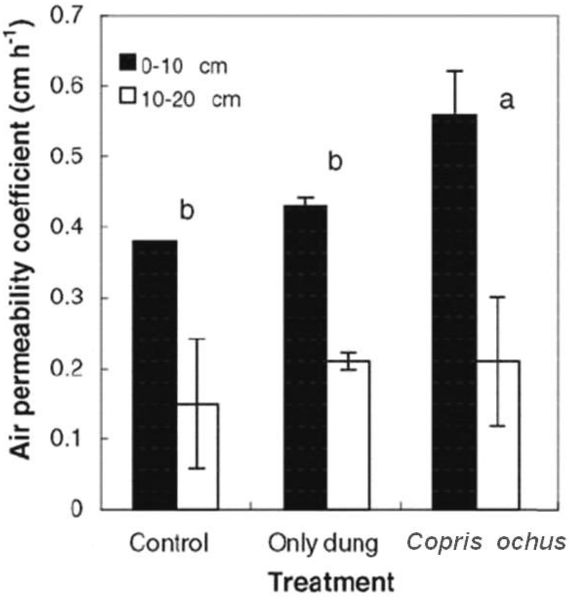
Appendix 3. Review and comments on benefits and risks

1. 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 Over 30 published and unpublished reports have also been sourced from colleagues.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.

Positive/beneficial effects of the organism on the environment:

Tunnelling by beetles leads to increased aeration of the soil, which reduces surface flooding and runoff into streams, leading to improved stream quality

2. Tunnelling by beetles, and the removal of dung from the soil surface are likely to improve waterway quality and the biodiversity values of streams and estuaries because dung beetles will increase the rate of infiltration of water through the soil, leading to reduced water runoff and surface movement of urine, nutrients and sediment, and hence to reduced pollution of waterways. As dung beetle activity is not the only factor that could benefit waterway eutrophication, the benefits to aquatic ecosystems are predicted to be significant but minor to moderate.
3. Burial of animal waste by beetles will directly reduce pollution of waterways adjacent to farms, an issue of great concern in New Zealand (Norman, 2010). Fertiliser and dung are the two largest contributors to water contamination by nutrients resulting from water runoff (Doube, 2005c). The quality of surface water influences not only the health of aquatic ecosystems, but also whether the water can safely be used for drinking (see paragraph 32-33), agriculture (see paragraph 35-47) or recreation. Dung burial results in substantially cleaner run-off from pastures (Fincher, 1981; Doube, 2005c, 2006a).



Comparison of air permeability coefficients of soil cores following 172 days of dung burial activity by paracoprid dung beetles. Means with the same letter are not significantly different using ANOVA. L.S.D. (5%). Modified from Bang *et al.* (2005)

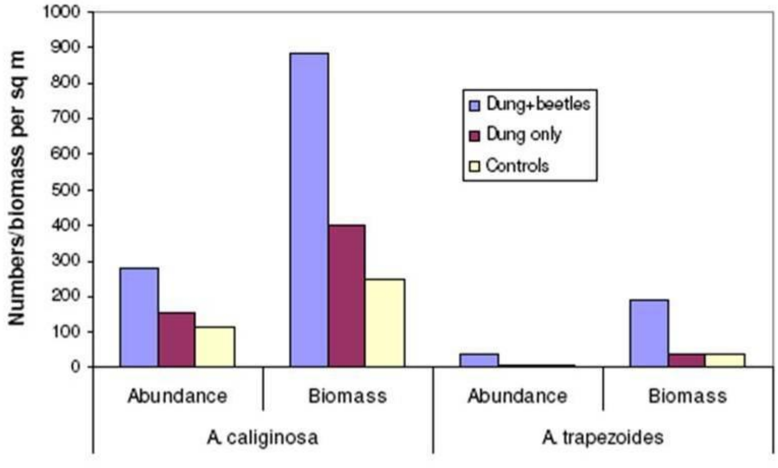
4. Benefits for aquatic ecosystems will be achieved by reducing the adverse environmental effects of soil compaction. Agricultural machinery and the hooves of grazing animals cause soils to compact over time, reducing macropore spaces (tunnels, burrows, cracks and other voids). Water moves by gravity into the open macropore spaces in the soil, and the size of the soil particles and their spacing determine how much liquid can flow in. If rainfall or urination intensity is greater than the

infiltration rate, liquids accumulate on the surface (ponding) and run off slopes. Compacted soils are therefore more prone to surface flooding and run-off to waterways than soils with larger pore spaces. The extensive tunnel systems created by beetles (and tunnels from subsequent increased earthworm activity, see paragraph 5-8) are expected to increase aeration and reduce compaction under dung pats, to increase the rates of water and urine infiltration, and assist agricultural inputs such as lime and fertilisers to enter the soil profile rather than running off to enter the waterways. A number of studies that demonstrate that dung beetles improve water infiltration are summarised in Appendix 2.8.

The release of dung beetles, leads to the increased aeration of the soil, which increases earthworm abundance

5. Soil compaction significantly influences the activity of soil micro-organisms and earthworms by altering soil chemistry, particularly pH, and by retarding the ability of soil organisms such as earthworms to move through the soil horizon (Chan and Barchia, 2007). Studies in Australia clearly show that tunnels created during the burial of animal waste by dung beetles are likely to increase the populations, biomass and activity of earthworms in New Zealand, leading to increased biodiversity, acceleration of nutrient cycling and improvement in soil structure.

6. In terms of both activity and biomass, Römbke *et al.* (2005) state that in most soils worldwide earthworms are the most important soil invertebrates, improving soil structure, chemistry and particularly organic matter decomposition, especially in the upper layer of the soil profile (e.g. Edwards, 2004). They are generally thought to improve the stability of soil through casts (droppings) and to create larger soil pores by moving throughout the soil horizon in which they are active. However, earthworms and dung beetles provide similar ecological services. They have complementary ecological and seasonal attributes that would provide significant year round improvements in the sustainability of New Zealand's pastoral ecosystems. As pastoral systems were developed around the world, and tend to be Eurocentric in origin, earthworm species were introduced long before dung beetles were known to have similar benefits.



The effects of dung and dung beetles on the numbers (per m2) and biomass (g live weight per m2) of *A. caliginosa* and *A. trapezoides* 15 months after the addition of dung and dung beetles to the field plots in red clay loam. Graph reproduced with permission from Doube (2006a)

7. Most earthworm species operate effectively from autumn to spring, when soils are sufficiently wet for them to move through. With two exceptions, the dung beetle species proposed for importation are active in the dryer summer season, and will not compete directly with earthworms for food resources. However, *Bubas bison* (winter to spring) and *Geotrupes spiniger* (summer to autumn) are likely to overlap with earthworm activity in the autumn. Rather than competing, Doube (2006a; 2008c) has recently shown that burial of pastoral dung by these two beetle species increases both the number and biomass of earthworms (see Figure above. Refer to Appendix 2.7 for more details). Dung beetle activity also increased the depth at which earthworms were active (Doube, 2005b). Excavation of

dung burial sites revealed *Bubas bison* breeding activity at about 40 cm depth. The dung beetle tunnels were lined with dung and contained numerous earthworms to a depth of about 30 cm and commonly packed with earthworm casts. In the absence of dung beetle tunnels earthworms were restricted to the top 5–10 cm of topsoil (Doube, 2005b).

8. Similarly, Chan and Barchia (2007) showed that soil compaction and pH can negatively affect earthworm abundance, biomass and distribution. This was offset by the tunnelling capability of dung beetles and their impact on improving soil chemistry and structure created a more favourable habitat for earthworms.

The release of dung beetles, leads to increased levels of animal waste being buried, increasing microbial productivity and nutrient cycling, and improving plant growth

9. Soil compaction impairs the root growth of plants, which results in reduced nutrient and water uptake, and poorer vegetation cover. Bang *et al.* (2005) suggest that the burrowing activity of tunnelling beetles improves the characteristics of soil in the top 10cm of the soil horizon in Australia, and increases the feed value of herbage by mixing and incorporating organic matter into the soil (see paragraph 39-42, and Appendix 2.5 for more detail).

10. The tunnelling of dung beetles is therefore likely to decrease soil compaction and increase the rate at which animal waste is buried in New Zealand. This will improve nutrient cycling with moderate benefits for the functioning of pastoral ecosystem through increased diversity and productivity of soil micro-organisms and plants.

11. Haynes and Williams (1993) provide a detailed analysis of the nutrients phosphorus, potassium, nitrogen, calcium and magnesium available in livestock faeces. 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 dung remains on the soil surface, a proportion of these beneficial nutrients are lost either to the atmosphere (contributing to greenhouse gas emissions, see paragraph 13-21), or are washed away to pollute waterways (see paragraph 2-4). Gillard (1967) estimates up to approximately 80% of the nitrogen content of dung is denatured by bacteria and lost by volatilisation as ammonia into the atmosphere when dung remains on the pasture surface. Where larger and more fecund or vigorous beetles are present, most available cattle dung pads are removed, reducing the loss of nitrogen through volatilisation to 5-15 % (Gillard, 1967). The effect of dung-derived nutrients on nutrient cycling and soil chemistry commonly occurs in the surface soil 2.5-5cm below dung patches in the grazed pastoral ecosystem (Haynes and Williams, 1993). Several studies have demonstrated an increase in nitrogen and other nutrients in soils associated with dung beetle activity (For more detail see Appendix 2.4).

12. There are no studies published that indicate that dung beetles have an adverse effect on nutrient cycling and distribution.

The release of scarab beetles, leads to increased levels of animal waste being buried, reducing greenhouse gas emissions

13. The burial of animal waste will reduce the production of methane and nitrous oxide, and is therefore likely to decrease emission of greenhouse gases associated with animal waste. As this is not a high proportion of the New Zealand's emissions profile, and there is uncertainty about the processes involved, on balance, the benefit is predicted to be minor. Uncertainty about the significance of gains from reduction of nitrogen emissions arises because the impact of dung beetles on non-CO_2 emissions from soils has yet to be adequately quantified.

14. It is possible that improved soil structure and tunnelling caused by dung beetles could facilitate escape rather than entrapment or sequestering of gaseous emissions in soils. The value of benefits may be reduced because increased carbon content of the soil resulting from burial of animal waste may foster denitrifying bacteria, partially nullifying the benefits of increased nitrogen capture.

Methane

15. As dung dries, or is aerated by movement by dung beetles, the microbial balance changes towards aerobic species, and CO_2 production replaces methane production (Holter, 1997). Methane has a global warming potential 25 times that of CO_2 over 100 years. Production of methane occurs from 2-18 days following deposition of the pat on a pasture surface with greatest concentrations of CH4 being released in the first few days followed by a steady decay in emissions as the dung dries and becomes aerated (Jarvis *et al.*, 1995; Holter, 1997). Dung beetles will stimulate such aerobic conditions, altering the micro-organism fauna in dung pats, brood balls and associated soils during feeding and nesting. Compared to unburied dung, the speed at which freshly deposited dung is buried is also likely to reduce CH_4 production. Jarvis *et al.* (1995) state that although CH_4 emissions from dung were significant, they represent less than 0.2% of the estimated total CH_4 release from a dairy livestock production system. This benefit is therefore significant but not large. More detail can be found in Appendix 2.9.

Nitrous Oxide

16. A cow excretes roughly 120 kg of nitrogen per year in animal waste of which about 1% is converted to nitrous oxide (N_2O) - about 5 kg per hectare per year (Whitehead, 2009). This emission is equivalent to 1600 kg of carbon dioxide per hectare per year because nitrous oxide is an extremely potent greenhouse gas.

17. Dung and urea within in the soil profile are normally hydrolysed, leading to an accumulation of ammonium which can either be bound to clay minerals and organic colloids, or nitrified (to NO_3^-) by the actions of oxygen loving bacteria in the soil. However when soils lack oxygen (for example when soil structure is poor through compaction) these nitrates are more likely to be 'denitrified' by organic-material-loving bacteria to form various nitrogenous gases including N_2O. In soils aerated by dung beetles and earthworms these bacteria are less active in denitrification because they use dissolved oxygen out of the water and are less reliant on stripping oxygen off nitrate molecules (Haynes and Williams, 1993).

18. These appear to be important benefits, but the impact of dung beetles on nitrogen cycling is not entirely clear. Yokoyama *et al.* (1991) found that denitrification in brood balls caused an nitrogen loss significantly greater than that from dung un-manipulated by dung beetles which could have been the result of the beetles increasing the endogenous $N\text{-}NO_3$ pool which would enhance the activity of denitrifying bacteria. On the other hand, castings (=cocoon made from dung evacuated by larvae prior to pupating) have been found to contain high concentrations of amino acids accumulated from what is thought due to fixation of gaseous nitrogen by microorganisms in the digestive tracts of developing larvae feeding in the brood balls (Rougon *et al.*, 1990). Overall a net benefit to greenhouse gas emissions is expected, although a full accounting of the influence of dung beetle activity on nitrogen emissions remains to be done (Nichols *et al.*, 2007).

Carbon

19. Soils store substantial amounts of carbon, with the total global soil carbon store being threefold greater than that present in the atmosphere and four-fold greater than that present in terrestrial vegetation (Bernard Doube, Dung Beetle Solutions Australia, pers. comm.).

20. While unquantified, dung beetles are likely to increase the amount of carbon in New Zealand soils by ensuring deep burial of livestock waste, and reducing carbon losses to the atmosphere. Given the enormous quantities of waste produced by livestock daily, the potential to sequester carbon is large. Doube (2008b, see Table below) found that in two years *Bubas bison* caused a matrix of permanent tunnels in the subsoil (20–45 cm deep) that increased capacity to store carbon as soil organic matter from 1.97% to 2.55% at one site and from 0.67% to 0.97% at another.

A comparison of the effect of dung burial activity by *B. bison on the organic carbon (%) concentration* in the subsoil (20–45 cm) in cores sampled between August 2006 and September 2007. Beetles and dung were added to the cores in mid-September 2005. Table modified from Doube (2008b).

	August 2006		November 2006		May 2007		September 2007	
Treatment	**Site 1**	**Site 2**	**Site 1**	**Site 2**	**Site 1**	**Site 2**	**Site 1**	**Site 2**
Controls subsoil	2.01	0.68	2.02	0.85	2.14	0.70	2.11	0.61
Dung-only subsoil			2.23	0.88	1.94	0.74	1.97	0.67
Total dung+beetles subsoil	2.56	1.10	2.66	1.54	2.54	1.21	2.55	0.97
Dung+beetles: tunnels+environs		4.12	7.20	4.25	4.80	2.70	3.35	1.38
Dung+beetles: remainder		0.79	2.27	1.20	2.49	1.15	2.32	0.89

21. Elevated carbon levels have persisted for at least two years (Doube, 2008b), indicating a permanent increase in the subsoil organic carbon pool could be possible. An absolute increase of 0.5% in the soil carbon content in the subsoil equates to an increase of about 19 tonnes of carbon/ha. Applying this rate over the grazing lands of southern Australia, results in what could be a permanent increase of many millions of tonnes of carbon in the dynamic soil organic matter pool.

Habitat of native dung beetles

22. Seldon (2002) compared the ground insect communities in native forest fragments and pasture in New Zealand. Native dung beetles (*Saphobius* spp.) were only caught in the native forest; none were caught in adjacent pine forest or pasture. However, in contrast more recent studies by Pawson *et al.* (2008) caught a very small number of *Saphobius* sp. adults 5 m from forest margin in pasture that was ungrazed and regenerating with native plant spp, and *S. squamulosus* in small numbers in both mature *Pinus radiata* forest with diverse under canopy of native plants and in clear fell habitat (see Appendix 2.3.2 for details). Apart from the study by Pawson *et al.* (2008), there appear to be no other findings of these species in native or improved grasslands (Barbara Barratt, Alison Popay, AgResearch; Rowan Emberson, pers. comm., Appendix 1). Equally, all major museum collections (NZ and international) of native New Zealand dung beetles have been examined by the author and no data accompanying any specimen indicated collection from pastoral habitat (Forgie, pers. observ.: Revision of NZ Canthonines, in prep.). For more detail, see Appendix 2.3.

Habitat of dung beetles proposed for introduction

23. Dung beetles worldwide tend to be confined to particular habitats. The dung beetle species we have selected for importation into New Zealand were introduced to Australia, beginning in the late 1960's (Edwards, 2003; 2007). These particular species were chosen because they specialised in the removal of livestock waste in open pastoral habitats. There has been no noticeable effect of exotic dung beetles on native dung beetles in open or semi-shaded grassland/pasture. There is little to no evidence that any exotic dung beetle species has permanently colonised unpredicted habitats since introduction to Australia (Dr James Ridsdall-Smith, CSIRO West Australia; Dr Bernard Doube, Dung Beetle Solutions Australia; John Feehan, SoilCAM Australia; Dr Adrian Davis, UP Scarab Research Group, South Africa, pers. comm., Appendix 1). Apart from the above stated, there have been very few formal or published studies in Australia of shifts in habitat preferences of these species post their introduction. Ridsdall-Smith and Edwards (In press) summarised a study conducted in three national parks and in one pasture nearby in SW Australia. Six native species were collected in the parks and a stray introduced beetle, whereas in the pasture there was one native species (16%) adapted to open grassland habitat and the rest were the introduced *E. intermedius* and *O. alexis*. There was no evidence of the introduced beetles entering natural vegetation (mostly heath banksia woodland and some eucalypts in gullies). For more detail, see Appendix 2.3.1.

24. Evidence for the stability of habitat specificity amongst dung beetle assemblages comes from a range of studies, around the world, of how these assemblages distribute across gradients from closed canopy (shaded) or open canopy (semi-shaded) undisturbed forest, scrub, and open grassland or modified habitats. These studies (for more detail see Appendix 2.3) provide strong evidence that most dung beetle species exhibit largely specific preference for certain habitats. One aspect relates to the beetle's preference for light and dark, which equates to grass and bush vegetation, with light intensity being an important factor in determining the distribution of beetles (Doube, 1983). Other aspects are the presence and type of dung, and the soil type and soil moisture levels (see Osberg *et al.*, 1992). Any or all of these could exclude the introduced species from establishing self-sustaining populations in native habitats. But the most important aspect the presence and distribution of a suitable breeding medium (Dr Bernard Doube, pers. comm., Appendix 1). What this means is if livestock are permitted to graze in native habitats, particularly along its fringes where scrub or forest canopy is open and the ground semi-shaded then very low numbers of some exotic dung beetles may utilise dung deposited there by these animals.

25. Further details and examples can be found in Appendix 2.3. Also, a number of dung beetle experts with experience working with the beetles proposed for introduction have provided personal communications regarding habitat specificity (Appendix 1). Their findings are summarised in the Table below.

Habitat and soil preference of exotic dung beetles proposed for introduction into New Zealand pastures.

Species	Habitat 0pen pasture/ grassland	Habitat open canopy grazed/disturbed	Habitat closed canopy	Soil preference	Personal Communication	Reference: soils or habitat
E. fulvus	Abundant Prefers v/open habitat	Rare. Scrub w/cover no greater than 50%	Not present	Compact silty soils, clay	Jean-Pierre Lumaret	Kirk & Wallace (1990)
G. spiniger	Abundant Prefers v/open habitat	Rare. Scrub w/cover no greater than 50%	Not present	wet soils, clay, or silty soils	Jean-Pierre Lumaret	Kirk & Wallace (1990)
O. binodis	Abundant Prefers v/open habitat	Not present	Not present	Sandy loam	Adrian Davis	Davis 1987
O. taurus	Abundant Prefers v/open habitat	Rare. Scrub w/cover no greater than 50%	Not present	Heavy clay, loam, sandy loam	Jean-Pierre Lumaret	Kirk & Wallace (1990)
O. vacca	Abundant Prefers v/open habitat	Rare. Scrub w/cover no greater than 50%	Not present	Heavy clay soils, also silty and sandy soils	Jean-Pierre Lumaret	Kirk & Wallace (1990)
O. gazella	Abundant Prefers v/open habitat	Possible in v/low number	Not present	Prefer clay soils, but also loam and sandy soils	Adrian Davis	Doube 1983 Davis1987 Davis1996
Onitis a. alexis	Abundant Prefers v/open habitat	Possible in v/low number	Not present	Clay, sand, loam soils	Adrian Davis	Davis 1996

Table 2 continued.

Species	Habitat open pasture/ grassland	Habitat open canopy grazed/disturbed	Habitat closed canopy	Soil preference	Personal Communication	Reference: soils or habitat
C. lunaris	Abundant Prefers v/open habitat	Rare. Scrub w/cover no greater than 50%	Not present	Prefer moist sandy soils,	Alan Kirk	Kirk & Wallace (1990)
C. h. hispanus	Abundant Prefers v/open habitat	Rare. Scrub w/cover no greater than 50%	Not present	clay substrate, loam and sandy loam	Jean-Pierre Lumaret	Kirk & Wallace (1990)
B. bison	Abundant Prefers v/open habitat	Rare in clear undergrowth w/cover no greater than 50%	Not present	Compact silty soils, clay	Jean-Pierre Lumaret	Kirk & Wallace (1990)
B. bubalus	Abundant Prefers open or v/open habitat	Rare. Scrub w/cover no greater than 50%	Not present	Compact silty soils, clay or loam	Jean-Pierre Lumaret	Kirk & Wallace (1990)

Lack of competition for food sources by native and exotic beetles

26. There will be no significant direct competition between introduced dung beetles and native dung beetles because they will not share a food resource to any significant extent:
    - The beetles to be introduced feed on the waste of herbivorous animals such as cattle, sheep, deer pigs etc. They will not utilise the highly unusual diet of the native species (Application Section 3).
    - Although native species can sometimes utilise the droppings of grazers such as deer and pigs in the forest, the introduced dung beetles are grassland specialists and will not be present in the forest.
    - Significant populations of introduced dung beetles will only develop in managed grasslands, where there is abundant animal waste. Native dung beetles have not been encountered in these habitats.
    - Restricted interactions may occur in rare transition zones between native forest and grassland, and then only where grazing animals are common.

Introduced dung beetles share natural enemies with native species, modifying trophic webs and adversely affecting populations of native insects.

27. Introducing dung beetles to New Zealand will not have indirect effects on related native species by changing the relative abundance of shared predators, parasitoids and pathogens, disturbing trophic webs and adversely affecting populations of native scarab beetles because:
    - Native and introduced dung beetle populations are not expected to overlap except at some forest margins (see Appendix 2.3)
    - Buried dung beetle larvae and adults in tunnels and fresh dung are not susceptible to generalist natural enemies and are unlikely to be attacked by New Zealand parasitoids, diseases and opportunist predators in pasture (kiwi, rats, mice).
    - Related native beetles such as grass grub that live in grasslands have few natural enemies that could be shared with introduced dung beetles.
28. No true parasitism of dung beetles has been reported in over 1,700 published articles and reports searched. Eggs, larvae and pupae of slow tunnelling dung beetles are encapsulated deep in brood balls or sausages of well-manipulated dung at the end of burrows and are unlikely to be available to non-specialist parasitoids. As an added protection, the immature stages of fast tunnelling beetles are

tended by female beetles that are known to clean and protect their brood thus representing an advanced form of parental breeding behaviour. It is very unlikely that parasitoids resident in New Zealand could use insects with such unusual behaviour.

29. Parasitoids for pest scarab beetles have been introduced to New Zealand (Cameron and Wigley, 1989; Cameron and Thomas, 1989; Dymock, 1989; Stufkens and Farrell, 1989). None have established, and so there is no risk that these could be shared with introduced larval dung beetles.

30. Cameron and Butcher (1979) have reported some predatory beetles found in New Zealand pastures as attacking larvae and adults of pastoral dwelling scarab species related to dung beetles. However, these were free-living beetles and not tunnelling species. Accounts of invertebrate predators of adult dung beetles are rare in the world literature. No predation on the previously introduced dung beetles inhabiting northern pastures was recorded by Cameron and Butcher (1979).

31. Pathogens of scarab beetles are usually moderately to highly host specific, and other parasites such as nematodes are not common in the native scarab beetles found in pastures (such as manuka beetle and grass grub). It is highly unlikely that introduced dung beetles could act as pathohgen sources and pass on diseases to native species (Dr Trevor Jackson, AgResearch, pers. comm., Appendix 1).

<u>Positive/beneficial effects on human health and safety (including occupational exposure):</u>

Burial of livestock waste by beetles reduces the incidence of pathogenic organisms, reducing the incidence of human disease.

32. The rapid and widespread burial of livestock waste by winter and summer active dung beetles will reduce the abundance of flies associated with dung (see paragraph 43-47) and contribute to reduction in reported cases of campylobacteriosis. *Giardia* and *Cryptosporidium* are found in the waste of mammals and birds, and can infect drinking water causing diarrhoea, abdominal cramps and nausea in people. These pathogens are problematic as they are resistant to conventional water treatment, remain infective for long periods, are difficult to detect and cross-infect different animal species. Research has found that burial of livestock waste results in substantially cleaner run-off from pastures (Fincher, 1981; Doube, 2005c; see paragraph 9-12) and by doing so dung beetles may also play a role in reducing the presence of harmful human pathogens (Doube, 2004).

33. Ingestion by certain dung beetle species can significantly reduce the abundance of viable protozoan cysts of *Giardia lamblia* (Miller *et al.*, 1961). Similarly, Mathison and Ditrich (1999) reported that although some oocysts of *Cryptosporidium parvum* ingested by the beetles *Anoplotrupes stercorosus*, *Aphodius rufus* and *Onthophagus fracticornis* are able to pass through the mouthparts and gastrointestinal tracts of the beetles, most are destroyed.

<u>Risks to human health and safety (including occupational exposure)</u>

34. No significant adverse effects to human health and safety have been identified.

<u>Positive/beneficial effects on the market economy:</u>

Introduced beetles bury animal waste, reducing contamination of forage, which increases the amount of forage available for consumption by livestock.

35. Burial of dung by dung beetles would improve the utilisation of pasture plants by grazing animals by reducing contamination of fodder plants, increasing the proportion of pasture grazed by stock, and decreasing the need for break-feeding. The removal of dung from the surface of paddocks by dung beetles is likely to significantly reduce the extent of contamination of forage by livestock excrement, to increase the amount of forage available to grazing livestock, and to increase the productivity of New Zealand pastures. The monetary benefits of increased pastoral productivity to the market economy are predicted to be major.

36. The presence of livestock waste significantly reduces the effective area of pasture available for grazing. Conservative estimates for coverage by individual cattle dung pats range from 0.05 - 0.09 m^{-2} (Haynes and Williams, 1993). Cattle produce 11-16 dung pats per day. The New Zealand beef and dairy herd is 9.6 million head. This equates to a daily loss of an estimated 570 – 950 hectares of

grazing forage area covered by cattle dung each day. This agrees with other calculations reviewed by Dymock (1993) who concluded that at any time up to 5% of cattle pastures might be excluded from production by dung. Further details of these calculations can be found in Appendix 2.5. Similar calculations for forage cover area by sheep manure and pellets provided in Haynes and Williams (1993), estimate that 910 - 2,840 ha of grazing land in New Zealand is excluded from production daily from on average 16 defecations by each of approximately 71 million sheep (including lambs). If each dung patch occupies its original coverage area even for one week the total number of hectares lost for grazing is large. In fact, high rainfall or irrigation, and high pastoral earthworm numbers coinciding with higher soil moisture levels tend to reduce the lag in dispers.al time of pastoral dung to just a few weeks. But in other circumstances dung can pers.ist from 2 weeks to several months.

37. This analysis alone underestimates loss of pastoral production because the adverse effects extend beyond direct contamination. Fincher (1981) estimated that a dung patch affects a grazing area five times its own area. Sheep and cattle reject pasture forage growing near animal dung, a response to the offensive properties of the dung itself (Marten and Donker, 1966). Hence the practice of sub-dividing farm paddocks into smaller areas to force livestock to feed around their own excrement and thereby graze all the pasture (break-feeding). While unproven, such practices may contribute negatively to livestock health and wellbeing. Dung beetles, particularly Autumn-winter active species such as *Bubas bison* and *Geotrupes spiniger*, will reduce the need to force stock to feed near dung by removing it.

38. An additional benefit from stemming from prolific dung beetle activity is expected to be the reduction or elimination of the need to harrow paddocks to break up dung, reducing fuel and labour costs. Further examples of benefits of dung beetles observed in Australia and USA can be found in Appendix 2.10.

Burial of dung by dung beetles increases soil fertility and health, increasing pastoral productivity.

39. It is highly likely that the transfer of dung into the soil profile will capture a higher proportion of nutrients, providing a fertilising effect. This will increase the quantity and nutritive quality of forage plants available for grazing, leading to moderate benefit to the market economy.

40. Numerous studies describe the role of dung beetles in facilitating increases in plant quality and yield through improved nutrient mobilisation, bioturbation and soil structure (see paragraph 2-4, and Appendix 2.4). A review by Nichols *et al.* (2008) found that the presence of dung beetles significantly increased plant height, above ground biomass, grain production, protein levels and nitrogen content.

41. Doube (2007) found, that after 9 months pasture growth plots with *Bubas bison* showed a 0.40 t ha-1 dry matter growth advantage over plots with dung beetles and other native beetles (a 26% increase), and a 1.60 t ha-1 dry matter growth advantage over the pooled control treatments (a 4.6-fold increase on baseline production of 0.34 tonnes per ha). Doube (2007) reported 2-fold and 1-fold increases in pasture growth over winter following dung burial activity by *Bubas bison* and *Geotrupes spiniger* respectively.

42. For those species, proposed for introduction, for which studies on plant productivity have been conducted, all have shown beneficial effects. For example, Doube (2008a) has estimated that burial by *Bubas bison* of the dung produced by 100 cattle has an estimated annual value of $A2,100 as hay (at $160 per tonne), or from zero to over $10,000 in live weight gain, depending upon stock management practices and price per kg live weight.

Burial of dung reduces the contamination of forage by parasites of livestock, reducing re-infection rates and improving the health of livestock.

43. It is considered very likely that the burial of livestock waste by dung beetles will reduce the infectious stages of a range of pest, parasitic and disease-causing organisms that are currently associated with the dung of grazing animals. The rate at which livestock are re-infected with parasites will be significantly reduced, and that there will be potential benefits from reduced incidence of disease, as well as reduced control costs

Parasitic nematodes of livestock

44. A number of studies (e.g. Waterhouse, 1974; Bryan, 1976; Fincher, 1975) have demonstrated that dung beetles suppress populations of the infective larvae of intestinal nematode worms of livestock that infect pasture via livestock waste. Waterhouse (1974) reported a 48-93% reduction in the number of infective larvae in cattle dung pads attacked by dung beetles compared to intact pads. Bryan (1976) showed that in moist climatic conditions two, 10 and 30 pairs of the beetle *O. gazella* reduced the numbers nematode larvae on grass surrounding dung pats by 40, 74 and 66 % respectively, compared with control pats not exposed to beetles. Control pads with no dung beetles contained 50 times more nematode larvae than those with dung beetles. An American field trial found that calves grazed on pastures without dung beetles acquired four times more nematode parasites (*Ostertagia* and *Cooperia*) than those in pastures with dung beetles (Fincher, 1975).

45. Whilst the benefits are clear, the specific mechanism for parasite suppression cannot be accounted for by burial of the dung alone and is not entirely understood (Nichols *et al.*, 2008). Miller *et al.* (1961) showed that nearly 100% of hook and round worm eggs were destroyed by the feeding action of *Canthon laevis* and *Phanaeus igneus*, since they rarely appeared at any level in the digestive tracts of both species. However, when *Dichotomius carolinus* swallowed eggs a high percentage was damaged, but many survived. The most likely causes for the destruction of eggs is during ingestion (e.g., Millar, 1961; Holter *et al.*, 2002 are discussed further in Appendix 2.6).

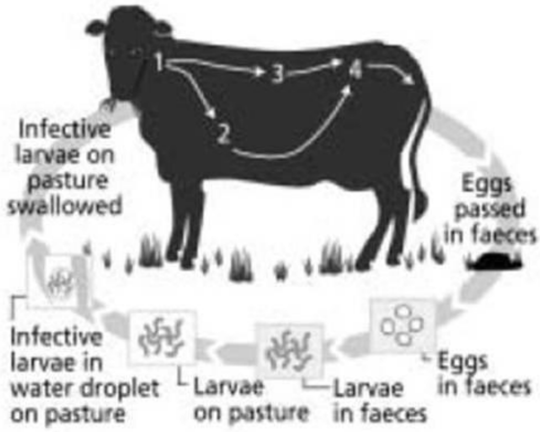
46. Sheep, beef and dairy farmers spend about $80 million on parasiticides annually, and the cost of parasitic nematodes to the New Zealand farming industry is estimated to be around $700 million per year (AgResearch, 2010). New, integrated worm control strategies are required on New Zealand farms to mitigate the costs associated with increasing drench resistance (estimated to cost about $20 million a year to the sheep industry) and market demands to minimise drench residues in animal products (Rattray, 2003). The introduction of exotic dung burying beetles represents a unique and sustainable opportunity to break parasitic life cycles, reduce worm loads of livestock and reliance on costly drenches. We expect dung beetles to reduce infection rates of livestock by parasitic gut worms, and significantly diminish costs to New Zealand's pastoral industries.

Dung breeding flies

47. Faster burial of dung will reduce the incidence of nuisance flies. Blowflies associated with sheep flystrike do not breed in animal waste but females use it as nutrient resource for maturing eggs. In New Zealand, other nuisance flies such as biting stable flies, house flies, and flesh flies are known to breed in livestock dung. When dung burying beetles and dung breeding flies compete in dung, the beetles win. Survivorship of fly eggs and larvae is significantly reduced by rapid conversion of the dung resource, mechanical damage during dung manipulation by the beetles and predation enhanced by the beetles (Nichols *et al.*, 2008). Many lab and field experiments confirm significant reductions in the numbers of dung breeding pest flies because of dung beetles (See Appendix 2.6.4 for more detail). Although a serious nuisance, flies associated with dung are not considered a significant concern to livestock health.

__Risks to the market economy:__

Burial of livestock waste increases the survivorship of infectious stages of animal parasites within it, increasing stock infection rates.



Lifecycle of Ostertagia, a common gut parasite of livestock.
Larvae in wall of abdomen, 1; Development of larvae in late spring and summer is arrested for several months, 2; larvae develop directly in 3-4 weeks, 3; adult worms in abdomen, 4. Image courtesy of: Meat and Livestock Australia Limited, ABN 39 081 678 364 (MLA). Feb., 2005 "The Cattle Parasite Atlas: a guide to parasite control in Australia"

48. There are some studies which suggest that dung beetles may transmit dung-borne pathogens present within their gut, or enhance enteric nematode transmission in livestock (see paragraph 48-52). Experimental research has shown that burial of dung increased survival of infectious stages of parasites (Dr Dave Leathwick, AgResearch, pers. comm., Appendix 1) notes that physical burial of dung increased survival of infectious stages of parasites in some studies. If this were a consequence of dung burial by beetles, and if this led to significant increase in livestock disease, then the economic effect would be moderate. However, none of the published studies present convincing evidence that dung beetles can enhance transmission and parasitic load in livestock, and the weight of research evidence suggests that this outcome is unlikely.

49. Evidence for this potential adverse effect is provided by several studies but is countered by others. Waghorn *et al.* (2003) found increased recovery of infective larvae from dung burial in soil (as might occur through the action of dung beetles), and suggested that soil may provide a protective reservoir for infective larvae infesting herbage. These trials, while informative of potential risks, did not use dung beetles to undertake the burial. This study therefore underestimates the impact on survivorship of eggs and/or larvae of accidental ingestion, physical damage from dung manipulation and burial depth; all factors that likely contribute to the reported successes of nematode suppression by dung beetles. This was demonstrated by Le Jambre (2009), who found that burying sheep faeces manually enhanced the amount of larvae recovered compared with faeces on the surface of soil when moisture was limited confirming the findings of Waghorn *et al.* (2003). Larvae developing underground were found to stay there until there was sufficient moisture to allow them to move to the surface. Le Jambre (2009) pointed out that if burying faeces by dung beetles was purely a mechanical movement of faeces, there would be a potential for larvae to develop underground and be sequestered there until rainfall enabled them to move to the surface and re-infect sheep, even when the sheep grazing the pastures were parasite free prior to rainfall. However, when *Onthophagus granulatus*, *O. australis* and *O. gazella* dung beetles were included in the experiments their action in burying faeces actually reduced the numbers of larvae obtained consistent with the total amount of faeces removed from the surface by the beetles indicating that all the larvae in the proportion of sheep faeces attacked by dung beetles are destroyed. Dung beetles were found to remove approximately 1g of faeces/beetle from

freshly deposited sheep dung. Thus, Le Jambre (2009) concluded dung beetle activity resulted in a reduction of parasitic larvae on pasture.

50. *Onthophagus granulatus* in New Zealand pastures was shown to reduce infective stages of *Trichostrongylus colubriformis* from dung and foliage however, trials involving similar sized *O. posticus* revealed an increase in nematode numbers on foliage (Popay and Marshall, 1996). Differences may be associated with varying moisture and temperature regimes known to effect nematode survivorship rather than differences in particulate utilisation during feeding by adult beetles.

51. Finally, Bryan (1976) found that infective larvae survived for at least 84 days in soil and buried faecal material. Fincher (1973) and Bryan (1973, 1976) showed that parasite larvae can migrate onto vegetation from dung buried only a few centimetres below the soil surface. However, burial depth and soil moisture content appear to be important factors in the ability of surviving infective larvae to vertically migrate to pasture 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 surface. All but one of the species proposed for introduction to New Zealand tunnel to depths of at least 20cm (Section 3.4, Table 1) ensuring that a proportion of infectious stages will be removed from pastures.

52. Few if any reports present convincing evidence that dung beetles could actually increase re-infection rates. Moreover, Nichols *et al.* (2008) point out that simple presence of infectious or non-infectious larval stages consumed or developing inside adult dung beetles is not adequate proof of dung beetles role as a host in a parasite's lifecycle.

Dung-burying beetles compete directly with earthworms for food, reducing soil health and pastoral production.

53. Earthworms currently play an important role in the breakdown of livestock dung, in the reduction of forage contamination, in nutrient cycling, and in the productivity of New Zealand pastures. However, earthworm activity can be spatially and climatically limited (see paragraph 5-8). If the introduction of dung beetles caused a significant decline in the beneficial ecosystem services currently provided by earthworms, then the effect on pastoral productivity and the market economy could be moderate. This scenario is considered to be highly unlikely because recent research shows that dung beetle activity enhances rather than detracts from earthworm activity, and because dung beetles themselves provide similar ecosystem services. Recent field studies by Doube (2006a, 2008c) provide substantial evidence of the positive impacts exotic dung beetles have on earthworm populations. These issues are discussed in paragraph 5-8 and Appendix 2.7 for more detail.

54. Fears over potential asymmetrical competition between earthworms and exotic dung beetles in the utilisation of livestock dung were a key issue in discussions around a previous application to introduce dung beetles into New Zealand (see Application Section 3), possibly coupled with the belief that earthworms alone are capable of significantly reducing forage foul all year round in New Zealand. In response to MAF concerns on potential adverse effects posed by dung beetles on earthworms a workshop was held in 1997 to determine the likely beneficial and adverse effects of further introductions of dung burying beetles into New Zealand (see Application Section 5; Dr Jenny Dymock, pers. comm. Appendix 1). Adverse effects were concluded as minimal in a presentation on benefits of earthworms to New Zealand by Dr Jo Springett, AgResearch (Dr Jenny Dymock, pers. comm., Appendix 1).

Dung burial by beetles removes the breeding site of nuisance flies, reducing the population of fly parasitoids and increasing the incidence of flystrike.

55. Flystrike in sheep causes annual production losses and control costs of $30-40 million. Bishop (1998) identified the dung breeding fly *Hybopygia varia* as a host for three parasitic wasps *Aphaereta aotea*, *Tachinaephagus zealandicus* and *Alysia manducator* that also attack blowfly species responsible for flystrike in sheep, and speculated that *H. varia* may act as an over-wintering host for these species. If the introduction of dung-burying beetles interfered in the population regulation of blowflies,

significantly increasing the incidence of flystrike, there could be an increase in the cost of flystrike to the market economy. However, this outcome is considered to be very unlikely because parasitism does not appear to be key factor in the population dynamics of flystrike blowflies. However, this was cited as another area of concern by the review committee of the first dung beetle application made by Dr Jenny Dymock in 1995 (see Application Section 5)

56. Bishop and Heath (1995) found only *Aphaereta aotea* to attack larvae breeding in dung, and so the population dynamics of other parasitoids are not likely to be reliant on dung-breeding flies. *Aphaerera aotea* was able to parasitize up to 100% of all larval stages of key flystrike blowflies in the laboratory, but in random samples of larvae obtained from more than 4000 North and South Island flystrike cases over a 10 year period the parasitism rate for *A. aotea*, *T. zealandicus* and *A. manducator* ranged from 0.02% to 0.6% and overall was 1.1% of all field strikes (Bishop *et al.*, 1996). Their effectiveness as biocontrol agents of flystrike flies has not been quantified explicitly, but it seems unlikely that larval parasitism at these levels is regulating blowfly numbers, or that any reduction in these rates of parasitism as a result of dung beetles introduction would significantly increase the severity of flystrike in New Zealand.

Overall cost benefit analysis.

57. Once established, the activity of dung beetles is not expected to cause significant net monetary costs to the New Zealand economy (see paragraph 48-59).

58. Losey and Vaughn (2006) evaluated the ecosystem services maintained by wild rather than unmanaged/ imported dung beetles native to the USA. They estimated benefits as the avoidance of losses in un-drenched pastured beef cattle production due to forage fouling, nitrogen volatilisation, livestock pests (parasites and flies), etc. The estimated annual net value to the pastoral beef cattle industry in the USA of native dung beetles was US$380m (see Appendix 2.10).

59. The methodology of Losey and Vaughan (2006) was used to estimate the potential economic benefits of introduced dung beetles to the farming of all cattle in New Zealand. Approximately 30% of the New Zealand cattle herd or 2.9 million cattle are not drenched, and their dung is available for burial by dung beetles. Based solely on non-drenched stock, dung beetles could be worth over NZ$50 million per year to the New Zealand economy (see Appendix 2.10 for detailed calculations). This figure is considered to be deeply conservative for the reasons above, and because:

- Dung beetles may also succeed on the waste of some of the 70% of the national herd that is treated, depending on treatment frequency and timing, and application method (pour on, injectable, spray, or oral).
- The chemical residue levels of some drug action families of parasiticide are more toxic to dung feeding fauna than others, and the period of time they have a negative impact varies (Wardhaugh, 2005).
- Reduction in the frequency of application through dung beetle activity could slow resistance development, reduce the use of 'cocktail formulations' to achieve control and, slow the increase in dose rates.
- Dung beetles provide a technological step change that will foster integrated pest management strategies that dung feeding fauna (e.g., pastoral earthworms) into consideration, leading to reduction in drench use on conventional farms and an increase in the proportion of cattle that are not treated.
- Estimates were based solely on pastured beef cattle while dung beetles also avert economic losses by burying dung from dairy, sheep, horse, deer, goat and pig livestock farming.
- There are no adequate data to estimate the economic value of ecosystem services such as soil and water quality improvement, decomposition of organic matter, suppression of pest organisms (gut parasites, flies, diseases), etc, which are omitted.
- By doing so, this value could eventually add as much as NZ$166 million annually. See Appendix 2.10 for details surrounding this estimate.

Beneficial or positive effects on the relationship of Māori and their culture and traditions with the environment :

Environmental

60. One correspondent noted the possibility of beneficial effects to mahinga kai through increase in the rate of nutrient cycling. This would be restricted to margins of natural systems as dung beetles are expected to be restricted to pastoral habitats. He noted that there could be benefits to land, water, air and valued flora and fauna, but noted that these might be negated by changes in farming practices following productivity increases resulting from dung beetle introduction. He noted the possibility of cultural issues surrounding faeces contamination of human food crops, but it seems likely that such effects will be beneficial rather than adverse. The hui at Kaipara asked what dung beetles do and why is introduction desirable. These questions are addressed in Application Section 3, and in see paragraph 2-33 and 35-47.

Effects on kaitiakitanga

61. No particular benefits were identified.

Effects on health and well-being

62. One respondent noted that water quality improvement resulting from the introduction of dung beetles would benefit all aspects of Māori health and wellbeing.

Te Tiriti o Waitangi

63. One respondent noted that the introduction of dung beetles potentially mitigates some of the environmental degradation imposed by western agri-practices and environmental use.

Effects on Māori economic and iwi/hapu development

64. One respondent noted that for those Māori with farming interests there will be benefits, but overall this may be negated by widening socio-economic barriers. There is little or no benefit for non-landholding Māori. He also noted that this proposal does not mention Māori participation at future levels. Future participation is under consideration. Participants at the Kaipara hui asked how beetles would deal with rotation, and with horse dung as fertiliser in marae organic gardens. It is planned to introduce species with different biologies to ensure that there are available to work all year round and in all climate types. Fresh horse dung placed onto a garden will be incorporated into the soil and 'composted' below ground. The potential for using dung beetles to deal with 'biosolids' from Auckland's wastewater stream was raised. The beetles have been selected for release in New Zealand have been chosen to deal specifically with the waste of herbivorous grazing animals such as sheep and cows. It is not clear whether these species would seek out and then bury biosolids, but they might if it is applied to open areas and moistened sufficiently to be usable by the beetles. If not, there would definitely be an opportunity to introduce a specialist dung beetle for this purpose.

Risks to the relationship of Māori and their culture and traditions with the environment :

Environmental

65. One correspondent asked whether interactions between introduced and native dung beetles could lead to adverse consequences for natives. This and related issues are covered in see paragraph 22-26. A second correspondent noted that increased productivity on dung-affected marginal land could lead to increased stocking rates with adverse consequences for the pastoral environment. However, the burial of dung will mitigate the adverse effects of existing high stocking rates, let alone the effects of additional stock units. He also noted that increased rate of processing of dung might have adverse effects for the environment, but see paragraph 13-21 indicates that in fact there will be a net environmental gain in air quality. Consultation over recent applications raised the potential adverse effects arising from genetic manipulation (Note: this is not applicable as these beetles are not

genetically modified), and interbreeding. The Kaipara hui asked if the dung beetles were indigenous and whether there were native relatives. The chosen species are from Europe, South Africa and Central America, but were introduced to Australia many years ago to manage animal waste. All will be introduced from there (see Application Section 3). New Zealand has 16 native species of dung beetle, but they are not closely related to the proposed species for introduction to allow interbreeding. All of the native species are wingless, and have never been recorded living outside the ngāhere. They are opportunist species, feeding on all sorts of organic matter under trees, such as rotting plant material and the droppings of birds and insects such as weta and stick insects.

66. Speakers at both the Kaipara and Network hui also raised the issue of potential effects on birds, and whether tunnelling will lead to increased direct pollution of the water table. The larvae of dung beetles will live in brood chambers deep in burrows (below 10 cm), and few will be available as food for probing native birds, even kiwi. Adult dung beetles are largely nocturnal, and spend the day either deeply buried in burrows, or hiding beneath animal waste. They are unlikely to be abundant anywhere except where animals are grazing. It will therefore be rare for day-feeding native bird species (including waders) to encounter dung beetle adults in any numbers. Dung beetles resemble native grass grub, a sporadic pest in improved grassland and forest margins. Night-feeding kiwi venturing into open pasture might encounter dung beetles, but they will be equivalent to grass grubs as a food source. Tunnelling will increase the rate at which water gets through the soil. However, by making the animal waste available below the soil surface, microbial and earthworm activity will be greatly accelerated, dung will be processed quickly, and nutrients will either be sequestered to soil particles or taken up quickly by growing plants. At the same time, removal of the waste from the surface will reduce the risk from ponding and surface runoff of nutrients to waterways.

Effects on kaitiakitanga

67. Respondents to consultation on previous applications have expressed a philosophical and principled opposition to the introduction of exotic organisms. A common view has been that introductions in general should be approached with caution because of uncertainty about how the new organism might affect complex ecological interactions, and hence on the whakapapa and mauri of the forest. This view is also held by some in the general population (Appendix 1). Dung beetles are restricted to pastoral habitats, and to mammalian dung, a resource not native to New Zealand. Dung beetles will interact only marginally with natives (see paragraph 22-26) and are not expected to adversely affect populations of any native species. Previous responses have also stressed the necessity for adequate monitoring and reporting of the effects of control agents following release. Concern has also been expressed about protocols for caring for the mauri and tapu associated with the transfer and release of new organisms. The applicant group will consult with Ngāti Whātua Ngā Rima o Kaipara Trust on this before introduction. One correspondent stated that all the world biota and natural interactions are the result of the activities of the atua Maori, and so net effects of introduction would be neutral.

68. The kaipara hui asked if the dung beetles were indigenous, whether there were native relatives, and whether interactions would be good or bad. The chosen species are from Europe, South Africa and Central America, but were introduced to Australia many years ago to manage animal waste. All will be introduced from there (see Application Section 3). New Zealand has 16 native species that are related to the introduced beetles, but are not sufficiently related to allow interbreeding. All of the native species are wingless, and have never been recorded living outside the ngāhere. They are opportunist species, feeding on all sorts of organic matter under trees, such as rotting plant material and the droppings of birds and insects such as weta and stick insects. While the native species will not leave the forest, the beetles selected for introduction are savannah species, and are not expected to colonise shaded areas such as forest. Habitat isolation is discussed paragraph 22-26, and Appendix 2.3. As dung beetles are restricted to dung, interactions can only occur where grazing animals such as sheep and cattle are present. Dung beetles are very unlikely to share any parasitoids, predators or diseases with native species (see paragraph 27-31).

Effects on health and well-being

69. No potential adverse effects of the proposal on human health were presented.

Te Tiriti o Waitangi

70. Respondents to current and previous consultations have asked whether there is Māori peer review of the application, and whether iwi/Māori were involved in the release decision. The application itself will not be peer reviewed by Māori before submission. The adequacy of treatment in the application of issues important to Māori will be assessed by ERMA New Zealand staff, and the advisory group to the Authority, Ngā Kaihautū Tikanga Taiao.
71. Respondents to previous consultations have asked who carries the risk for adverse effects resulting from the introduction of a biological control agent. Once the Crown (in the form of its Agency ERMANZ) has approved release of a new organism, subsequent mitigation of any adverse effects related to the exercise of that approval will fall to the Crown.

Effects on Māori economic and iwi/hapū development

72. No further comments were received.

References

Refer to Appendix 4. Application References.