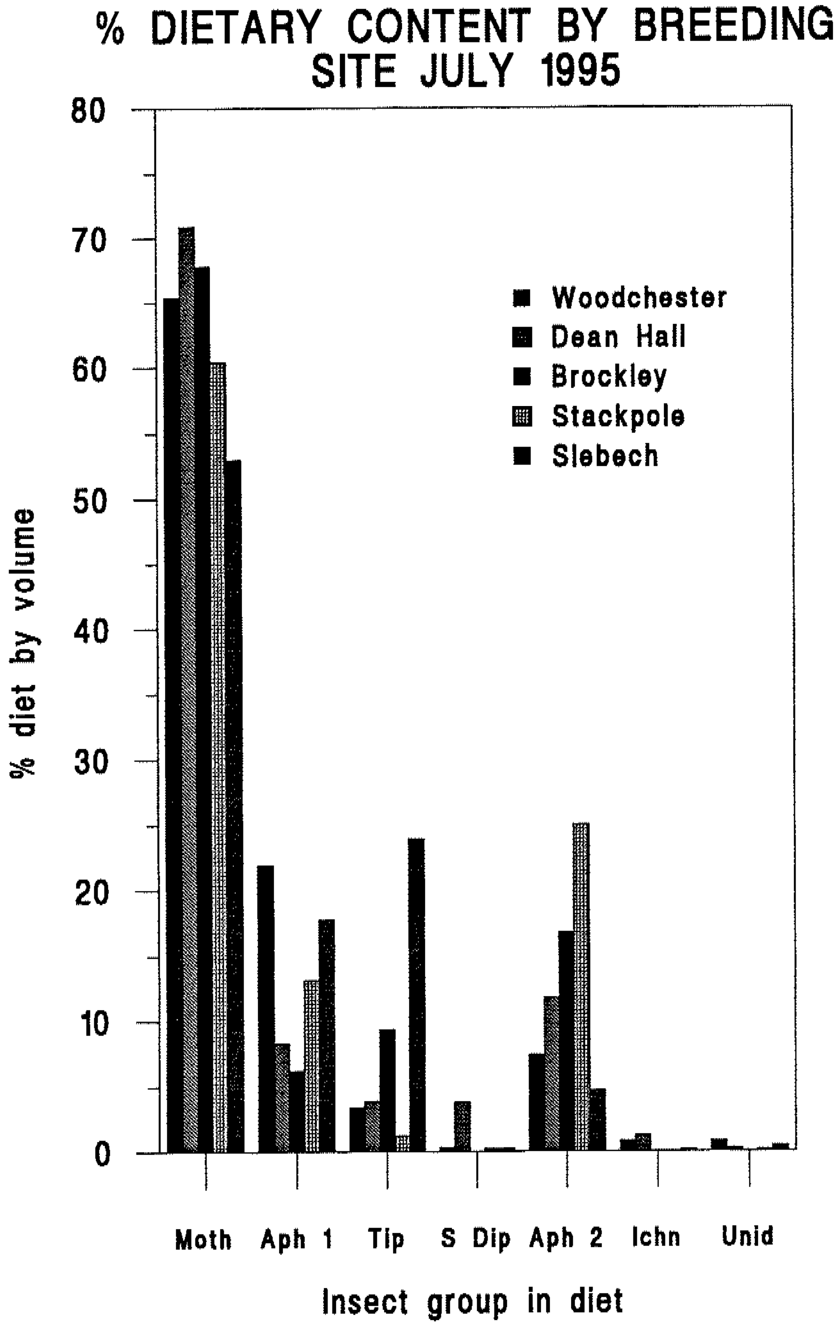

% DIETARY CONTENT BY BREEDING SITE JULY 1995
80
70
60
50
40
30
20
10
0
% diet by volume
Woodchester
Dean Hall
Brockley
Stackpole
Slebech
Moth
Aph 1
Tip
S Dip
Aph 2
Ichn
Unid
Insect group in diet

Figure 1

Figure 2(a)

Woodchester 1995 diet by volume

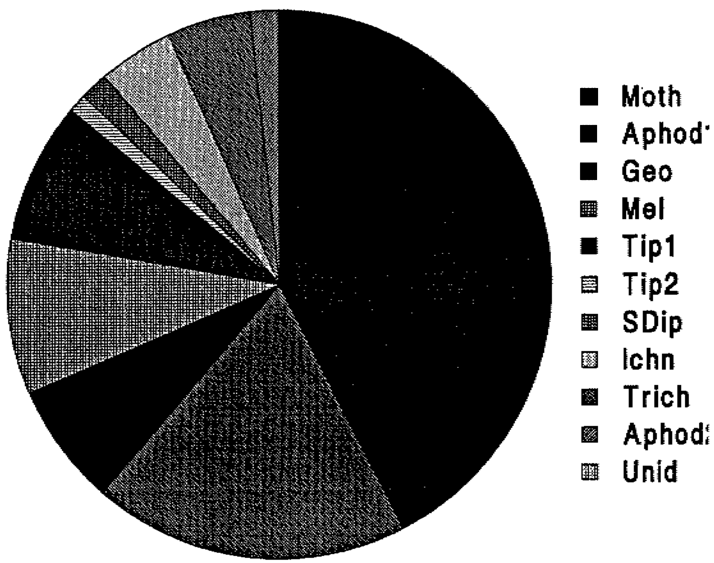


Figure 2(b)

Dean Hall 1995 diet by volume

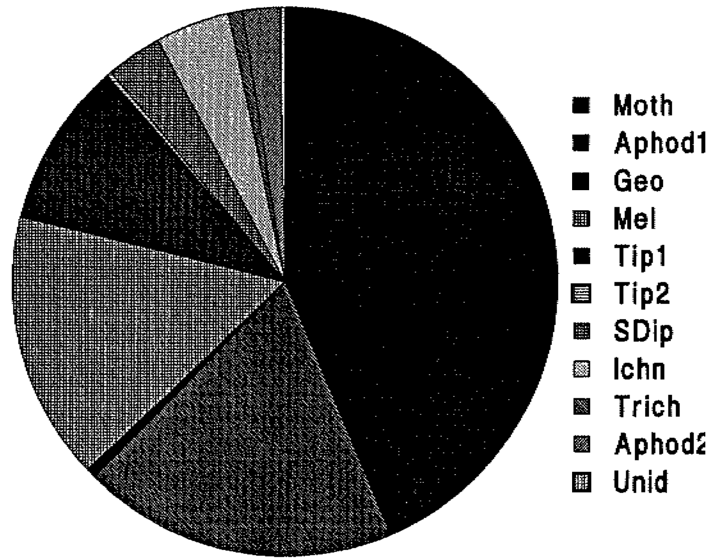


Figure 3(a)

Woodchester 1986 diet by volume

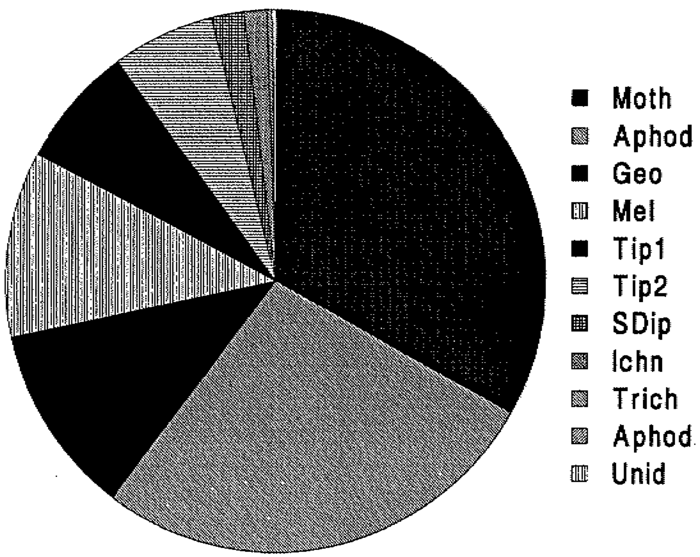
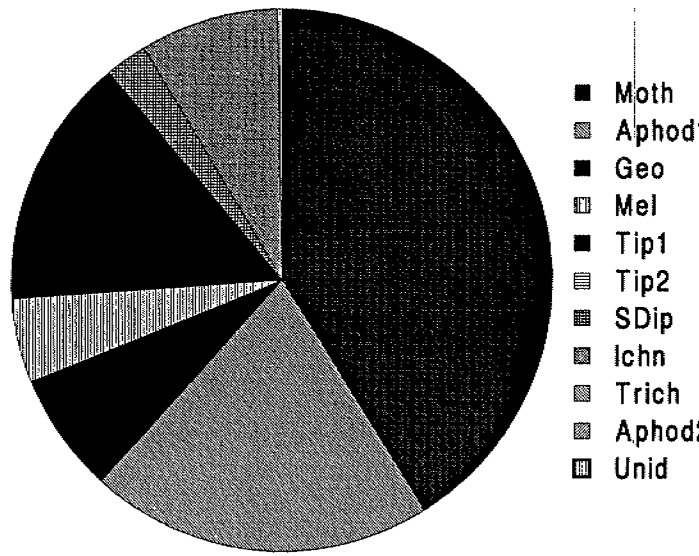


Figure 3(b)

Clapton/Brockley 1988 diet by volume (Jones 1990)



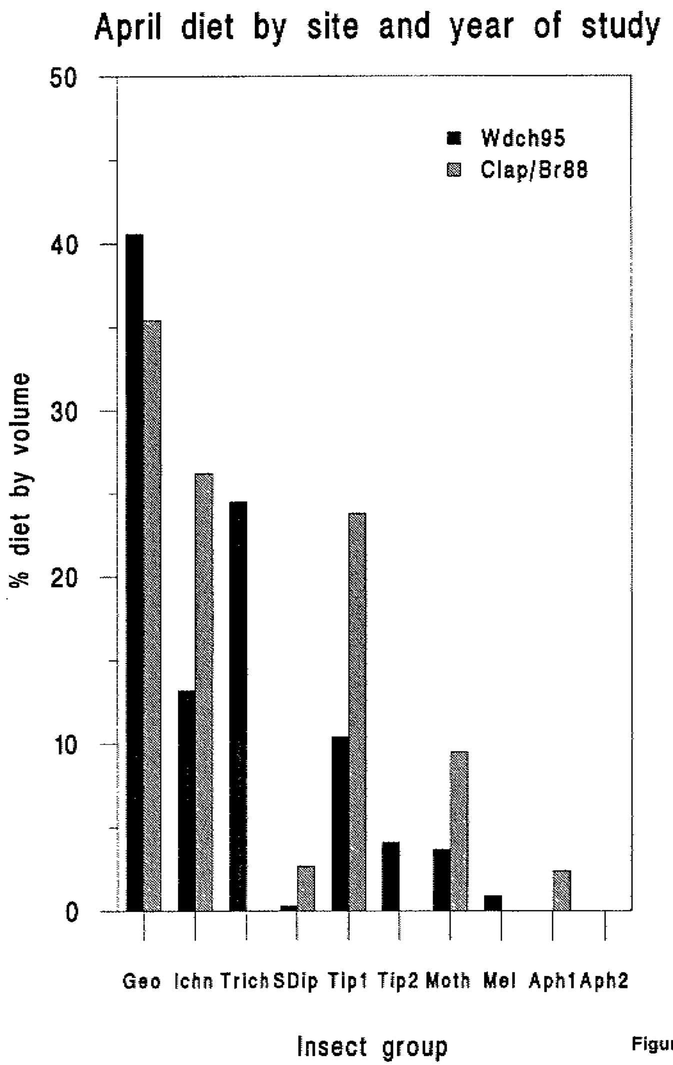


Figure 4

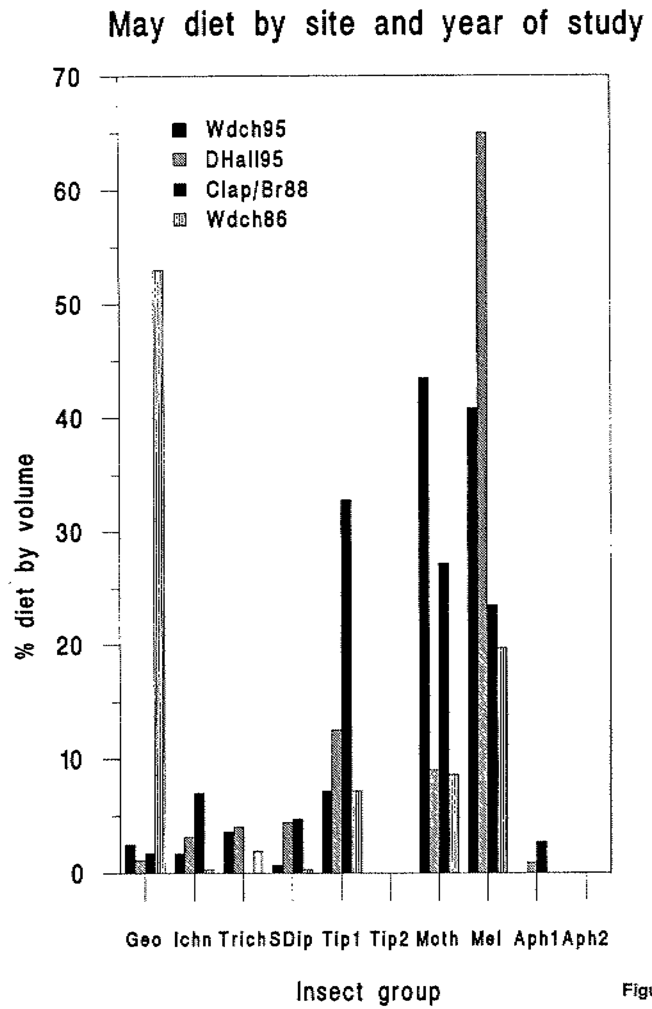


Figure 5

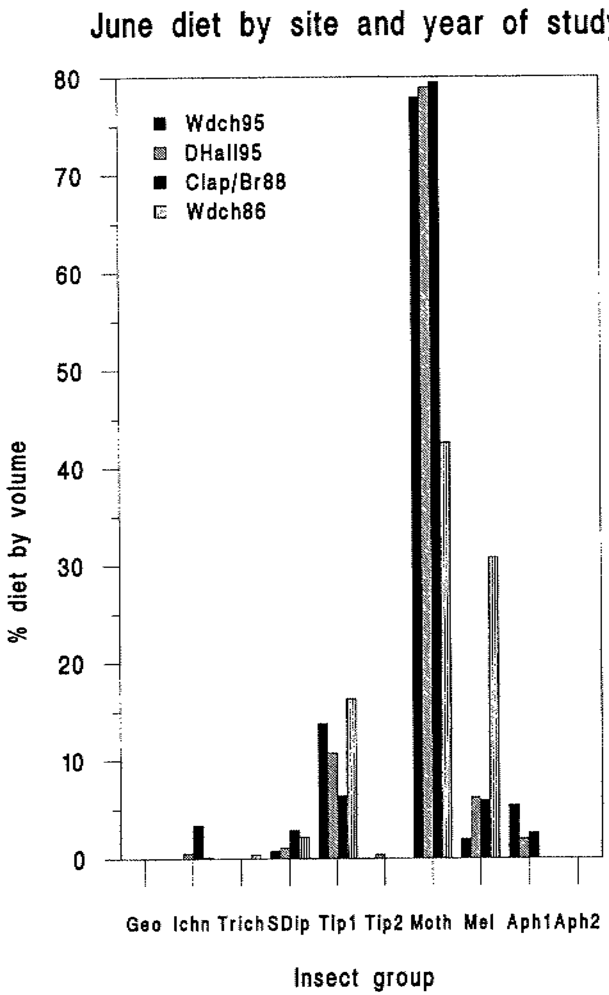


Figure 6

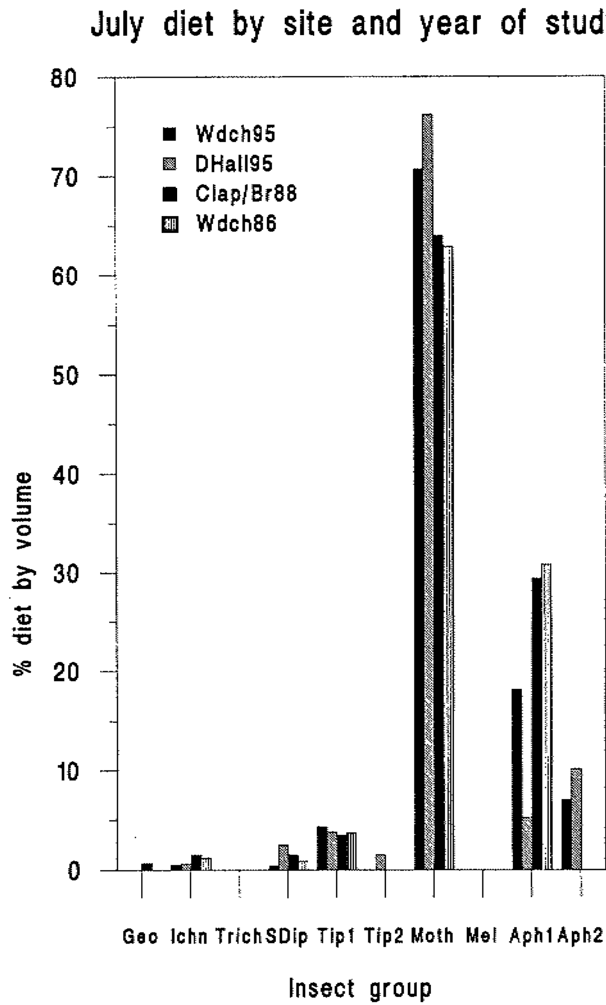


Figure 7

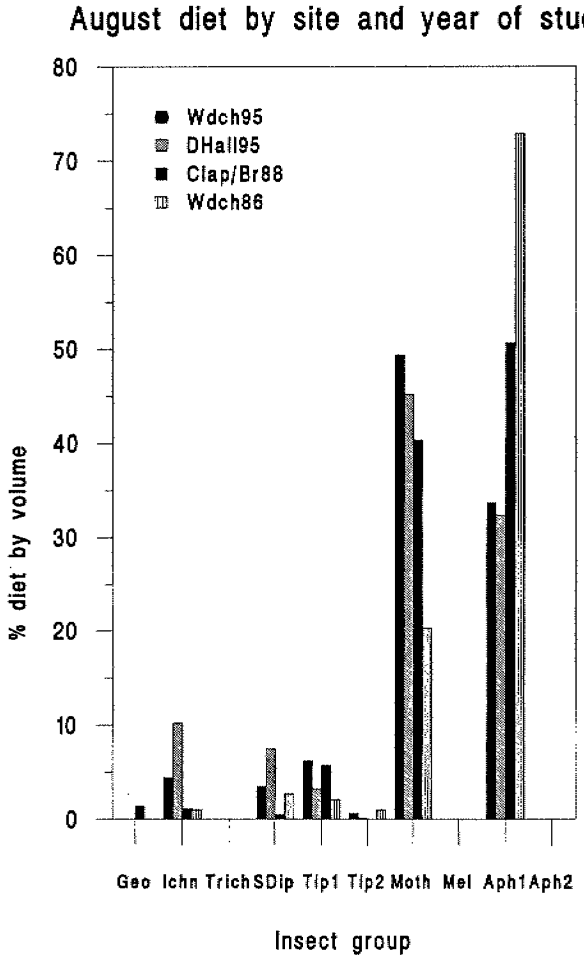


Figure 8

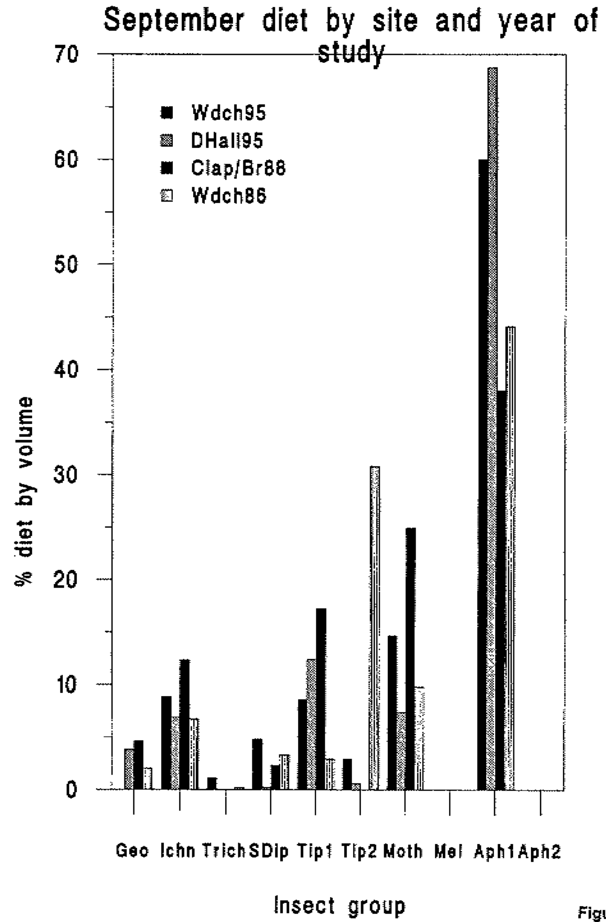


Figure 9

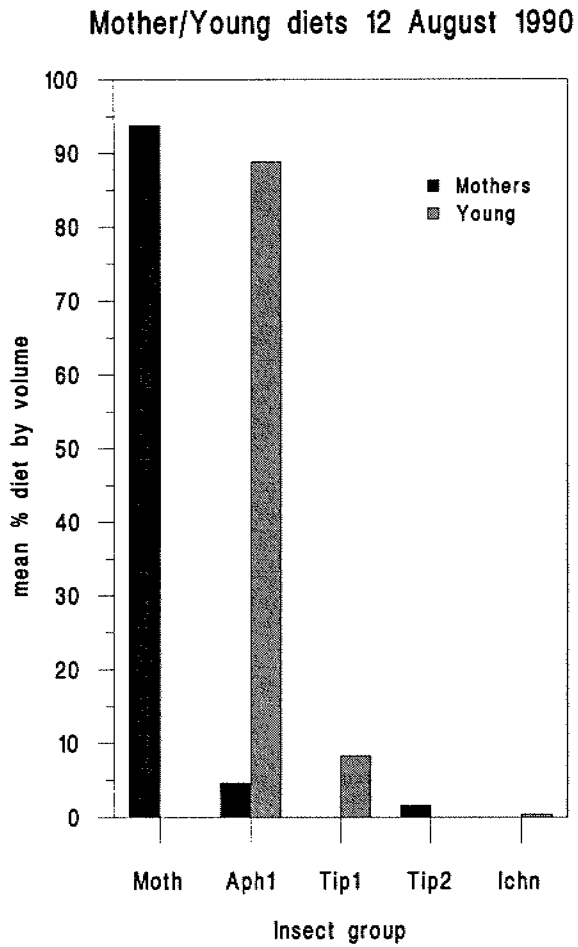


Figure 10

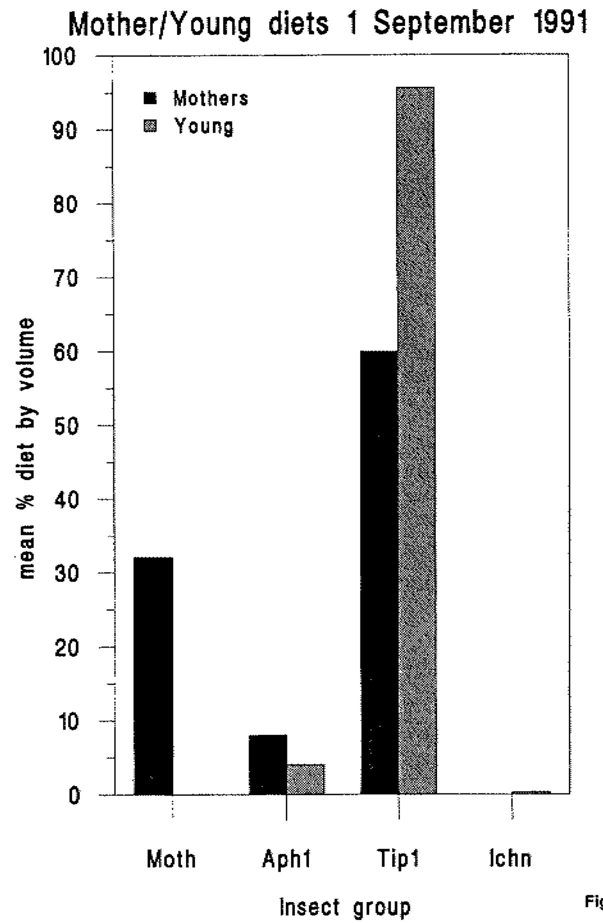


Figure 11

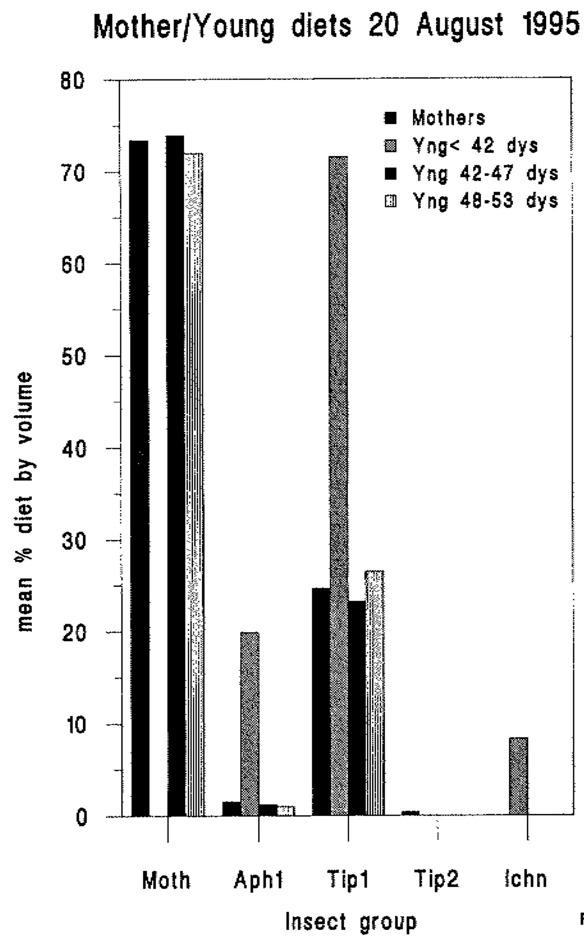


Figure 12

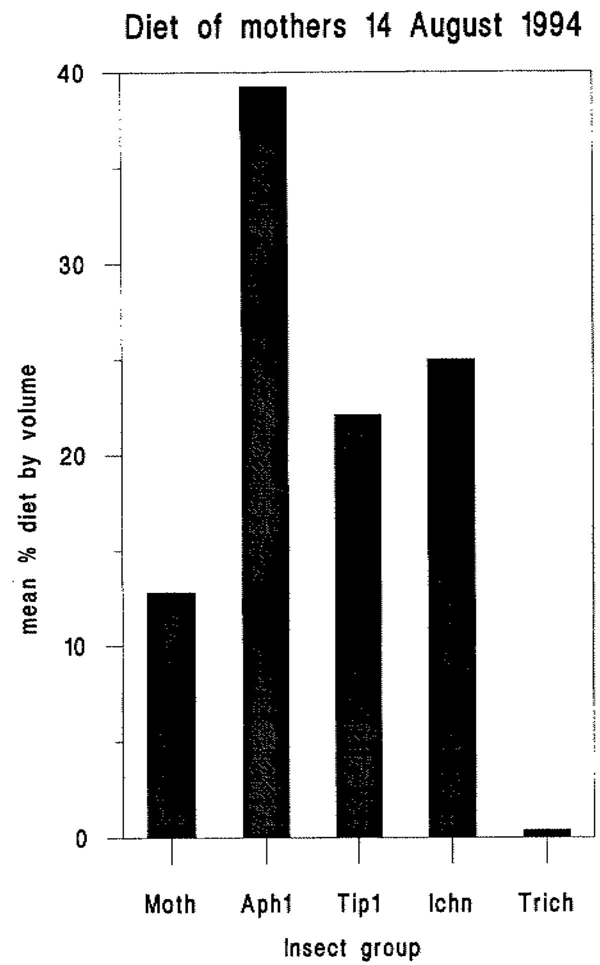


Figure 13

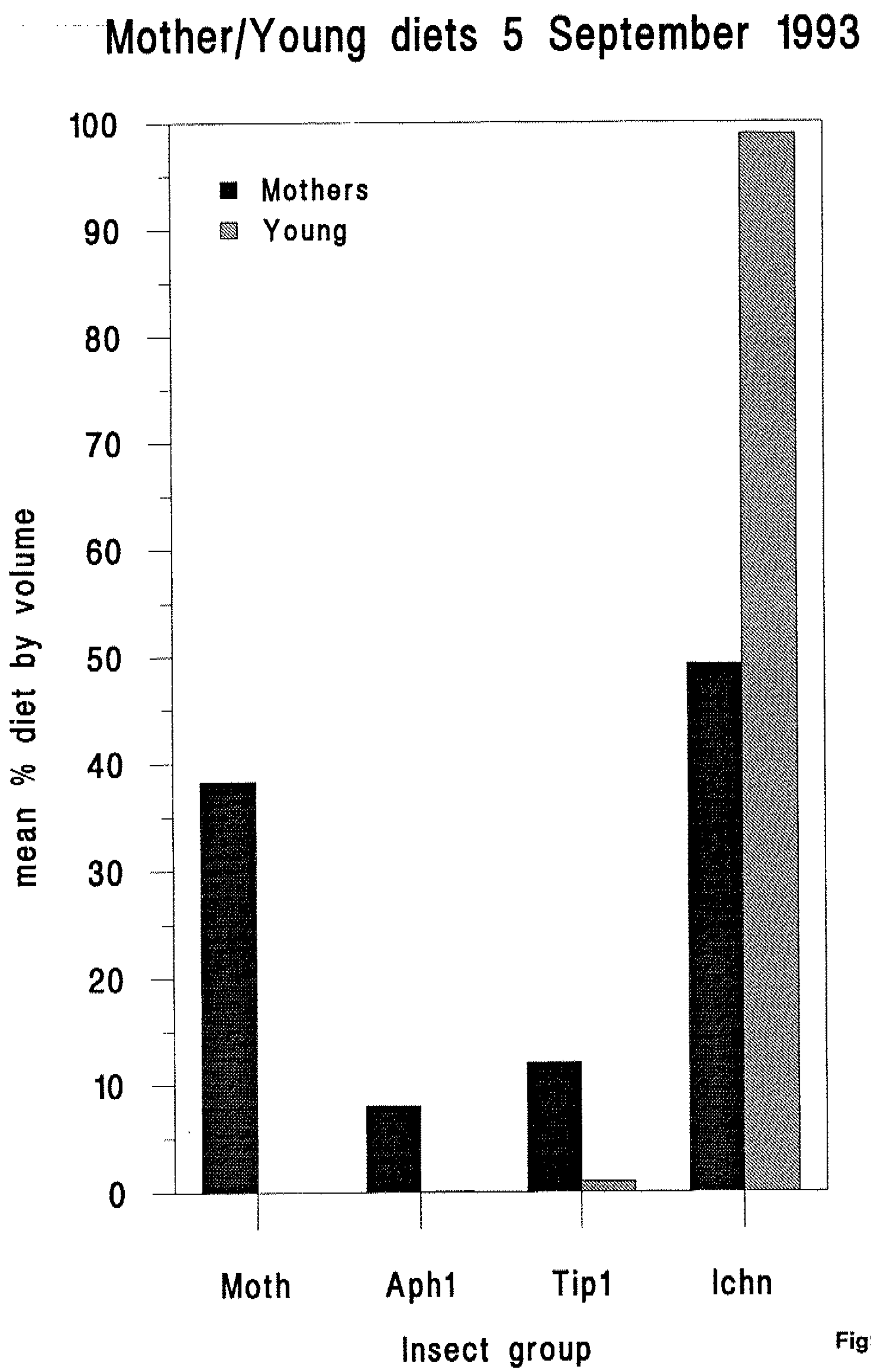

Mother/Young diets 5 September 1993
100
90
80
70
60
50
40
30
20
10
0
mean % diet by volume
Mothers
Young
Moth
Aph1
Tip1
Ichn
Insect group

Figure 14

PART 2: HABITAT FEATURES PROMOTING HIGH DENSITIES OF KEY PREY ITEMS WITHIN KNOWN FORAGING RANGE THROUGHOUT THE SUMMER

Foraging Range

Radiotracking studies carried out by Jones and Duvergé (Jones *et. al.*,1995) at three different maternity sites near Bristol have established the typical foraging range of this species. After the first year of life they average between 2 and 3 km distance from the day roost to feeding sites, sometimes exceeding 4 km. Within these ranges the mean total distance travelled by females varies with reproductive state, ranging from about 7.5 km in pregnant females, rising to 12.9 km during lactation, and falling to 8.1 km during post-lactation. They considered that the conservation of foraging areas up to 3-4 km from the maternity roost should be considered crucial for the maintenance of populations of this species.
Young bats, radiotracked simultaneously with their mothers, were shown to feed independently of their mothers. They make exploratory flights at about 24 days of age, and begin to feed soon afterwards, rapidly increasing the amounts captured from 29/30 days up to 55 days. During their early feeding flights (age 30-50 days) they travel increasingly farther, between about 0.3 and 1.5 km, averaging 1 km at age 40 days. At this age growth of forearm length ceases, and soon afterwards the young have fully developed ultrasonic capabilities, permitting them to catch the whole range of their prey items. Between age 50 and 55 days they rapidly increase their range to adult levels (mean 2.8 km).

Foraging Habitat Used

Jones and Morton (1992) in a study of a single maternity site near Bristol established that this species forages mainly in, or at the edges of, ancient woodland during the spring, and over pastures during late summer. Duvergé, in a follow-up study at three maternity sites (Duvergé, unpubl.) supports this finding. Both studies confirmed the suggestions made by Stebbings (1982) after preliminary radiotracking work in Wales. The habitat shift agrees with the major dietary findings of Jones (1990) and the present study. Young greater horseshoe bats are likely to be particularly dependent upon livestock-grazed pastures close to the maternity roost when they first start to forage for insects, since the small dung beetle *Aphodius rufipes* is their key prey item (Part 1).

Key Prey Species and Habitats

Evidence provided in Part 1 showed that various moths, *Aphodius rufipes*, *Geotrupes* spp. *Melolontha melolontha*, brown tipulids and ichneumonids were either key prey species in different months through the summer, or important back-up prey which may become key items in certain years in spring and autumn. The first two key prey items, moths and *Aphodius*, are probably of greatest concern to population levels, since they provide the bulk of the diet during late pregnancy and lactation, both events causing additional stress to female bats. The others are important in early pregnancy during spring, when climatic temperatures affect birth-timing and subsequent survival of the young of the year (Ransome and McOwat, 1994). Brown tipulids and ichneumonids are normally important secondary prey items if densities of key species fall too low for profitable feeding, such as during severe weather, especially when cold or very wet. They are valuable because they fly for extended periods of the year.

It is therefore important that the habitat for 3-4 km radius from a maternity roost should provide substantial areas of high densities of these prey items annually. The preferred habitat for foraging from April to September includes areas of mixed semi-natural deciduous woodland and permanent pasture habitat.

The following review of the literature concerning key insect species attempts to isolate key habitat features promoting high density populations of key and secondary prey species for bats to reliably feed on.

Habitat Features Promoting Key Prey Species

Moths

Although the present study did not identify individual moth species from faecal analysis, evidence from culled remains (Jones, 1990; *pers. obs.*) suggests that various common noctuid species such as the Heart and dart, *Agrostis exclamationis* (L.), Dark arches, *Apamaea* (= *Xylophasia) monoglypha*, Large yellow underwing, *Noctua pronuba* (L.), and Lesser yellow underwing, *Noctua comes* (Hübner), are important. Moth trapping in the summers from 1980 to 1995 in Dursley, Gloucestershire, some 9 km from Woodchester Mansion, showed that these species dominate light-trap catches in every year, with populations of each species peaking in the same order, as in the list above, from late May (Heart and dart) to early September (Lesser yellow underwing). The populations usually show considerable overlap so that two or more common species are available at any one time or (Ransome, unpubl.).

Taylor & Carter (1961) used suction traps to gain an unbiased set of data on various aspects of moth behaviour. Diurnal flight periodicity and height of flight were highly specific with an interaction between them which was associated with the moth's population level. The typical pattern was a peak after dusk followed by a long tail (Mouse, Beaded Chestnut, Large yellow underwing, Garden dart, Setaceous Hebrew character, Knot grass). Only Dark arches (*Apamaea monoglypha*) was bimodal with dusk and dawn peaks, and it flew at the same height each time with a peak of 6 metres. These data suggest that the Dark arches is especially likely to be available as prey for greater horseshoe bats.

Population estimates of moths

Light traps are generally used to sample moth availability and for population estimations, since they capture much larger numbers than suction traps but they are highly selective

(Taylor and Carter, 1961). The interpretation of the number of moths caught in a light-trap catch is contentious since it has a very uncertain relationship to the local moth population available to predatory bats (see Appendix A for a detailed discussion of this point). Certain species are much less attracted to lights than others. At least some populations of some species show little response to the lamps, and this variable response may be partly due to whether they are in a migratory phase (Baker, 1985). There is substantial evidence suggesting that many noctuid moths, including *Noctua pronuba*,, can be highly migratory, travelling huge distances from their larval habitats. It may be these migrations which result in high and erratic catches in traps (as argued by Gregg *et al.*, 1993, 1994), rather than variable illumination conditions.

As migratory species feature strongly in greater horseshoe bat diets, it may be argued that the local environment around a roost is of little importance in conservation measures taken. This seems not to be the case for the following reasons:

(a) migrating moths travel in surges which seem to be erratic and often of brief duration. They come to rest at intervals and seem to be selective in the choice of site, preferring dense woodland, preferably deciduous (Waring, 1989).

(b) migrating moths, which can result in large densities of moths in an area, have been shown to fly at higher levels than these bats normally feed, as shown by Taylor and Carter (1961), and therefore may only be of use to bats feeding at low levels as they land or take off.

(c) resident moths, possibly derived from larvae in the local area, and therefore subject to plant biomass population restrictions, are the ones more likely to be exposed to greater horseshoe bat predation over long periods

These considerations indicate that it would clearly benefit greater horseshoe bat populations to have high-quality moth habitat nearby in considerable abundance. If the resident moth population is the most important, because it is reliable and available for long periods, then the provision of abundant larval food plants, as well as roosting sites, is essential. Migratory swarms of moths may be worth attracting by providing many roosting sites, but their erratic presence may do no more than provide occasional bat feasts.

Resident moth levels are likely to fluctuate less than migratory ones, but will be subject to variations caused by the vagaries of climate, diseases and also other predators besides bats, or parasites such as ichneumonid hymenoptera (which have been shown to be important secondary prey items at low climatic temperatures in Part 1).

Factors influencing moth densities

Taylor, French and Woiwod (1978) investigated the effect of various habitats upon the numbers and diversity of moth species over many years, using data collected from light traps from 172 sites around Britain. A series of sites in the north and south of the country were graded from woodland to urban habitats (range: woodland, gardens, arable land, buildings).

They showed that moth numbers declined dramatically from thousands to hundreds across this series. The diversity index used was more stable, but also showed declines, especially in the south. The most obvious feature of their results was the similarity in the abundance of species in all of the woodland sites, and the drop between them and the typical agricultural site. This was often explained as being due to the loss of larval food plants in the case of resident moth species.

Waring (1989) showed that there were lower moth populations in a conifer plantation and a fresh coppice region than in adjacent dense deciduous coppice. The differences may have been greater than he detected, because he used corrections to his data based on Bowden & Morris (1975) who assumed a large zone of attraction operates around light-traps. Waring thought that the availability of suitable roosting sites is a likely explanation for the high numbers of *Noctua pronuba* in the overgrown woodland he showed were present in 1984. Hence it may be the quality of a habitat in attracting migratory moths for temporary resting stops, as well as its capacity to generate its own resident populations, which determine the overall densities of moths available to foraging bats.

Requirements of important prey species of moths

Besides the resting habitats necessary for adult moths, it is important to provide conditions promoting the successful completion of the life-cycle. Details of some of the larval foods, habitats and life-cycles are given in Appendix B, so only a brief summary is given here.

The larvae of *Agrostis exclamationis* and *Apamaea monoglypha* can all tolerate a wide range of open land habitats, including gardens, waste ground, fields and meadows. The first moth can feed successfully on a wide range of low herbaceous plants such as dandelion, chickweed and dock, with various grasses, and the second one feeds entirely on grasses. *Noctua pronuba* and *N. comes* needs similar habitats, but can also occupy mature, open woodland as they feed on primrose and other woodland herbaceous plants as well as dandelion, chickweed, dock and various grasses.

Management objectives to sustain high densities of important moth populations near roosts

1) Restrain creeping urbanisation into the 3-4 km area around breeding sites (the roost sustenance zone) by opposing building developments through planning procedures.

2) Restrain agricultural practices such as intensive arable cultivation within the roost sustenance zone by financial inducements.

3) Encourage the planting of extensive areas of deciduous woodland up to 50% of the area within the roost sustenance zone, if low woodland cover exists. Replace coniferous plantations with deciduous trees gradually over a period of time, avoiding extensive clear-felling. Woodlands should be permeated by grassy rides, and surrounded by regions of permanent pasture, especially close to roosts.

4) Strongly oppose the removal of mature ancient semi-natural deciduous woodland within the roost sustenance zone. Use statutory protection and/or financial inducements.

Aphodius rufipes

This is the major *Aphodius* species utilised by greater horseshoe bats, especially the young (Part 1), despite the fact that 19 species occur in England (Denholm-Young 1978). Many of these other species are very common. This apparent selection appears to be due to a combinations of characters. It is large and therefore a profitable food item (10-13mm length; 93 mg wet mass; 30 mg dry mass), exceeded only by *A. fossor* in dry mass (37 mg dry mass). Most *Aphodius* species in Britain are <8 mm long and <15 mg dry mass. It is one of the few *Aphodius* species which is truly nocturnal (Landin 1961), and will fly throughout the night if ambient temperatures permit flight (>9 °C.). *A. fossor* is diurnal, and although there are other nocturnal species, they are <6 mg dry mass. It is abundant in pastures in late summer, with up to 63 adult individuals per cow pat and an average of about 100 larvae per cow pat (Holter 1975). It is also common in European woodlands (Hanski 1979).

Although it is seasonal, it is long-lived, and is usually readily available to feeding greater horseshoe bats in large numbers from late July until October, usually with a peak in early August, at a time when young bats start to feed, and female bats are in the last third of lactation, and often greatly stressed. Thus it provides a safety net if moths, the preferred dietary item of the mothers, and brown tipulids, are both in short supply. It does well in a cold wet summer as its preferred temperature range is 14 - 17 °C.

Population estimates of ***Aphodius rufipes***

These may be made using two types of method, but only the first avoids the difficult identification of different species of larvae, although there are few large larvae present in cow pats in late August which are not *Aphodius rufipes* as other large species breed earlier in the year.

Baited traps may be excavated in fields containing bowls of fresh dung (about 2 kg) beneath wire mesh grid covers (about 4 mm prevents penetration to the dung) to catch them as they arrive. To sample *Aphodius rufipes* and not other species, traps should be operated at dusk in early August, and observed frequently after dark by torchlight for the arrival of adults over a fixed time period if quantitative comparisons with other sites are needed..

Aged cow pats can be examined for larvae after 21 days to find the levels of populations present in late August, by which time they should be present in large numbers. The dryish pat is lifted whole and sealed in a large plastic bag. In a garden or laboratory it is broken up finely and soaked in a 12 litre bucket fitted with a 5 cm diameter pipe. Running water flowing into the bucket causes effluent to run out through the pipe into two stacking sieves with mesh sizes 2 mm and 1 mm. Larvae can be removed from the finer sieve to a white tray for identification (Strong submitted). At 21 days they should be in their third stage, and be about 15 mm long. This involves a system of pat marking which is not hazardous to grazing animals, and is not easily destroyed, as well as larval identification.

Factors influencing adult <u>Aphodius rufipes</u> densities

Its potential abundance may be due to its capacity to feed on many types of herbivorous dung (in order of preference: cow, horse, sheep (Landin 1961)), and because it will utilise dung in a wide range of habitats, from exposed open fields to dense forests (Landin 1961).

It shows a wide range of habitat utilisation which gives it considerable protection against climatic extremes. In droughts shaded habitats will act as refuges allowing the survival of adults and the successful growth of the larvae. In severe prolonged droughts larvae may be killed within dung in most habitats, and adult survival may involve entering the soil. The adults are not killed, but reproduction is delayed for up to two months as occurred in Sweden in 1959 (Landin 1961). In prolonged heavy rain dung is washed away into the soil killing the larvae in exposed habitats, but dung remains intact in forests (Landin 1961). Hence shaded habitats act as refuges against climatic extremes. In normal climatic conditions exposed cow pats may be the most suitable for successful growth, and horse dung can produce successful development in shaded conditions such as forests, orchards and park lands (Landin 1961).

High densities of *Aphodius rufipes* are promoted by high densities of dung from grazers. As this species can only feed on fresh dung, which it leaves within a day or two, it means that a constant fresh supply from grazing animals, especially cattle, should be kept close to maternity roosts (< 1 km) to benefit the growth of the young by improving their insect capture success rates when they start foraging. Adult beetles find dung by smell, flying into the wind, and Landin argued that they are attracted by wind scent from considerable distances, possibly up to 10 km.

Denholm-Young quotes mean figures from 15 studies as follows. Grazing season = 188 days; average stock level (cattle) = 1.4 per ha; pats/cow/day = 11.9.

This translates into 16.7 pats/ha/day, and a maximum of 1052 adult beetles/ha/day. At 93 mg wet mass/adult this represents about 98 g/ha/day of adult beetles or about 0.1 kg/ha/day. Adult bats eat about 3-4 g of wet mass of insect food/feed, or 6-8 g/bat/day. Juveniles eat from 0 to 3 g/bat/day between 29 and 45 days of age whilst they feed close to the roost at a mean distance of 1 km. This range covers an area of 314 ha. If all the area were grazed pasture 0.1 x 314 = 31.4 kg of adult beetles could arrive at fresh pats per day. 100 pre-weaning young bats eating 3 g/day would consume 0.3 kg adult beetles/day if they ate no other food. This represents about 1% of available beetles if they were at maximum densities in the pats.

In practice stocking levels of 2-3 cows/ha can be maintained from mid July to late August in most years, so only 50% of the close surrounding habitat of a roost is needed to be grazed pasture to keep predation levels at about 2%, and allows for 50% woodland areas to favour moths for the adults to feed on. There are allowances for lower levels than the maximum in the pats, since predation levels can probably reach 5%. Furthermore, since juveniles are normally born over at least a three week period, and since they steadily increase their foraging range after they are 30 days old, several hundred juveniles are likely to be supported by these stocking levels.

If 157 ha of the land around a roost up to a distance of 1 km (50%) is grazed by cattle at up to 3/ha it means that 471 cattle (maximum) should be kept to sustain a bat colony with 100 young. Smaller colonies may require lower stocking levels, but it is probably inadvisable to drop much below 220 cattle within the young sustenance range (1 km). This is because low densities of fresh dung from grazers are much less attractive to colonising dung beetles than high ones, and population levels of adult beetles may fall disproportionately.

Adult greater horseshoe bats travel much further than pre-weaned young - up to 4 km; mean 2.84 ± 0.91 km (Jones *et al.* 1995). At 3 km radius, the minimum range which should be conserved for colony safeguarding, individuals may feed over 2828 ha. This area is the roost sustenance zone. It subsumes the young sustenance zone. 50% of the roost sustenance zone outside the 1 km range as grazed pasture represents 1257 ha of grazed pastures (2828 - 314 = 2514 ha; 2514/2 = 1257 ha). With 1.4 cows/ha and adult beetles = 0.1 kg/ha/day available it represents 126 kg of adult beetles/day. A colony of 700 adults eating 8 g/bat/day within this range would consume 5.6 kg beetles/day if they ate nothing else. This represents about 4.4 % of those in the area. Since fresh dung may attract beetles from a distance of many kilometres (see 8) above in Research Findings) the removal of a part of the local population by bat predation may promote immigration from further afield, if grazers are abundant there. Furthermore, in most years adult bats feed mainly on moths (Part 1) so the densities of cattle could be lower than 1.4 /ha without serious risk of shortages, especially as moths are only likely to be in short supply in cold wet summers. Such weather promotes the levels of *Aphodius rufipes*.

The key requirement to promote populations of greater horseshoe bats may be the presence of abundant grazers, especially cattle and sheep, within the 1 and 3 km radii. The most crucial for juvenile growth and survival, as well as helping reduce commuting distances for lactating females, will be 2-3 cows/ha, or 11-16 sheep/ha, in the 157 ha of grazing pastures which should be available (50% of 314 ha @ 1 km radius from roost). This area can support 314-471 cows for a the period between July and August, in normal summer weather, and up to 220 long-term. Equivalent sheep levels would be from about 1727 to 2512 sheep in July/August, and 1256 long term.

If sheep are used instead of cattle, which is the less preferable option, especially in dry weather because their dung rapidly dries out, they should be kept at levels of at least 11-16 sheep/ha, depending on grass productivity, to generate sufficient beetles. Mixed grazing in rotation with cattle is preferable, as it helps control nematode parasitic infections and reduce the need for drug treatment with anthelmintics (Appendix D).
Horses may also be beneficial in small numbers, especially if grazed in park land, orchards and grassy rides within woodland. Their dung also rapidly dries, and may become useless for breeding beetles, so the shade in these habitats should reduce desiccation rates.

Avermectin usage and its potential effect on dung insects

Avermectins belong to a family of compounds derived from a naturally-occurring soil actinomycete fungus, *Streptomyces avermitilis*. They were discovered in the mid 1970's. It includes the brand ivermectin marketed by Merck, Sharp and Dohme.

Ivermectin is a broad spectrum antiparasitic drug introduced onto the international animal health market in 1981. In Britain it is approved for use in cattle, sheep, goats, pigs and horses. It is particularly effective against gutworms and lungworms, and also some arthropod ectoparasites. It is absorbed systemically after administration by drench (pour-on), injection or stomach bolus, and is excreted mainly in the faeces. Residues of ivermectin in cow dung have been shown to reduce the number and variety of insects in the dung. This includes certain types of fly larvae, and various dung beetles which are important in promoting the rapid decomposition of dung. Besides delaying dung degradation, leading to pasture fouling, there is concern over the effects that long-term ivermectin usage in any area could have upon populations of these insects. Since they occur in significant numbers in untreated cattle-grazed pastures, the loss of their biomass may have important consequences to bird and mammal predators (McCracken and Bignal JNCC).

Control programmes recommended by Merck, Sharp & Dohme.

This company produced and marketed the first avermectin in 1981. They called it ivermectin. It contains two chemically-modified avermectins (at least 80% 22,23-dihydroavermecinB_{1a} and no more than 20% of the equivalent B_{1b} homologue). The brand names used for sales are Avomec^R injection for cattle, and Ivomec^R oral dose for sheep.

First season animals:

Strategic: (i) Up to 3 treatments, minimum 5 weeks apart early in grazing/transmission period.
(ii) treatment at the end of period of transmission e.g. housing, entry to feedlot, start of dry season.

Evasive: Treat once in mid season.

Therapeutic: Treat as clinically required.

Second season animals:

Strategic: Treat at a lower frequency than for first year animals.