a dozen traps set for 4 days along one transect in pasture within 15m of contiguous forest margin. Moreover, Klein (1989) states none of the 47 forest species were captured along this transect, further corroborating evidence that habitat specificity is prevalent in a majority of species and most importantly that habitat specificity is equally applicable for forest specialists as it is for open grassland species.

3.2 Habitat preferences of native dung beetles

Research in New Zealand by Seldon (2002) looked at a comparison of ground insect communities in native forest fragments that were adjoined by pine forest along one edge and grazed or un-grazed pasture along another edge. One-hundred and twenty pitfall traps were used at two sites, and multiple transects running across native / pine edge and native/ pasture habitats were serviced every 7 days for 5 weeks from mid-January 2001-mid February 2002 recovering over 600 samples. The results from a subsample of 200 of these showed that *Saphobius* spp. were caught in the native forest only, none were caught in the pine forest or the pasture.

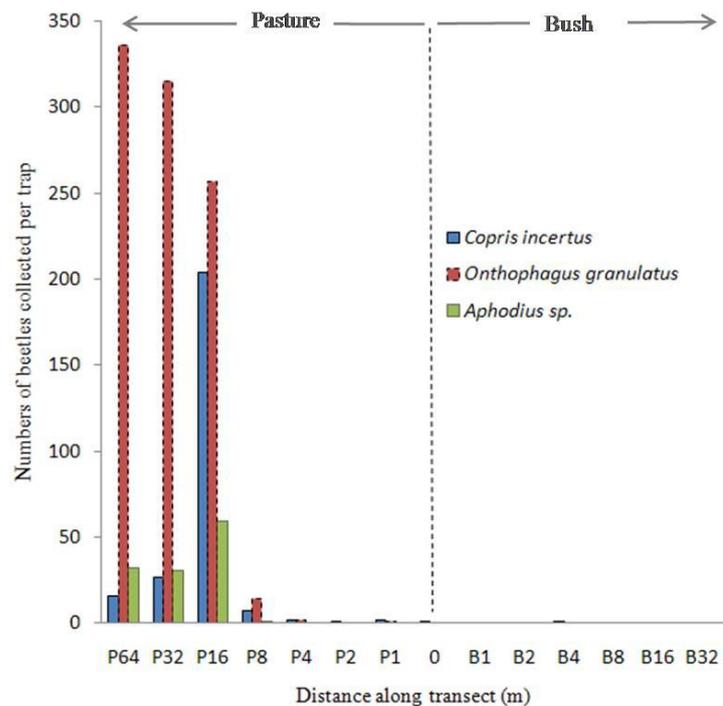
In contrast, in a more recent study in New Zealand, Pawson *et al.* (2008) collected beetles from 126 pitfall traps placed along three independent replicate edge gradients in each of the six possible comparisons between pairs of the following habitats: mature 26-year-old *P. radiata* comprising a diverse array of native under storey plants, recently clear felled *P. radiata* stands, native forest and pasture. Along each of the 18 edge gradients, individual pitfall traps were placed at seven distances from the habitat boundary, at -125, -25, -5, 0, +5, +25 and +125 m perpendicular to the edge. New Zealand's smallest and most abundant native dung beetle, *Saphobius squamulosus* was recovered in greatest number as expected in native forest. But while site-based partial canonical correspondence analysis (pCCA) of beetle species relative abundance showed *S. squamulosus* to be significantly associated with native forest habitat small numbers were recovered from clearfell and mature *Pinus* forest habitat. No *S. squamulosus* were recovered from open pasture traps yet a small number of a second unidentified species of *Saphobius* were recovered from pasture pitfall traps placed 5 meters from the forest margin. This could be explained by several factors including presence/ absence of exotic species (including predators), light intensity and food. In this study, the proportional relative abundance of exotic beetles in pasture decreased exponentially with increasing proximity to native forest suggesting that there may be increased spill-over of native species into the adjacent pasture habitat (Magura *et al.*, 2001). Equally, the proportion of exotic beetles was consistently low in mature plantation stands. Some species living near forest margins, may venture into open modified habitats (clear-fell and pasture) if attracted by a nearby food resource, and presumably for nocturnal dung beetles like *Saphobius*, light intensity is not a factor determining habitat specificity when searching for this resource at night. Pawson *et al.* (2008) state that estimated species richness (Michaelis–Menten) was greater in production habitats than native forest; however this was largely due to the absence of exotic species in native forest which was shown to be the case for exotic pastoral dung beetles (Forgie, unpublished data, see Section 3.3 below) .

3.3 Habitat preferences of pastoral dung beetles in New Zealand

In New Zealand undisturbed forest tends to be densely structured and heavily shaded under the canopy while margins, fringes or transitional zones tend to be densely populated by sub-canopy shrubs, bushes and tree ferns. These factors are likely to restrict flight movement of any pastoral dung beetles into the forest. It is a key limiting factor in the range expansion of the Mexican dung beetle (*Copris incertus*) out from founding pastures in Whangarei that are largely surrounded by forest and bush clad ranges. Natural spread of this species has been confined to the pastoral corridors to the

north-west and north-east of the city (Forgie, pers. observ.). In Mexico, it is found both in tropical habitats and pastureland, such as areas with remnant trees. It is not typical of tropical forest. It is particularly abundant in cattle dung but is also found in the excrement of other animals (Gonzalo Halffter, National Researcher Emeritus, Mexico, pers. comm., 2010). Home range distribution data for *C. incertus* is centred on wet tropical uplands and very wet (>3900 mm) lowlands (<250 m). Climatic data suggest that the species may be fairly adaptable as wide standard deviations are shown for all geoclimatic variables (ALV Davis, Scarab Research Group, University of Pretoria, unpubl. data). Hence, the ability of *C. incertus* to survive in parts of New Zealand that offers microclimatic conditions within these deviations.

Recently, Forgie (Unpubl. data) investigated habitat preference of the existing exotic pastoral beetles, *C. incertus*, *O. granulatus* and *Aphodius* sp., in Auckland's Rodney district by setting out dung baited pitfall traps for 5 days along a transect spanning recently grazed pasture and adjoining bush/forest not exposed to livestock activity. A one tail t-tests assuming unequal variance was used to test the hypothesis that these species (expressed as species abundance) exhibit greater preference for pasture than bush. Results in the accompanying bar graph show significant preference by *C. incertus*, *O. granulatus* and *Aphodius* sp. ($p < 0.01$, $p < 0.01$, $p < 0.05$ respectively) for open pastoral habitat. One individual of *C. incertus* was recovered from a dung-baited pitfall trap located on the bush margin and another 4 meters into the bush margin after 5 days of trapping (Forgie, unpubl. data). Interestingly, the bush margin infiltrated by *C. incertus* was fairly open with broken canopy providing semi-shaded habitat beneath. In similar recent studies by Dymock in Northland *C. incertus* ($n=1$) was found to infiltrate a stock disturbed forest patch surrounded by paddock whereas thick undisturbed forest adjoining grazed pasture inhabited by *C. incertus* and *O. granulatus* was not invaded by these species (Dymock, unpubl. data).



Habitat specificity of pastoral dung beetles at Shelly Beach, South Kaipara attracted over 5 days to dung baited pitfall traps placed along a transect running from pasture (P) into bush (B). Forgie (Unpubl. data).

Appreciation of this is essential to the success of establishment programmes, where poor habitat matching of donor and target areas or selection of species not exhibiting clear habitat preference may result in conflict with native fauna in target areas over habitat and resource partitioning. The dung beetle species we have selected for importation into New Zealand predominately target livestock dung in open pastoral habitat. Floral margins, fringes or transitional zones between pasture and native forest where habitat specific boundaries are determined between open grassland and forest beetles make up a small proportion of the native habitat proper. Thus any potential interaction between pastoral and forest dwelling dung beetles is likely to be minimal, localised and sporadic. Again, the only reason for pastoral dung beetles to invade fringes of fringe habitats transitioning to native contiguous habitat where native dung beetles occur is in the pursuit of dung deposited by non-native browsing or grazing animals being allowed to infiltrate these areas.

3.4 Soil preference

While most dung beetles will utilise any medium they occur on to prepare nesting burrows (John Feehan, SoilCam, South Australia, pers. comm., 2010), many species have shown clear preference for specific soil types which can in turn influence abundance and distribution. Nealis (1977) suggested soil type is a major determinant of the distribution of dung beetle species and found that South Texas clay soils were depauperate in both dung beetle diversity and biomass. Osberg *et al.* (1992) found that soil was the most important habitat determinant in two closely related ball-rolling species collected from different vegetation and soil types in the Mkuzi Game Reserve, South Africa, with one species preferring sand, and the other preferring heavy clay soils. Similarly, Doube (1983) states differences in levels of abundance of species in bush habitat on sandy loam and on clay loam are more likely to result from differences in these soil types than from differences in specific composition of the bush in the Hluhluwe Game Reserve, South Africa. However, it was also noted that differences in soil hardness and texture in bush habitat and grass land may also mediate the tunneling ability and thus breeding success of dung beetles. Findings by Doube (1983) indicate the largest species diversity and largest numbers of beetles were associated with bush habitat on sandy loam. Davis (1996a) found that considerable spatial variance among certain South African dung beetle communities for which soil type was primarily responsible. Davis (1996a) noted differences between harder (clay) and softer soil types (sand) include lower biomass of dung-burying and lower abundance of predatory dung beetles, lower rates and amounts of dung removal, and greater shredding of pad remnants on clay. Positive correlations between dung beetle biomass and dung removal were most frequent for large, fast-burying tunnelers on sand and for ball rollers on clay. In another study by Davis (1996b), clay specialists were represented in the three smaller size classes and soil generalists primarily in the two smallest size classes. On sand, large body size may be related to lower constraints on dung burial as sand is softer than clay and varies little in hardness with depth. On clay, smaller body size and greater biomass of ball rollers, which disperse dung horizontally, may be related to greater constraints on dung burial since clay is harder than sand and increases in hardness with depth.

4. Benefits to the pastoral habitat above and below ground

4.1 Soil compaction

There are no empirical studies that assess whether soil aeration by dung beetles (or earthworms) is sufficient to offset soil compaction by grazing livestock. However, in one study by Doube (2005b) soil penetrometer readings indicated that the presence of dung beetles extended the median depth of soft surface soil from about 12 cm (for controls and dung-only plots) to about 24 cm directly beneath the dung pads where dung beetles had been actively burying dung. Conversely, study by Bang *et al.* (2005) evaluating the effect of dung beetle tunnelling on air permeability without including the extent of any soil horizon effects indicated larger tunnels created by larger bodied beetles would significantly increase soil permeability only up to 10cm compared to controls and smaller sized beetles.

4.2 Nutrient cycling

Nitrogen and phosphorus are commonly in short supply in farmed soils and are added to pasture surfaces as costly fertiliser inputs. Considering the amount of available dung accumulating on pastoral surfaces, losses from nitrogen volatilisation and run-off represent an under-utilised source of fertiliser.

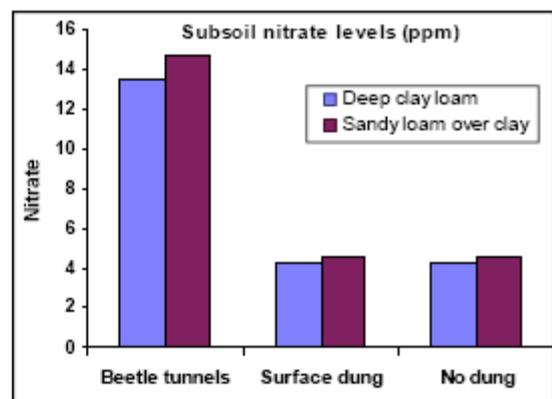
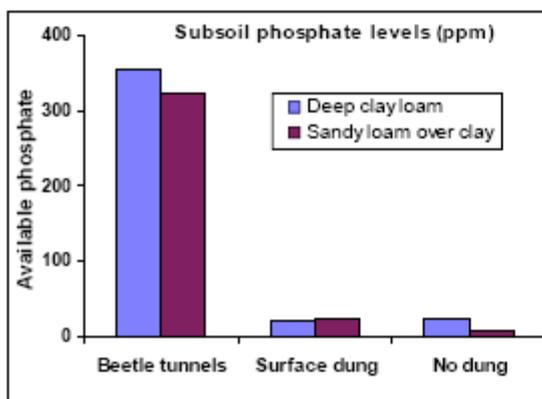
Bornemissza and Williams (1970) reported the direct effects of dung beetle activity on plant growth using the Australian dung beetle, *Onthophagus australis*, to determine its effects on the growth of

Japanese millet, *Echinochloa frumentacea* (cited as *Echinochloa crus-galli* var. *frumentacea*), in the laboratory. With dung and no beetles applied to the surface of pots, millet yield was 17.3 g in the tops and 12.7 g in the roots. With 20 pairs of beetles added to the same experimental setup, plant yield was increased to 31.3 g in the tops and 14.7 g in the roots. This increase was comparable to the 32.1 g in the tops and 14.0 g in the roots produced by the addition of phosphorus [0.3 g $\text{Ca}(\text{H}_2\text{PO}_4)_2\text{H}_2\text{O}$] and nitrogen (0.3 g NH_4NO_3) to similar pots without dung or beetles. This is equivalent to a fertilisation rate of 150 kg of the same nitrogen and phosphorus combination per hectare of pasture (or 60 kg per acre).

The nutrient value of fresh cattle dung for beardless wheatgrass grown in depleted British Columbian rangeland soils over two years was evaluated by Macqueen and Beirne (1975), who report 5 pairs of the dung beetle *Onthophagus nuchicornis*, buried on average 37% of fresh dung (200g) provided to them. After cessation of beetle burial activity the remaining dung was removed and the beetles allowed to escape. Nitrogen incorporated into the soil from residual dung not utilised by dung beetle larvae resulted in a 38% increase in crude protein production of grass over that of the control treatments equating to 134kgN/ha over 2 years. In contrast, treatments in which 200g of dung was hand-mixed with the soil to simulate total burial of the dung by dung beetles increased total crude production at a rate of about 370kg N/ha which exceeded results from treatments where fertilisers were applied at rates of 67 and 269 kg N/ha respectively. Under optimal conditions in areas where larger and more fecund or vigorous beetles are present, beetles may remove a majority of dung pads available and increase the crude protein production of pastoral grasses to levels shown by Macqueen and Beirne (1975). Thus, large amounts of nitrogen returned to soil could prove to be an important factor in sustainable cost-free improvements in pastoral productivity (see Section 7.4), given that plants can make the most efficient use of faecal nitrogen if the fresh dung is buried beneath the soil surface (Bang *et al.* 2005: See Section 7.4.1.2).

Fincher *et al.* (1981), observed the yield of coastal Bermuda grass (*Cynodon dactylon* (L.) Pers.), when exposed to different treatments in the field using 11 species of locally abundant pastoral dung beetles. Treatments included dung alone, dung plus 11 species of beetles, and several plots fertilised at different rates. The plots that received dung beetle activity had significantly higher yield over the season (7,791 kg DM /ha) than those without dung beetles (6,364 kg DM /ha) and those that received fertiliser at a rate of 112 kg N/ha (5,369 kg DM/ha). Furthermore, the yield from the dung beetle plots was not significantly less than plots that received fertiliser at a rate of 224 kg N/ha (8,305 kg DM/ha).

Recent field studies by Doube (2008a) show that deep tunnelling beetles increase levels of plant nutrients in the subsoil compared to soils without beetles. Doube's Appendix 11 (2008a) graphs show the effects on subsoil 16 months after dung was buried by *Bubas bison*. Similar results were obtained for subsoil levels of ammonia, sulphur and organic carbon. The effects have persisted for at least 2.5 years.



Bubas bison is one of the species proposed for introduction to New Zealand. Doube (2008a) found dung burial by this deep tunnelling dung beetle resulted in elevated levels soil carbon, soil organic matter, soil pH and electrolyte conductivity in the subsoil 20–45 cm below dung pads. These effects were dramatic, particularly in the vicinity of the beetle tunnels, and persisted for more than 2 years. Moreover, elevated levels of phosphate, sulphur, electrolyte conductivity and soil pH moved from the tunnel contents and the dung lining the tunnel walls into the surrounding bulk soil. Although not specifically measured in this study, soil chemistry in the 0-20cm horizon below dung pads is likely to show similar if not greater effects because this is the layer directly affected by dung beetle activity (Doube 2008a).

5. Benefits to availability of pasture and calculating dung production

It is estimated that one cow excretes 18 kilograms of dung each day. For approximately 9.6 million head of cattle of which more than 5 million are dairy in production per year in New Zealand (MAF, No Date) this represents roughly 180 million kg or 180 thousand tonnes of dung a day. Cattle dung contains many important essential plant nutrients, particularly nitrogen and phosphorus. These nutrients are commonly in short supply in most farmed soils that lack populations of dung burying beetles and are added to pasture surfaces as costly fertiliser inputs.

Pasture fouling by dung significantly reduces the area available for grazing. The area covered by individual livestock dung patches is highly variable, and largely dependent on quality of diet. Thus, conservative estimates for coverage by individual cattle dung pads range from 0.05 - 0.09 m² (Haynes and Williams, 1993, and references therein). Cattle on average produce between 11-16 defecations per day. Assuming all animals defecate at least 11 times a day then each animal of roughly covers at least 0.6 - 1m² of available pastoral forage. This equates to a daily loss of at least 570 – 950 hectares of grazing forage area each day from more than 100 million dung pats produced by cattle which amounts to approximately 5% of grazing pasture unavailable as forage at any one time (Dymock 1993). Similar calculations using figures for forage cover area by sheep manure (incl. pelleted dung) provided in Haynes and Williams (1993), estimate between 910 - 2,840 hectares of grazing area is lost on a daily basis from on average 16 defecations by each of approximately 71 million sheep (incl. lambs) in production per annum in New Zealand. If each dung pat occupies its original coverage area even for one week the total number of hectares lost for grazing is large.

Nutrient content in dung is variable being dependent on a number of factors but in particular the animal's diet. Williams and Haynes (1995) found that for every 100 kg of dry cattle dung there was 0.82 kg of phosphorus and 2.7 kg of nitrogen. When considering the amount of available dung accumulating on pastoral surfaces, this represents a significant under utilised resource of fertiliser.

Dung remaining on the pasture surface has an effect somewhat like a noxious weed because cattle and sheep will not graze on the rank growth around these dung patches, also known as the zone of repugnance, for a significant period of time (Bornemissza 1960, Marten and Donker 1966). Similar estimates have been calculated in countries where there has been a growing awareness of the waste of pasture and loss of productivity resulting from the accumulation of dung. Bornemissza (1960) stated that approximately 33 million tonnes of dung (dry weight) was produced by domesticated livestock each year. A lag in the dispersion of this dung would reduce the effective acreage of pasture by at least 300,000 acres annually, resulting in a 30% loss of production each year.

Fincher (1981) estimated that cattle on farms in the United States deposited approximately one billion cow pats a day during 1979 most of which remained on the pasture surface for several months. Fincher (1981) estimated that dung pat affects a grazing area five times its own area. If 335,678 ha of

pasture was continuously covered by cattle dung each year in the United States, then 1,678,390 ha of grazing area would be lost from production because of dung contamination.

The loss associated with cattle pasture fouling and resulting rank growth is substantial. It is estimated that five cows will decrease the effective area of pasture by one acre over one year (Bornemissza, 1960). For a herd of 100 cattle this equates to a loss of 20 acres per year. An American economic analysis estimated that pasture fouling causes an annual loss of 7.63 kg of beef per head of cattle and places the cost of reduced pasture fouling at \$122 million per annum (Losey and Vaughan, 2006).

6. Benefits to the health of livestock

6.1 Destruction of nematode eggs

Miller (1961) stated that the grinding efficiency of the mandibles, which varies between species, may be a significant factor in the susceptibility of beetles to infection by ingested parasites. Recent work by Holter *et al.* (2002) postulate that tunnelling and dung dwelling scarabs filter out large material using setae on the mouthparts and retain a slurry of minute particles (5-50µm) which is concentrated and ingested following excision of superfluous liquid between the mandibular molars.

6.2 Dung Beetles and the suppression of nematodes

Fincher (1973) found that herbage samples from a pasture plot without dung beetles had 14.7 times more parasitic larvae than samples from a plot containing a five-fold increase in dung beetle numbers above natural population levels. Also, herbage samples from a plot with natural dung beetle numbers had 3.7 times as many larvae as samples from a plot containing a larger beetle population. Similar reductions in parasite numbers resulting from the burial activity of dung beetles have been shown by Bryan (1973, 1976). However, reports by Bryan (1973) and Fincher (1973) have shown that parasite larvae can migrate onto vegetation from dung buried only a few centimetres below the soil surface. Fincher and Stewart (1979) found that species of dung beetles that bury dung containing nematode eggs to at least 15 cm will prevent larval migration back to the soil surface.

Bryan (1973) tested the effects of *Digitonthophagus gazella* (referred to hereafter as *O. gazella*) on the mortality of parasitic nematode larvae (*Haemonchus placei*, *Cooperia pectinata* and *Oesophagostomum radiatum*) in dung pats in irrigated and non-irrigated pastures. When dung pats were left intact, without dung beetle activity, parasitic nematode recovery from vegetation surrounding the pats was high. As expected, the vegetation around dung pats with beetle activity showed far less parasitic nematode larvae. Interestingly though, the recovery of larvae around pats with low beetle densities was less than those with higher beetle densities. Bryan attributed this to larvae being buried by the beetles. At high densities of beetles, more dung containing larvae was buried and these larvae survived in the moist soil, travelling to the surface under wet conditions. When beetle densities were low, less larvae containing dung was buried. However, sufficient destruction of the dung pats reduced the larvae recovered from the surrounding areas.

Fincher (1975) studied the effects of dung beetles on the number of parasitic nematodes that were acquired by uninfected calves on pasture. He used three adjacent pastures of similar size, and contaminated each by putting infected steers on the plots. Each plot was then subjected to low, natural or high dung beetle densities. A high density plot was created by adding 1,500 *Phanaeus vindex*, *P. igneus* and *Dichotomius carolinus*, initially and augmenting the population with beetles throughout the experiment. Two uninfected calves were placed on each plot with the infected steers after sufficient time for dung beetle activity. They were allowed to graze and were subsequently

necropsied to count any nematodes. A total of six different species of nematode worms were found in the calves (*Ostertagia ostertagi*, *Haemonchus placei*, *Cooperia pectinata*, *Cooperia oncophora*, *Cooperia punctata* and *Oesophagostomum radiatum*). Calves that grazed the low-density plot had an average of 21,513 individual nematodes. Those that grazed the natural density plot contained an average of 9,582 nematodes. Calves that grazed the plot with higher than natural dung beetle density had the lowest number of nematodes, averaging 2,404 nematodes per calf (Fincher 1975).

6.3 Dung beetles aiding in parasitic survival and dispersal

Dung beetles have been implicated in the transmission of parasitic nematodes and other organisms, by acting as intermediate hosts (e.g., Mathison and Ditrich, 1999). Miller (1961) stated that the grinding efficiency of the mandibles, which varies between species, may be a significant factor in the susceptibility of beetles to infection by ingested parasites. Miller *et al.* (1961) found that nematode eggs were destroyed by the action of the mouth parts of *Canthon laevis* and *Phanaeus igneus*, since they rarely appeared at any level of the digestive tracts of both species. *Pinotus carolinus*, however, swallowed many eggs which survived, although a high percentage was damaged.

Results by Chirico *et al.* (2003) indicate that activity by *Aphodius* spp. in fresh dung can optimise conditions for nematode development to the infective larval stage if favourable environmental conditions prevail. Such synergistic effect may be due to the fact that dung beetles used in this study are dung dwellers, i.e., no substantial amount of the dung is removed or burrowed as these beetles feed, lay their eggs and the larval development takes place in brood chambers inside the dung.

It is therefore reasonable to say that under certain conditions dung beetles can be beneficial in reducing parasitic nematode numbers, while under other circumstances they can have a neutral or potentially enhance worm transmission in cattle.

6.4 Dung beetle burial activity reduces pest fly numbers

The benefit provided by dung beetles as biological control agents of nuisance flies has been studied extensively. Five main nuisance flies (Diptera: Muscidae) are considered important pests because of their injurious effects on cattle. These are the horn fly (*Haematobia irritans irritans*), face fly (*Musca autumnalis*), buffalo fly (*Haematobia irritans exigua*), African buffalo fly (*Haematobia thirouxi potans*), and Australian bush fly (*Musca vetustissima*). All lay eggs in cattle dung, where the larvae feed and mature. These species have followed the introduction of livestock globally. Infestations owing to accumulation of unutilised dung have been responsible for reductions livestock productivity, hide quality and financial burden on livestock farmers seeking chemical controls. Increasing concerns about chemical residues in meat and rising levels of fly resistance to chemicals used for their control formed an instrumental part in the development of the original CSIRO dung beetle project.

The Afro-Asian dung beetle *O. gazella* has been the focus of various studies on dung-breeding fly survival. Efficient at burying dung, *O. gazella* has been introduced into various countries for fly control. Bush fly survival was reduced significantly when *O. gazella* was introduced to dung pats containing fly eggs (Bornemissza, 1970). With no beetle pressure (in 1000 cc pats), an average of 90.7 offspring emerged from the eggs of 10 female bush flies. The introduction of 10 pairs of *O. gazella* reduced fly survival to 7.5, and as little as 20 pairs of *O. gazella* reduced survival to zero.

Many factors contribute to the dung beetle-induced mortality of dung breeding flies including arrival time by flies and beetles to the dung resource. Fly eggs are more affected by physical damage from dung beetle activity than established fly larvae although the latter suffer more from a loss of food resource. Bornemissza (1970) compared the survival of flies produced from the eggs of 5 gravid

females, on 100 cc dung pats, with 50 larvae seeded on the same size pats. Similar mean survival numbers occurred in the controls (44 and 39.5 respectively). However, when beetles were introduced at densities of 1, 2, and 3 pairs, mean survival of bush fly eggs was 4.5, 2.5 and 0.0 respectively, while the larval survival was 22.5, 11.8 and 8.0.

The size of dung pats can influence fly survival under beetle pressure. Blume *et al.* (1973) showed that 30 pairs of *O. gazella* could control 83.7% of fly emergence in dung pats weighing 454g, but could only control 29.1% of the flies in a pats double the size. This demonstrates that dung beetles control flies by resource competition, rather than by direct mortality.

6.5 Benefits to pest fly control in Australia

Fresh mammalian dung is an important resource for a variety of dung breeding flies of economic importance (e.g., *Musca autumnalis* (face fly), *M. vetustissima* (bush Fly), *H. irritans exigua* (horn fly), *H. irritans irritans* (buffalo fly)) and act as a nutrient resource for completion of egg development in non-dung breeding flies like those associated with sheep flystrike (e.g., *Lucilia cuprina*, *Chrysomya rufifacies*). In contrast several fly species have been the focus of several dung beetle projects overseas, particularly in Australia in which, a major objective of the original CSIRO dung beetle project was to control buffalo fly and bush fly populations.

Subsequently, many lab and field experiments have report significant reductions in the numbers of dung breeding pest flies but none as dramatic as experiments on the island of Hawaii in 1966 that reported a 95% reduction in the number of horn flies emerging from dung when the introduced dung beetle *O. gazella* was present compared with dung where beetles had been excluded (Bornemissza 1970). Similarly, the CSIRO Division of Entomology in Western Australia demonstrated an 88% reduction in bush fly activity caused by the activity of introduced dung beetle species (Ridsdill-Smith and Matthiessen, 1988), and Fay *et al.* (1990) found massive reductions in fly survival resulting from the activities of intact dung beetle assemblages, a more realistic community level approach than manipulative studies focusing on single dung beetle species highlighted by Nichols *et al.* (2008).

6.6 Dung removal and human disease transmission by flies

New Zealand has particularly high rate of campylobacteriosis compared to other OECD countries with up to 14000 cases notified per annum (Nelson and Harris, 2006). The primary source of infection in this country is suggested to be livestock, particularly beef and dairy cattle. Flies are the likely path of transmission by foraging on or breeding in the dung of these animals then subsequently contaminating food being prepared for human consumption and commonly touched surfaces.

Livestock excretia plays an important role in water quality and its contamination from various bacteria (faecal coliforms and cyanobacteria) and pathogens (*Cryptosporidium* and *Giardia*) that are of importance to human health.

For example, *Giardia* and *Cryptosporidium* are found in the faeces of warm-blooded animals and can infect drinking water causing diarrhoea, abdominal cramps and nausea. These pathogens are problematic as they're resistant to conventional water treatment, remain infective for long periods, are difficult to detect and cross-infect different animal species. Water quality research has found that dung burial results in substantially cleaner run-off from pastures (Fincher, 1981; Doube, 2005c, 2006b) and by doing so dung beetles may also play a role in reducing the presence of harmful human pathogens. Doube (2004) conducted a pilot study of the recovery of *Cryptosporidium parvum* oocysts from dung buried by dung beetles over a 60 day period. Between 80–90% of the dung was buried within three weeks, and was used to line tunnels or was formed into brood masses at the bottom of

each soil column. Doube (2004) found after 60 days in the treatments where dung beetles were added, the numbers of oocysts in the surface dung was reduced by 99.7% compared with the beetle-free control pat. Moreover, oocyst numbers (per g dry dung) recovered from the tunnel walls and the brood masses was lower by roughly two-thirds than the numbers in the control dung, although the extent to which *Cryptosporidium* oocysts in brood dung are killed by the feeding activities of larval beetles was not ascertained. Finally, oocyst numbers (144×10^3 - 396×10^3 oocytes) recovered from the control dung did not decrease over the 60 days of the experiment.

7. Dung beetle activity increases earthworm populations and depth at which earthworms are found.

In New Zealand the two most common earth worms are *Aporrectodea caliginosa* and the European, *Lumbricus rubellus*, which bury dung in addition to mixing topsoil (Martin and Charles, 1979). Martin and Charles (1979) found that dung from the previous summer and autumn disappeared within 10-15 weeks following the onset of earthworm activity, and dung pats deposited during winter could disappear within 6 weeks. Dung deposited in early spring may not be completely removed before soil conditions become too dry for earthworm activity.

Doube (2006a) investigated the impact of dung burial by three deep tunnelling species (*Bubas bison*, *Geotrupes spiniger*, *Onthophagus pentacanthus*) on earthworm populations (*A. caliginosa*, *A. trapezoides*, *A. rosea*, and *M. dubius*) in the Central Highlands of Victoria. Rapidity and persistence of the earthworm response following introduction of the dung beetles was significant. Soon after dung beetle activity was complete earthworms responded quickly to *B. bison* activity, with a massive increase in biomass (between 2-fold and 33-fold, depending upon species and location) within 2 months of adding beetles to the dung. Earthworms responded to *G. spiniger* activity, with a substantial increase in biomass (between 3-fold and 6-fold, depending upon species and location) during the first winter after adding the dung beetles to the dung. Similarly, earthworms responded to *B. bison* and *G. spiniger* activity with a substantial increase in biomass (up to 3-fold depending upon location) during the second winter after adding the beetles to the dung.

Doube (2006a) noted that in the first winter the earthworms ate the decomposing dung that lined the beetle tunnels. In the following winter, the earthworms responded to the altered soil conditions associated with the dung burial, principal among which was a substantial increase in the biomass of plant roots in the soil beneath the buried dung pats. Doube (2006a) suggested that the elevated levels of root turnover provided the basis for an increased food supply for the earthworms. Furthermore, the response of earthworms to dung beetle activity appeared to be similar for the three species of dung beetle tested (*B. bison*, *G. spiniger*, and *O. pentacanthus*).

Doube (2006a) concluded that dung burial activity of dung beetles commonly increased the numbers and biomass of earthworms in soil. The response was evident two months after introducing dung beetles and persisted into the second pasture growing season. It also appears likely that all four earthworm species responded positively to dung beetle activity and that the effect of the presence of dung alone on earthworm populations diminished relatively quickly. Finally, Doube's (2006a) results suggest the abundance and biomass of a range of species of introduced endogeic earthworms, those that live and feed in the soil, increase in response to the dung burial activity by a range of introduced and native tunnelling dung beetle species.

In a more recent study Doube (2008c) found adult *A. trapezoides* earthworms from plots containing both dung and beetles plots were larger than those from the dung-only plots ($P < 0.001$) and the control plots ($P < 0.01$) and there was no difference between the latter two ($P > 0.05$). These data indicate that the presence of dung mixed through the soil by dung beetle activity created a favourable environment for earthworm growth and development, resulting in larger adult worms than in the

dung-only and control cores. Interestingly, Doube (2008c) found in the same study there was no significant effect of dung or beetles on the mean weight of the developing larvae and pupae of the beetles, indicating that the transition from sub-adult to adult occurred at the same earthworm size in all treatments and was not affected by the food supply.

Similarly, the earthworm *A. rosea* was dispersed throughout the soil profile. An analysis of the average weight of adult earthworms indicated that there was no consistent change in size with soil depth for adults or sub-adults in any of the three treatments. However, there was a strongly significant effect ($P < 0.001$) of treatment on the size of the adult earthworms but not on the size of the sub-adults ($P > 0.05$). The adult earthworms in the dung-only treatment plots were substantially heavier (+23%) than the adults in the dung and beetles treatment plots ($P < 0.001$), which in turn were heavier (+12%) than those in the control plots ($P < 0.001$). The presence of earthworm food (cattle dung) appears to have created an environment that was highly favourable for earthworm growth and development (Doube 2008c).

Finally, in a study assessing the impacts of parasiticides on dung feeding fauna Strong (1992) found that earthworms alone were unable to degrade dung containing anthelmintics (nematode drenches) when dung beetles were excluded.

8. Effect of dung beetles on the rate at which water infiltrates soil

Richardson and Richardson (2000), reported dung beetles in Oklahoma buried about 2,000 kg wet manure/hectare/day. This increased water infiltration an average of 129% (ranging from 42-346%) over six study plots. Each extra inch (25 mm) of water absorbed adds over 254,000 l/ha of water to the soil, reducing flooding and drought. This is in accordance with findings by Waterhouse (1974) that loamy soils manipulated by dung beetles required 5x more water to get saturated than did undisturbed soil.

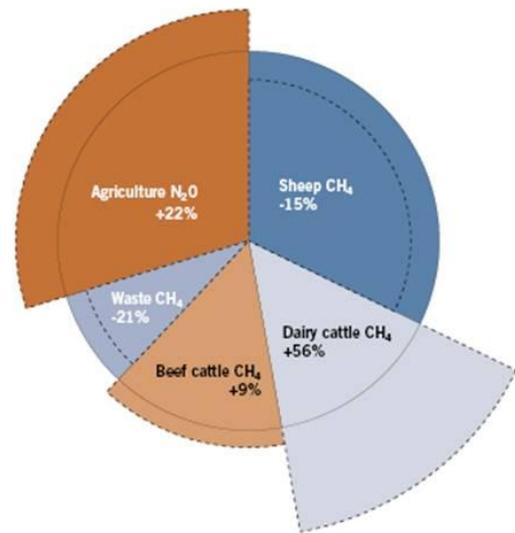
Doube (2005b) investigated the impact of dung beetle activity on soil properties in the Barham river catchment, Victoria. Plots were established comprising three treatments “dung only” “dung and beetles” and a control “no dung – no beetles”. After four months of activity, the median time for 600 ml of water to soak into plots with beetles was 1-2 minutes and 8-16 minutes in plots without beetles. In a study evaluating pasture growth due to the late summer/autumn-active dung beetle *Geotrupes spiniger*, Doube (2006b) reported dung beetle activity substantially increased the permeability of soil to water (7-fold over the controls), and this effect persisted for at least 2 years after the dung beetles had buried the dung. During phase one of the project (2004–05), dung burial activity increased the permeability of soil to water significantly (up to 40-fold) in dry conditions but to a lesser extent during winter when the soil was saturated with water.

9. Agricultural emissions

The agriculture sector is the largest single source of greenhouse gas emissions (GHG) in New Zealand, making up approximately 48 per cent of our total emissions (MfE, 2010) and emissions in the sector are continuing to grow. The term ‘agriculture emissions’ refers to the non-carbon dioxide (CO₂) greenhouse gas emissions from agricultural production. These consist of methane (CH₄) from livestock (approximately two-thirds), and nitrous oxide (N₂O) from animal excrement and the use of nitrogen fertiliser (the remaining one-third). To ensure that New Zealand can meet its international commitments on climate change, our current knowledge and future research needs on N₂O emissions from agricultural soils for example need to be identified (de Klein *et al.*, 2001).

9.1 Methane

In agriculture, the vast majority of all of the methane comes from livestock, particularly cattle flatulence and, to a lesser extent, their dung. Emission rates from livestock dung alone in New Zealand have not been fully estimated. However, Holter (1997 and references therein) obtained values between 37 to 170 ml CH₄ per dung pat on grazed pastures in Denmark from spring-autumn but estimates this is up to 4% of the emissions likely from same dung production stored as liquid slurry which in Scandinavia may contribute as much as 30% of the total national emissions. Jarvis *et al.* (1995) state that although CH₄ emissions from dung were significant, they represent less than 0.2% of the estimated total CH₄ release from a dairy farm's complete livestock production system. Methane production rates from dung are quite variable due mainly to diet (e.g., grain/silage/ hay and concentrates, fertilised/ unfertilised grasses etc. (Jarvis *et al.*, 1995)), climatic conditions, and numbers and level of activity of organisms utilising the dung (e.g., microbes, bacteria, earthworms, dung beetles, etc.). Studies using field pats from cattle fed various diets found a greater rate of CH₄ release from dung with higher nitrogen status (Jarvis *et al.*, 1995). Holter (1996) states that wet dung or dung prevented from drying out by rain maintains anaerobic conditions necessary for CH₄ production, whereas pats that dry out facilitate aerobic conditions halting methanogenesis. Hot dry conditions whilst stimulating microbial activity and CH₄ production would dry out unutilised dung pats quickly but in doing so would create a crust that would initially maintain the anaerobic status of the pat (Jarvis *et al.*, 1995). Thus, both authors state a range of methanogenic activity from 2-18 days following deposition of the pat on a pasture surface with greatest concentrations of CH₄ released in the first few days followed by a steady decay in emissions with increased aerobicity after this time. Dung beetles by stimulating aerobic conditions and altering microorganism fauna in dung pats, brood balls and associated soils during feeding and nesting, may contribute to reducing CH₄ production from livestock dung. Rapid utilisation of freshly deposited dung is likely to further enhance dung beetle contributions to CH₄ reduction in dung.



Percentage increases and decreases in methane and nitrous oxide emissions from key agriculture categories and waste. The solid lines indicate 1990 emissions, and the dotted lines indicate estimated current emissions. Pie chart courtesy of: <http://www.mfe.govt.nz/publications/climate/greenhouse-gas-emissions/greenhouse-gas-emissions.pdf>

10. Economic benefits

It is very difficult to assign an accurate economic value to the ecological services provided by beneficial insects in general. However, even rough estimates of the fiscal equivalent of various ecological services are likely to be a useful means to further supporting benefits of the relevant organisms providing these services. Losey and Vaughn (2006) evaluated the ecosystem services maintained by wild rather than unmanaged/ imported dung beetles native to the USA. These authors calculate conservative minimum estimates which are attributed to the fact that: their estimates are based solely on pastured beef cattle while dung beetles also avert economic losses by burying dung from dairy cattle, sheep, horse, deer, goat and pig livestock farming; and, the true economic worth to important ecosystem services such as soil and water quality improvement, decomposition of organic matter, suppression of pest organisms (gut parasites, flies, diseases), etc, are not taken into consideration simply because there are no t any available data to reliably calculate the monetary equivalents of them. Losey and Vaughn (2006) rightfully stress that quantification of these missing

ecosystem services would, as estimated by Fincher (1981), add billions of dollars annually to their overall estimate.

Losey and Vaughn (2006) estimate the annual net value of ecosystem services provided by dung beetles to the pastoral beef cattle industry alone in the USA would be around US\$380 Million (M). This value is based on an estimated 32 million cattle, out of a total of 100 million in production each year that are not drenched. Their dung is therefore not contaminated with insecticides and safe to dung beetles. Losey and Vaughn's (2006) estimate is attributed to losses from forage fouling (averted annual losses of \$120M), nitrogen volatilisation (averted annual losses of \$60M), livestock parasites (averted annual losses of \$70M), and pest flies (averted annual losses of \$130M). This estimate does not take into account additional profit gained by more productive pastures, savings from reductions in cost of fertiliser inputs etc. So it is an underestimation. The real figure is likely to be in the billions according to Fincher

10.1 Calculating future benefits of dung beetles in New Zealand

We applied a very simplified application of the total US estimate to the New Zealand cattle industry but included both beef and dairy numbers.

According to Statistics New Zealand, agricultural production census/survey there are on average 9.6 million (m) beef (4.4 m) and dairy (5.2 m) cattle in annual production in this country (MAF, No Date). Estimates of the numbers of these cattle drenched as at 30 June equates to 2.7 m (61%) beef cattle and 3.9 m (74%) dairy cattle or when numbers are combined 69% of cattle in production are drenched (Tony Rhodes, PGG Wrightson, pers. comm.: Tables (a)-(c)). Conversely, 30% or 3.0 m out of 9.6 m head of cattle are not drenched and therefore their dung not contaminated with insecticides (Table (c)).

Tables (a) - (c) provide estimates of drench/non-drench use on beef(a) and dairy(b) cattle in production in New Zealand based on averages of 2002-2007 livestock numbers sourced from Statistics New Zealand, agricultural production census/survey. Combined beef and dairy totals (c) are also provided. Tables (a), (b) modified from: <http://www.maf.govt.nz/statistics/pastoral/livestock-numbers/>

(Numbers as at 30 June: http://www.maf.govt.nz/statistics/pastoral/livestock-numbers/)											
(a) Beef Cattle	Beef Breeding Bulls	Beef Cows and Heifers (breeding) 1 to 2 Years Old	Beef Cows and Heifers (breeding) 2 Years Old and Over	Beef Cows and Heifers (not breeding) 1 to 2 Years Old	Beef Cows and Heifers (not breeding) 2 Years Old and Over	Beef Heifers (Rising 1 Year Old) and Calves	Beef Non-breeding Bulls	Steers, 1 to 2 Years Old	Steers, 2 Years Old and Over	Steer Calves, Under 1 Year Old	Total Beef Cattle
Average of 2002-2007 totals	73 986	162 681	1 092 316	360 121	141 892	565 927	871 724	471 175	274 664	479 085	4 425 945
Estimated percentage of cattle drenched	20	100	15	40	15	100	100	60	40	100	
No. cattle drenched	16 085	162 681	154 182	144 753	21 618	565 927	871 724	290 065	11 828	479 085	2 717 948

(Numbers as at 30 June: http://www.maf.govt.nz/statistics/pastoral/livestock-numbers/)						(c)					
(b) Dairy Cattle	Dairy Breeding Bulls	Dairy Cows and Heifers 1 Year Old and Over, In Milk or Calf	Dairy Cows and Heifers 1 Year Old and Over, Not in Milk or Calf	Dairy Heifers (Rising 1 Year Old) and Heifer Calves	Total Dairy Cattle	Combined totals	Average of 2002-2007 totals	No. cattle therefore drenched	Percentage drenched	No. cattle not drenched	Percentage not drenched
Average of 2002-2007 totals	45 686	4 073 973	225 460	828 557	5 166 333	Beef cattle	4425945	2717948	61.40%	1707997	38.60%
Estimated percentage of cattle drenched	10	70	90	100		Dairy cattle	5166333	3887821	75.30%	1278512	24.70%
No. cattle drenched	4 569	2 851 781	202 914	828 557	3 887 821	Total cattle in production	9592278	6605769	69.90%	2986509	30.10%

If we assume the benefits to NZ are the same as those for the US, based solely on non-drenched stock, dung beetles could be worth over NZ\$50 million (USD35.6m; 1 USD =1.46 NZD) per year to the NZ economy. However, even on farms using drenches dung beetles will contribute towards a reduction in drench use if integrated pest management strategies taking dung beetles and other dung feeding

fauna (e.g., pastoral earthworms) into consideration are implemented. By doing so, this value could eventually reach as much as NZ\$166 million annually. It is important to note there are many factors regarding drenching that are not taken into consideration in these estimates. First, these values do not account for the number of occasions an animal class may be treated within the year e.g. lactating dairy cows may receive only one treatment per annum; dairy heifers (rising one year old), heifer calves, and beef non-breeding bulls may receive 3 to 8 treatments per annum. Secondly, the treatment drug action family may result in dung with chemical residue levels that range from toxic (e.g. synthetic pyrethroid ectocides) to non-toxic (e.g., moxidectin within the macrocyclic lactone family) for dung beetles and which could have significant or minimal to no negative impacts on dung feeding fauna in general (Wardhaugh, 2005). Additionally, the level of impact on these fauna can also be influenced by timing, dosage rates, the use of combinations of anthelmintics in treatments to counter parasite resistance development. Moreover, the period of time that drug action family residuals have a negative impact on these fauna is also dependent on the lifespan of their constituent active chemicals in the pastoral environment. Every year our sheep, beef and dairy farmers spend about \$80 million on parasiticides used to destroy the parasitic worms and the cost of these nematodes to the NZ farming industry is estimated to be around \$700 million per year (AgResearch, 2010). Much of this cost is attributed to farmer dependency on cocktails of drenches needed to control chemical resistant strains of intestinal parasites. We expect this cost to diminish significantly if dung beetles can be established and they become sufficiently abundant to make a noticeable impact on dung burial and the reduction of infection rates of livestock by intestinal parasites. Two concluding statements emerge when considering these estimates:

- These estimated values represent the postulated avoided costs of reported production losses due to forage fouling, nitrogen volatilisation, live stock pests (parasites and flies), etc. Thus, the effective economic value of the services provided by dung beetles is actually greater when the additional profit gained by improved soil health and more sustainable productive pastures are taken into consideration (Losey and Vaughn, 2006).
- Even if only 10% of these estimates are achieved it still represents a significant added benefit stemming from the establishment of a variety of exotic dung beetles suitable to NZ's climate and soils compared to not having them at all.

*10.2 Estimating production increases from dung burial by *Bubas bison*, a winter active species considered for release in New Zealand*

Efforts to place a value on additional pasture production was achieved by Doube (2008a). Knowing the volume of beetle-buried dung that gave rise to the increased pasture production, it was possible to estimate the increased production that could be attributed to each litre of buried dung. The average of 5 estimates was 0.057 kg DM per litre of buried dung for dry matter produced during the 2006 and 2007 growing seasons (Doube, 2008a). This estimate of the impact of dung beetle activity on pasture production is independent of stocking rate, live weight of cattle, dung beetle abundance and seasonal activity and relies only upon a measure of dung burial by *B. bison*. This statistic can be used to estimate production benefits due to *B. bison* wherever the beetle will survive and bury dung.

A simplistic model examining the economic benefit of this for a herd of 100 cattle was generated. About 0.23 million kg of dung were buried over a 123-day period (the seasonal activity period of *B. bison*) and the corresponding increased pasture production was estimated to be 13,000 kg DW of pasture. This has an estimated value of \$2100 AUD as hay (at \$160 per tonne), or from zero up to over \$12,300NZD value in live weight gain, depending upon stock management practices and price per kg cattle live weight (Doube, 2008a).

11. References.

Refer to: Appendix 4. Application references