PART C

SUPPLEMENT FOR TEACHERS

MORE INFORMATION ON DUNG BEETLE BIOLOGY

C-1 What is a dung beetle?

Dung beetles can be rather arbitrarily defined as those beetles (Order Coleoptera) of the super family, Scarabaeoidea, whose larvae feed on and in dung (that is, the families, Scarabaeidae, Geotrupidae and Aphodiidae).

This definition effectively isolates these scarabs from other families in the super family Scarabaeoidea. It also separates out those beetles that do not feed on dung but are still to be found in and around dung. For example, while some beetles and their larvae can be found in dung, some insects are predacious, and feed upon fly eggs and larvae present in the dung, but not dung. These families include the Histeridae, Carabidae, Hydrophylidae and Staphylinidae which can be found hunting in and on the dung patch. Some of the saprophytic (humus feeding) members of the Tenebrionidae, can also be found feeding under dung.

C-2 Basic morphology

The dung beetle is made up of three visibly separate components. Please refer to *Common dung beetles in pastures of south-eastern Australia* in BIOSCAN kit.

C-2.1 The head

The obvious features of the head are the mandibles, two compound eyes and a pair of antennae. The head is usually saucer-shaped and the resulting 'shovel' (the clypeus) is used effectively by the beetle. The head may also be ornamented with horns, bumps, ridges and notches, which are useful taxonomic aids (as well, these may be exaggerated in the male beetles — these males are known to use the horns to overturn other rival males during competition for mates and to block tunnels from entry by competitors and predators).

C-2.2 The thorax

The cuticle of the thorax of the dung beetle is barrel-shaped and is the anchorage point of the two pairs of wings and the three pairs of legs. The conspicuous part of the thorax is termed the pronotum. Viewed from above, it is often ornamented with bumps and camouflaging colours and patterns.

C–2.3 Wings

The second pair of wings are transparent and are actively used in flight by the beetle. The first pair of wings are hard, casing–like structures which close over the abdomen and protect the second pair of wings and the soft parts of the abdomen. The hardened first pair of wings are termed the elytra.

C–2.4 Legs (three pairs)

Notably, the forelegs are modified for digging and are flattened, notched and thickened at the tarsus (foot). The hind pair of legs sometimes carry spurs as in the males of the genera *Onitis* and *Sisyphus*. In the latter genus (the 'rollers') both males and females have elongated hind legs for rolling and guiding their dung balls.

C–3 Life stages of the dung beetle

The life stages of the dung beetle provide a good example of a life cycle with complete metamorphosis (holometabolous, that is, egg, larva, pupa, adult) of an insect. This can be contrasted with the partial metamorphosis (hemimetabolous, that is, egg, various stages of nymphs, adult) found in other insect groups such as roaches, locusts, etc.

C–3.1 Egg

Eggs can range in size from a fraction of a millimetre in the *Aphodius* species, upwards in size to that of *Copris hispanus*. This dung beetle produces eggs approximately 5 mm in length, but which swell over a few days, taking moisture from the brood ball and more than doubling in volume. Large species found in elephant dung in Africa, no doubt lay much larger eggs.

Some small species such as *Onthophagus binodis* are very productive and a female and her mate may produce up to 80 cigar–shaped dung broods and eggs. There is no brood caring in the Onthophagini and the beetle pair abandon the broods and tunnels when the dung supply is no longer suitable. Large species, such as *Copris hispanus*, tend to produce larger brood balls. However, only four to six brood balls and eggs are produced under field conditions. The Coprini are brood–carers and the female (and sometimes the male) remains buried in the brood chamber with these balls until the offspring complete their development.

C–3.2 Larvae

Hatching time of the egg varies with each beetle species, and with average field incubation temperatures. It may take a few days or a few weeks. On hatching, the first instar commences feeding upon the dung provided by its parents. It grows rapidly and moults twice more.

Eventually the third instar becomes quiescent. Large quantities of fat are laid down and the larva turns pale yellow. The gut contents during this time have been voided and smeared around the walls of the larval chamber. This hardens and a hollow sphere results, safely housing the pre–pupa (that is, a squat, yellow version of the third instar).

C–3.3 Pupae

The next moult produces a delicate pupa, which on close inspection resembles the adult beetle. The eyes, legs, wings, and mouth parts etc. can all be seen. The pupal duration varies across species and is temperature–dependent. Various environmental cues, such as desiccation of the faecal shell in drought, or a rise or fall in soil temperatures trigger the change from pupa to beetle.

C–3.4 Beetle

Further development and darkening of the pupa yields an adult beetle. Hardening of the beetle's chitin (the substance from which the hard exoskeleton is made) occurs within the faecal shell.

On cue (perhaps a temperature change, or the onset of seasonal rains) the beetle emerges (ecloses) from the faecal shell and tunnels its way upwards. It now seeks out a fresh dung pat and eventually, a mate.

C–3.5 General

Each beetle species has its general requirement for dung. However, each species has its own peculiarities. Some are found in deserts living with prairie dogs in their tunnels, and others can be found in tropical rain forests, perching in trees and feeding on monkey dung. Beetles imported into Australia have been selected because of their preference for bovine dung. Climate (including soil moisture) is particularly important to dung beetles. Each climatic zone has its own complement of dung beetle species.

In simple terms, Australia has two climate zones:

- tropical, with hot wet summers and dry warm winters; and
- temperate, with warm summers and cool wet winters.

(Temperate Mediterranean climates are marked by a conspicuous drought period at the height of summer.)

It is necessary, because of the climatic needs of dung beetles, to identify key climatic indices in regions of Australia. Then, using these data, searches for corresponding regions in other parts of the world can commence. Examination of dung beetle faunas in these matched foreign climatic regions has provided the basis for selection of dung beetles for Australian regions.

Once a climatic match is made, other factors should be considered – for example, soil type. Many southern African species are abundant in sandy soils, but this abundance tails off in heavy clay soils. Soil types therefore have created niches for dung beetles within their particular climatic ranges (we have already seen that dung preference produces other niches).

C–3.6 Biocontrol – dung beetles as competitors

Dung beetles are not the only inhabitants of the dung pat. They are preyed upon by predatory beetles, for example. The dung beetles' interest in the dung pat is for the bacteria–rich juices which they seek out and consume; and for the fibrous and 'colloidal' components which they remove down into their tunnels for provisioning their offspring. The dung is assembled into various types of brood balls, brood cakes or brood sausages (depending upon the species).

Each beetle then, in search of nourishment for itself, removes some nutrient value from the dung pat. The combined result of 3000 beetles in one pat, can quickly reduce it down to little more than a blot of 'chaff' on the pasture.

Similarly, breeding beetles, in a scramble for brood ball material, compete amongst themselves, and remove large quantities of dung to their tunnels and brood chambers. Large numbers of beetles can completely remove a four–litre pat within 30 minutes (JFA, pers. obs.).

C–3.7 Interference competition

The beetles, apart from competition amongst themselves and some predation, are little affected by other insects in the dung pat.

However, in the beetles' scramble for dung juice and for dung for brood balls, the pat is rendered unsuitable for other species, such as the bush fly.

Few suitable sites remain for flies to lay eggs. Little or no suitable dung remains for maggots to live in or feed from.

Fly predators such as the beetle, *Hister nomas* and the phoretic mite, *Macrocheles perigrinus* are tied to the bush fly population dynamics. As their prey numbers rise, so to do predator numbers, but not by the same magnitude. Their population rise necessarily lags behind that of their prey. Inevitably prey numbers decline and so too do those of the predators.

Unlike fly predators, dung beetle population dynamics are independent of the dung breeding flies with which they may share the dung pat. Fortunately, when and where dung beetles are abundant, bush flies are severely affected by the dung beetle's activities.

C–4 The role of dung beetles in pastures

C–4.1 Nutrient cycling

Significant amounts of plant nutrients are locked up in dung. These include the macro–nutrients, nitrogen (N), phosphorus (P), potassium (K) and the micro–nutrients or trace elements such as iron (Fe), copper (Cu), calcium (Ca) and sodium (Na).

Consider a paddock littered with cow dung. This represents to the farmer an investment of much time and toil and money, with dung sitting on the pasture obscuring up to 10 to 20 per cent of the available pasture (depending on stocking density). Eventually, over 12 to 18 months in a Mediterranean climate, dung will degrade by physical activities.

However, if we look at one nutrient, nitrogen, we can give an insight into the potential benefits that can be gained by the farmer arising from dung beetle activities.

This nutrient (nitrogen) is essential to plant growth and development and the nitrogen content in animal forage is a critical factor in livestock nutrition. This in turn is important to a farm's economy as it acts as a factor limiting stock weight gains, stocking capacity of a paddock and ultimately the profitability of the farm enterprise (these comments apply more or less to other plant nutrients too).

The farmer may: import nitrogen as synthetic soluble salts (for example, ammonium nitrate) for fertilising pastures; feed costly nitrogen–rich grain such as lupin; feed protein supplements (nitrogen) such as fish or meat meal; increase the average nitrogen content of the pasture by establishing various nitrogen–fixing legumes such as clovers, subterranean clover, and serradellas; or grow nitrogen–fixing trees and shrubs for browse, such as *Albizia*, *Acacia*, Tagasaste, etc. Livestock farmers, in fact, employ a combination of one or more of these strategies for increasing the eventual uptake of nitrogen for their livestock. However, each strategy represents a loss in terms of toil, time and money from the farm, and probably from the district as well.

Nitrogen is imported, exported and recycled within pasture ecosystems. By increasing the relative significance of the recycling, the farmer can get significantly more 'bites at the nutrient cake'. Recycling of nitrogen, in cost–effective ways (dung beetle activity for example), allows the farmer to realise an increased return on the current nutrient investment, and on the costs asociated with that investment.

Nitrogen is a valuable nutrient in a biological sense. It is rapidly used when available in the food chain. Unfortunately for the farmer, nitrogen (as pasture) is broken down rapidly after it is voided as dung, sometimes within two days, and finds its way back to the atmosphere as nitrogen gas. The farm must therefore employ a strategy to re–establish and maintain the nitrogen status of the pasture.

Dung beetles delay the loss of nitrogen due to volatilisation in pastures. Dung and its nitrogen component is mixed into soil and at various depths by the beetle's tunnelling and dung burial activities. Simply burying dung immediately slows nitrogen loss: and increasing the dung's contact with soil and soil water ensures that much of the nitrogen is mineralised in reactions with the colloids in the soil and is also dissolved as nitrogen salts in the soil water.

All this furthers the opportunities of pasture plants to access and use the previous year's nitrogen. The recycling of nitrogen in pastures has its own peculiar problems associated with its volatility. Ideally nitrogen should be reincorporated into the soil rapidly to obtain maximum recycling benefits.

The situation with other nutrients — phosphorus, potassium and trace — in a recycling sense is the same as that discussed for nitrogen, but with two major differences. These other nutrients are not lost to the pasture by volatilisation. However they cannot be 'created' in pasture in the way that nitrogen is fixed by legumes. Instead, the farmer must apply these as fertilisers, and with all the ensuing costs.

Dung beetles allow the farmer more 'bites at these other nutrient cakes' too!

C–4.2 Nutrient banding

Most dung beetle activity is confined to an area just under the dung pad and up to a depth of 300 mm. Of course this is influenced by the soil type and the physical difficulties faced by the beetle working that soil, soil moisture, and the species of dung beetle itself. However, generally we can say that dung (and its locked up nutrients) is banded at the root zone by the dung beetles and at a site where it will most benefit the pasture plants.

With the removal of dung from the soil surface, dung beetles alleviate the problem of nutrient loss from pastures into catchments, in two ways:

(1) Initially dung is physically removed and banded at the root zone of the pasture. Some nutrients may be mobilised, but lateral or downward movement of these dissolved immobile nutrients in soil is considerably slower than the movement of nutrients dissolved in run–off (or even as whole cow pats floating down stream!).

(2) Furthermore, at the time that the rains are mobilising dung–borne nutrients in the soil, pasture plants are starting their growth. These banded nutrients are well placed for use by pastures at the root zone, and they are then locked up in plant tissue until again consumed by livestock.

In summary, dung beetles can play an important role in recycling macro– and micro–nutrients in a pasture. In turn this can bring cost benefits to farmers and farming communities. Dung beetle activity provides nutrients in a form and at a site readily accessible by pasture roots and also allows the pasture to recapture the nutrients rather than them being lost from the pasture and into the catchments.

Footnote: The dung beetle, *Onitis caffer* is becoming increasingly common on the south–west coastal plain from Bindoon and southwards to Pinjarra. In the early days of the CSIRO dung beetle project, pasture improvement and defouling were important considerations in the selection of dung beetle species for subsequent importation.

Recent research at Moloto in southern Africa has shown that *caffer* buries dung at an average depth of 1 m (and up to 1.3 m). Generally, nutrients banded at such a depth would be unavailable to shallow–rooting annual pastures. This knowledge may have eliminated *caffer* from consideration for importation by the CSIRO.

However, farming shifts have seen a new wave of pasture species being evaluated, with a recent emphasis on perennial legumes and grass species. These plants are often deep–rooting and have lower fertiliser demands than traditional annual pasture species.

So, while dung buried by *caffer* may be beyond the reach of annual pastures, deep-rooted perennial pastures may derive much benefit from *caffer* activity. Could it be that *caffer* was 20 years ahead of pasture trends in Australian agriculture?

C-5 Keys and classification

The basis of the knowledge used in classifying the beetles and flies for BIOSCAN is drawn from an existing plethora of scientific literature. Our base knowledge of taxonomy itself evolves — its foundations based initially upon commonalities and now fine-tuned with today's science tools (for example, the molecular biologist's examination of the sameness — or otherwise — of a beast's DNA and enzyme systems).

Ultimately we aim to classify organisms into a phylogenetic ('natural') system albeit with its underpinning evolutionary assumptions.

But, for practical reasons it is often more convenient to classify our samples according to an arbitrary, artificial system. We cannot always access a dissecting microscope to count the number of chetae of the prothorax of a bluebottle fly! We hope that the BIOSCAN classification keys provided for nuisance flies and dung beetles, enable a class to identify, hopefully to species level, the flies and beetle samples with our user-friendly keys.

Note: The level (of difficulties) for classification of nuisance flies is outlined in BIOSCAN Activity sheet 2, Stages I, II and III. The class has the option of following the key to identify the flies to a level determined by the teacher and the class' ability and level of knowledge and understanding.

Dung beetles comprise an artificial grouping based conveniently on the beetles' dietary habits. In this arbitrarily defined grouping, as we have seen, only those beetles which feed primarily on dung, and whose larvae in turn feed only on dung, are termed, dung beetles.

We will illuminate the way a little, by way of example. The introduced species *Geotrupes spiniger* (adults and larvae) feeds on dung, whereas Australian species of Geotrupidae generally do not feed on dung. While the Scarabadae are assumed to all be dung beetle, some species are not, and have evolved new strategies for survival, for example, beetles of *Coptorhina* and *Delopleuru* species that feed upon fungi, and *Onthophagus latigibber* buries dead millipedes for its larvae.

Therefore, to summarise, this artificial assemblage (the dung beetles) is comprised of all those species of the super family, Scarabaeoidea, of which both adults and their larvae feed upon dung.

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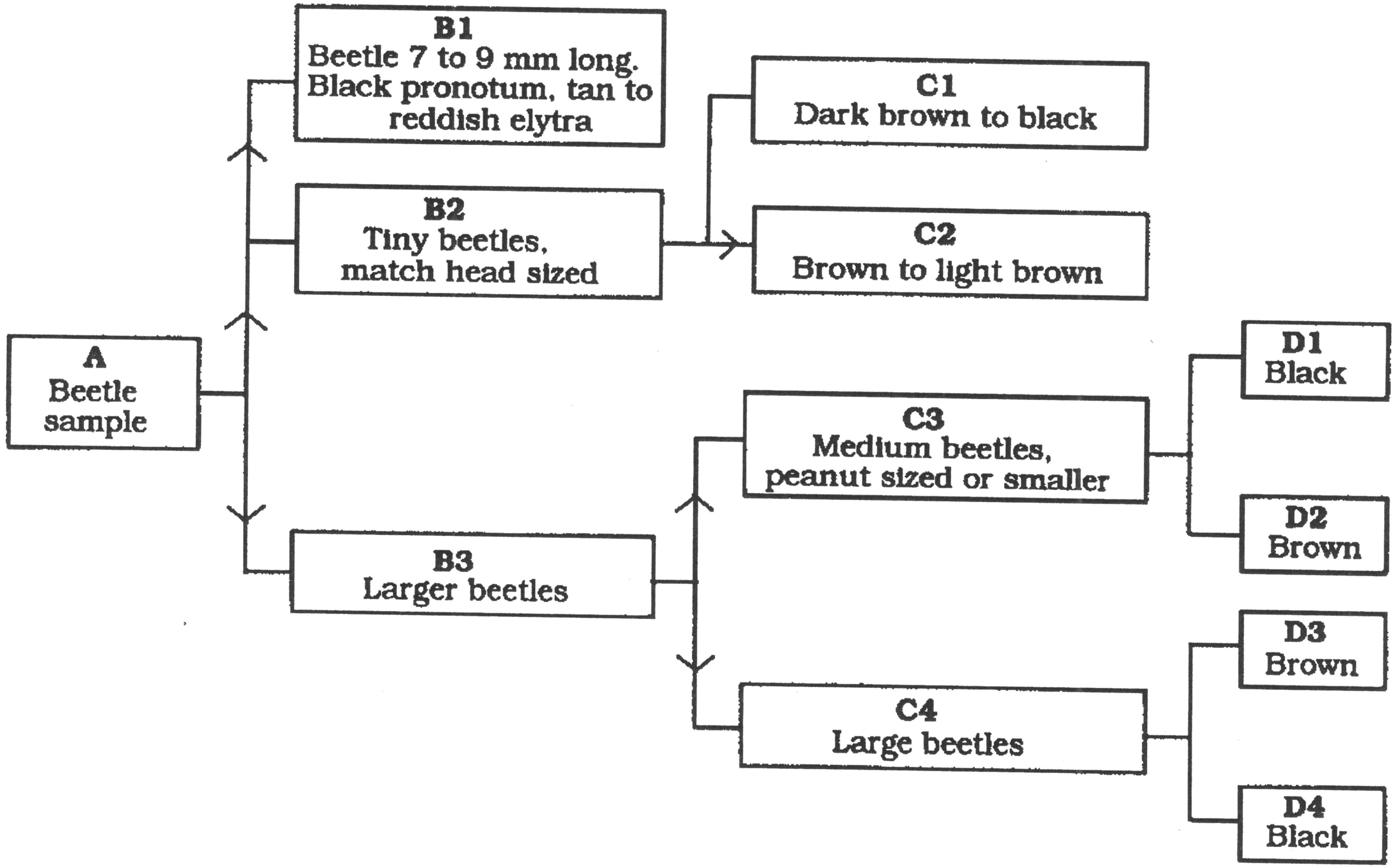
DUNG BEETLE KEY

STAGE I



DUNG BEETLE KEY