



***CARCINOPS PUMILIO* (ERICHSON) (COLEOPTERA:
HISTERIDAE) AS A PREDATOR OF HOUSE FLIES IN
POULTRY MANURE**

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by

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Declaration

I, the undersigned hereby declare that the work presented in this dissertation is my own original work and has not previously been submitted in its entirety or in part in candidature at any university for any other degree

Signature.

Date.

ABSTRACT

In surveys carried out on poultry farms in the Western Cape Province, South Africa, the larvae of the flies *Musca domestica* L., *Fannia canicularis* (L.) and *Leptocera* sp. were found to be numerous. The majority of *M. domestica* larvae and the mite *Proctolaelaps* sp. were recovered from manure with temperatures between 20 and 26°C while the larvae of *F. canicularis* and *Leptocera* sp. were mostly found between 14 and 22°C.

Predominant predatory arthropods in the manure were the histerid *Carcinops pumilio* (Erichson), the staphylinid *Philonthus sordidus* (Gravenhorst) and the mite *Macrocheles muscaedomesticae* (Scopoli). These had a manure temperature tolerance of between 12 and 31°C. *Macrocheles muscaedomesticae* and *P. sordidus* preferred fresh manure, whilst *C. pumilio* preferred aged manure. Therefore these two predators could complement one another in integrated pest management programmes.

From a study of the vertical cross-sectional profile of the manure cone it was clear that the larvae of the prey species *M. domestica* and *F. canicularis* and predator *P. sordidus* distinctly occupy the crest of the manure cone.

The succession of arthropods in accumulating poultry manure and the effect of manure height on their numbers was studied. The prey species *M. domestica* and *F. canicularis* were the first colonizers followed by the predators *P. sordidus* and *M. muscaedomesticae*. *Carcinops pumilio* was a late colonizer. The numbers of *M. domestica* and *F. canicularis* larvae were negatively correlated with the increase in manure height whilst the numbers of the predators *C. pumilio* and *M. muscaedomesticae* were positively correlated with this.

The total developmental time of *C. pumilio* from egg to adult emergence at 30°C was 20.5 days. Two larval instars were recorded. The immature stages sustained about 50% mortality before adult emergence. *Carcinops pumilio* adults can live up to 130 days at 30°C and had a Type I survivorship curve. The intrinsic rate of natural increase (r_m) was 0.064943 and net reproduction rate (R_0) was 20.191.

The rate of oviposition was directly proportional to body size and weight. Increase in density had a dampening effect on fecundity and led to an increase in developmental time. Thus density will be a critical factor in any mass rearing programme for this predator of fly larvae. In addition, an increase in density stimulated the dispersal of *C. pumilio*. A crowding level of 50 *C. pumilio* adults per 200ml container resulted in the least dispersal which did not exceed 2.5% per day, compared with up to 24.0% at a crowding level of 400.

The predation rate of flies by *C. pumilio* in the laboratory decreased with an increase in predator density, but increased with an increase in starvation. Starvation had no effect on predation rate of *M. muscaedomesticae*.

A technique exploiting *Drosophila melanogaster* Meig. as a source of prey was successfully developed for rearing *C. pumilio*, which could be of commercial value. *Drosophila melanogaster* appeared to be an ideal candidate as a source of prey for mass rearing *C. pumilio* due to its short developmental time of about ten days. It is also inexpensive and easy to breed, and has a very high biotic potential.

Carcinops pumilio that were fed on artificial diet had a prolonged developmental time and increase in weight, and laid fewer eggs than those fed on natural diet. *C. pumilio* completed its development on the artificial diet and both the F₁ and F₂ generations fed on an artificial diet were able to lay eggs. This could be the first step towards finding an artificial diet that would allow continuous rearing of *C. pumilio* and their availability at all times for utilization in the biological control of houseflies.

OPSOMMING

In opnames wat op pluimveeplase in die Westelike Kaapprovinsie, Suid-Afrika

uitgevoer is, is gevind dat die vliegsoorte *Musca domestica* L., *Fannia canicularis* (L.) en *Leptocera* sp. volop is. Die meeste van die *M. domestica* larwes en die myt *Proctolaelaps* sp. is versamel in hoendermis met temperature tussen 20 en 26°C en die larwes van *F. canicularis* en *Leptocera* tussen 14 en 22°C.

Die volopste predatoriese arthropode in die mis was die histerid *Carcinops pumilio* Erichson, die staphylinid *Philonthus sordidus* (Gravenhorst) en die myt *Machroscheles muscaedomesticae* (Scopoli). Hulle temperatuurtoleransie in die mis was tussen 12 en 31°C. *Machroscheles muscaedomesticae* en *P. sordidus* het vars mis verkies, terwyl *C. pumilio* voorkeur aan ouer mis gegee het. Gevolglik behoort hierdie twee predatore mekaar te komplementeer in programme van ge-integreerde plaagbestuur.

'n Studie van die vertikale deursnee-profiel van die miskeël het duidelik getoon dat die prooispesies *M. domestica* en *F. canicularis* en die predator *P. sordidus* in die kroon van die miskeël voorkom.

Die opeenvolging van die arthropode in die ophopende hoendermis en die invloed van mishoogte op hulle getalle is bestudeer. Die prooispesies *M. domestica* en *F. canicularis* was die eerste koloniseerders, gevolg deur die predatore *P. sordidus* en *M. muscaedomesticae*. *Carcinops pumilio* was 'n laat koloniseerder. Die getalle van die larwes van *M. domestica* en *F. canicularis* was negatief gekorreleer met die toename in mishoogte terwyl die getalle van die predatore *C. pumilio* en *M. muscaedomesticae* positief daarmee gekorreleer was.

Die totale ontwikkelingstyd van *C. pumilio* van eier tot die volwassene se verskyning was 20.5 dae by 30°C. Twee larwale instars is gevind. Die onvolwasse stadia het 50% mortaliteit ondergaan voor die verskyning van die volwassenes. Die volwassenes van *C. pumilio* kan tot 130 dae lank by 30°C lewe en het 'n Tipe 1 oorlewingskurwe gehad. Die intrinsieke tempo van natuurlike toename (r_m) was 0.064943 en die netto reproduksietempo (R_0) 20.191.

Die tempo van eierlegging was in direkte verhouding tot die liggaamsgrootte en massa. Toename in digtheid het 'n onderdrukkende effek op vrugbaarheid gehad en tot 'n toename in ontwikkelings tyd gelei. Digtheid sal dus 'n kritieke faktor wees in enige program van massateling vir hierdie predator van vliegslarwes. Daarmee saam het 'n toename in digtheid die verspreiding van *C. pumilio* gestimuleer. By 'n digtheid van 50 *C. pumilio* volwassenes per houër het die verspreiding nie 2.5% oorskrei nie, in vergelyking met tot 24.0% by 'n digtheid van 400.

Die predasietempo van vlieë deur *C. pumilio* in die laboratorium het afgeneem met 'n toename in predatordigtheid, maar toegeneem met 'n toename in verhongering. Verhongering het nie 'n invloed gehad op die predasietempo van *M. muscaedomesticae* nie.

'n Tegniek met *Drosophila melanogaster* Meig. as bron van prooi in die teling van *C. pumilio* is suksesvol ontwikkel en dit kan van kommersiële waarde wees. Dit blyk dat *D. melanogaster* ideaal kan wees as 'n bron van prooi in die massateling van *C. pumilio* vanweë sy kort ontwikkelings tyd van ongeveer tien dae. Die spesies is ook goedkoop en maklik om te teel, en het 'n baie hoë biotiese potensiaal.

Carcinops pumilio wat op 'n kunsmatige dieet gevoed het, het 'n verlengde ontwikkelings tyd en gewigstoename gehad, en het minder eiers gelê as dié wat op 'n natuurlike dieet gevoed het. *C. pumilio* het sy lewensloop op die kunsmatige dieet voltooi en beide die F₁ en F₂ generasies wat op die kunsmatige dieet gevoed het, was in staat om eiers te lê. Dit kan die eerste stap wees in 'n poging om 'n kunsmatige dieet te vind wat dit sal moontlik maak om *C. pumilio* aaneenlopend te teel sodat dit deurlopend beskikbaar kan wees vir gebruik in die biologiese beheer van huisvlieë.

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INTRODUCTION

The members of the coleopteran family Histeridae are saprophytes (Hinton 1945) and are found associated with fecal material, carrion and other rotting material (Clausen 1940, Smith 1975, Crowson 1981, Rutz & Patterson 1990, Scholtz & Holm 1996). Some of them feed on the maggots in carrion (Hinton 1945) and in manure (Peck & Anderson 1969, Smith 1975, Legner & Olton 1968, Geden *et al.* 1988, Hulley & Pfeiderer 1988, Rutz & Patterson 1990).

Entomophagous Histeridae were utilized in biological control as early as 1909 when *Hister bimaculatus* L. was introduced into Hawaii from Germany to control the horn fly (Clausen 1940), while *Pachylister chinensis* Quensel was used in Fiji in the 1920's to control the house fly, *Musca domestica* L. (Simmonds 1929). Legner & Olton (1968) cited *Carcinops pumilio* Erichson as a predator of house flies and stable flies in USA.

The Histeridae are found in various parts of the world, as was shown by Legner & Olton (1970) in a worldwide survey of predators associated with artificially and naturally accumulated animal manure, including poultry manure, where histerids such as *C. pumilio* were predominant. They have been studied in various parts of the world, eg. *H. bimaculatus* L. in Germany, *Plaesius javanus* Erichson in Java (Clausen 1940), *H. chinensis* (Quens.) in Java (Sweetman 1958), *C. troglodytes* Paykull in South Africa (Hulley 1983, Hulley & Pfeiderer 1988), *C. pumilio* in USA (Peck & Anderson 1969, Pfeiffer & Axtell 1980, Geden & Stoffolano Jr. 1987) and *H. lutarius* (Fabricius) in India (Bai & Sankaran 1977).

The Histeridae are found in diverse habitats, including nests of birds (Hinton 1945, Sweetman

1958, Scholtz & Holm 1996). Hinton (1943) and Hicks (1959) speculated that some histerid predators appear to have been recruited from species previously living in association with birds' nests, nests of social bees or wasps, spider webs etc., whilst Geden (1990) stated that *C. pumilio* probably evolved as an associate of the nests of wild birds in Africa. A paucity of information exists concerning the developmental history of manure-inhabiting species (Summerlin *et al.* 1981) and relatively little is known about the biology of predatory histerids (Geden 1984).

Studies to acquire information on the biology and predatory potential of histerids were undertaken by Summerlin *et al.* (1981) who worked on *Hister coenosus* Erichson and *Placodes caffer* Erichson. Extensive work on the life history of *C. pumilio* was carried out by Smith (1975), Morgan *et al.* (1983) and Geden (1984). Smith (1975) fed *C. pumilio* with eggs of *M. domestica* in his studies, while Bai & Sankaran (1977) and Hulley & Pfeleiderer (1988) found that *C. troglodytes* preferred *M. domestica* eggs and small larvae in their laboratory feeding studies. Bai & Sankaran (1977), in their studies on predators of flies in India, found that the histerids *H. lutarius* Erichson, *H. bimaculatus* L. and *H. parallelus* Redtenbacher attacked the eggs and larvae of *M. domestica*. Geden *et al.* (1988) also found *Carcinops* sp. to be predatory on *M. domestica* eggs in the laboratory.

Hymenolepis carioca, a chicken tapeworm, uses *C. pumilio* as its intermediate host (Jones 1929). This infection, however, occurs exclusively in barnyard situations with "backyard flocks" and poses no threat to caged chicken poultry farmers who wish to encourage *C. pumilio* as a house fly predator (Smith 1975). Geden (1990) stated that *C. pumilio* harboured no known parasites or pathogens.

Carcinops pumilio prefers dark, protected habitats and is sensitive to changes in manure

quality, especially moisture content (Rutz & Patterson 1990). Peck & Anderson (1969) and Bills (1973) found that histerids (including *C. pumilio*) preferred dry and partially decomposed manure. Adults of *C. pumilio* could be found in manure with a 10 to 70% moisture range (Peck & Anderson 1969, Smith 1975), whereas the larvae are most abundant in the 50 to 70% moisture range (Geden & Stoffolano 1988). Smith (1975) stated that oviposition occurred in manure containing from 40 to 50% moisture. Predator performance was poor in manure with greater than 70% moisture (Rutz & Patterson 1990).

Peck & Anderson (1969) found that *C. pumilio* had the highest predatory potential among the arthropod predators in manure, and Bills (1973), Pfeiffer & Axtell (1980) and Axtell (1986) maintained that they are naturally capable of bringing about biological control of filth flies in poultry houses. Legner & Olton (1968) and Geden & Stoffolano (1988) stated that predators also aided in the aeration of the manure. Bills (1973) mentioned that the drying of the manure effected by *C. pumilio* was of considerable importance in facilitating house clearing and that the acceleration of drying achieved made an important contribution to the overall fly control. The predators also hastened the rate of decomposition of the breeding site, thus making it unsuitable for fly breeding (Legner & Olton 1968).

In poultry manure, *C. pumilio* is considered as the most important predator (Peck & Anderson 1969, Bills 1973, Pfeiffer & Axtell 1980, Morgan *et al.* 1983, Geden 1984, Geden & Stoffolano 1987, Hulley & Pfeleiderer 1988). In light of this, it is appropriate for further efforts to be made to study and manipulate *C. pumilio* for augmentative or inoculative releases in IPM programmes.

The goals of the present study were therefore as follows: (1) To study the assemblage of

arthropods found in the poultry manure in Western Cape, South Africa, and to determine whether or not the beetle fauna is similar to those described elsewhere. (2) To determine the developmental rates of the dominant predator *C. pumilio* at different temperatures. This knowledge would be useful in the mass rearing of this species for both experimental and IPM purposes. (3) To determine the feeding preferences and predation rates of the dominant predators of *M. domestica* found in poultry production systems in the Western Cape, South Africa in order to evaluate their usefulness. (4) To monitor the succession of arthropods in accumulating poultry manure, with emphasis on arthropod predators and their prey, as well as the relationship between their numbers and manure height. (5) To determine the dispersion patterns of arthropods associated with poultry manure in order to gain an understanding of the degree of interaction between predators and prey within the manure and to develop a strategy to enhance this in filth fly IPM programmes. (6) To establish how food, temperature and crowding mediate in the dispersal of *C. pumilio* under laboratory conditions. (7) To improve on the technique of mass rearing of the predominant predator, *C. pumilio*, by exploiting *Drosophila* sp. as source of prey. (8) To develop an artificial diet for rearing *C. pumilio*.

REFERENCES

- AXTELL, R. C. 1986. Fly management in poultry production: cultural, biological and chemical. *Poultry Science* **65**: 657-667.
- BAI, G. M. & SANKARAN, T. 1977. Parasites, predators and other arthropods associated with *Musca domestica* and other flies breeding in bovine manure. *Entomophaga* **22**: 163-167.
- BILLS, G. T. 1973. Biological fly control in deep pit poultry houses. *British Poultry Science* **14**: 209-212.

- CLAUSEN, C. P. 1940. *Entomophagous Insects*. McGraw-Hill Book Company, Inc., New York.
- CROWSON, R. A. 1981. *The biology of the Coleoptera*. University of Glasgow, Scotland.
- GEDEN, C. J. 1984. *Population dynamics, spatial distribution, dispersal behaviour and life history of the predaceous histerid, Carcinops pumilio (Erichson), with observations of other members of the poultry manure arthropod community*. Ph.D. dissertation, University of Massachusetts, Amherst.
- GEDEN, C. J. & STOFFOLANO, J. G. 1987. Succession of manure arthropods at a poultry farm in Massachusetts, USA, with observations on *Carcinops pumilio* (Coleoptera: Histeridae) sex ratios, ovarian condition and body size. *Journal of Medical Entomology* **24**: 212-220.
- GEDEN, C. J., STINNER, R. E. & AXTELL, R. C. 1988. Predation by predators of the house fly in poultry manure: effects of predator density, feeding history, interspecific interference, and field conditions. *Entomological Society of America* **17**: 320-329.
- GEDEN, C. J. & STOFFOLANO, J. G. 1988. Dispersion patterns of arthropods associated with poultry manure in enclosed house in Massachusetts: spatial distribution and effects of manure moisture and accumulation time. *Journal of Entomological Science* **24**: 136-148.
- GEDEN, C. J. 1990. Coleoptera and acarine predators of house fly immatures in poultry production system In: Rutz, D. A. and Patterson, R. S. *Biological control of arthropods affecting livestock and poultry*. Westview Press, Oxford.
- HICKS, E. A. 1959. *Checklist and bibliography of the occurrence of insects in birds' nest*. Iowa State College, Ames, Iowa.
- HINTON, H. E. 1943. Natural reservoirs of some beetles of the family Dermestidae known to infest stored products, with notes on those found in spider webs. *Proceedings of the Royal Entomological Society of London* **18**: 33-42.

- HINTON, H. E. 1945. The Histeridae associated with stored products. *Bulletin of Entomological Research* **35**: 309-340.
- HULLEY, P. E. 1983. A survey of the flies breeding in poultry manure, and their potential natural enemies. *Journal of the Entomological Society of Southern Africa* **46**: 38-47.
- HULLEY, P. E. & PFLEIDERER, M. 1988. The Coleoptera in poultry manure-potential predators of the house fly, *Musca domestica* Linnaeus (Diptera: Muscidae). *Journal of the Entomological Society of Southern Africa* **51**: 18-29.
- JONES, M. F. 1929. *Hister (Carcinops) 14-striatus* as intermediate host of *Hymenolepis carioca*. *Journal of Parasitology*. **15**: 224.
- LEGNER, E. F. & OLTON, G. S. 1968. Integrated control of house and stable flies. *California Agriculture* **22**: 1-4.
- LEGNER, E. F. & OLTON, G. S. 1970. Worldwide survey and comparison of adult predator and scavenger insect populations associated with domestic animal manure where livestock is artificially congregated. *Hilgardia* **40**: 225-266.
- MORGAN, P. B., PATTERSON, R. S. & WEIDHAAS, D. E. 1983. A life-history study of *Carcinops pumilio* Erichson (Coleoptera: Histeridae). *Journal of Georgia Entomological Society* **18**: 353-359.
- PECK, J. H. & ANDERSON, J. R. 1969. Arthropod predators of immature Diptera developing in poultry droppings in Northern California. *Journal of Medical Entomology* **6**: 163-167.
- PFEIFFER, D. G. & AXTELL, R. C. 1980. Coleoptera of poultry manure in caged-layer houses in North Carolina. *Environmental Entomology* **9**: 21-28.
- RUTZ, D. A. & PATTERSON, R. S. 1990. *Biocontrol of arthropods affecting livestock and poultry*. Westview Press, Boulder, San Francisco.

- SCHOLTZ, C. H. & HOLM, E. 1996. *Insects of Southern Africa*. University of Pretoria, Pretoria.
- SIMMONDS, H. W. 1929. Introduction of natural enemies against the house fly in Fiji. *Journal of Agricultural Development Fiji* **2**: 46.
- SMITH, K. A. 1975. *Observations on the life history, ecology and behaviour of Carcinops pumilio* (Erichson). MSc. Thesis, Department of Entomology, University of New Hampshire, Durham.
- SUMMERLIN, J. W., BAY, D. E., HARRIS, R. L. & RUSSEL, D. J. 1981. Laboratory observations on the life cycle and habits of two species of Histeridae (Coleoptera): *Hister coenosus* and *Hister incertus*. *Annals of the Entomological Society of America* **74**: 316-319.
- SWEETMAN, H. L. 1958. *The principles of biological control*. W. C. Brown Company Publishers, Dubuque, Iowa.

CHAPTER 1

SURVEY OF DIPTERANS AND OTHER ARTHROPODS BREEDING IN POULTRY MANURE AND THE ABIOTIC FACTORS AFFECTING THEIR NUMBERS

ABSTRACT

The predominant arthropods breeding in manure in the Western Cape Province, South Africa were larvae of the flies *Musca domestica* L., *Fannia canicularis* (L.) and *Leptocera* sp., and the mite *Proctolaelaps* sp. The 1st and 2nd instar larvae of *M. domestica* and *F. canicularis* were numerous within the first three weeks post-cleanout. The peak numbers of these instars occurred in summer and winter, respectively. The highest numbers of larvae of *M. domestica*, *F. canicularis*, and *Leptocera* sp. and all stages of *Proctolaelaps* sp. were found between 65 to 80%, 70 to 80%, 75 to 80% and 70 to 75% manure moisture levels respectively. The majority of *M. domestica* (about 65%), *F. canicularis* (about 48%), and *Leptocera* sp. (> 85%) 1st and 2nd instar larvae and all stages of *Proctolaelaps* sp (> 85%) were recovered at manure temperatures between 20 to 26°C, 18 to 22°C, 14 to 18°C and 22 to 26°C respectively.

Key words: Poultry manure, manure temperature, manure moisture, *Fannia canicularis*, *Leptocera* sp., *Proctolaelaps* sp., *Musca domestica*.

1. INTRODUCTION

Farmers involved in poultry production in high-density confined systems had to deal with the problem of manure handling, disposal and the concurrent problem of fly control (Wilhoit *et al.* 1991). Filth breeding Diptera are major pests on poultry farms (Anderson &

Poorbough 1964, Zchori-Fein *et al.* 1992). The house fly, *Musca domestica* L. is the major pest fly species associated with poultry manure (Conway 1973; Toyama & Ikeda 1976; Hulley 1983, 1986; Axtell 1986; Hulley & Pfeleiderer 1988; Rutz & Patterson 1990) together with the lesser house fly, *Fannia canicularis* (L.) (Anderson & Poorbaugh 1964, Axtell 1970, Conway 1973, Hulley 1986, Fatchurochin *et al.* 1989, Wilhoit *et al.* 1991). *M. domestica* is an *r*-type species with an enormous potential rate of increase (Kettle 1993). They can breed prolifically in accumulated manure in poultry houses (Axtell & Edwards 1983, Wilhoit *et al.* 1991), resulting in high densities (Axtell 1968). High densities of *M. domestica* and other flies also cause a significant nuisance to farm workers in and around animal production facilities (Tanada *et al.* 1950, Armitage 1985, Axtell 1986, Hulley 1986, Axtell & Arends 1990, Howard & Wall 1996). They also tend to gravitate to nearby residences and businesses (Tanada 1950, Pfeiffer & Axtell 1980, Axtell 1986, Axtell & Arends 1990), which could result in considerable social and expensive legal problems (Axtell & Arends 1990, Howard & Wall 1996).

Flies also provide a reservoir for a wide variety of pathogenic organisms (Axtell & Arends 1990) and serve as transmitters of diseases such as cholera, amoebic dysentery, anthrax, diphtheria, and tuberculosis that affect man (Kettle 1993). They could also serve as a vector and an intermediate host of certain cestodes and nematodes of poultry (Kettle 1993). Schroeckenstein *et al.* (1988) state that workers could develop an occupational allergy to *M. domestica* which could result in work-related symptoms of urticaria, rhinitis and asthma. Furthermore, Armitage (1985), Axtell (1986) and Axtell & Arends (1990) mention that flies by defecation and regurgitation cause spotting on structures and equipment, reduction in the illumination from lighting fixtures, and when they do this on newly laid poultry eggs, present potential for pathogen transmission. Howard & Wall (1996) add that it decreases the

aesthetic appearance and value of eggs. Armitage (1985) states that flies disturb laying birds which could result in lower egg production.

There is a paucity of basic information required for the development of an integrated fly control program in South Africa poultry farms. The only work on fly breeding on poultry farms in South Africa was by Hulley (1983, 1986). The study was therefore to supplement Hulley's work so as to obtain information that would contribute towards a fly control program on poultry farms in South Africa.

In this chapter the aims were: (1) to determine the fly species that are dominant on two poultry farms in the Western Cape, South Africa and (2) to relate the environmental factors to the populations of the fly species.

2. MATERIALS AND METHODS

2.1 Study site and house design

A survey of dipterans and other arthropods breeding in poultry manure was carried out between 29-11-1999 and 20-11-2000 at Rosendal Poultry Farm (a private enterprise), Paarl, Western Cape Province, South Africa (33° 43'S; 19° 01'E) and the University of Stellenbosch Experimental Poultry Farm, Elsenburg, Western Cape Province, South Africa (33° 51'S; 18° 50'E). At the University House sampling was terminated after nine months as the house was cleaned out due to an excessive amount of water in the manure.

The Rosendal Farm had a two-storied commercial egg production unit, about 12m wide and 180m long. The birds were kept on the top-story where there were wooden walkways

between the banks of tiered cages and no floor beneath the cages. There were four birds per cage with 0.45m²-floor space per bird. The cages were set parallel to the length of the second floor with the cages stacked four high, with each level set back to allow manure to drop beneath the cages. The manure accumulated on the dirt floor and was allowed to remain for 12 months. Ventilation and temperature control was by natural means. The manure from which samples were taken was about one week old.

The house at the University Farm was an open sided commercial egg laying type with ventilation and temperature control by natural means. Birds were housed in single-tier cages suspended about 1m from the floor, with four birds per cage and 0.45m²-floor space per bird. Cages were in rows crosswise in the building. Paths between the rows were concrete with manure accumulating beneath the cage in dugout sand. The manure from which samples were taken was also one week old.

2.2 Sampling

Manure samples were taken bi-weekly from the two houses starting one week post-cleanout (PC) of the old manure. Samples were taken from each of 10 positions in each house with an auger of 5.0cm in diameter and 9.0cm in length. At each position, the auger was inserted at a 45° angle just below the tip of the manure cone so as to avoid freshly deposited manure. The auger was gently rotated before pulling it out together with the manure. During the first four weeks PC, a hand trowel was used to fill the auger with manure. Each sampling position was marked with small flagged sticks to avoid sampling the same point again. Sampling of manure was done along central rows to avoid edge and side bias. The total sample was placed in an ice-cream container and taken to the laboratory where the manure

was placed in Tullgren funnels with 60 w bulbs as source of heat for 72 hrs. The arthropods were extracted into 70% ethanol and later counted. Only the first two instars of *M. domestica* and *F. canicularis* were counted. Counts of acarine mites were determined volumetrically.

At each position an adjacent sample was taken to determine the moisture content of the manure. The total sample was also placed in an ice-cream container that was immediately covered with its lid and returned to the oven to be dried. It was reweighed after one week. The percentage moisture content of the manure was calculated using the formula: $w = [(y - \chi) / y] \times 100$, where, w = % of manure moisture content, y = weight of wet manure and χ = weight of dry manure, in grams. A thermometer (mercury) was inserted 6 cm deep vertically at the top of the manure cone at each position and the temperature read before the samples were taken. The 6 cm mark on the thermometer was marked with a tape.

Some samples were taken from which puparia were extracted by flotation on water. The floating pupae were collected with a pair of forceps and placed in test tubes. The emerged adult flies were then identified.

To determine the number of class intervals for the frequency distribution of arthropod numbers occurring at the different manure moisture and temperature levels the rule of Sturge was used, thus; $K = 1 + 3.3 \log_{10} N$, where K = the number of classes and N = total number of observations. The value obtained was used to establish the size of the classes by means of the following formula:

$$C = \frac{\text{range (max-min)}}{K}$$

where C = the size of the class, \max = largest value, and \min = smallest value of data obtained. The value that falls on the limit was transferred to the higher class (Coetzee 1991).

Values for atmospheric temperature during the experimental period were obtained from the Department of Meteorology, ARC, Infruitec, Stellenbosch, Western Cape Province. Each temperature data point used was the mean of the daily maximum and minimum values.

2.3 Analysis

The mean numbers of the most common and predominant species were plotted against time. The frequency distribution of arthropod numbers at the different levels manure moisture and temperature were also plotted.

3. RESULTS

3.1 Arthropod numbers

At the Rosendal Farm numbers of 1st and 2nd instar larvae of *M. domestica* were relatively high at the beginning of the sampling period. Thereafter they remained low to peak at 6.7 ± 1.6 and 18.7 ± 1.86 per core sample about a year later at the end of the sampling period (53wks PC) respectively (Fig. 1a, b). The numbers of 1st and 2nd instar larvae of *F. canicularis* had early minor peaks at 2.5 ± 0.43 and 7.1 ± 1.10 per core sample (3wks PC) and later more pronounced peaks occurred at 4.2 ± 1.23 and 7.8 ± 2.90 per core sample respectively (39wks PC) (Fig. 1c, d). *Leptocera* sp. did not appear on the Rosendal Farm. *Proctolaelaps* sp. peaked at 15102.8 ± 9294.39 per core sample towards the end of the census period (41wks PC) (Fig. 1e).

The numbers of *M. domestica* at the University House followed a similar trend to those at the Rosendal Farm. The numbers of 1st and 2nd instar larvae were very high in 1wk PC at 107.6 ± 37.39 and 165.0 ± 33.3 per core sample respectively. The 1st and 2nd instar larvae of *F. canicularis* also peaked at 145 ± 26.69 and 158.8 ± 34.23 per core sample respectively during the same period. The numbers declined thereafter and remained low throughout the census period (Fig. 2a, b, c, d). The 1st and 2nd instar larvae of *Leptocera* sp. started appearing 29wks PC and peaked about a month later at 138.0 ± 22.17 and 46 ± 8.51 per core sample respectively. Their numbers declined thereafter (Fig. 2e, f). *Proctolaelaps* sp. were initially present in low numbers but peaked at 1285.6 ± 569.2 per core sample (5wks PC) (Fig. 2g). Their numbers then declined but remained steady at an average of about 342 per core sample until the census ended.

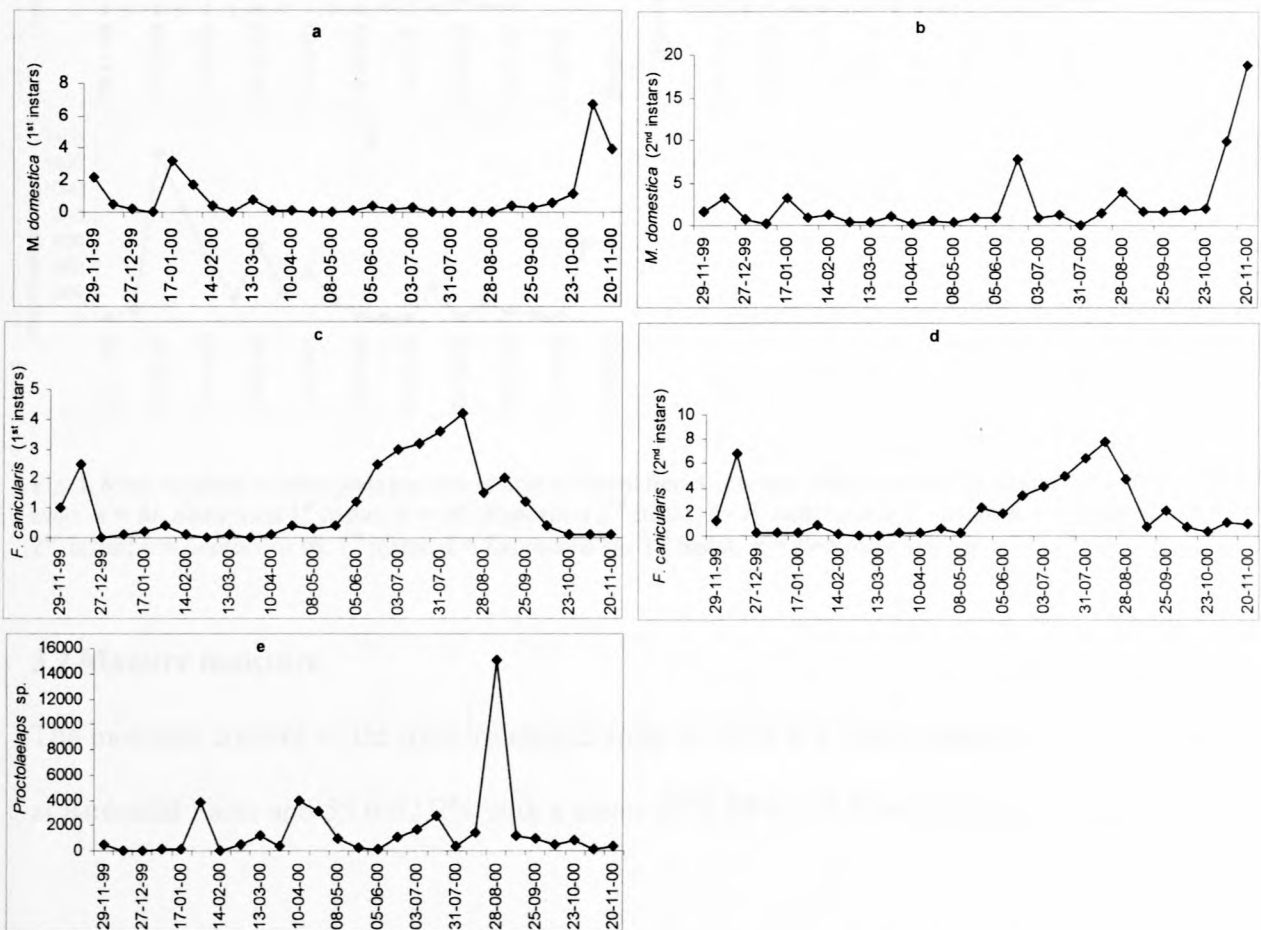


Fig. 1. Mean numbers of arthropods per core sample collected from Rosendal Farm throughout manure accumulation cycle. **a** = *M. domestica* 1st instar; **b** = *M. domestica* 2nd instar; **c** = *F. canicularis* 1st instar; **d** = *F. canicularis* 2nd instar; **e** = *Proctolaelaps* sp.

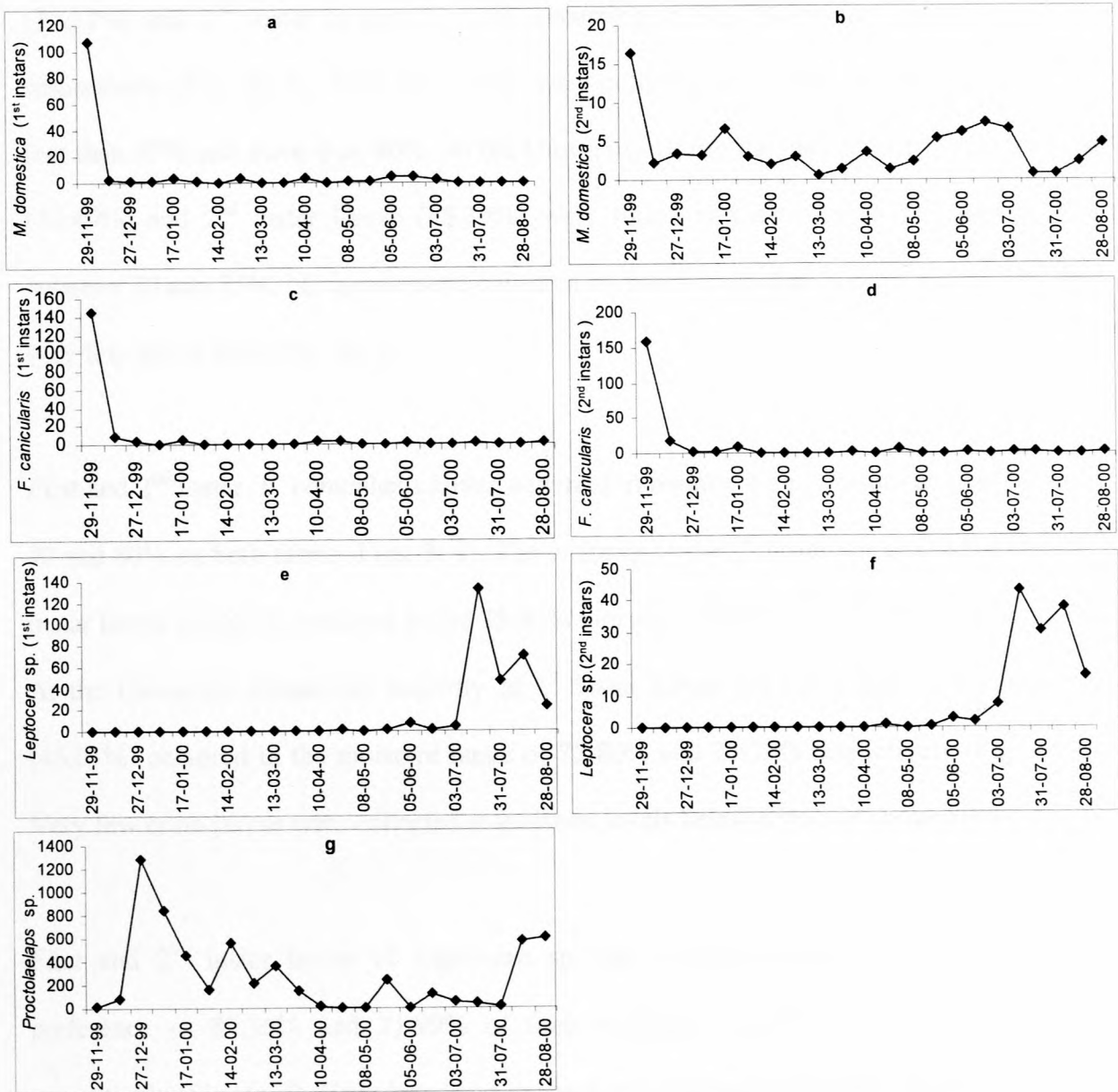


Fig. 2. Mean numbers of arthropods per core sample collected from University House throughout manure accumulation cycle. **a** = *M. domestica* 1st instar; **b** = *M. domestica* 2nd instar; **c** = *F. canicularis* 1st instar; **d** = *F. canicularis* 2nd instar; **e** = *Leptocera* sp. 1st instar; **f** = *Leptocera* sp. 2nd instar; **g** = *Proctolaelaps* sp.

3.2 Manure moisture

The moisture content of the manure ranged from 47.6-78.4% with a mean of 72.19% ± 0.28 at Rosendal Farm and 55.6-92.2% with a mean of 73.88% ± 0.39 at University House.

At Rosendal Farm the 1st and 2nd instar larvae of *M. domestica* were mostly distributed in manure with moisture content between 65 and 80% with the majority of the 1st instar larvae

(39.22%) and 2nd instar larvae (53.75%) occurring at 70-75% manure moisture content respectively (Fig. 3a, b). Very few larvae were collected where the moisture content was less than 65% and more than 80%. At the University House the majority of 1st instar larvae (53.40%) and 2nd instar larvae (45.39%) were found in manure with moisture content between 70 and 75%. No larvae were collected at manure moisture content below 55% and very few above 80% (Fig. 4a, b).

First and 2nd instar *F. canicularis* larvae occurred in manure with moisture content between 70 and 80% on both farms (Figs. 3, 4). The majority of the 1st instar larvae (58.6%) and 2nd instar larvae (54.82%) occurred in the 75-80% moisture range at Rosendal Farm (Fig. 3c, d). At the University House the majority of 1st instar larvae (67.11%) and 2nd instar larvae (46.01%) occurred in the moisture range of 75-80% and 70-75% respectively (Fig. 4c, d). Very few or no larvae were collected at moisture levels below 65% and above 80%.

First and 2nd instar larvae of *Leptocera* sp. had a narrow range of manure moisture preference as 80.36% and 71.99% of their numbers occurred between 75 and 80% respectively (Fig. 4e, f). Very few or no larvae were collected at moisture levels below 70% and above 80%.

The numbers of *Proctolaelaps* sp. at both the Rosendal Farm and University House also had a narrow range of manure moisture preference (70-75%) with 59.56% and 90% occurring within this range (Figs. 3e, 4g). Very few or no mites were collected at moisture levels below 70% and above 80%.

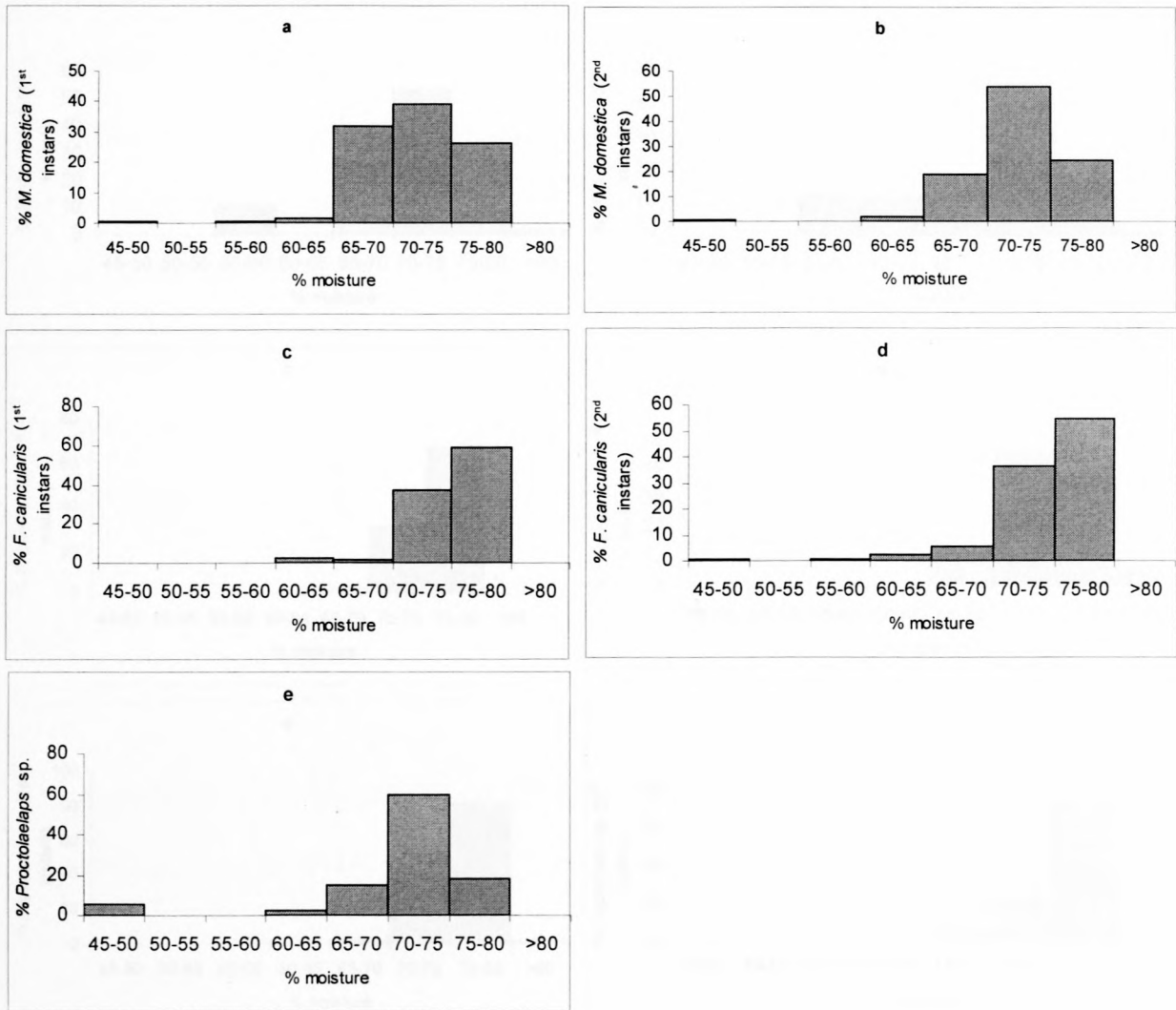


Fig. 3. Frequency distribution of percentage of individual arthropods and manure moisture per core sample collected at Rosendal Farm throughout manure accumulation cycle.

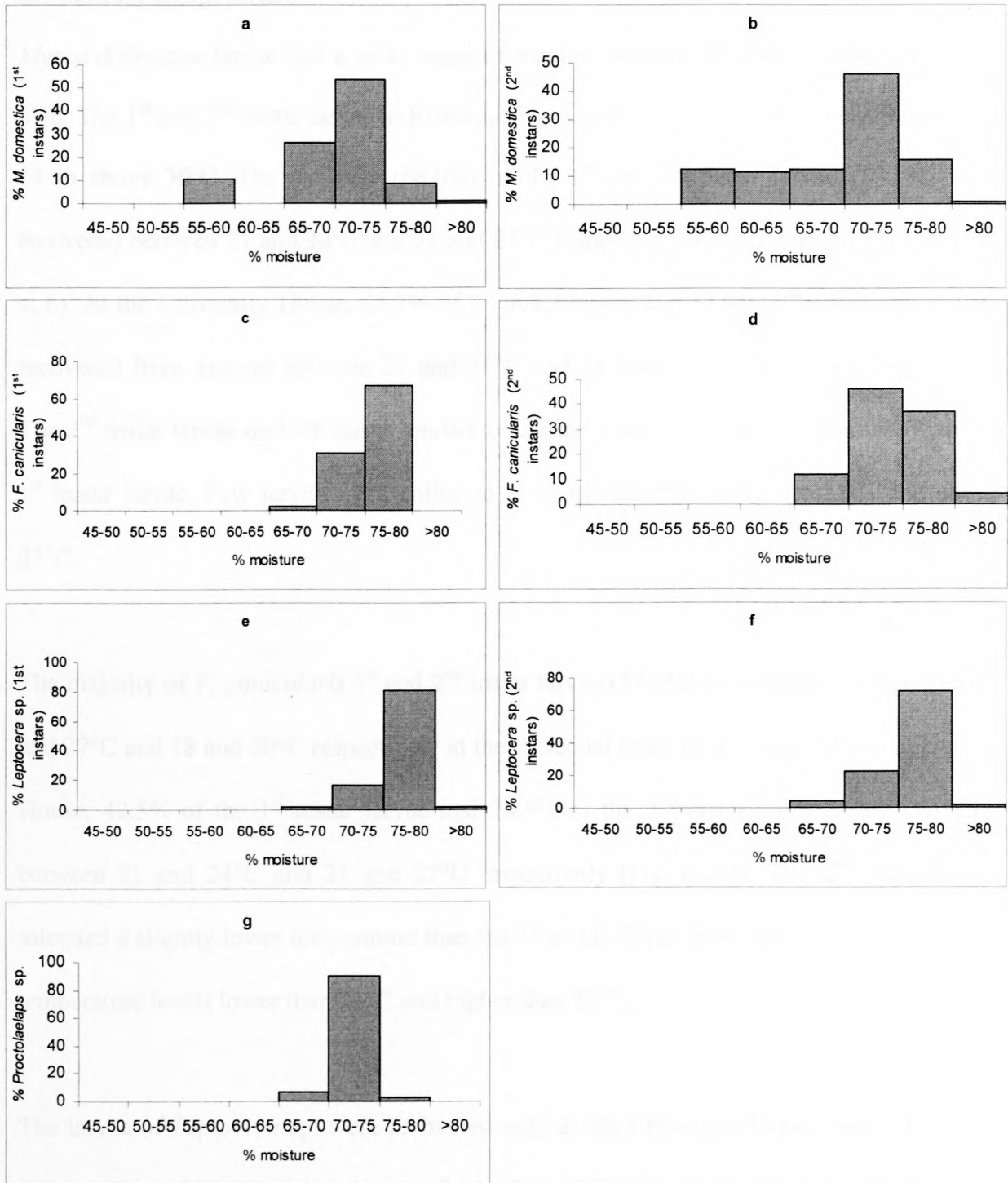


Fig. 4. Frequency distribution of percent arthropods and manure moisture per core sample collected at University House throughout manure accumulation cycle.

3.3 Manure temperature

Musca domestica larvae had a wide range of manure temperature preference at a depth of 6cm. The 1st and 2nd instar larvae at Rosendal Farm and University House were found from 14 to above 30°C. The majority (68.0%) of the 1st and 2nd instar larvae (78.1%) were recovered between 21 and 24°C and 21 and 27°C respectively at the Rosendal Farm (Fig. 5 a, b). At the University House, 66.3% of 1st instar larvae and 57.9% 2nd instar larvae were recovered from manure between 21 and 24°C and 21 and 27°C respectively (Fig. 6a, b). The 2nd instar larvae on both farms tended to tolerate a slightly higher temperature than the 1st instar larvae. Few larvae were collected at temperature levels below 21°C and above 27°C.

The majority of *F. canicularis* 1st and 2nd instar larvae (37.3%) were recovered between 24 and 27°C and 18 and 20°C respectively at the Rosendal Farm (Fig. 5c, d). At the University House, 42.5% of the 1st instar larvae and 76.3% of the 2nd instar larvae were recovered between 21 and 24°C and 21 and 27°C respectively (Fig. 6c, d). The 2nd instar larvae tolerated a slightly lower temperature than the 1st instar larvae. Few larvae were collected at temperature levels lower than 21°C and higher than 27 °C.

The larvae of *Leptocera* sp. were recovered only at the University House, and exhibited a narrow range of temperature tolerance from 15 to 18°C (Fig. 6e, f). The majority of 1st and 2nd instar larvae 88.0% and 82.1% were recovered between 12 and 18°C respectively (Fig. 6 e, f). Few larvae were collected above 18°C.

The majority of *Proctolaelaps* sp. (84.8%) at Rosendal Farm was recovered when the temperature was between 21 and 27°C (Fig. 5e). At the University House 42.5% was

recovered between 24 and 27°C (Fig. 6g). Few mites were recovered at temperature levels below 22°C and above 26°C.

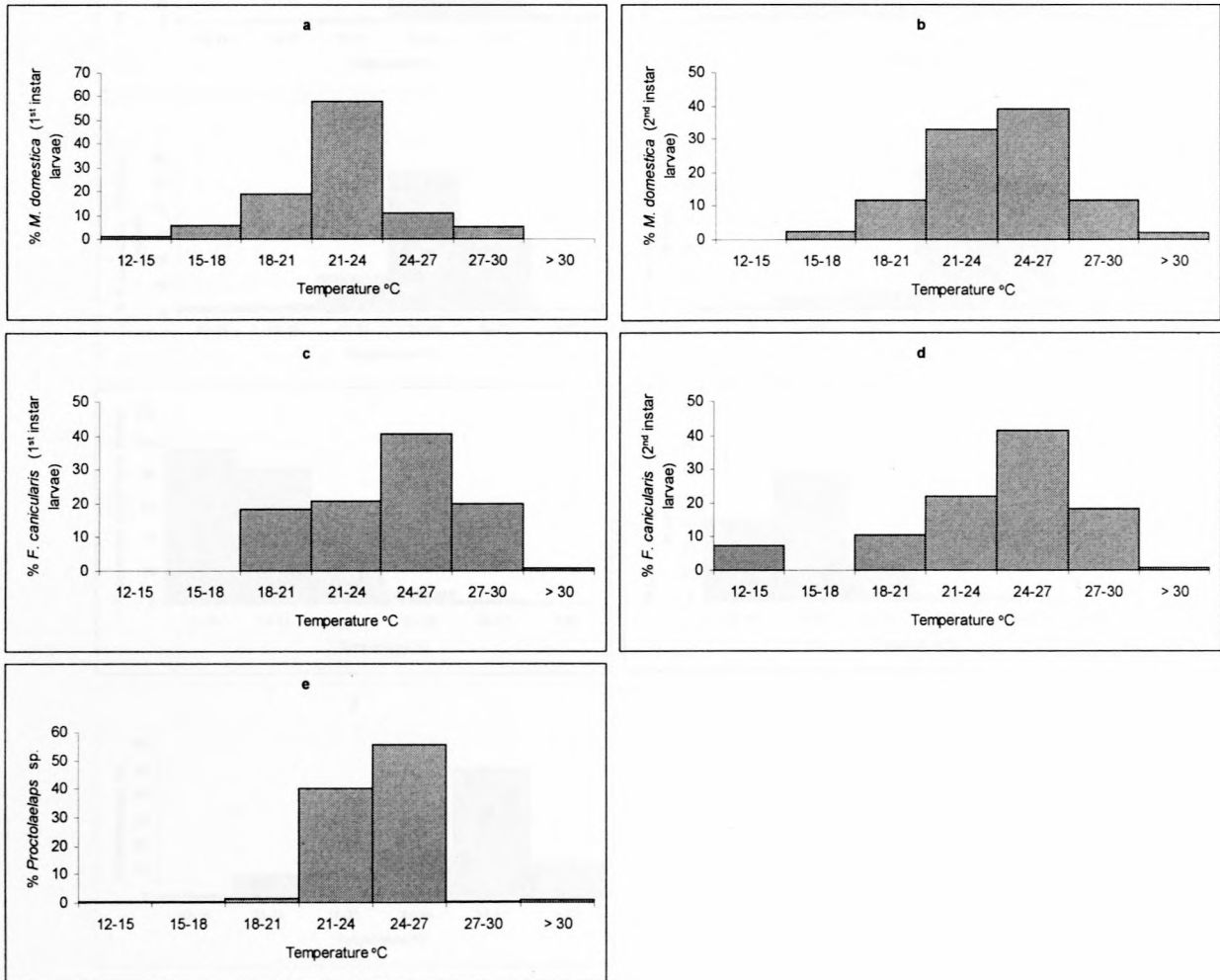


Fig. 5. Frequency distribution of percent arthropods and manure temperature per 0.45-liter core sample collected at Rosendal Farm throughout manure accumulation cycle.

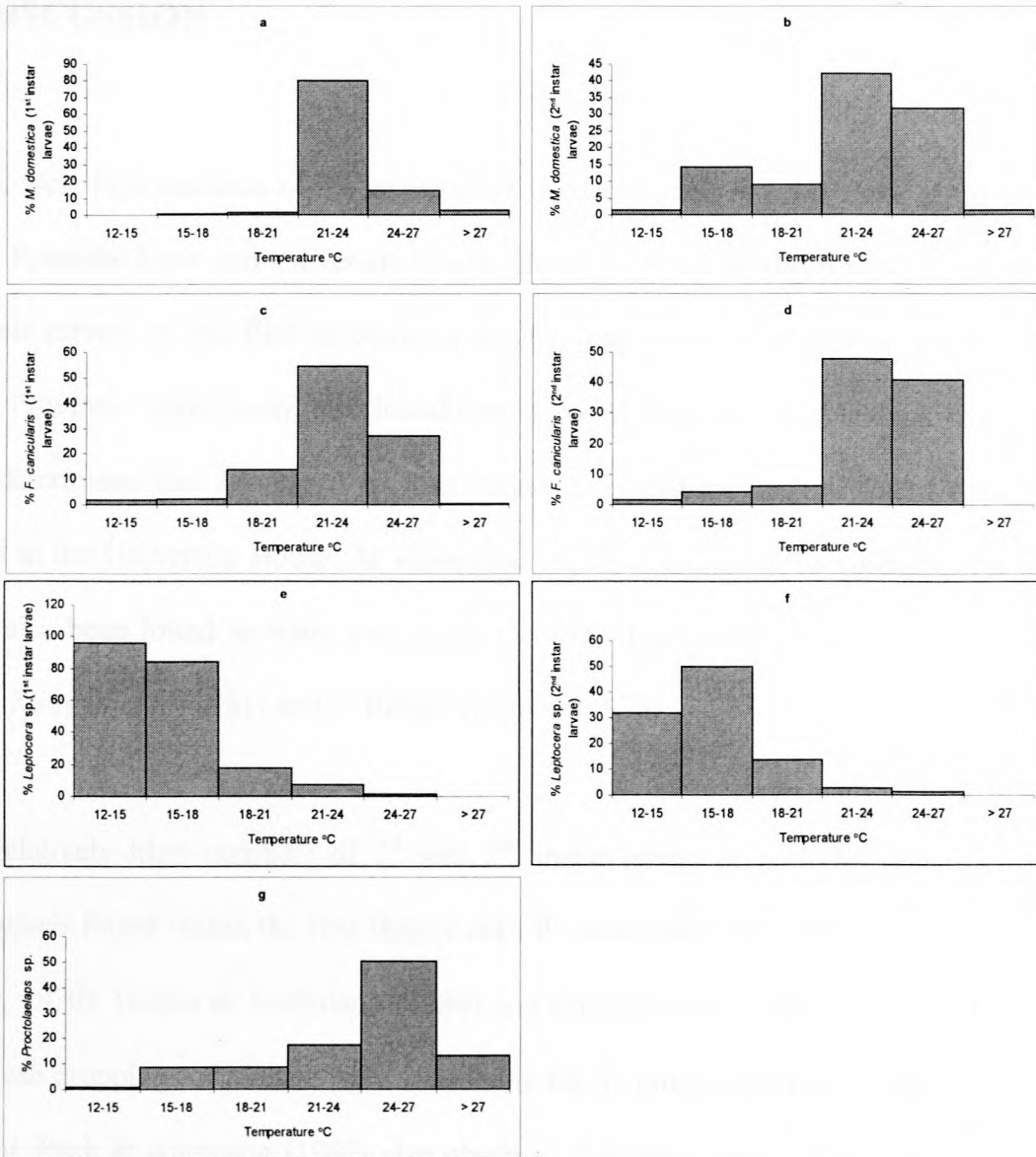


Fig. 6. Frequency distribution of percent arthropods and manure temperature per 0.45-liter core sample collected at University House throughout manure accumulation cycle.

The atmospheric temperature curves showed that there was a general trend of warmer months from October to April and cooler months from May to September (Fig. 7).

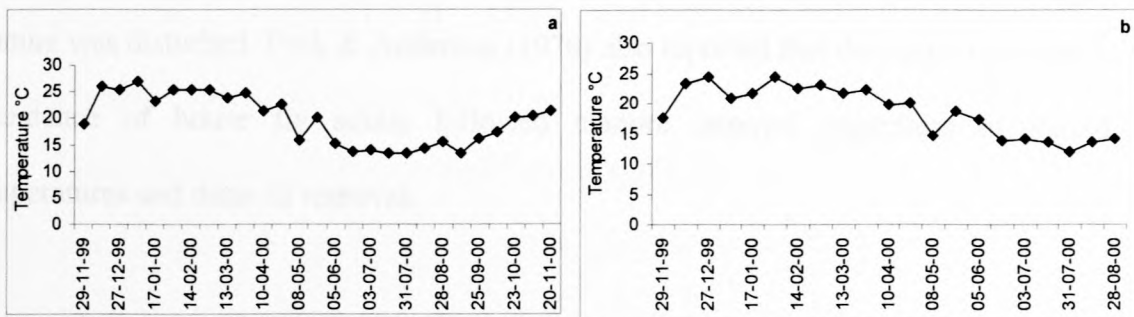


Fig. 7. Mean daily atmospheric temperature at **a:** Rosendal Farm, **b:** University House throughout the manure accumulation cycle.

4. DISCUSSION

There were high numbers of the larvae of *M. domestica* and *F. canicularis* at the two study sites, Rosendal Farm and University House. Hulley (1983) and Matanmi & Giliomee (2002) in their surveys of the flies breeding in poultry manure in the Eastern Cape and Western Cape Province, respectively, also found these two fly species to be abundant. Hulley (1983) also determined that *Leptocera* sp. was abundant in manure in the Eastern Cape, as was found at the University House. *M. domestica* and *F. canicularis*, as cosmopolitan species, have also been found to attain pest status in places like North America (Legner & Olton 1971, Morgan *et al.* 1981) and in Britain (Conway 1973).

The relatively high numbers of 1st and 2nd instar larvae of both *M. domestica* and *F. canicularis* found within the first three weeks PC were also observed by Peck & Anderson (1969, 1970), Geden & Stoffolano (1984) and Mullens *et al.* (1996). Axtell (1970) stated that fresh droppings of manure were favourable for fly production due to their high moisture content. Peck & Anderson (1969) also observed that immatures of filth flies were usually found in wet manure. The relatively high numbers could also in part be due to the disturbance in the manure. The smell emanating from the manure removed tended to be strong and thus attracted more flies from adjacent houses within the farm. Mullens *et al.* (1996) stated that fly resurgence tended to occur regardless of the time of the year the manure was disturbed. Peck & Anderson (1970) also reported that the initial increases in the abundance of house fly adults followed manure removal regardless of varied air temperatures and dates of removal.

The 1st and 2nd instar larvae of *M. domestica* at Rosendal Farm had a maximum peak in summer (53wks PC) whilst *F. canicularis* also attained a maximum peak earlier in winter (39wks PC). Peck & Anderson (1969), Legner & Dietrick (1974), Hulley (1986) and Matanmi & Giliomee (2002) also observed that *M. domestica* occurs in abundance during the warmer months and *F. canicularis* during cooler months. Black & Krafusur (1986) reported winter proportions of parous female house flies to be less than summer populations, suggesting that relatively few winter flies oviposited. Jones *et al.* (1999) also mentioned that house fly populations plummeted in winter and larval growth decreased drastically as temperatures near 0°C. In this study, *Leptocera* sp. was also found to be abundant in cooler months. *Musca domestica* and *F. canicularis* lacked peaks at the University House due to an excessive amount of water in the manure in some parts (> 80% moisture content) (see Fig. 4). This was in conformity with Stafford & Bay (1987), who found few *M. domestica* larvae in manure with a moisture level of more than 80%. Fatchurochim *et al.* (1989) also found that at high moisture levels (80-90%) there was no larval survival of either *M. domestica* or *F. canicularis*.

In this study the highest numbers of *M. domestica* larvae were found between 65 to 80% manure moisture levels on both farms. Peck & Anderson (1969) also observed that *M. domestica* larvae preferred manure moisture which was above 70%. Stafford & Bay (1987) found that the optimum manure moisture for *M. domestica* larvae was 70-79%, whilst Fatchurochim *et al.* (1988) found that their development time was similar from 50 to 70% manure moisture level, although adults which emerged from larvae reared at 70% moisture were significantly larger. In this study the majority of the larvae occurred at 70-75% moisture tolerance level, an indication of the preferred moisture range for proper growth. Few or no larvae were collected at moisture levels of < 55% and > 80%. Stafford & Bay

(1987) and Fatchurochim *et al.* (1989) also found few larvae or none at moisture levels of < 40% and > 80% and < 30% and > 80-90%, respectively. Barnard & Harms (1992) determined that the wettest manure yielded the lowest proportion of pupae that survived to emergence.

The manure moisture tolerance range of 70 to 80% observed in this study for *F. canicularis* was higher than the 50 to 70% reported by Peck & Anderson (1969) and 40 to 70% reported by Fatchurochim *et al.* (1989). However, the latter also found that the size of *F. canicularis* was greatest among larvae reared in manure with 70% moisture. In this study, very few or no *F. canicularis* larvae were located at a moisture level of < 65%. This differed considerably from < 30% reported by Fatchurochim *et al.* (1989). However, both our study and Fatchurochim *et al.* (1989) found that moisture levels of > 80% were not conducive for larval survival.

Leptocera sp. was very discriminating of moisture tolerance with more than 70% of the larvae occurring in the 75 to 80% range. *Leptocera* sp. started appearing after 30wks PC and numbers of both 1st and 2nd instar larvae peaked at 36wks PC. Their presence was probably due to the high manure moisture level which was experienced at the University Farm. Conway (1973) ascribed the presence of *Leptocera* sp. to flooding or excessive water retention in poultry droppings.

Proctolaelaps sp. in this study had a moisture level tolerance of 70-75%. Similar observations were made by Geden & Stoffolano (1988) who also found most of them at 60-70% moisture.

The amount of moisture in confined animal manure is obviously a critical factor in determining the abundance of filth flies. Since little fly development can be expected in manure having less than 40% or greater than 80% moisture, a manure management program could be expected to be most successful in reducing fly numbers if one or the other of these levels is maintained.

The studies showed that *M. domestica* larvae had a wide range of temperature tolerance, a phenomenon also observed by Stafford & Bay (1987) who found their tolerance to be from 15°C to 35°C. Stafford & Bay (1987) recovered the majority of larvae at 27 to 28°C which was slightly higher than the 21 to 27°C of this study. The 2nd instar larvae of *M. domestica* preferred slightly higher temperatures than the 1st instar larvae. This was in contrast with Thomsen & Thomsen (1937), who in their study of the thermotropic activity of house fly larvae in response to temperature gradients, observed that young larvae preferred higher temperatures (between 30-37°C) but migrated to regions of successively lower temperatures as they matured. In this study, it appeared that the 2nd instar larvae sought out a much higher temperature as they matured. *Leptocera* sp. 1st and 2nd instar larvae preferred the same temperature range and showed intolerance to temperatures above 20°C.

REFERENCES

- ANDERSON, J. R. & POORBAUGH, J. H. 1964. Observation on the ethology and ecology of various Diptera associated with Northern California poultry ranches. *Journal of Medical Entomology*. **1**: 131-147.
- ARMITAGE, D. M. 1985. Environment of deep-pit poultry houses: survey of air and manure temperatures in British houses. *British Poultry Science* **26**: 275-278.

- AXTELL, R. C. 1968. Integrated house fly control: Populations of fly larvae and predaceous mites, *Macrocheles muscaedomesticae*, in poultry after larvicide treatment. *Journal of Economic Entomology* **61**: 245-249.
- AXTELL, R. C. 1970. Integrated fly-control program for caged-poultry houses. *Journal of Economic Entomology* **63**: 400-405.
- AXTELL, R. C. 1986. Fly management in poultry production: cultural, biological and chemical. *Poultry Science* **65**: 657-667.
- AXTELL, R. C & ARENDS J. J. 1990. Ecology and management of arthropod pests of poultry. *Annual Review of Entomology* **35**: 101-126.
- AXTELL, R. C. & EDWARDS T. D. 1983. Efficacy and nontarget effects of Larvadex® as a feed additive for controlling house flies in caged-layer poultry manure. *Poultry Science* **62**: 2371-2377.
- BARNARD, D. R. & HARMS, R. H. 1992. Growth and survival of house flies (Diptera: Muscidae) in response to selected physical properties of poultry manure. *Journal of Economic Entomology* **85**: 1213-1217.
- BLACK, W. C. & KRAFSUR, E. S. 1986. Population biology and genetics of winter house fly (Diptera: Muscidae) populations. *Annals of the Entomological Society of America* **79**: 636-644.
- COETZEE, R. 1991. *Energy and matter in the lithosphere*. Department of Geography, Vista University, Pretoria.
- CONWAY, J., A. 1973. The micro-fauna of California-system poultry houses in Britain. *British Poultry Science* **14**: 213-216.
- FATCHUROCHIM, S., GEDEN, C. J. & AXTELL, R. C. 1989. Filth fly (Diptera) oviposition and larval development in poultry manure of various moisture levels. *Journal of Entomological Science* **24**: 224-231.

- GEDEN, C. J., STINNER, R. E. & AXTELL, R. C. 1988. Predation by predators of the house fly in poultry manure: effects of predator density, feeding history, interspecific interference, and field conditions. *Entomological Society of America* **17**: 320-329.
- GEDEN, C. J. & STOFFOLANO, J. G. 1988. Dispersion patterns of arthropods associated with poultry manure in enclosed house in Massachusetts: spatial distribution and effects of manure moisture and accumulation time. *Journal of Entomological Science* **24**: 136-148.
- HOWARD, J. & WALL, R. 1996. Control of the house fly, *Musca domestica*, in poultry units: current techniques and future prospects. *Agricultural Zoology Review* **7**: 247-265.
- HULLEY, P. E. 1983. A survey of the flies breeding in poultry manure, and their potential natural enemies. *Journal of the Entomological Society of Southern Africa* **46**: 38-47.
- HULLEY, P. E. 1986. Factors affecting numbers of *Musca domestica* Linnaeus (Diptera: Muscidae) and some other flies breeding in poultry manure. *Journal of the Entomological Society of Southern Africa* **49**: 19-27.
- HULLEY, P. E. & PFLEIDERER, M. 1988. The Coleoptera in poultry manure - potential predators of the house fly, *Musca domestica* Linnaeus (Diptera: Muscidae). *Journal of the Entomological Society of Southern Africa* **51**: 18-29.
- JONES, C. J., ISARO, S. A. & CORTINAS, M. R. 1999. Dispersal of synanthropic Diptera: Lessons from the past and technology for the future. *Annals of the Entomological Society of America* **92**: 829-839.
- KETTLE, D.S. 1993. *Medical and veterinary Entomology*. CAB. International, Wallingford, Oxon.
- LEGNER, E. F. & OLTON, G. S. 1971. Distribution and relative abundance of dipterous pupae and their parasitoids in accumulations of domestic animal manure in the southwestern United States. *Hilgardia* **40**: 505-535.

- LEGNER, E. F. & DIETRICK, E. I. 1974. Effectiveness of supervised control practices in lowering population densities of synanthropic flies on poultry ranches. *Entomophaga* **19**: 467-478.
- MATANMI, B.A. & GILIOME, J. H. 2002. Arthropods associated with poultry manure in the Western Cape Province, South Africa. *African Entomology* **10**: 365-370.
- MORGAN, P. B. WIEDHASS, D. E. & PATTERSON, R. S. 1981. Host-parasite relationship: programmed releases of *Spalangia endius* Walker and *Muscidifurax raptor* Girault and Sanders against estimated population of *Musca domestica*. *Journal of Medical Entomology* **18**: 158-166.
- MULLENS, B. A. HINKLE, N. C. & SZIJJ, C. E. 1996. Impact of alternating manure removal schedules on pest flies (Diptera: Muscidae) and associated predators (Coleoptera: Histeridae, Staphylinidae; Acarina: Macrochelidae) in caged layer poultry manure in Southern California. *Journal of Economic Entomology* **89**: 1406-1417.
- PECK, J. H. & ANDERSON, J. R. 1969. Arthropod predators of immature Diptera developing in poultry droppings in Northern California. *Journal of Medical Entomology* **6**: 163-167.
- PECK, J. H. & ANDERSON, J. R. 1970. Influence of poultry-manure removal schedules on various Diptera larvae and selected arthropods predators. *Journal of Economic Entomology* **63**: 82-90.
- PFEIFFER, D. G. & AXTELL, R. C. 1980. Coleoptera of poultry manure in caged-layer houses in North Carolina. *Environmental Entomology* **9**: 21-28.
- RUTZ, D. A. & PATTERSON, R. S. 1990. *Biocontrol of Arthropods Affecting Livestock and Poultry*. Westview Press, Boulder, San Francisco.

- SCHROECKENSTEIN, D. C., MEIER-DAVIS, S., GRAZIANO, F. M., FOLOMO, A. & BUSH, R. K. 1988. Occupational sensitivity to *Aphitobius diaperinus* (Panzer) (lesser mealworm). *Journal of Allergy and clinical Immunology* **82**: 1081-1088.
- STAFFORD, K. C. & BAY, D. E. 1987. Dispersion pattern and association of house fly, *Musca domestica* (Diptera: Muscidae), larvae and both sexes of *Macrocheles muscaedomesticae* (Acari: Macrochelidae) in response to poultry manure moisture, temperature and accumulation. *Environmental Entomology* **16**: 159-164.
- TANADA, Y., HOLDAWAY, F. G. & QUISENBERRY, J. H. 1950. DDT to control flies breeding in poultry manure. *Journal of Economic Entomology* **43**: 30-36.
- THOMSEN, E. & THOMSEN, M. 1937. Über das thermopräferendum der larven einiger fliegenarten. *Zeitschrift für Vergleichende Physiologie* **24**: 343-380.
- TOYAMA, G. M. & IKEDA, J. K. 1976. An evaluation of fly breeding and fly parasites at animal farms on leeward and central Oahu. *Proceedings, Hawaiian Entomological Society* **22**: 353-368.
- WILHOIT, L. R., STINNER, R. E. & AXTELL, R. E. 1991. Computer simulation model of house fly management in confined-animal production systems. *North Carolina Agricultural Research Service, Technical Bulletin* **296**:1-81.
- ZCHORI-FEIN, E., GEDEN, C. J., & RUTZ, D, A. 1992. Microsporidiosis of *Muscidifurax raptor* (Hymenoptera: Pteromalidae) and other pteromalid parasitoids of muscoid flies. *Journal of Invertebrate Pathology* **60**: 292-298.

CHAPTER 2

THE ENVIRONMENTAL FACTORS AFFECTING POPULATIONS OF MANURE INHABITING COLEOPTERANS AND OTHER ARTHROPOD PREDATORS OF THE HOUSE FLY

ABSTRACT

The predominant predatory arthropods breeding in manure in the Western Cape Province, South Africa were *Carcinops pumilio* (Erichson) (Coleoptera: Histeridae), *Macrocheles muscaedomesticae* (Scopoli) (Acarina: Macrochelidae), and *Philonthus sordidus* (Gravenhorst) (Coleoptera: Staphylinidae). This was similar to other localities in the world. The peaks of *C. pumilio* adults occurred at 6-8 weeks intervals, out of phase with larval peaks. The majority of *C. pumilio*, *P. sordidus* and *M. muscaedomesticae* showed preference for a narrow range of manure moisture (70-75%). Very few or no predators occurred at moisture levels above 80%. The three species showed a wide range of temperature tolerance, (12-31°C). *Carcinops pumilio* preferred aged manure, and *M. muscaedomesticae* and *P. sordidus* fresh manure. Thus they could be used to complement one another in IPM augmentation strategies.

Key words: Predators, manure temperature, manure moisture

1. INTRODUCTION

In modern poultry production large numbers of birds are accommodated at high density, while a minimum amount of labour is used. The accumulation of poultry manure which results from this provides excellent development sites for the larvae of the house fly, *Musca domestica* L., the lesser house fly, *Fannia canicularis* (L.), and other dipterans. Many egg producers in South Africa now allow the manure to accumulate beneath the

cages of hens for 3-6 months in the narrow, open-sided units and for 2-3 years in the high-rise two storied units before cleanout. The accumulation of manure over long periods results in it being colonized later by an array of predaceous and parasitic arthropods (Bills 1973, Mullens *et al.* 1996), thus forming an ecological food web capable of suppressing manure dwelling flies (Bills 1973).

A number of studies has been conducted on the population of predaceous arthropods in manure. In surveys conducted in the United States, the key fly predators found in poultry manure were the histerid beetle, *Carcinops pumilio* (Erichson), and the mite, *Macrocheles muscaedomesticae* (Scopoli) (Legner & Olton 1971, Legner *et al.* 1975, Axtell 1986, Axtell & Arends 1990, Wills *et al.* 1990). Hulley & Pfleiderer (1988) found that *C. troglodytes* (Payle) was plentiful in poultry manure in South Africa. The prominent parasitoids that attack fly pupae elsewhere, the pteromalid wasps *Muscidifurax* and *Spalangia* species, were also encountered by Hulley (1983) and Matanmi & Giliomee (2002) in South Africa.

Few studies have been conducted on the environmental factors affecting predaceous arthropods in manure. Armitage (1985a, b) examined air and manure temperatures, and manure moisture changes with air movement in British deep-pit houses. He related his observations to the potential development and activity of flies and predaceous beetles. Bills (1973) and Hulley (1986) also related temperature and relative humidity (RH) to the activity of the beneficial *C. pumilio*.

Chicken droppings accumulated at the rate of 0,1kg wet manure/bird/day (Hart 1963), equaling a depth of about 1cm per day (Mullens *et al.* 1996), and created conditions for fly populations to increase (Peck & Anderson 1970). Eventually, accumulated manure must be removed. Due to the importance of natural enemies in controlling fly numbers, it was essential that any deleterious effects on them resulting from manure cleanout

should be avoided or reduced. Before that, conditions should be created if possible that are favourable to the natural enemies. However, little is known about the effect of environmental factors on them. Legner & Olton (1970) stated that in the Afrotropical region, little was known of the predaceous beetles breeding in poultry manure. Thus the aims of the study were to determine: (1) if the predaceous beetle fauna of poultry manure in the Western Cape, South Africa was similar in general to those described elsewhere, (2) the seasonal fluctuations in numbers of predaceous beetles and other arthropods and (3) the effect of the environmental factors such as temperature and manure moisture on their numbers.

2. MATERIALS AND METHODS

2.1 Study site and house design

As in Chapter 1

2.2 Sampling

Sampling method as given in Chapter 1

In addition further adjacent samples were taken at each sampling point from which beetles were extracted using the floatation method of Hulley & Pfeleiderer (1988). The manure was first moistened and stirred to form slurry. More water was later added to form a suspension. The floating beetles as well as those that were stimulated to climb the sides of container were collected individually with a camel's hair brush. They were then placed on a paper towel, in a 500ml beaker covered with a sieve to avoid the escape of any beetles.

2.3 Analysis

The average number of the predominant species was plotted against time. The frequency distribution between arthropod numbers per core sample, and manure moisture and temperature was also plotted.

3. RESULTS

3.1 Numbers of beetles and mites

The bi-weekly average numbers of beetles, both adults and larvae, and adult mites collected per core sample of manure at the University House and Rosendal Farm are shown in Figs.1 & 2 respectively.

3.1.1 University House

At 5 weeks PC *C. pumilio* adults were present in low numbers at 1.70 ± 0.53 per core sample and increased to a maximum of 18.80 ± 0.03 per core sample (13wks PC) (Fig.1a). This was followed by a minor peak at 9.0 ± 3.65 per core sample (19wks PC), and numbers then declined sharply (Fig 1a). The numbers of *C. pumilio* adults were higher than those of the 1st and 2nd instar larvae throughout the census (Fig.1a, b, c). *C. pumilio* 1st instar larvae started appearing in the sample at 3wks PC and reached a peak of 3.9 ± 2.44 per core sample at 19wks PC. Their numbers declined to insignificant levels thereafter (Fig. 1b). *C. pumilio* 2nd instar larvae were already present 3wks PC in low numbers (3.41 ± 0.13 , per core sample) and increased gradually to reach peak numbers of 4.10 ± 1.29 at 5wks PC and 4.10 ± 0.77 per core sample at 8wks PC (Fig.1c). The numbers declined thereafter and followed a similar trend as the 1st instar larvae after 19wks PC (Fig. 1c).

The numbers of *Philonthus sordidus* (adults & larvae) were low at about 0.5 per core sample throughout the census, but rose to 1.90 ± 0.41 (9wks PC) and 1.1 ± 0.53 per core sample (19wks PC) (Fig.1d).

The counts of *M. muscaedomesticae* were variable. Numbers were generally high (14 to 183) during the first 21wks PC and peaked at 183.50 ± 88.44 per core sample (19wks PC) (Fig.1e). Numbers then declined sharply and remained low for a period of 10 weeks after which they started rising again gradually.

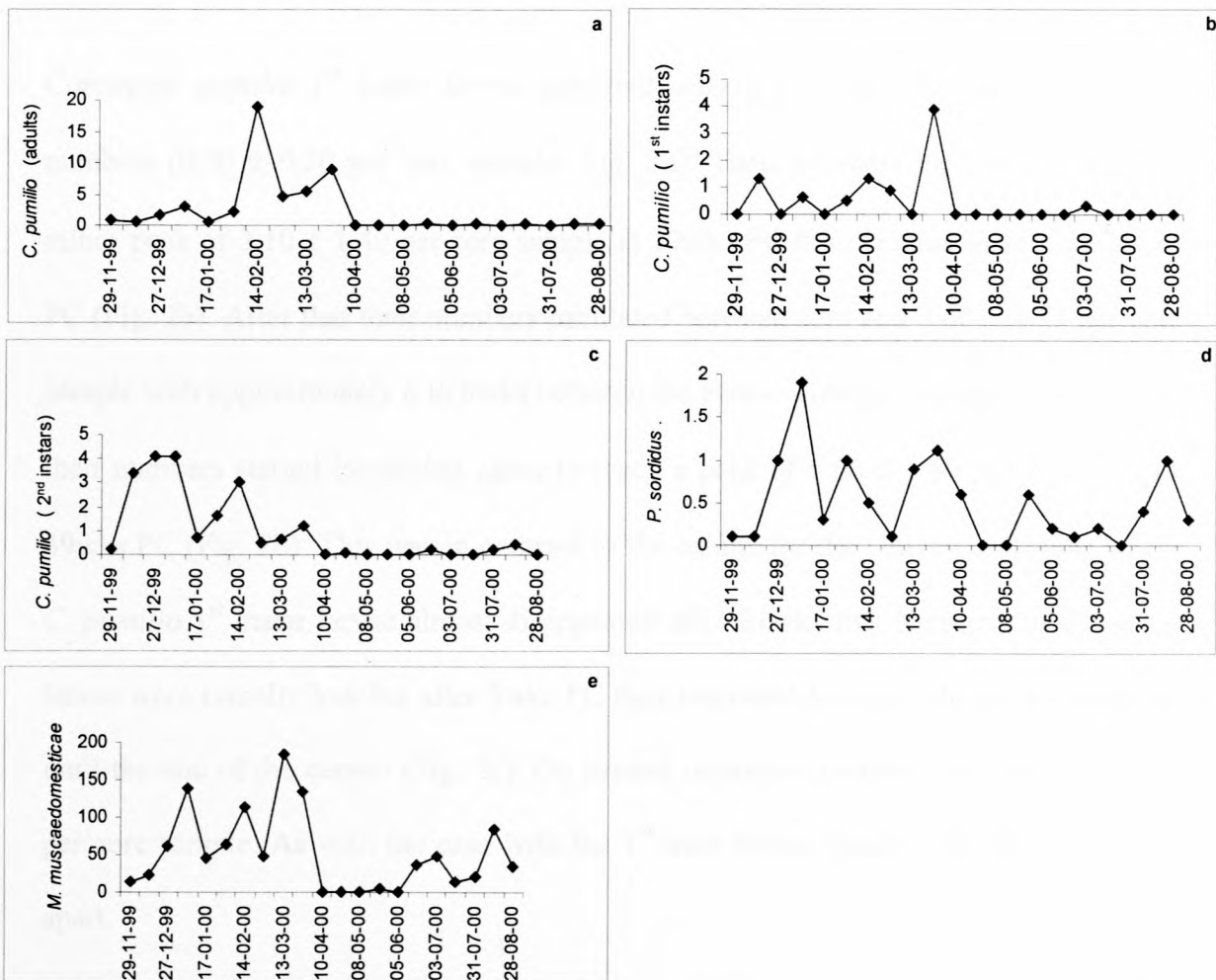


FIG. 1. Mean numbers of arthropod predators per 0.45 liter core sample collected from University House throughout the manure accumulating cycle. **a** = *C. pumilio* adult; **b** = *C. pumilio* 1st instar; **c** = *C. pumilio* 2nd instar; **d** = *P. sordidus*; **e** = *M. muscaedomesticae*.

3.1.2 Rosendal Farm

The numbers of adult *C. pumilio* were low at about 1.6 per core sample during the first 2-9wks PC, but rose to a peak of 18.6 ± 10.2 per core sample at 11wks PC (Fig. 2a). The numbers then declined to 0.60 ± 0.31 per core sample (13wks PC). The numbers started increasing again until the end of the census and, unlike the situation at the University House, where their numbers declined after 21wks PC, they attained a maximum of 28.10 ± 14.61 per core sample (35wks PC), followed by another peak of 24.60 ± 6.27 per core sample (49wks PC) (Fig. 2a).

Carcinops pumilio 1st instar larvae appeared only after 7wks PC but in very low numbers (0.20 ± 0.20 per core sample; Fig. 2b). Their numbers increased to reach a minor peak of 3.10 ± 1.40 per core sample at 19wks PC but declined to zero at 25wks PC (Fig. 2b). After that their numbers oscillated between zero and 3.60 ± 1.71 per core sample with approximately 6 to 8wks between the peaks. Towards the end of the census their numbers started increasing again to reach a peak of 6.60 ± 1.60 per core sample 49wks PC (Fig. 2b). This was in contrast to the results for the University House where *C. pumilio* 1st instar larvae almost disappeared after 21wks PC. Numbers of 2nd instar larvae were initially low but after 3wks PC they increased to over 2.20 per core sample until the end of the census (Fig. 2c). On several occasions numbers reached 6 or more per core sample. As with the case with the 1st instar larvae, peaks were about 8 weeks apart.

The numbers of *M. muscaedomesticae* were low (< 18 per core sample) during the first 21wks PC but abundant (> 208 per core sample) from 23wks PC until the end of the census. This was in contrast to findings for the University House where their numbers were high during the first 21wks PC and low in the subsequent weeks. The numbers peaked only once at 367.80 ± 28.53 per core sample (23wks PC) (Fig. 2d). In addition

to *C. pumilio*, *P. sordidus* and *M. muscaedomesticae*, other species of beetles and arthropods were encountered in low numbers in the poultry manure samples collected. These are listed in Table 1.

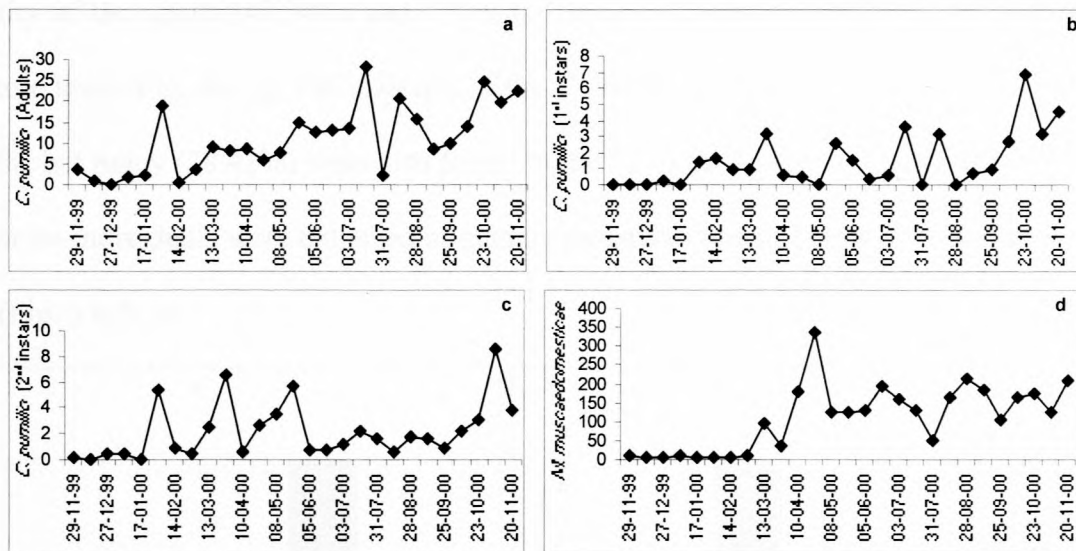


FIG. 2. Mean numbers of arthropod predators per 0.45-liter core sample collected from Rosendal Farm throughout the manure accumulating cycle. **a** = *C. pumilio* adult; **b** = *C. pumilio* 1st instar; **c** = *C. pumilio* 2nd instar; **d** = *M. muscaedomesticae*

Table 1. List of beetles and other arthropods encountered in poultry manure*.

COLEOPTERA

Hydrophilidae

Dactylosternum abdominale (Fabricius)

Staphylinidae

Anotylus caffer (Erichson)

Oxytelus sculptus Gravenhorst

Philonthus rectangular Sharp

Histeridae

Carcinops troglodytes (Paykull)

Dermestidae

Attagenus laetus (Péringuey)

Dermestes maculatus DeGeer

Carabidae

Somotrichus bifasciatus Dejean

Tenebrionidae

Alphitobius diaperinus (Panzer)

Palorus subdepressus (Wollaston)

Tribolium castaneum (Herbst)

Tribolium confusum du Val

Cleridae

Necrobia ruficollis (Fabricius)

Melyridae

Pagurodactylus sp.

Cerynolidae

Euxestus sp.

Silvanidae

Oryzaephilus sp.

Mycetophagidae

Litargus sp.

HEMIPTERA

Anthocoridae

Lyctocoris campestris Fabricius

HYMENOPTERA

Pteromalidae

Muscidifurax raptor Girault & Sanders

Nasonia vitripennis Walker

Pachycrepoideus vindemiae (Rodani)

Spalangia cameroni Perkins

Spalangia endius Walker

Braconidae

Apanteles sp.

*Identification by specialists at the National Collection of Insects, LRN Plant Protection Research Institute, Pretoria.

3.2 Manure moisture

At the University House adult *C. pumilio* as well as the 1st and 2nd instar larvae were found where the moisture content of the manure was between 55 and 80% (Fig. 3). The majority of the adults (40.34%) and 2nd instar larvae (32.75%) occurred at 70 to 75% moisture level (Fig. 3a, c). The majority of the adults (40.34%) and 2nd instar larvae (32.75%) occurred at 70 to 75% moisture level (Fig. 3a, c). The majority of the 1st instar larvae (39.77%) occurred at 55 to 60%, but many (28.42%) were also found in the 75 to 80% moisture range (Fig. 3b). Few or no individuals were collected at manure moisture content below 55% and above 80% (Fig. 3 a, b, c).

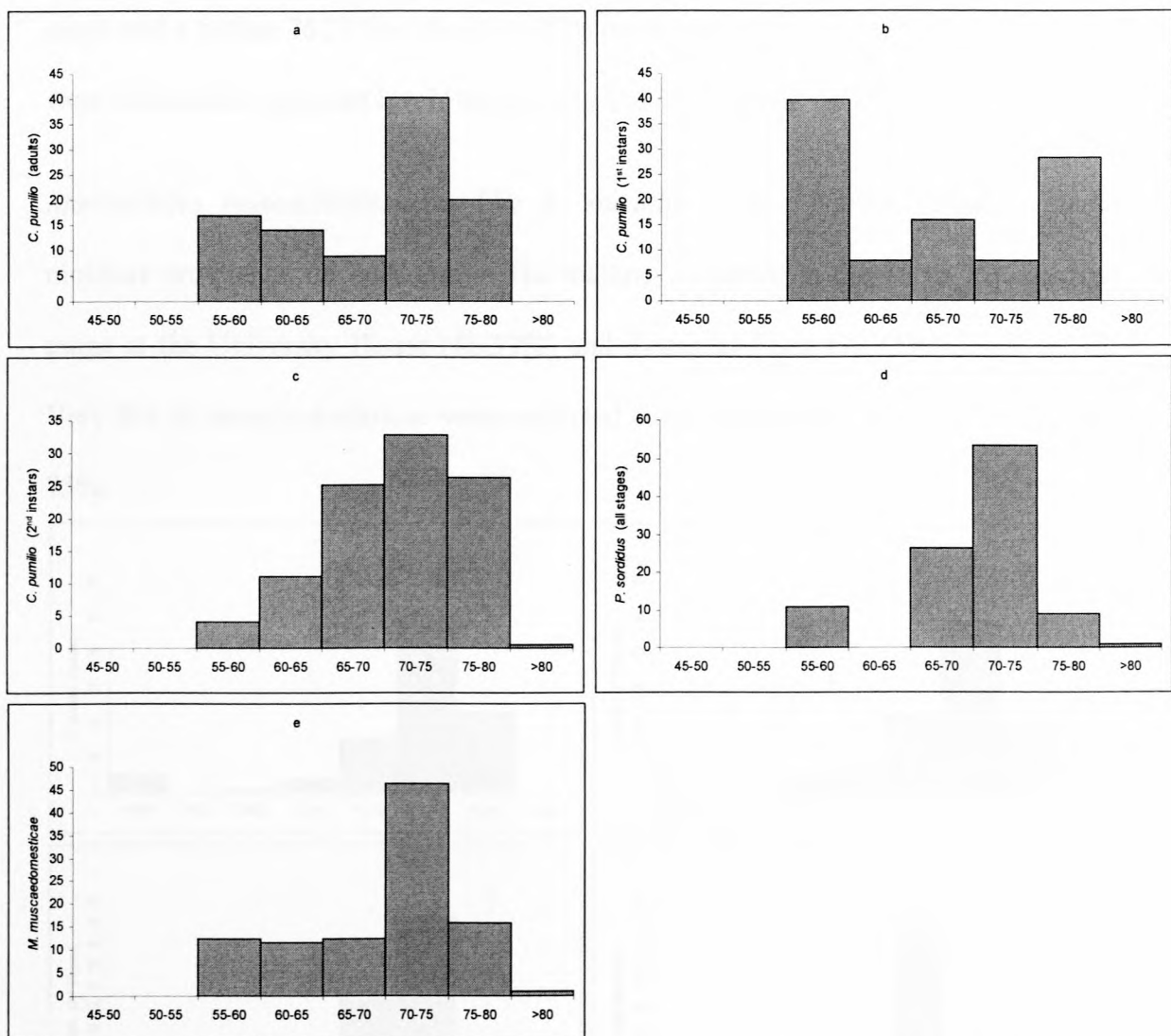


FIG. 3. Frequency distribution of percent arthropod predators per 0.45 liter core sample at different moisture levels collected from University House throughout the manure accumulating cycle. . a = *C. pumilio* adult; b = *C. pumilio* 1st instar; c = *C. pumilio* 2nd instar; d = *P. sordidus*; e = *M. muscaedomesticae*.

At the Rosendal Farm *C. pumilio* adults, 1st and 2nd instar larvae were found in manure between 45 and 80% moisture level (Figs. 4 a, b, c). They preferred manure at the higher moisture ranges (Figs. 4 a, b, c). This was also observed at the University House (Figs. 3a, b, c). The majority of the adults (51.38%), 1st instar (49.24%) and 2nd instar larvae (46.45%) occurred in the 70 to 75% moisture level (Figs. 4a, b, c). Very few or no individuals were collected at moisture levels of less than 55% and greater than 80%.

Philonthus sordidus, which was not encountered at the Rosendal Farm, had narrow range of manure moisture preference. The majority (53.4%) occurred in the 70 to 75% range and a further 26.21% in the 65 to 70% moisture range. Very few or no *P. sordidus* were collected at moisture levels below 65% and above 80%.

Macrocheles muscaedomesticae, like *P. sordidus*, had a narrow range of manure moisture preference on both farms. The majority occurred in the 70 to 75% moisture range at the University House (46.39%) and Rosendal Farm (72.15%) (Figs. 3c, 4d). Very few *M. muscaedomesticae* were collected at moisture levels below 70% and above 75%.

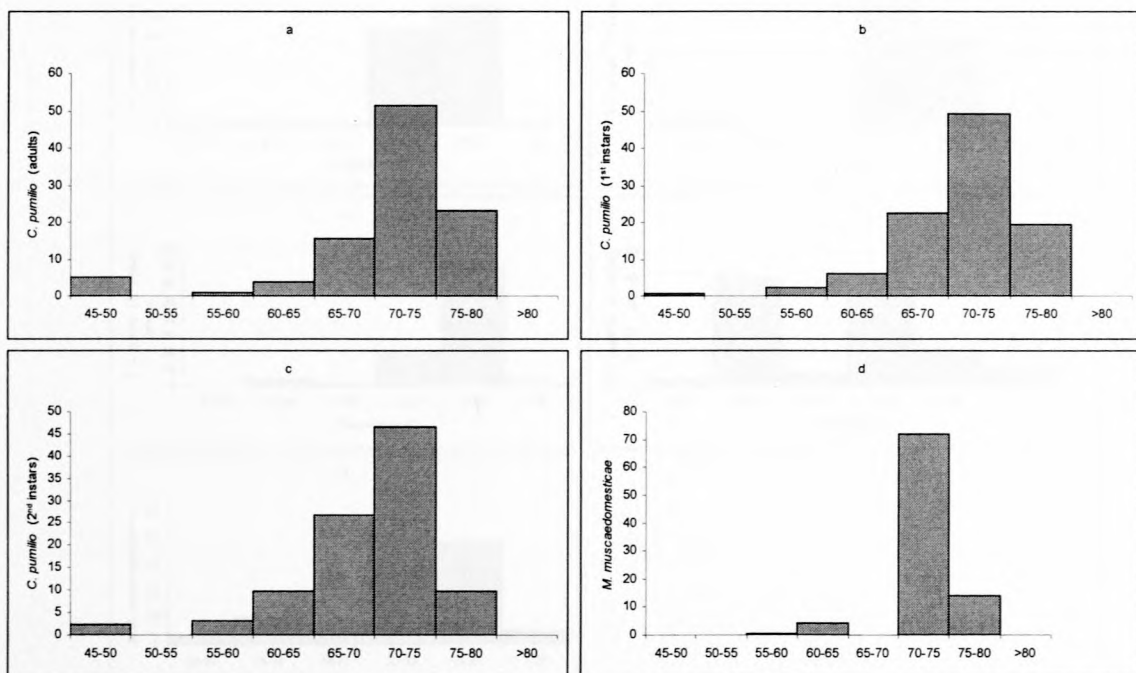


FIG. 4. Frequency distribution of percent arthropod predators and manure moisture per 0.45 liter core sample at different moisture levels collected from Rosendal Farm throughout the manure accumulating cycle. **a** = *C. pumilio* adult; **b** = *C. pumilio* 1st instar; **c** = *C. pumilio* 2nd instar; **d** = *M. muscaedomesticae*

3.3 Temperature

All stages of *C. pumilio* were found at a wide range of temperatures, from 12 to 30°C on both farms (Figs. 5, 6). The majority occurred at temperatures between 21 and 27°C at the University House (95.67%) and Rosendal Farm (82.37%). Very few individuals were found at temperatures below 21 and above 27°C at the University House and Rosendal Farm.

Adults of *P. sordidus*, which were only encountered at the University House, were mostly (40%) found in the temperature range of 15 to 18°C, but some individuals were collected at temperatures less than 15°C and greater than 27°C.

The numbers of *M. muscaedomesticae* at the University House and Rosendal Farm were found within a wide range of manure temperatures, ie. from 12 and above 27°C (Figs. 5e, 6d). However, on both farms, few mites were recovered at temperatures below 21°C, or above 27°C (Figs. 5e, 6d).

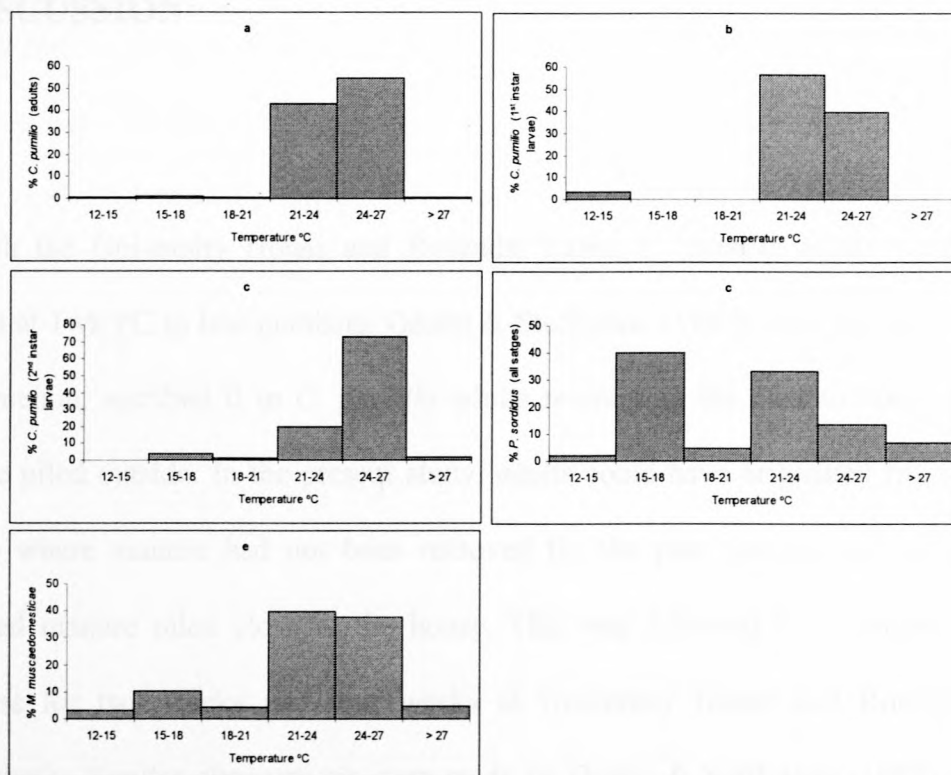


FIG. 5. Frequency distribution of percent arthropod predators in relation to manure temperature per 0.45 liter core sample collected from University House throughout the manure accumulating cycle. **a** = *C. pumilio* adult; **b** = *C. pumilio* 1st instar; **c** = *C. pumilio* 2nd instar; **d** = *P. sordidus*; **e** = *M. muscaedomesticae*.

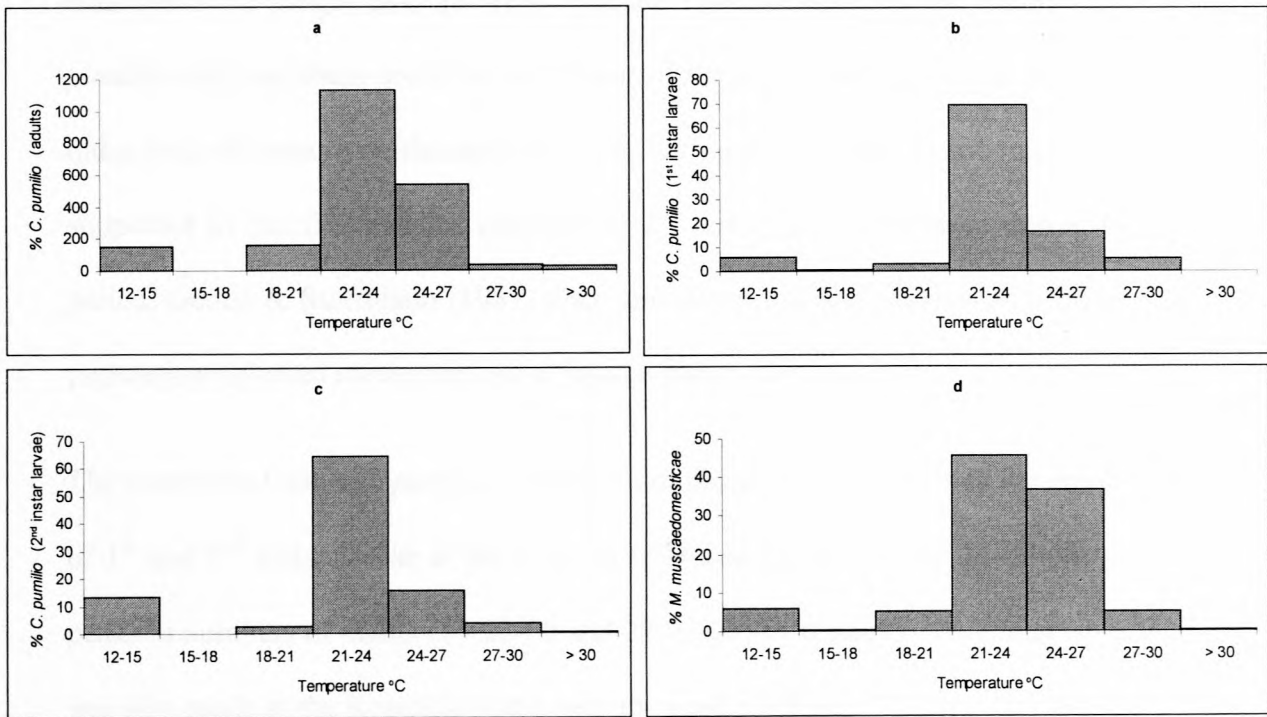


FIG. 6. Frequency distribution of percent arthropod predators in relation manure temperature per 0.45 liter core sample collected from Rosendal Farm throughout the manure accumulating cycle. **a** = *C. pumilio* adult; **b** = *C. pumilio* 1st instar; **c** = *C. pumilio* 2nd instar; **d** = *M. muscaedomesticae*

4. DISCUSSION

At both the University House and Rosendal Farm, *C. pumilio* adults were already present at 1wk PC in low numbers. Geden & Stoffolano (1987), who also observed this phenomenon, ascribed it to *C. pumilio* adults re-entering the cleared house from old manure piled outside. In the present study, adults could have originated from adjacent houses where manure had not been removed for the past year as well as from the removed manure piled close to the house. This was followed by a decline in adult numbers for two weeks and four weeks at University House and Rosendal Farm respectively. Similar observations were made by Geden & Stoffolano (1987) who also found that *C. pumilio* adult numbers declined four weeks after the initial peak. Since the

adults can live longer than 34 weeks (Geden 1984, Chapter 5), the sudden drop in *C. pumilio* adult numbers could be as a result of the adults seeking refuge in the isolated older pads of manure deliberately left over during the removal of the manure. This is supported by the fact that the numbers of 2nd instar larvae increased during the same period. Geden & Stoffolano (1987) also considered that this sudden drop in the beetle population reflected movement out of habitat rather than mortality.

The numbers of adult *C. pumilio* peaked out of phase with the peaks of the larvae. Peaks of 1st and 2nd instar larvae at the University House (04-01-00 and 14-02-00) preceded peaks in numbers of adults (14-02-00 and 27-03-00) by 6 weeks. A similar observation was also made at the Rosendal Farm with the peak of 1st and 2nd instar larvae (31-01-00, 27-03-00 and 22-05-00) preceding peaks in adult numbers (27-03-00, 22-05-00 and 17-07-00) by 8 weeks. The peaking period of 6 to 8 weeks was the approximate time it took *C. pumilio* to develop from egg to adult at 25.5°C. Morgan *et al.* (1983) found the developmental period from egg to adult to be about 6.67 weeks at 25.5°C.

The repopulation of *C. pumilio* adults was only observed at 13wks PC at both farms. This confirmed the observations of Peck & Anderson (1970) and Mullens *et al.* (1996) that repopulating of newly accumulating manure by predaceous beetles did not begin until at least 6 weeks post cleaning.

A peculiar observation was that the adults of *C. pumilio* were more abundant than the 1st and 2nd instar larvae throughout the census on both farms, while the 2nd instar larvae were sometimes more numerous than the 1st instar larvae. This might partly due to sampling error as the three stages were progressively smaller and less easily seen. However Smith (1975), Pfeiffer & Axtell (1980) and Geden & Stoffolano (1987) also mentioned that *C. pumilio* adults were more numerous than the larvae during most of the sampling period. With time, as was also observed by Geden & Stoffolano (1987),

the ratio of adults to immatures became more biased towards adults. This could have been as a result of competition for food (Geden & Stoffolano 1987) and oviposition sites (Wilhoit *et al.* 1991), decrease in fecundity due to increase in density (Geden 1984, see Chapter 6) and adult longevity (Chapter 5). When beetle larvae were crowded with adults in the laboratory one adult would attack a larva just behind the head. As the haemolymph oozed out it attracted more adults, which converged on the larva, consuming it within 2 minutes and only leaving behind the heavily sclerotized head. Thus the cannibalistic nature of *C. pumilio* could be a significant factor in limiting their numbers, a view shared by Wilhoit *et al.* (1991).

In this study the number of adults increased with time at the Rosendal Farm. Geden & Stoffolano (1987) also noted that populations of adults were greatest later in the sampling period while Peck & Anderson (1970) observed that *C. pumilio* were most abundant in unremoved manure. This phenomenon was not observed at the University House due to high moisture content in the manure. This might have stimulated the adults to migrate to other near by houses where conditions were more favourable (see Chapter 7).

The numbers of adult *P. sordidus* attained repopulation levels as early as 7wks PC. This was an indication that, unlike *C. pumilio*, *P. sordidus* may have greater preference for the fresh manure with high moisture content. Peck & Anderson (1970) also noted that *P. sordidus* did not become common in newer manure until it had accumulated for at least 8wks.

The numbers of *M. muscaedomesticae* at both the University House and Rosendal Farm were low at 1wk PC. Peck & Anderson (1970) and Mullens *et al.* (1996) also found low numbers of *M. muscaedomesticae* in 1 wk-old manure. The increase in numbers of *M. muscaedomesticae* lagged behind those of the dipterans (see Chapter 1). Predaceous mite

populations increased much more slowly after manure removal than those of the fly populations (Peck & Anderson 1970). In this study *M. muscaedomesticae* became abundant at the University House and Rosendal Farm 7 and 23wks PC respectively. This supports the finding of Peck & Anderson (1969), Geden & Stoffolano (1987) and Mullens *et al.* (1996) that predaceous mites could be depressed for 6 wks or more after total manure clean out.

The population of *M. muscaedomesticae* on both farms achieved a maximum peak, and then declined sharply to lower, more stable densities as the manure aged. Willis & Axtell (1968) and Peck & Anderson (1969) also found that this species had a tendency to decline in density with further accumulation and aging of the manure.

The results of this study and those previously cited indicated that the dominant species of predaceous beetle and mite in poultry manure were similar in most localities. The principal predatory species were *C. pumilio*, *M. muscaedomesticae* and to some lesser extent *P. sordidus*. They formed part of a complex manure ecosystem, in which arthropod numbers were affected by biotic and abiotic factors. The predators such as *C. pumilio* contributed substantially to the natural mortality of the fly populations in poultry houses (Pfeiffer & Axtell 1980). Therefore there is a need for a fly IPM program that would include measures to enhance the predator numbers. One method for accomplishing this, as suggested by Axtell (1968, 1970), is the judicious removal of the accumulated manure. This involves the periodic or alternate removal of parts of the manure during periods of reduced fly activity (see Chapter 4), as a way to prevent the total depletion of the predator population that occurs with total manure removal.

Another strategy, as suggested by Geden & Stoffolano (1988) and Mullens *et al.* (1996), is to leave a pad of old manure at cleanout which will elevate the fresh droppings for faster drying and provide an instant inoculum of manure residents for the new manure.

The old pad will accelerate those physical and chemical changes in fresh droppings that are necessary to promote predator colonization (Geden & Stoffolano 1988, Mullens *et al.* 1996). Alternatively, the manure could be left for 1-2 years and only the portions that overflow onto the walkways removed.

The adults of *C. pumilio* were distributed over a wide range of manure moisture content, 45 to 80%. Peck & Anderson (1969) and Geden & Stoffolano (1988) also observed that *C. pumilio* preferred manure moisture of 50 to 70%.

The preference of *P. sordidus* (all stages) for high moisture levels (65-80%) found in this study was also observed by Peck & Anderson (1969) who found that *P. sordidus* preferred a moisture range from 50 to 70%. The study further showed that *P. sordidus* was discriminating in its moisture preference with more than 50% occurring between 70 to 75% moisture. In Chapter 1 it was shown that the majority of *M. domestica* larvae also occurred in the 70 to 75% moisture range. With such an overlap, this species could be an ideal candidate for introduction into the farms at 1wk PC when other predator numbers are low, as fresh manure is not very attractive to them.

Machrocheles muscaedomesticae also had a profound sensitivity to moisture levels in that 72% of their numbers occurred within a narrow range of 70 to 75%. This phenomenon was also observed by Stafford & Bay (1987) who found large numbers of *M. muscaedomesticae* in manure with a moisture range of 70 to 79%. This allowed the mites a higher probability of encountering eggs and 1st instar larvae of fly because adult flies, as mentioned by Willis & Axtell (1968) and Sing *et al.* (1966), deposited eggs on the outer layer near fresh accumulations on top of the manure cone.

The observations made on both farms indicated that very few or no predators occurred at moisture levels above 80%. Wilhoit *et al.* (1991) also found that *C. pumilio* could not survive in very wet manure while *M. muscaedomesticae* could not also live in manure

that was highly fluid (Willis & Axtell 1968, Rutz & Patterson 1990). Hulley & Pfeiderer (1988) suggested that the "stability" of the manure must be maintained while Pfeiffer & Axtell (1980), Rutz & Patterson (1990) and Wilhoit *et al.* (1991) stated that cultural management practices should be in place to enhance predatory populations by keeping the manure dry. This can be achieved by allowing it to fall onto a well drained, preferably porous substrate and preventing accumulation of excess water like leakage from the drinking water system (Hulley 1986). Ventilation and airflow affected the rate of evaporation that could cause sufficient drying of the manure (Rutz & Patterson 1990, Wilhoit *et al.* 1991) and must therefore be incorporated into the basic design of the poultry house. This approach, whilst aimed at enhancing the numbers of the existing complex of predators in the manure, will in addition suppress fly breeding (Chapter 1).

Cacinops pumilio and *P. sordidus* were not sensitive to temperature as they were found from 12 to 30°C. Bills (1973) also concluded that the former was relatively indifferent to temperature. Similarly, *M. muscaedomesticae* showed a wide range of temperature tolerance, a phenomenon also observed by Stafford & Bay (1987) who found that they tolerated temperatures from 15 to 44°C as compared with 12 to 31° C observed in this study.

Carcinops pumilio, *P. sordidus* and *M. muscaedomesticae* could be used to complement one another in regulating populations of nuisance flies such as *M. domestica* and *F. canicularis*. Since *C. pumilio* preferred aged manure, and *M. muscaedomesticae* and *P. sordidus* fresh manure, mass releasing of these predators in augmentation programs could be conducted in two phases, as was also suggested by Rutz & Patterson (1990). It is suggested that *P. sordidus* and *M. muscaedomesticae* be released within a few days post clean out and followed by a *C. pumilio* release at 6wks PC.

REFERENCES

- ARMITAGE, D. M. 1985a. Environment of deep-pit poultry houses: survey of air and manure temperatures in British houses. *British Poultry Science* **26**: 275-278.
- ARMITAGE, D. M. 1985b. Environment of deep-pit poultry houses: changes in manure moisture with air movement. *British Poultry Science* **26**: 281-285.
- AXTELL, R. C. 1968. Integrated house fly control: Populations of fly larvae and predaceous mites, *Macrocheles muscaedomesticae*, in poultry manure after larvicide treatment. *Journal of Economic Entomology* **61**: 245-249.
- AXTELL, R. C. 1970. Integrated fly-control program for caged-poultry houses. *Journal of Economic Entomology* **63**: 400-405.
- AXTELL, R. C. 1986. Fly management in poultry production: cultural, biological and chemical. *Poultry Science* **65**: 657-667.
- AXTELL, R. C & ARENDS J. J. 1990. Ecology and management of arthropod pests of poultry. *Annual Review of Entomology* **35**: 101-126.
- BILLS, G. T. 1973. Biological fly control in deep pit poultry houses. *British Poultry Science* **14**: 209-212.
- GEDEN, C. J. 1984. *Population dynamics, spatial distribution, dispersal behaviour and life history of the predaceous histerid, Carcinops pumilio (Erichson), with observations of other members of the poultry manure arthropod community*. Ph.D. dissertation, University of Massachusetts, Amherst.
- GEDEN, C. J. & STOFFOLANO, J. G. 1987. Succession of manure arthropods at a poultry farm in Massachusetts, USA, with observations on *Carcinops pumilio*

(Coleoptera: Histeridae) sex ratios, ovarian condition and body size. *Journal of Medical Entomology* **24**: 212-220.

GEDEN, C. J. & STOFFOLANO, J. G. 1988. Dispersion patterns of arthropods associated with poultry manure in enclosed house in Massachusetts: spatial distribution and effects of manure moisture and accumulation time. *Journal of Entomological Science* **24**: 136-148.

HART, S. A. 1963. Fowl fecal facts. *World's Poultry Science Journal* **19**: 262-266.

HULLEY, P. E. 1983. A survey of the flies breeding in poultry manure and their potential natural enemies. *Journal of the Entomological Society of Southern Africa* **49**: 19-27.

HULLEY, P. E. 1986. Factors affecting numbers of *Musca domestica* Linnaeus (Diptera: Muscidae) and some other flies breeding in poultry manure. *Journal of the Entomological Society of Southern Africa* **46**: 37-47.

HULLEY, P. E. & PFLEIDERER, M. 1988. The Coleoptera in poultry manure potential predators of the house fly, *Musca domestica* Linnaeus (Diptera: Muscidae). *Journal of the Entomological Society of Southern Africa* **51**: 18-29.

LEGNER, E. F. & OLTON, G. S. 1970. Worldwide survey and comparison of adult predator and scavenger insect populations associated with domestic animal manure where livestock is artificially congregated. *Hilgardia* **40**: 225-266.

LEGNER, E. F. & OLTON, G. S. 1971. The distribution and relative abundance of dipterous pupae and their parasites in accumulations of domestic animal manure in the Southwestern United States. *Hilgardia* **40**: 505-535.

LEGNER, E. F., OLTON, G. S., EASTWOOD, R. E. & DIETRICK, E. J. 1975. Seasonal density, distribution and interactions of predatory and scavenger arthropods in accumulating poultry wastes in coastal and interior southern California. *Entomophaga* **20**: 269-283.

- MATANMI, B.A. & GILIOMEE, J. H. 2002. Arthropods associated with poultry manure in the Western Cape Province, South Africa. *African Entomology* **10**: 365-370.
- MORGAN, P. B., PATTERSON, R. S. & WEIDHAAS, D. E. 1983. A life-history study of *Carcinops pumilio* Erichson (Coleoptera: Histeridae). *Journal of Georgia Entomological Society* **18**: 350-353.
- MULLENS, B. A. HINKLE, N. C. & SZIJJ, C. E. 1996. Impact of alternating manure removal schedules on pest flies (Diptera: Muscidae) and associated predators (Coleoptera: Histeridae, Staphylinidae; Acarina: Macrochelidae) in caged layer poultry manure in Southern California. *Journal of Economic Entomology* **89**: 1406-1417.
- PECK, J. H. & ANDERSON, J. R. 1969. Arthropod predators of immature Diptera developing in poultry droppings in Northern California. *Journal of Medical Entomology* **6**: 163-167.
- PECK, J. H. & ANDERSON, J. R. 1970. Influence of poultry-manure removal schedules on various Diptera larvae and selected arthropods predators. *Journal of Economic Entomology* **63**: 82-90.
- PFEIFFER, D. G. & AXTELL, R. C. 1980. Coleoptera of poultry manure in caged - layer houses in North Carolina. *Environmental Entomology* **9**: 21-28.
- RUTZ, D. A. & PATTERSON, R. S. 1990. *Biocontrol of Arthropods Affecting Livestock and Poultry*. Westview Press, Boulder, San Francisco.
- SINGH, P., KING, W. E. & RODRIQUEZ, J. G. 1966. Biological control of muscids as influenced by host preference of *Macrocheles muscaedomesticae* (Acarina: Macrochelidae) a predator of the house fly. *Journal of Medical Entomology* **3**: 78-81.

- SMITH, K. A. 1975. *Observations on the life history, ecology and behaviour of Carcinops pumilio* (Erichson). MSc. Thesis, Department of Entomology, University of New Hampshire, Durham.
- STAFFORD, K. C. & BAY, D. E. 1987. Dispersion pattern and association of house fly, *Musca domestica* (Diptera: Muscidae), larvae and both sexes of *Macrocheles muscaedomesticae* (Acari: Macrochelidae) in response to poultry manure moisture, temperature and accumulation. *Environmental Entomology* **16**: 159-164.
- WILHOIT, L. R., STINNER, R. E. & AXTELL, R. E. 1991. Computer simulation model of house fly management in confined-animal production systems. *North Carolina Agricultural Research Service, Technical Bulletin* **296**:1-81.
- WILLIS, R. R. & AXTELL, R. C. 1968. Mite predators of the house fly: a comparison of *Fuscuropoda vegetans* and *Macrocheles muscaedomesticae*. *Journal of Economic Entomology* **62**: 1669-1676.
- WILLS, L. E., MULLENS, B. A. & MANDEVILL, J. D. 1990. Effects of pesticides on filth fly predators (Coleoptera: Histeridae, Staphylinidae; Acarina: Macrochelidae, Uripodidae) in caged-layer poultry manure. *Journal of Economic Entomology* **83**: 451-457.

CHAPTER 3

DISPERSION PATTERNS OF ARTHROPODS IN POULTRY MANURE WITH RESPECT TO SPATIAL POSITION, MANURE MOISTURE AND TEMPERATURE

ABSTRACT

Examination of vertical cross-section profile samples of poultry manure accumulating in caged layer houses showed that the 1st and 2nd instar larvae of the predatory beetles, *Carcinops pumilio* (Erichson) (Coleoptera: Histeridae) and *Philonthus sordidus* (Gravenhorst) (Coleoptera: Staphylinidae), congregated more in the base five and upper four sections of manure cone respectively. *Carcinops pumilio* adults tended to be evenly dispersed, with slightly higher numbers in the lower portions of the manure. On the surface of the manure *C. pumilio* numbers increased from the crest to the base of the pile while the moisture levels of the manure also decreased from the crest to the base. The larvae of *Musca domestica* L. and *Fannia canicularis* (L.) (Diptera: Muscidae) occupied the crest with 70% moisture content. Within the interior of the manure *C. pumilio* (all stages), *Macrocheles muscaedomesticae* (Scopoli) (Acarina: Macrochelidae), *F. canicularis*, *M. domestica* and *Proctolaelaps* sp. (Acarina: Ascidae) had a wide range of temperature preferences (from 12 to above 30°C), whilst near the surface all the arthropods had a narrower range of temperature preference (from 15 to 24°C). Regular removal of the crest is suggested as a fly management tool.

Key words: Dispersion, arthropods, poultry manure, moisture, temperature.

INTRODUCTION

The housefly, *Musca domestica* L. and lesser housefly, *Fannia canicularis* (L.) (Diptera: Muscidae) are important pests on poultry and other livestock farms (Tanada *et al.* 1950, Conway 1973, Toyama & Ikeda 1976, Hulley 1983, Fatchurochim *et al.* 1989, Rutz & Patterson 1990, Smith & Rutz 1991). Flies breeding in chicken manure on poultry farms can increase in such numbers as to constitute a health hazard through the transmission of pathogens (Tanada *et al.* 1950, Greenberg 1973) as well as being a general nuisance.

Anderson (1966) gives four reasons why the problems with flies are generally on the increase. These are: (1) The increase in the number of poultry and other livestock rearing facilities. (2) The economics of shipping and marketing favours the location of livestock concentrations near metropolitan consumer centres. (3) The rapidly expanding suburban populations are bringing more people in closer proximity and daily contact with previously relatively isolated rural communities. (4) Recent changes in agricultural technology economically favour large concentrations of livestock like poultry.

The modern poultry production practices parallel the monoculture of other facets of agriculture (Anderson 1966). These practices, which involve poultry production in high density confined systems, provide an ideal habitat for the development of the housefly and other filth flies as a result of the massive accumulation of manure (Wilhoit *et al.* 1991).

The control of these flies is difficult, due to their enormous biotic potential (Axtell 1968, Bailey *et al.* 1968, Axtell & Edwards 1983). There are also the increasing problems associated with the loss in effectiveness of conventional insecticides (Bailey *et al.* 1968, Bloomcamp *et al.* 1987) as well as insect growth regulators (Bloomcamp *et al.* 1987).

Most chemicals used for fly control on poultry farms are toxic enough to threaten destruction of the predaceous manure-inhabiting arthropods (Bradley *et al.* 1966). Residues of cyromazine could be retained in bird meat and eggs (Howard & Wall 1996), and in calf tissue (Miller *et al.* 1996). Consumers may refrain from buying chicken products should such information come to their knowledge.

Considering the problems encountered with the use of chemicals to control filth-breeding flies, it is appropriate to investigate the use of biological control methods. One aspect of this would be enhancing the number of natural enemies through manure management and habitat stability. This requires a better understanding of where the fly larvae and their predators are found in the manure cone.

The objectives of this study were therefore to study the distribution patterns of the dominant predatory arthropods and filth flies in poultry manure and the environmental factors that affect their distribution. Also to find means of enhancing their degree of interaction and determine which predator would be a suitable candidate to be reared for augmentation in IPM projects.

2. MATERIALS AND METHODS

2.1 Study site and house design

Studies on the dispersion patterns of dominant predatory arthropods and filth breeding flies were conducted weekly between June 14, 1999 and November 18, 1999 at University of Stellenbosch Experimental Poultry Farm, Elsenburg, Western Cape Province, South Africa (33° 51'S, 18° 50'E).

The house at the University Farm was an open sided, commercial egg laying type with ventilation and temperature control by natural means. Birds were housed in single-tier cages suspended about 1m from the floor, four birds per cage with 0.45m-floor space per bird. Cages were in rows crosswise in the building. Paths between the rows were concrete with manure accumulating beneath the cage in dugout sand. The manure from which samples were taken had accumulated for six months.

2.2 Vertical cross-sectional profile samples, manure moisture content and temperature

In the rows of accumulating manure, several cones are formed under the cages. Cones selected for sampling were located in the middle of alternate rows in the central part of the house to avoid edge effects. To determine within-habitat dispersion patterns of arthropods, vertical cross-sectional profile samples were taken. To take samples, the manure cone was divided vertically into two equal parts and one-half scraped away with a trowel. This allowed access to the cross-sectional profile. The height of the manure cone at each location was measured and it was divided into top, middle and bottom portions. At each position, as shown in Fig.1, an auger (5.0 cm diameter x 3.0 cm length), with a volume of 58.90 cm³, was plunged horizontally into the manure and slowly rotated before pulling it out. The ten samples from each location were placed in an ice-cream container (each with location labels as in Fig.1) and taken to the laboratory where the manure was placed in Tullgren funnels with 60w bulbs as source of heat for 72 hrs. The arthropods were extracted into 70% ethanol and later counted. A thermometer (mercury) was inserted 3cm deep horizontally at each position in Fig. 1 and the temperature read before the samples were taken. At each position, a core sample was also taken to determine the moisture content. The total sample of each location was placed in an ice-cream container, which was immediately covered with its lid and taken to an oven to be dried. It was reweighed after

one week. The percentage moisture content of the manure was calculated using $w = [(y - \chi) / y] \times 100\%$, where, $w = \%$ of manure moisture content, $y =$ weight of wet manure and $\chi =$ weight of dry manure, in grams. Differences in the percentage manure moisture between each position were determined at $P < 0.05$ using LSD.

The spatial coincidence between the numbers of each predator species and their prey, Ic , was calculated using:

$$Ic (\text{Predator}) = \sum_{i=1}^n NT(i) / \sum_{i=1}^n N(i) \quad (\text{Griffiths 1969}).$$

NT is the number of the predators *Carcinops pumilio* (Erichson) (Coleoptera: Histeridae) (adults, 1st and 2nd instar larvae), *Macrocheles muscaedomesticae* (Scopoli) (Acarina: Macrochelidae), *Philonthus sordidus* (Gravenhorst) (Coleoptera: Staphylinidae) or *Xylocoris galactinus* (Fallén) (Hemiptera: Anthocoridae) that occurred in at least one prey per sample, i , and N is the number of predators in the i th sample.

The spatial coincidence between prey numbers and their predators was similarly calculated as:

$$Ic (\text{Prey}) = \sum_{i=1}^n TN(i) / \sum_{i=1}^n T(i),$$

where: TN is the number of *Musca domestica* L., *Fannia canicularis* (L.) (Diptera: Muscidae) (1st and 2nd instar larvae) or *Proctolaelaps* sp. (Acarina: Ascidae) (all stages), that occurred with at least one predator per sample, i , and T is the total number of prey in the i th sample. The lack of coincidence between predator and prey was calculated as a refuge index: $IR = 1 - Ic (\text{Prey})$.

The spatial distribution of each species at various positions in the interior of the manure and the correspondence analysis was drawn to determine where they might overlap and compete for the same resources.

All stages of coleopterans, the hemipteran, *X. galactinus* the 1st and 2nd instar larvae of *M. domestica* and *F. canicularis* and all stages of *M. muscaedomesticae* were counted individually, but the numbers of *Proctolaelaps* sp. were determined volumetrically from the known number per 5 ml.

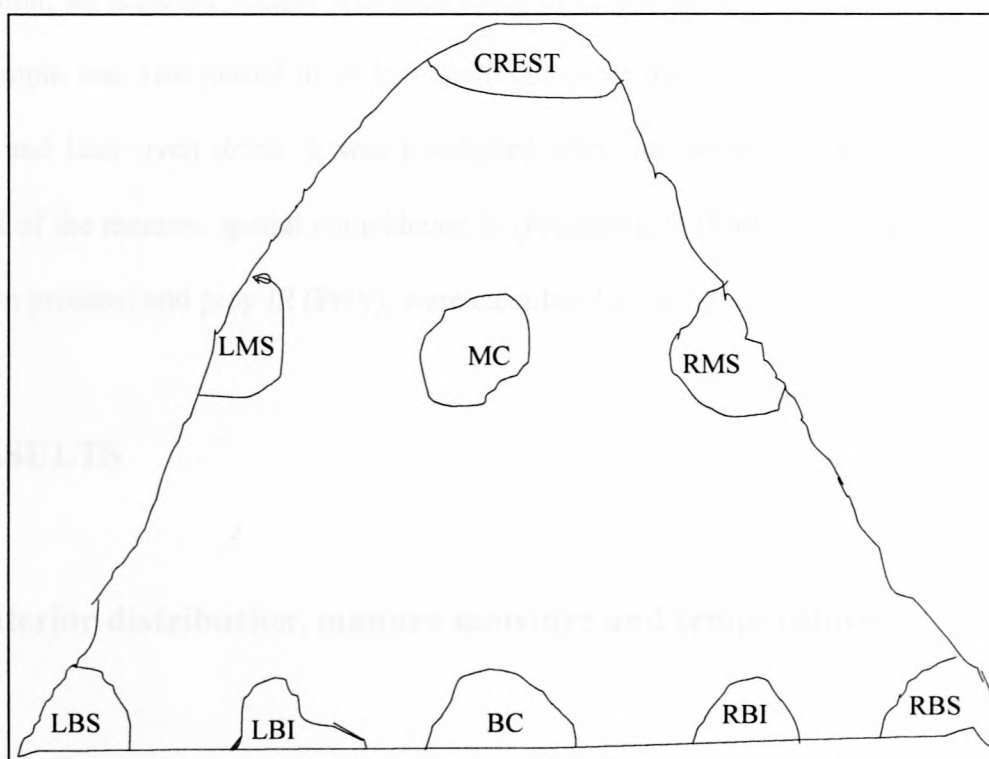


Fig.1. Schematic illustration of a poultry manure cone at the University House, and positions where samples were taken. (LMS = left-middle side; MC = middle center; RMS = right-middle side; LBS = left-base side; LBI = left-base interior; BC = base center; RBI = right-base interior; RBS = right-base side).

2.3 Surface distribution, manure moisture level and temperature

The dispersion patterns of arthropods near the surface of the manure cone and the effect of manure moisture levels and temperature on their distribution were determined by taking

samples from five surface positions (CREST, LMS, RMS, LBS, RBS) shown in Fig. 1. The same auger as described in 2.2 was plunged horizontally along the surface, avoiding the interior as much as possible, and slowly rotating before pulling it out with the manure. The total sample from each position was placed in an ice-cream container (each with position labels as in Fig. 1) and taken to the laboratory where the manure was placed in Tullgren funnels with 60w bulbs as source of heat for 72 hours. The number of samples taken and arthropods were treated in the same way as in section 2.2. The temperature of each position (Fig. 1) was taken by inserting a thermometer 3cm deep directly under the surface. The 3cm point on the thermometer was marked with a tape. For each sample extracted for arthropod dispersion, an adjacent sample was also taken to determine the manure moisture content. The sample was also placed in an ice-cream container that was immediately covered with its lid and later oven dried. It was reweighed after one week. The percentage moisture content of the manure, spatial coincidence I_c (Predator), I_c (Prey), and lack of coincidence between predator and prey IR (Prey), were calculated as in 2.2.

3. RESULTS

3.1 Interior distribution, manure moisture and temperature

3.1.1 Arthropod numbers

The results of vertical cross-sectional profile samples of all arthropods collected are given in Table 1. The adults of *C. pumilio* had an even distribution throughout the various positions within the manure cone. Ten percent or more of their numbers occurred in all the positions except LMS and MC. More than 60% were dispersed within the five basal positions of the manure cone (Table 1). *C. pumilio* 2nd instar larvae and *X. galactinus* had a mid-belt distribution within the manure with 60.3% and 40.3% occurrence respectively. *P.*

sordidus had 50% of their numbers dispersed in the CREST. Distribution in the interior positions was most pronounced in the case of *C. pumilio* 1st instar larvae, *M. muscaedomesticae* and *Proctolaelaps* sp. with 80.7%, 71.8% and 80.4% found in the first four interior positions (CREST, LMS, MC, RMS) (Table 1) (Fig.1).

Three of the four top positions (CREST, LMS, MC) accounted for 89.7%, 77.2%, 95.4%, and 63.5% of *M. domestica* and *F. canicularis* 1st and 2nd instar larvae, respectively and the CREST accounted for more than 50% of each of these stages.

Table 1. Percent of arthropods collected from each of the nine positions along five cross-sectional profiles of six month old accumulating manure

| Position* | Predators | | | | | |
|--------------------------|--|--|---------------------------------|----------------------------------|-------------------------------|----------------------------|
| | Species | | | | | |
| | <i>C. pumilio</i> | | | <i>P. sordidus</i> | <i>X. galactinus</i> | <i>M. muscaedomesticae</i> |
| Adults (Total = 1013) | 1 st instar larvae (Total = 129) | 2 nd instar larvae (Total = 161) | Adults & larvae (Total = 16) | Adults & nymphs (Total = 146) | all stages (Total = 30376) | |
| CREST | 10.6 | 12.4 | 5.0 | 49.8 | 4.1 | 18.0 |
| LMS | 8.6 | 15.5 | 11.2 | 2.8 | 26.7 | 16.0 |
| MC | 8.3 | 29.5 | 13.0 | 16.3 | 18.5 | 18.3 |
| RMS | 10.0 | 23.3 | 16.1 | 6.3 | 15.1 | 19.5 |
| LBS | 13.4 | 6.2 | 8.1 | 0.0 | 8.9 | 9.2 |
| LBI | 11.8 | 5.4 | 19.9 | 0.0 | 2.1 | 4.1 |
| BC | 12.9 | 0.7 | 9.9 | 6.3 | 8.9 | 4.7 |
| RBI | 11.6 | 3.9 | 8.1 | 0.0 | 7.5 | 5.5 |
| RBS | 12.8 | 3.1 | 8.7 | 18.5 | 8.2 | 4.7 |

| Position* | Prey | | | | |
|--|--|---|---|--------------------------------|--------------------------|
| | Species | | | | |
| | <i>M. domestica</i> | | <i>F. canicularis</i> | | <i>Proctolaelaps</i> sp. |
| 1 st instar larvae (Total = 425) | 2 nd instar larvae (Total = 311) | 1 st instar larvae (Total = 1067) | 2 nd instar larvae (Total = 1317) | All stages (Total = 144448) | |
| CREST | 71.1 | 65 | 91.3 | 50.5 | 13.1 |
| LMS | 2.8 | 3.5 | 2.5 | 10.2 | 31.9 |
| MC | 15.8 | 8.7 | 1.6 | 2.8 | 22.5 |
| RMS | 8.0 | 3.9 | 1.0 | 13.3 | 12.9 |
| LBS | 0.5 | 5.5 | 1.0 | 4.6 | 4.8 |
| LBI | 1.2 | 1.3 | 0.7 | 5.6 | 7.4 |
| BC | 0.2 | 7.6 | 0.6 | 3.7 | 3.8 |
| RBI | 0.0 | 1.3 | 0.3 | 3.1 | 1.5 |
| RBS | 0.4 | 3.2 | 1.0 | 6.2 | 2.1 |

* See Fig.1 for location of sample positions. N = 5, 58.90-cm³ samples/position.

3.1.2 Manure moisture and arthropod dispersion

The moisture content of manure tended to decrease from the top of the cone (68.17% ± 1.20) (CREST) to the base (43.38% ± 3.52) (RBS) (Table 2).

The distribution of all arthropods with respect to manure moisture is represented in Fig. 2. *Carcinops pumilio* (all stages), *Proctolaelaps* sp., *M. muscaedomesticae* and *X. galactinus* were found over a broad range of moisture levels, from 21% to above 70% (Fig. 2a, c, d, g). *M. domestica* (1st instars) and *F. canicularis* (1st and 2nd instar larvae) were mainly found in manure with a moisture range from 61 to 70% (Fig. 2e, f), whilst for *C. pumilio* and *X. galactinus* adults it was 51 to 60% (Fig. 2a, c). *Philonthus sordidus* was found mainly where the moisture was more than 70% (Fig.2b). At less than 30% moisture level all species were present or absent in low numbers (Fig. 2).

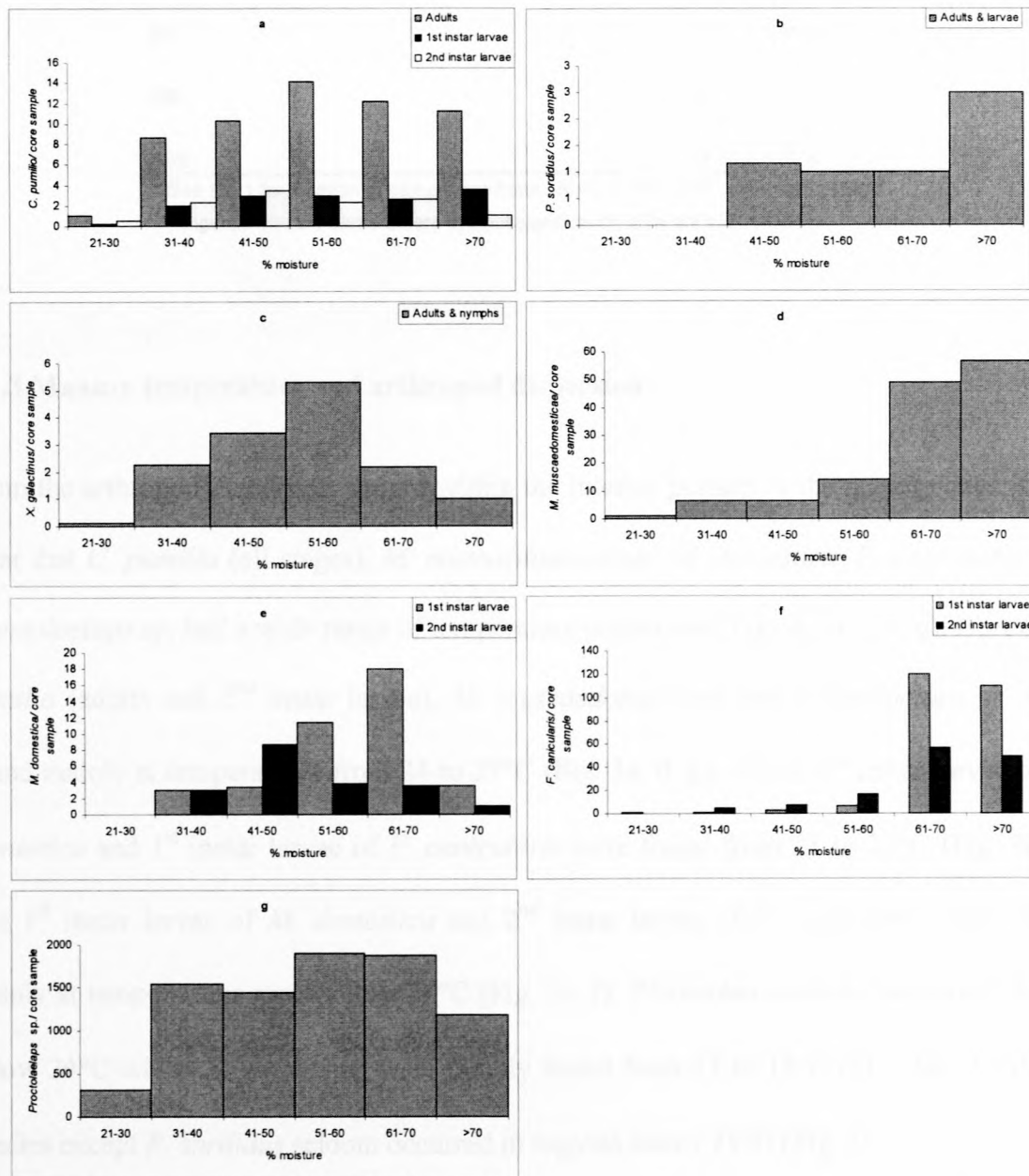


Fig. 2. Dispersion patterns of arthropods inside poultry manure in relation to manure moisture levels. Bars represent numbers of individuals recovered per moisture content level. **a** = *C. pumilio*; **b** = *P. sordidus*; **c** = *X. galactinus*; **d** = *M. muscaedomesticae*; **e** = *M. domestica*; **f** = *F. canicularis*; **g** = *Proctolaelaps* sp.

Table 2. Percent of manure moisture from each of the nine positions along five cross-sectional profiles of six months old accumulating manure

| Position * | % manure moisture** |
|------------|---------------------|
| CREST | 68.17 ± 1.20 c |
| LMS | 51.96 ± 2.19 b |
| MC | 48.77 ± 2.83 ab |
| RMS | 48.24 ± 2.44 ab |
| LBS | 48.17 ± 2.01 ab |
| LBI | 49.62 ± 1.23 ab |
| BC | 48.51 ± 1.58 ab |
| RBI | 46.17 ± 2.30 ab |
| RBS | 43.38 ± 3.52 a |

* See Fig.1 for location of sample positions . N = 10, 58.90-cm³ samples/position

** Figures with the same letters are not significantly different at P < 0.05

3.1.3 Manure temperature and arthropod dispersion

From the arthropod dispersion pattern within the interior portion of the manure cone it was clear that *C. pumilio* (all stages), *M. muscaedomesticae*, *M. domestica*, *F. canicularis* and *Proctolaelaps* sp. had a wide range of temperature preference (Fig. 3a, d, e, f, g). *Carcinops pumilio* (adults and 2nd instar larvae), *M. muscaedomesticae* and *Proctolaelaps* sp. were found mainly at temperatures from 24 to 27°C (Fig. 3a, d, g), whilst 2nd instar larvae of *M. domestica* and 1st instar larvae of *F. canicularis* were found from 21 to 24°C (Fig. 3e, f). The 1st instar larvae of *M. domestica* and 2nd instar larvae of *F. canicularis* were found mainly at temperatures greater than 27°C (Fig. 3e, f). *Philonthus sordidus* were only found below 24°C whilst *X. galactinus* were mainly found from 15 to 18°C (Fig. 3b, c). All the species except *P. sordidus* seldom occurred in regions below 15°C (Fig. 3).

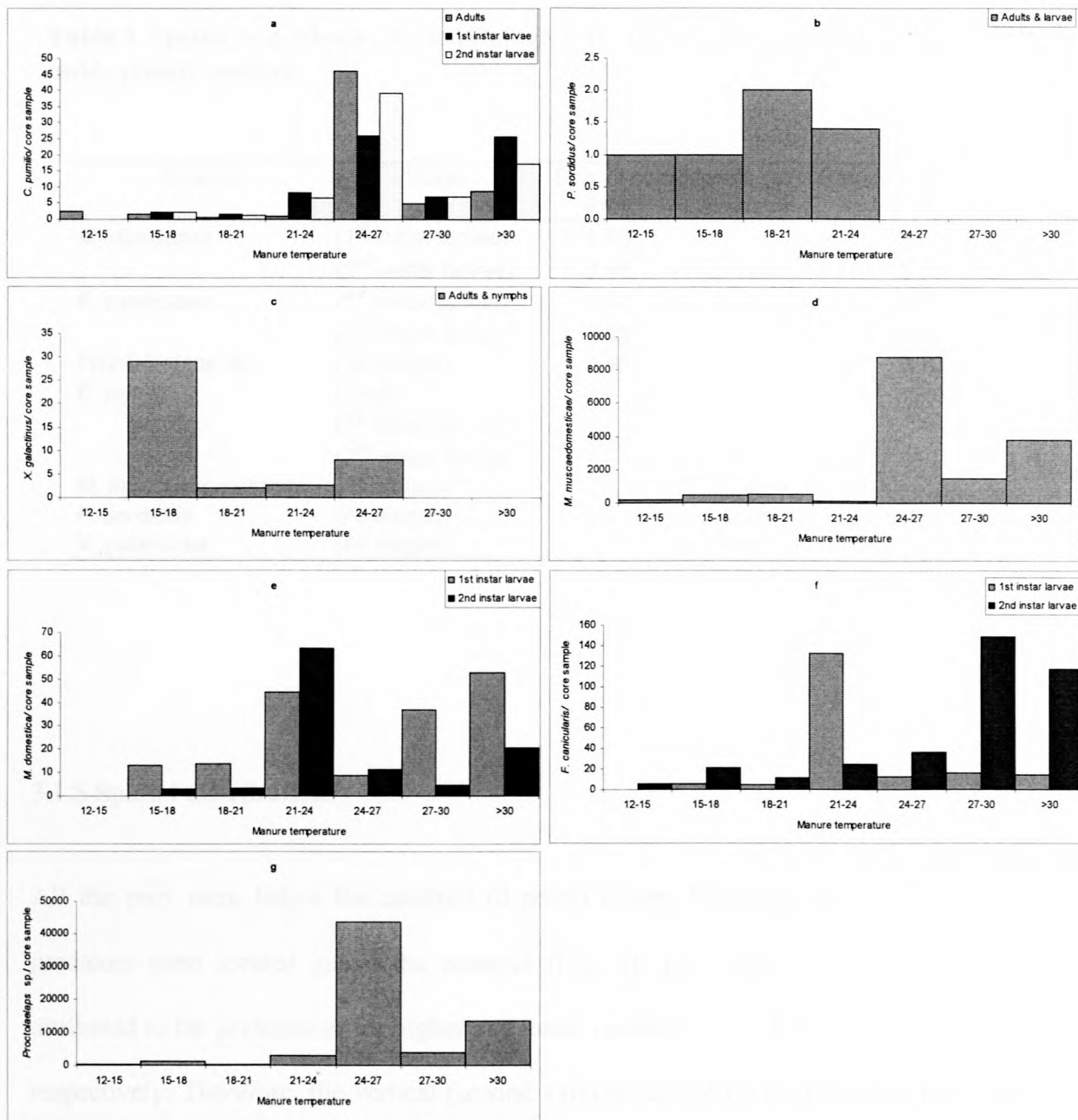


Fig. 3. Dispersion patterns of arthropods inside poultry manure in relation to manure temperature levels. Bars represent numbers of individuals recovered per manure temperature level. .a = *C. pumilio*; b = *P. sordidus*; c = *X. galactinus*; d = *M. muscaedomesticae*; e = *M. domestica*; f = *F. canicularis*; g = *Proctolaelaps* sp.

3.1.4 Spatial coincidence (*Ic*) of prey and predators and refuge index (*IR*) of prey

Ic (Prey) was high in all species exceeding 0.50, whilst *IR* (prey) was low in all species except *F. canicularis* 2nd instar larvae which was high (Table 3). *Ic* (Predator) was high in all species except in *C. pumilio* 1st instar larvae and *P. sordidus* which were below 0.20 (Table 3).

Table 3. Spatial coincidence (*Ic*) and Refuge index (*IR*) of prey and predator arthropods inside poultry manure.

| Species | Stage | Spatial coincidence (<i>Ic</i>) | | Refuge index (<i>IR</i>) |
|----------------------------|---------------------------------|-----------------------------------|----------|----------------------------|
| | | Prey | Predator | Prey |
| <i>M. domestica</i> | (1 st instar larvae) | 0.98 | – | 0.02 |
| | (2 nd instar larvae) | 0.95 | – | 0.05 |
| <i>F. canicularis</i> | (1 st instar larvae) | 0.97 | – | 0.03 |
| | (2 nd instar larvae) | 0.59 | – | 0.41 |
| <i>Proctolaelaps</i> sp. | (All stages) | 0.90 | – | 0.10 |
| <i>C. pumilio</i> | (Adult) | – | 0.67 | – |
| | (1 st instar larvae) | – | 0.13 | – |
| | (2 nd instar larvae) | – | 0.53 | – |
| <i>M. muscaedomesticae</i> | (All stages) | – | 0.62 | – |
| <i>P. sordidus</i> | (All stages) | – | 0.20 | – |
| <i>X. galactinus</i> | (All stages) | – | 0.97 | – |

3.1.5 Spatial distribution

All the prey were below the centroid (0 point) except *Proctolaelaps* sp., whilst all the predators were located above the centroid (Fig. 4). The horizontal separation could be attributed to the preferences for higher and lower moisture levels for the prey and predators respectively. Therefore, the vertical (second axis) described the two species (predator and prey). *M. domestica* and *F. canicularis* (1st and 2nd instar larvae) corresponded with the CREST position in the manure, whilst *Proctolaelaps* sp. corresponded closely with LMS, MC and LBI (Fig. 4). *Carcinops pumilio* adults and 2nd instar larvae corresponded with RBI whilst the 1st instar larvae corresponded with both LBS and RMS positions (Fig. 4).

The prey, *M. domestica* and *F. canicularis* (1st and 2nd instar larvae), both occurred in very high numbers in the CREST (Fig. 5). The predator, *C. pumilio* adults, were found in high numbers mostly in the basal positions of the manure cone (LBS, LBI, BC, RBI, RBS, LMS) (Fig. 5). *Microcheles muscaedomesticae*, *C. pumilio*, 1st and 2nd instar larvae were found

3.2 Surface distribution

3.2.1 Arthropod numbers

The surface distribution of all arthropods collected is shown in Table 4. *Carcinops pumilio* (all stages) was dispersed evenly in the manure surface but the 2nd instar larvae of this species was significantly more abundant at the LBS. *Philonthus sordidus* was most abundant in the CREST surface with 50% of their numbers occurring in that position. *Xylocoris galactinus* was evenly dispersed in the manure surface, but with relatively few in the CREST. *Macrocheles muscaedomesticae*, like *C. pumilio*, was dispersed evenly in the manure surface with most of them occurring at LMS and the least at RBS.

Musca domestica and *F. canicularis* were more abundant in the surface of the CREST than in the other positions (Table 4) while *Proctolaelaps* sp. were abundant in the LBS and RBS manure surface positions.

Table 4. Percent and total numbers of arthropods collected from each of the five positions near the manure surface

| Position* | Predators | | | | | |
|-----------|-------------------------|--|--|---|--|---|
| | Species | | | | | |
| | Adults (Total = 719) | <i>C. pumilio</i> 1 st instar larvae (Total = 75) | 2 nd instar larvae (Total = 132) | <i>P. sordidus</i> Adults & larvae (Total = 13) | <i>X. galactinus</i> Adults & nymphs (Total = 279) | <i>M. muscaedomesticae</i> all stages (Total = 37572) |
| CREST | 11.7 | 1.9 | 0.0 | 50.0 | 5.0 | 12.9 |
| LMS | 20.7 | 11.5 | 16.6 | 28.6 | 16.4 | 37.8 |
| RMS | 18.9 | 3.9 | 19.7 | 0.0 | 31.3 | 26.1 |
| LBS | 20.8 | 28.9 | 37.6 | 21.4 | 30.5 | 13.2 |
| RBS | 27.9 | 53.8 | 26.1 | 0.0 | 16.8 | 10.0 |

| Position* | Prey | | | | |
|-----------|---|--|--|---|---------------------------------|
| | Species | | | | |
| | <i>M. domestica</i> | | <i>F. canicularis</i> | | <i>Proctolaelaps</i> sp. |
| | 1 st instar larvae (Total = 83) | 2 nd instar larvae (Total = 142) | 1 st instar larvae (Total = 656) | 2 nd instar larvae (Total = 1688) | all stages (Total = 2099994) |
| CREST | 66.2 | 54.0 | 57.5 | 34.8 | 6.9 |
| LMS | 13.3 | 16.2 | 25.9 | 25.6 | 2.3 |
| RMS | 19.3 | 12.1 | 11.0 | 10.0 | 10.6 |
| LBS | 1.2 | 10.6 | 0.3 | 5.3 | 40.8 |
| RBS | 0.0 | 7.1 | 5.3 | 24.3 | 39.4 |

* See Fig. 1 for location of sample positions. N = 10 ; 58.90cm³ samples/position

3.2.2 Manure moisture and arthropod dispersion

The moisture content of the manure surface decreased from the top (CREST) to the base as was the case in the interior of the manure. The position of the manure cone with the highest moisture level was the CREST with $63\% \pm 1.3$ and the lowest was the base RBS with $36\% \pm 1.6$ (Table 5). The distribution pattern of all arthropods collected with respect to moisture content of manure surface is shown in Fig. 6. *Carcinops pumilio* (adults), *P. sordidus*, *M. muscaedomesticae*, *M. domestica* (1st instars) and *F. canicularis* (1st and 2nd instars) were mainly found in manure with a moisture level greater than 70% (Fig. 6a, b, d, e, f), whilst the 1st and 2nd instar larvae of *C. pumilio*, *X. galactinus* and the 2nd instar larvae of *M. domestica* were mostly found from 41 to 50% moisture level (Fig. 6a, c, e). *Proctolaelaps* sp. was mostly found at lower moisture levels, from 31 to 40% (Fig. 6g). Very few or no arthropods were found at moisture levels below 31% except *X. galactinus* (Fig. 5).

Table 5. Percent manure moisture at each of the five positions along the surface of six months old accumulating manure at the University House.

| Position * | % manure moisture** |
|------------|---------------------|
| CREST | 63.0 ± 1.3 c |
| LMS | 54.1 ± 2.11 b |
| RMS | 47.3 ± 2.10 ab |
| LBS | 43.1 ± 1.23 ab |
| RBS | 36.0 ± 1.50 a |

* See Fig.1 for location of sample positions . N = 5, 58.90-cm³ samples/position

** Figures with the same letters are not significantly different at P < 0.05

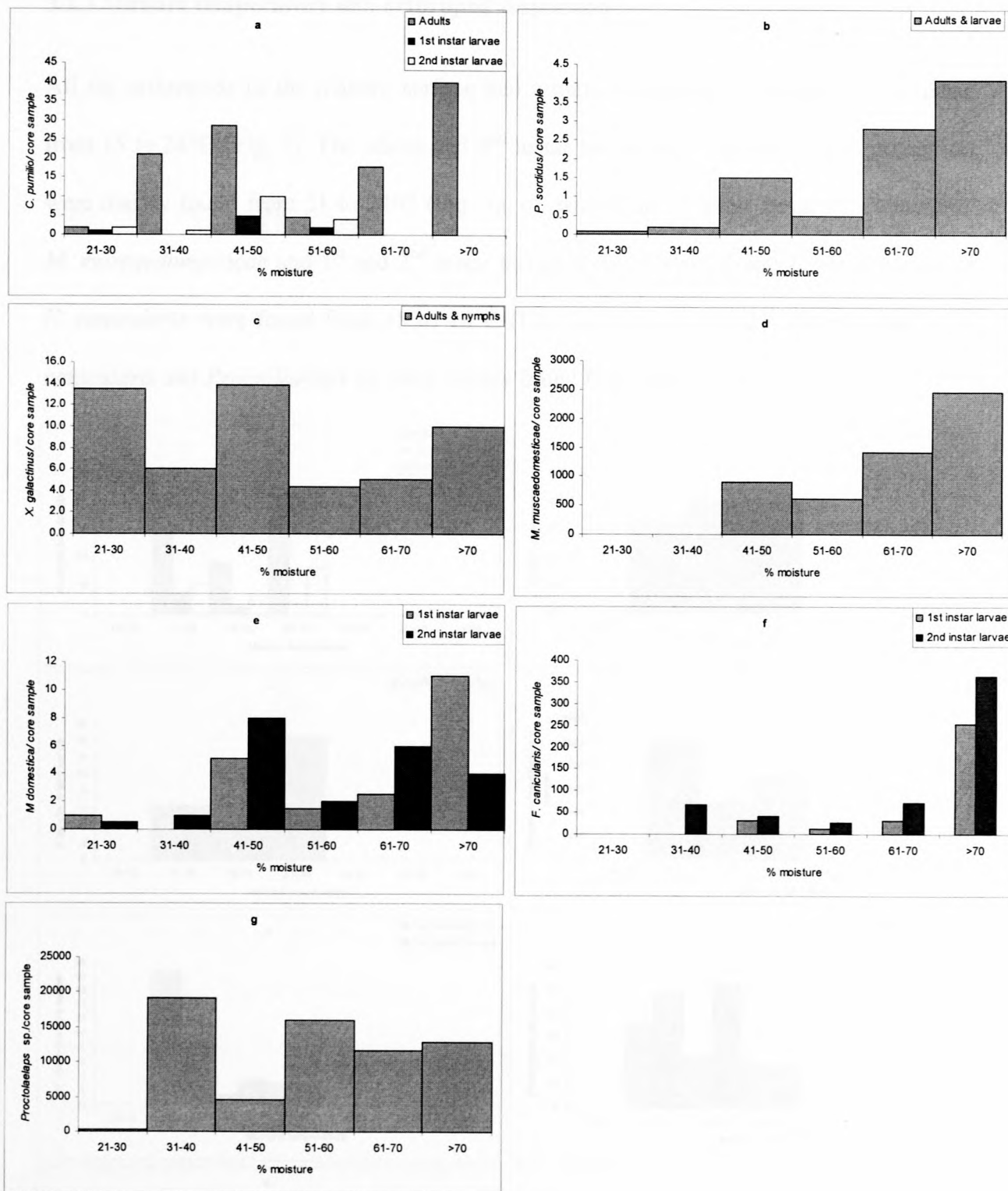


Fig. 6. Dispersion patterns of arthropods near the surface of poultry manure in relation to manure moisture levels. Bars represent numbers of individuals recovered per moisture content level. **a** = *C. pumilio*; **b** = *P. sordidus*; **c** = *X. galactinus*; **d** = *M. muscaedomesticae*; **e** = *M. domestica*; **f** = *F. canicularis*; **g** = *Proctolaelaps* sp.

3.2.3 Manure temperature and arthropod dispersion

All the arthropods in the manure surface had a narrow range of temperature preference, from 15 to 24°C (Fig. 7). The adults and 2nd instar larvae of *C. pumilio* and *X. galactinus* were mainly found from 21 to 24°C (Fig. 7a, c), whilst the 1st instar larvae of *C. pumilio*, *M. muscaedomesticae* and 1st and 2nd instar larvae of *M. domestica* and 1st instar larvae of *F. canicularis* were found from 15 to 18°C (Fig. 7a, d, e, f). The 2nd instar larvae of *F. canicularis* and *Proctolaelaps* sp. were mostly found from 18 to 21°C (Fig. 7f, g).

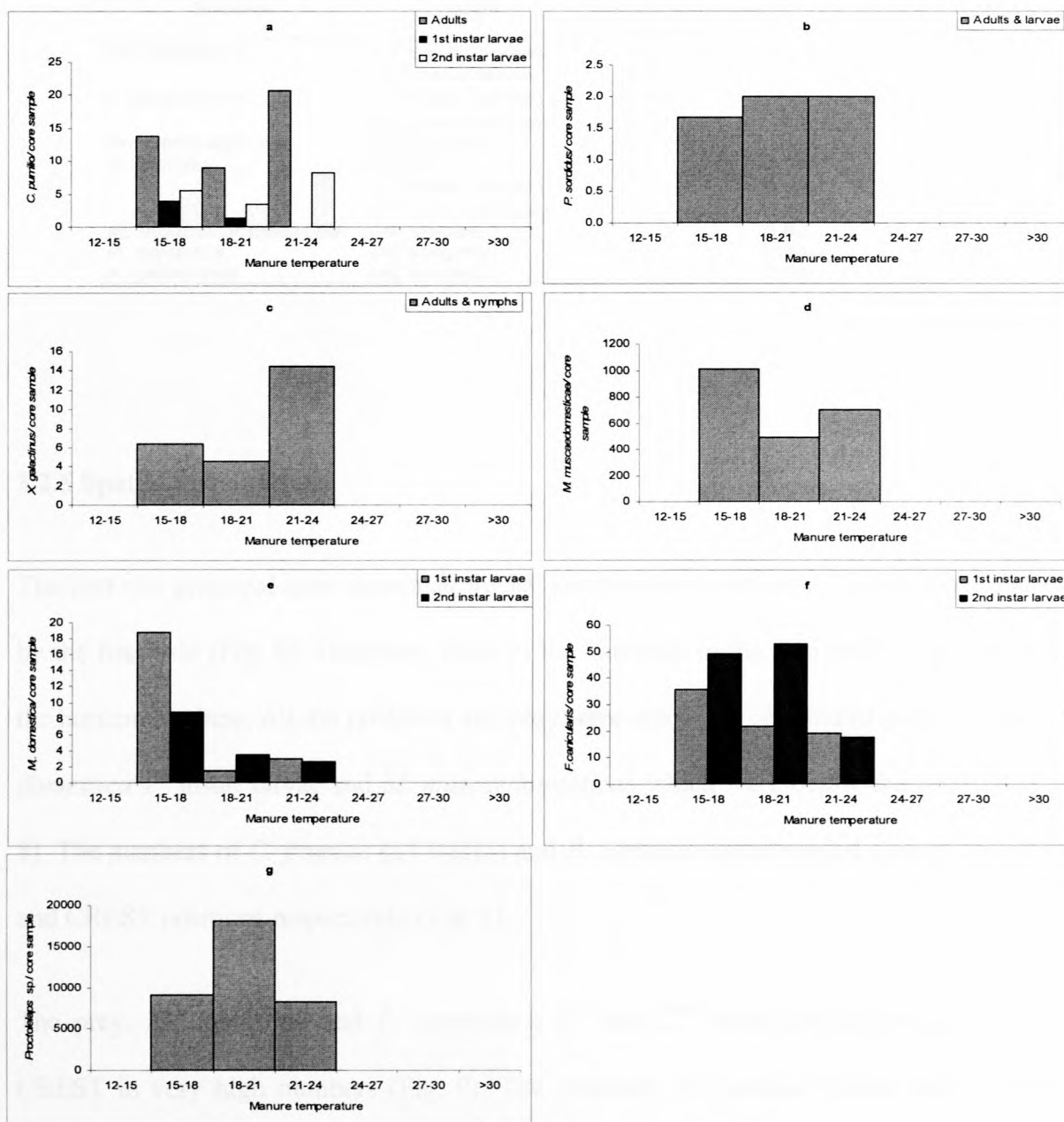


Fig. 7. Dispersion patterns of arthropods near the surface of poultry manure in relation to manure temperature levels. Bars represent numbers of individuals recovered per manure temperature level. **a** = *C. pumilio*; **b** = *P. sordidus*; **c** = *X. galactinus*; **d** = *M. muscaedomesticae*; **e** = *M. domestica*; **f** = *F. canicularis*; **g** = *Proctolaelaps* sp.

3.2.4 Spatial coincidence (*Ic*) of prey and predators and refuge index (*IR*) of prey

The *Ic* of both prey and predator near the surface of the manure was high, exceeding 0.50 (Table 6). The *IR* (prey) was very low for *M. domestica* and *F. canicularis* 1st instar larvae and *Protolaelaps* sp. but high for *M. domestica* and *F. canicularis* 2nd instar larvae

Table 6. Spatial coincidence (*Ic*) and Refuge index (*IR*) of prey and predator arthropods inside poultry manure.

| Species | Stage | Spatial coincidence (<i>Ic</i>) | | Refuge index (<i>IR</i>) |
|----------------------------|---------------------------------|-----------------------------------|----------|----------------------------|
| | | Prey | Predator | Prey |
| <i>M. domestica</i> | (1 st instar larvae) | 1.00 | – | 0.00 |
| | (2 nd instar larvae) | 0.57 | – | 0.43 |
| <i>F. canicularis</i> | (1 st instar larvae) | 1.00 | – | 0.00 |
| | (2 nd instar larvae) | 0.79 | – | 0.21 |
| <i>Proctolaelaps</i> sp. | (All stages) | 1.00 | – | 0.00 |
| <i>C. pumilio</i> | (Adult) | – | 0.73 | – |
| | (1 st instar larvae) | – | 0.92 | – |
| | (2 nd instar larvae) | – | 0.86 | – |
| <i>M. muscaedomesticae</i> | (All stages) | – | 0.82 | – |
| <i>P. sordidus</i> | (All stages) | – | 0.85 | – |
| <i>X. galactinus</i> | (All stages) | – | 0.51 | – |

3.2.5 Spatial distribution

The first two principal axes accounted for 98% of the inertia whilst 93% was accounted for by the first axis (Fig. 8). Therefore, most of the variation in the data was accounted for in the horizontal plane. All the predators and prey were above the centroid (0-point) except *M. domestica* 1st instar larvae and *M. muscaedomesticae* which were below the centroid (Fig. 8). The numbers of *C. pumilio* (all stages) and *P. sordidus* corresponded closely with RBS and CREST positions respectively (Fig. 8).

The prey, *M. domestica* and *F. canicularis* (1st and 2nd instar larvae), occurred in the CREST in very high numbers (Fig. 9). The predators, *C. pumilio* (adults and 2nd instar larvae) *M. muscaedomesticae*, *P. sordidus* and *X. galactinus* were distributed in different positions in very high numbers in the RBS, LBS, LMS, CREST and RMS positions

respectively (Fig. 9). *Philonthus sordidus* was the only predator that overlapped with prey in the CREST (Fig. 9).

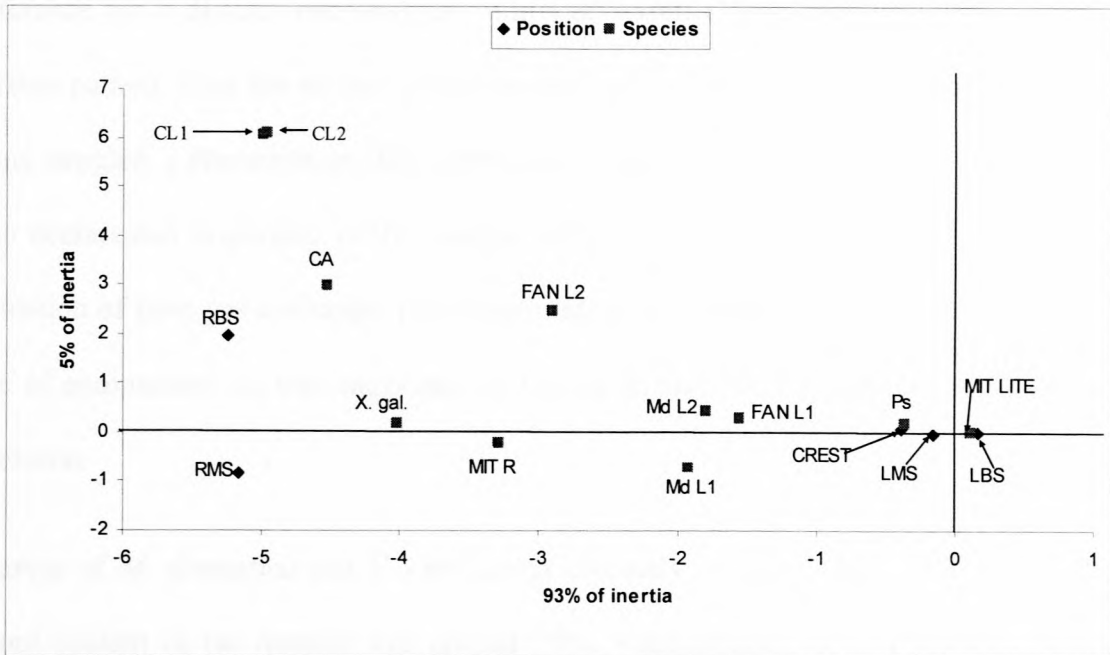


FIG. 8. Correspondence analysis of positions and species of arthropods near the manure surface. CA = *C. pumilio* (adults); CL1 = *C. pumilio* 1st instar larvae; CL2 = *C. pumilio* 2nd instar larvae; Ps = *Philonthus sordidus*; X. gal. = *X. galactinus*; MIT R = *M. muscaedomesticae*; MIT LITE = *Proctolaelaps* sp.; MdL1 = *M. domestica* 1st instar larvae; MdL2 = *M. domestica* 2nd instar larvae; FANL1 = *F. canicularis* 1st instar larvae; FANL2 = *F. canicularis* 2nd instar larvae.

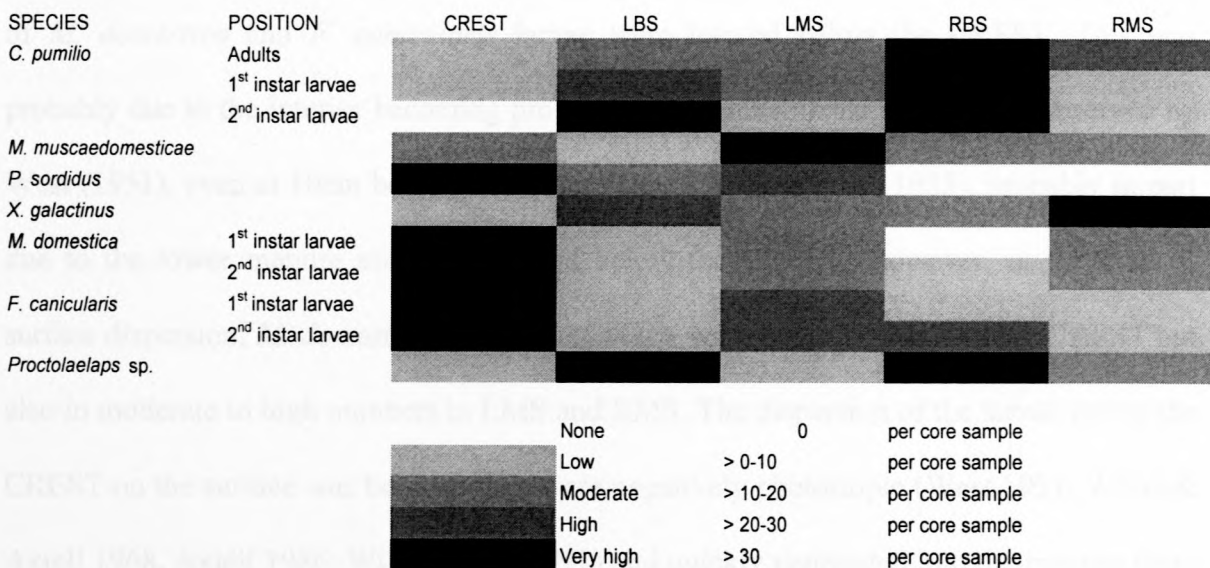


Fig. 9. Spatial distribution of arthropods per core sample near the manure surface.

4. DISCUSSION

The species in the interior of the manure were not uniformly distributed and tended to have a preference for a distinct microhabitat. Willis & Axtell (1968) also observed a similar dispersion pattern. Near the surface of the manure, almost every species occurred in all the sections sampled, a phenomenon also observed by Geden & Stoffolano (1988). The reasons for the demarcated dispersion in the interior were not clear, but probably involved some combination of poor gas exchange, prior exploitation by saprophytic organisms and a high degree of compaction, as was suggested by Geden & Stoffolano (1988), or avoidance of competition.

The larvae of *M. domestica* and *F. canicularis* distinctly occupied the CREST where the moisture content of the manure was around 70%. Fatchurochim *et al.* (1989) found the adults of *M. domestica* and *F. canicularis* discriminatory as far as manure moisture was concerned, and they oviposited mostly in manure with 70% moisture. Axtell (1970) also stated that fresh droppings of manure were favourable for fly production due to their high moisture content. Similarly, Peck & Anderson (1969) observed that immatures of filth flies were usually found in wet manure, as was also shown in Chapter 1. Insignificant numbers of *M. domestica* and *F. canicularis* larvae were located below the CREST. This was probably due to the interior becoming progressively uninhabitable as was also observed by West (1951), even at 10cm below the manure cone (Wallace *et al.* 1985), probably in part due to the lower manure moisture content below the CREST. However, in the case of surface dispersion, *M. domestica* and *F. canicularis* were not only found in the CREST but also in moderate to high numbers in LMS and RMS. The dispersion of the larvae below the CREST on the surface was because they were negatively phototropic (West 1951, Willis & Axtell 1968, Axtell 1986, Wilhoit *et al.* 1991) and quickly penetrated into the manure upon hatching (Wilhoit *et al.* 1991).

Very little larval development of flies occurred in manure with a moisture content of less than 40%. Stafford & Bay (1987) and Fatchurochim *et al.* (1989) also observed little or no fly larval development at moisture levels of less than 40% and 30% respectively. It therefore appeared that by manipulating the manure to keep it as dry as possible the habitat conducive for filth fly reproduction could be eliminated or reduced in size. This could be employed, as suggested by Axtell & Arends (1990), in an IPM approach to achieve an acceptably low level of the filth flies in a confined poultry facility. Furthermore, the predominant predator, *C. pumilio*, was mostly found in relatively drier manure with less than 60% moisture in the interior. Smith (1975) also found relatively high numbers of *C. pumilio* in manure containing 40% moisture whilst Peck & Anderson (1969) mention that *C. pumilio* favoured drier manure.

Relatively dry manure would not only expand the microhabitat favourable for predators like *C. pumilio* but also, as stated by Axtell (1986), provided a desirable habitat for the predators to locate and attack fly eggs and larvae. The drying up of accumulated manure could be accomplished by a building design for the poultry house that maximizes the ventilation of the manure and make provision for water drainage away from the house. These measures should be coupled with careful maintenance of the watering system to minimize leaks, as suggested by Axtell (1970) and Axtell & Arends (1990).

Macrocheles muscaedomesticae was dispersed in moderate numbers in the CREST and very high numbers in LMS slightly beneath in the interior of the manure cone, which was in agreement with the findings of Willis & Axtell (1968). It was also dispersed on the entire surface of the manure cone, as was also observed by Geden & Staffolano (1988). These regions were where they could find their prey: fly eggs and 1st instar larvae. In this study, most of the mite's dispersion zone overlapped with that of *M. domestica* and *F. canicularis* larvae in the manure cone. This placed the mite in an excellent position to prey upon the filth fly eggs laid on the outer layer of the manure cone and 1st instar larvae that

would hatch from them. Like *M. muscaedomesticae*, *P. sordidus* was mainly found in the CREST.

Adults of *C. pumilio* occurred at all depths within the interior of the manure, a phenomenon also observed by Armitage (1985). They also appeared to move across a wide range of manure moisture levels in the interior of the manure, an observation also made by Geden & Stoffolano (1988). However, near the manure surface, a significant number was found where the manure moisture level was greater than 70%. This overlapped spatially with the position of the prey, *M. domestica* and *F. canicularis* 1st instar larvae, which also had occurred in high numbers at that moisture range. This appeared to indicate that *C. pumilio* had a wide range of moisture tolerance and forages wherever prey could be located within and near the surface of the manure. *C. pumilio* also had a wide range of temperature tolerance within the manure, an indication that it could adapt to a wide range of physical conditions, as was also reported by Bills (1973). These adaptive features could stem from transition from avian manure to an almost mono-agricultural system like poultry farming where relatively wet chicken droppings accumulate over a long period. *C. pumilio* has been collected in diverse habitats such as stored grain, glue factories and carrion (Hinton 1945, Geden & Staffolano 1988, Rutz & Patterson 1990).

The position at which manure samples were taken for an arthropod census in a manure cone, could have profound effects on the perceived predator and prey abundance, as was also observed by Geden & Stoffolano (1988).

Among the predators encountered *C. pumilio* appeared to have a high level of foraging ability both within and near the surface of the manure cone. It was much more abundant than the other predators, and could tolerate a wide range of environmental factors. Thus, it could be an ideal candidate to be reared for agumentation in filth fly IPM programs.

The majority of the arthropod predators, especially *C. pumilio*, were dispersed below the CREST within the interior where the manure was drier. In contrast, *M. domestica* and *F. canicularis* larvae were mostly found in the CREST where the manure was wet. This seemed to suggest that the regular removal of the upper portions of the manure as a fly management strategy, with the lower base providing an absorbent pad for freshly accumulating droppings, a system also suggested by Legner (1971).

REFERENCES

- ANDERSON, J. R. 1966. Recent developments in the control of some arthropods of public health and veterinary importance. *Bulletin of the Entomological Society of America* **12**: 342-348.
- ARMITAGE, D. M. 1985. Environment of deep-pit poultry houses: survey of air and manure temperatures in British houses. *British Poultry Science* **26**: 275-278.
- AXTELL, R. C. 1968. Integrated house fly control: Populations of fly larvae and predaceous mites, *Macrocheles muscaedomesticae*, in poultry after larvicide treatment. *Journal of Economic Entomology* **61**: 245-249.
- AXTELL, R. C. 1970. Integrated fly-control program for caged-poultry houses. *Journal of Economic Entomology* **63**: 400-405.
- AXTELL, R. C. 1986. Fly management in poultry production: cultural, biological and chemical. *Poultry Science* **65**: 657-667.
- AXTELL, R. C. & ARENDS J. J. 1990. Ecology and management of arthropod pests of poultry. *Annual Review of Entomology* **35**: 101-126.
- AXTELL, R. C. & EDWARDS, T. D. 1983. Efficacy and nontarget effects of Larvadex® as a feed additive for controlling house flies in caged-layer poultry manure. *Poultry Science* **62**: 2371-2377.

- BAILEY, D. L., MEIFERT, D. W. & BISHOP, P. M. 1968. Control of house flies in poultry houses with larvicides. *Florida Entomologist* **51**: 107-111.
- BILLS, G. T. 1973. Biological fly control in deep-pit poultry houses. *British Poultry Science* **14**: 209 - 212.
- BLOOMCAMP, C. L., PATTERSON, R. S. & KOEHLER, P. G. 1987. Cyromazine resistance in the house fly (Diptera: Muscidae). *Journal of Economic Entomology* **80**: 352-357.
- BRADLEY, U. E., MEIFERT, D. W. & LABRECQUE, G. C. 1966. Residual sprays for the control of house flies in field tests. *Journal of Economic Entomology* **59**: 1522-1523.
- CONWAY, J., A. 1973. The micro-fauna of California-system poultry houses in Britain. *British Poultry Science* **14**: 213-216.
- FATCHUROCHIM, S., GEDEN, C. J. & AXTELL, R. C. 1989. Filth fly (Diptera) oviposition and larval development in poultry manure of various moisture levels. *Journal of Entomological Science* **24**: 224-231.
- GEDEN, C. J. & STOFFOLANO, J. G. 1988. Dispersion patterns of arthropods associated with poultry manure in enclosed house in Massachusetts: spatial distribution and effects of manure moisture and accumulation time. *Journal of Entomological Science* **24**: 136-148.
- GREENBERG, B. 1973. *Flies and disease, Biology and disease transmission*. Princeton University, Princeton, N. J.
- GRIFFITHS, K. J. 1969. The importance of coincidence in the functional responses of two parasites of the european pine sawfly, *Neodiprion sertifer*. *Canadian Entomologist* **101**: 673-713.
- HINTON, H. E. 1945. The Histeridae associated with stored products. *Bulletin of Entomological Research* **35**: 309-340.
- HOWARD, J. & WALL, R. 1996. Control of the house fly, *Musca domestica*, in poultry units: current techniques and future prospects. *Agricultural Zoology Reviews* **7**: 247-265.
- HULLEY, P. E. 1983. A survey of the flies breeding in poultry manure, and their potential natural enemies. *Journal of the Entomological Society of Southern Africa* **46**: 38-47.

- LEGNER, E. F. 1971. Some effects of the ambient arthropod complex on the density and potential parasitization of muscoid Diptera in poultry wastes. *Journal of Economic Entomology* **64**: 111-113.
- MILLER, R. W., SCHMIDTMANN, E. T., WAUCHOPE, R. D., CLEGG, C. M. HERNER, A. E., & WEBER, H. 1996. Urine delivery of cyromazine for suppressing house and stable flies (Diptera: Muscidae) in outdoor dairy calf hutches. *Journal of Economic Entomology* **89**: 689-694.
- PECK, J. H. & ANDERSON, J. R. 1969. Arthropod predators of immature Diptera developing in poultry droppings in Northern California. *Journal of Medical Entomology* **6**: 163-167.
- RUTZ, D. A. & PATTERSON, R. S. 1990. *Biocontrol of arthropods affecting livestock and poultry*. Westview Press, Boulder, San Francisco.
- SMITH, K. A. 1975. *Observations on the life history, ecology and behaviour of Carcinops pumilio* (Erichson). MSc. Thesis, Department of Entomology, University of New Hampshire, Durham.
- SMITH, L. & RUTZ, D. 1991. Relations of microhabitat to incidence of house fly (Diptera: Muscidae) immatures and their parasitoids at dairy farms in central New York. *Environmental Entomology* **20**: 669-674.
- STAFFORD, K. C. & BAY, D. E. 1987. Dispersion pattern and association of house fly, *Musca domestica* (Diptera: Muscidae), larvae and both sexes of *Macrocheles muscaedomesticae* (Acari: Macrochelidae) in response to poultry manure moisture, temperature and accumulation. *Environmental Entomology* **16**: 159-164.
- TANADA, Y., HOLDAWAY, F. G. & QUISENBERRY, J. H. 1950. DDT to control flies breeding in poultry manure. *Journal of Economic Entomology* **43**: 30-36.
- TOYAMA, G. M. & IKEDA, J. K. 1976. An evaluation of fly breeding and fly parasites at animal farms on leeward and central Oahu. *Proceedings, Hawaiian Entomological Society* **22**: 353-368.

WALLACE, M. M. H., WINKS, R. G. & VOESTERMANS, J. 1985. The use of beetle, *Alphitobius diaperinus* (Panzer) (Coleoptera: Tenebrionidae) for the biological control of poultry dung in high-rise layer houses. *The Journal of the Australian Institute of Agricultural Science* **51**: 214-219.

WEST, L. S. 1951. *The house fly: its natural history, medical importance and control*. Comstock Publishing Company, Ithaca, New York.

WILHOIT, L. R., STINNER, R. E. & AXTELL, R. E. 1991. *Computer simulation model of house fly management in confined-animal production systems*. North Carolina Agricultural Research Service, North Carolina State University, Raleigh, North Carolina. Technical Bulletin **296**:1-81.

WILLIS, R. R. & AXTELL, R. C. 1968. Mite predators of the house fly: a comparison of *Fuscuropoda vegetans* and *Macrocheles muscaedomesticae*. *Journal of Economic Entomology* **62**: 1669-1676.

1. INTRODUCTION

Modern egg production systems house many hens in confinement. The subsequent manure accumulation creates an unhygienic environment and the breeding of certain arthropods. The housefly, *Musca domestica* L. (Diptera: Muscidae) has become a major pest (West 1951; Comby 1972; Tzipora & Pardo 1980; Van der Meulen 1977; Hulley 1983, 1986; Axteff 1988; Hulley & Pridmore 1988; Ryan & Perreault 1991).

CHAPTER 4

THE SUCCESSION OF ARTHROPODS IN ACCUMULATING POULTRY MANURE AND THE RELATIONSHIP BETWEEN MANURE HEIGHT AND THEIR NUMBERS

ABSTRACT

A succession pattern of arthropods in accumulating poultry manure was censused throughout a 16 week period (6 December 1999 to 19 March 2000) at two sites in the Western Cape Province, South Africa. The early colonizers were the dipterans, *Musca domestica* L. and *Fannia canicularis* (L.), followed by the mite *Proctolaelaps* sp., the staphylinid *Philonthus sordidus* (Gravenhorst) and the mite *Macrocheles muscaedomesticae* (Scopoli). The histerid *Carcinops pumilio* (Erichson) was a late colonizer. The numbers of *M. domestica* and *F. canicularis* were very high one week post-cleaning but declined steadily thereafter, whilst *C. pumilio* was only present in high numbers after 8 to 10 weeks post cleaning. *Macrocheles muscaedomesticae* was relatively abundant throughout the census period. In most cases the breeding habitat exerted a major influence on the number of both prey and predatory arthropods. All the predators increased with an increase in manure accumulation whilst the number of fly larvae declined.

KEY WORDS: Arthropods, manure height, *Carcinops pumilio*, predators, succession.

1. INTRODUCTION

Modern egg production systems house many hens in suspension cages in a small area. The subsequent manure accumulation creates an artificial ecosystem, which is favourable for the breeding of certain arthropods. The housefly, *Musca domestica* L.(Diptera: Muscidae) can become a major pest (West 1951; Conway 1973; Toyama & Ikeda 1976; Bai & Sankaran 1977; Hulley 1983, 1986; Axtell 1986; Hulley & Pfliegerer 1988; Rutz & Patterson 1990) as

can also the lesser housefly *Fannia canicularis* (L.) (Diptera: Muscidae) (Axtell 1970, Conway 1973, Fatchurochim *et al.* 1989, Hulley 1986, Wilhoit *et al.* 1991). Chicken manure droppings accumulate at about 0.1kg per bird per day (Hart 1963) and increase in depth at about 1cm per day (Mullens *et al.* 1996). Bills (1973) estimated it to be at a rate of 3cm per week. Many South African egg producers allow the manure to be present for 3-6 months (narrow, open-sided housing) to up to 2-3 years (deep pit, natural environmentally controlled housing) before cleanout, allowing flies to develop in large numbers. They could be obnoxious to farm workers and affect near by residents and businesses (Tanada 1950; Axtell 1970, 1986; Pfeiffer & Axtell 1986; Axtell & Arends 1990), which could result in considerable social and expensive legal problems (Toyama & Ikeda 1976, Axtell & Arends 1990, Rutz & Patterson 1990, Howard & Wall 1996).

Ecological succession, as stated by Kesh *et al.* (1997), involves changes in species structure and community processes with time. Succession is community controlled even though the physical environment determines patterns and rates of change, and often limits how far its development can go. The phenomenon of succession may end in the formation of a stable biocenosis. DeAngeles (1992) states that the succession of species could result from one or a combination of the following factors: (a) Phenotypic characteristics of species, (b) changes in one or more environmental parameters that favours some species over others and (c) changes in the environment caused by the populations themselves.

Peck & Anderson (1969) observed that frequent disruption, such as complete manure removal from poultry houses, cause fly population increases that endure until stability is achieved. Manure habitat stability is synonymous with low numbers of filth flies in poultry houses (Legner & Olton 1970). Stability of the manure also results in a robust population of

scavenger, predatory and parasitic arthropods. Peck & Anderson (1969) state that certain physical and chemical changes occur in the composition of accumulated manure with time, making it less suitable for fly oviposition and development.

Most chemicals, including cyromazine (Larvadex[®]) used by South African egg producers to control flies, are toxic enough to threaten the destruction of the predaceous manure-inhabiting arthropods (Bradley *et al.* 1966, Axtell 1970). Residues of cyromazine could be retained in body tissues of bird meat and eggs (Howard & Wall 1996) as Miller *et al.* (1996) found for tissues of calves. Thus, consumers may refrain from buying chicken products should such information come to their knowledge. These problems, together with the possibility of resistance developing, highlight the limitations of chemical control and the need for an IPM approach.

IPM will involve proper manure management (Axtell 1970, Peck & Anderson 1970), biological control, and the judicious use of chemicals as a supplement (Axtell & Arends 1990), coupled with appropriate monitoring of the fly population and their effective natural enemies. This requires a better understanding of the community of arthropods in the manure and the changes in this community as the manure accumulates.

The objectives of this study were therefore (1) to monitor the succession of principal arthropods in the accumulating manure and (2) to determine the effect of manure accumulation on arthropod numbers.

2.3 Sampling

Manure samples were taken on a weekly basis from the two farms during the period of removal of the old manure (1994, 1995). Samples were taken from both of the

2. MATERIALS AND METHODS

2.1 Study sites and house design

The study on the succession pattern of arthropods in accumulating poultry manure was carried out between 06-12-1999 and 19-03-2000 at a University of Stellenbosch Experimental Poultry House, Elsenburg, Western Cape Province, South Africa (33° 51'S; 18° 50'E) at 177m altitude and at Rosendal Poultry Farm (a private enterprise), Paarl, Western Cape Province, South Africa (33° 43'S; 19° 01'E), at an altitude of 831m.

The University House was an open sided commercial egg laying type with ventilation and temperature control by natural means. Birds were housed in single-tier cages suspended about 1m from the floor, four birds per cage with 0.45m-floor space per bird. Cages were in rows crosswise in the building. Paths between the rows were concrete with manure accumulating beneath the cage in dugout sand.

The house at Rosendal Farm was a two-storied commercial egg production unit about 12m wide and 180m long. The birds were kept on the top-story where there were wooden walkways between the banks of tiered cages and no floor beneath the cages. There were four birds per cage with 0.45m floor space per bird. The cages were set parallel to the length of the second floor with the cages stacked four high, with space to allow manure to drop below. The manure accumulated on the dirt floor and was allowed to remain for 12 months. Ventilation and temperature control was by natural means, ie. the opening and closing of windows.

2.2 Sampling.

Manure samples were taken on a weekly basis from the two houses starting one week after the removal of the old manure (1wk PC). Samples were taken from each of 10 positions in each

house with an auger of 5.0cm diameter and 9.0cm length, with a core volume of about 0.18 litres. At each position, the auger was inserted at a 45° angle just below the tip of the manure cone to avoid freshly deposited manure. The auger was gently rotated before pulling it out together with the manure. During the first four weeks post-cleanout (PC), a hand trowel was used to fill the auger with manure. Each sampling position was marked with small flagged sticks to avoid sampling the same point again. Sampling of manure was done along central rows to avoid edge and side biases. The total sample was placed in an ice-cream container and taken to the laboratory where the manure was placed in Tullgren funnels with 60w bulbs as source of heat for 72 hours. The arthropods were extracted into 70% ethanol and later counted. The average number per sample and the standard error were calculated. All stages of dominant coleopterans and first and second instar larvae of *M. domestica* and *F. canicularis* were counted. All stages of the mite *Macrocheles muscaedomesticae* (Scopoli) (Acarina: Macrochilidae) were counted individually as they could be seen with the naked eye, but the numbers of the minute mite *Proctolaelaps* sp. (Acarina: Ascidae), also all stages, were determined volumetrically from the known number per 5ml.

In order to identify the fly species, further adjacent samples were taken from which puparia were extracted by flotation on water. The floating pupae were collected with a pair of forceps and placed in test tubes. The emerged adult flies were then identified. The height of the manure was measured every week at each sampling position by inserting a meter rule vertically and pushing it down until it reached the firm ground.

2.3 Analysis

The mean number of each species collected versus time was plotted. In addition, the regression relationship between mean manure height (x) and number of arthropods ($\log y + 1$) was estimated.

3. RESULTS

3.1 Arthropod numbers at University House

3.1.1 Prey Numbers

The three major prey species found in the manure were the two dipterans *M. domestica* and *F. canicularis* and the mite *Proctolaelaps* sp. The numbers of the 1st and 2nd instar larvae of *M. domestica* were initially very high at 107.6 ± 37 and 16.5 ± 3.33 larvae/core sample (1wk PC). The numbers then declined and remained low throughout the census period (Fig. 1a, b). Like *M. domestica*, the numbers of 1st and 2nd instar larvae of *F. canicularis* were initially (1wk PC) very high at 145.0 ± 26.69 and 158.8 ± 34.23 larvae/core sample respectively. This was followed by a sharp decline in larval numbers at 2wks PC after which few larvae were found (Fig. 1c, d). The numbers of *Proctolaelaps* sp. (all stages) were initially low (2wks PC) but attained a peak of 1285.6 ± 569.20 larvae/core sample at 3wks PC.

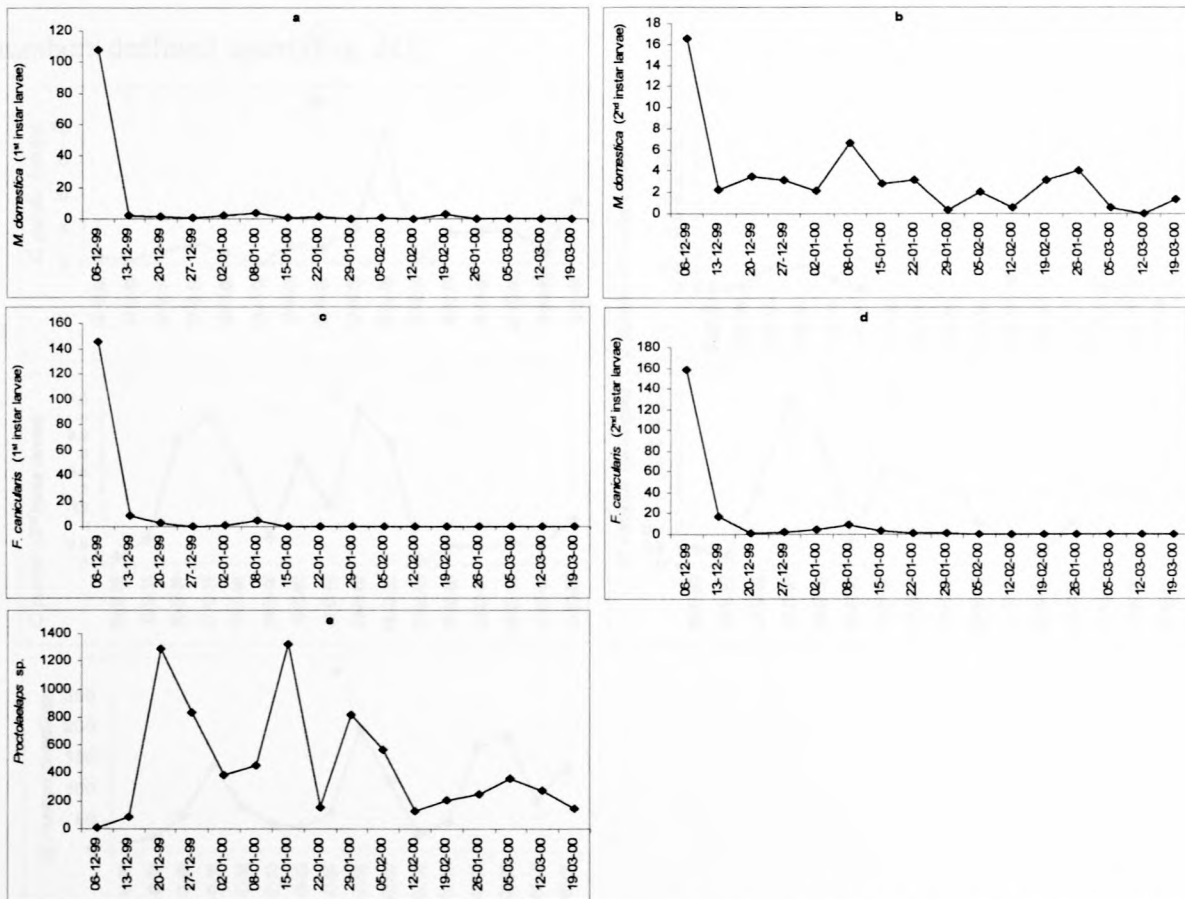


Fig. 1. Mean numbers of arthropod prey per 0.18 litre core sample collected from University House throughout a three month manure accumulating cycle.

3.1.2 Predator Numbers

The dominant predators found in the manure were *Carcinops pumilio* (Erichson) (Coleoptera: Histeridae), *Philonthus sordidus* (Gravenhorst) (Coleoptera: Staphylinidae) and the mite *M. muscaedomesticae*. The numbers of adult *C. pumilio* were very low after the cleanout (Fig. 2a). The first minor peak was 2.9 ± 1.29 larvae/core sample at 4wks PC and then numbers declined again. They had a maximum peak of 18.8 ± 6.03 larvae/core sample at 10wks PC. This was followed by two minor peaks of 6.2 ± 2.35 and 9.0 ± 3.65 larvae/core sample around 13wks PC and at 16wks PC, respectively (Fig. 2a). The first instar larvae of *C. pumilio* initially oscillated at fairly low numbers and reached a maximum of 3.9 ± 2.44 larvae/core sample at 16wks PC, the last census week (Fig. 2b). The second instar larvae reached 4.1 ± 0.77 larvae/core sample at 4 and 9 wks PC (Fig. 2c). The numbers of *P. sordidus*, remained low and reached a peak of 1.9 ± 0.41 larvae/core sample at 4wks PC (Fig. 2d), whilst the numbers of *M. muscaedomesticae* had three peaks about five weeks apart. After the peaks, the numbers declined again (Fig. 2e).

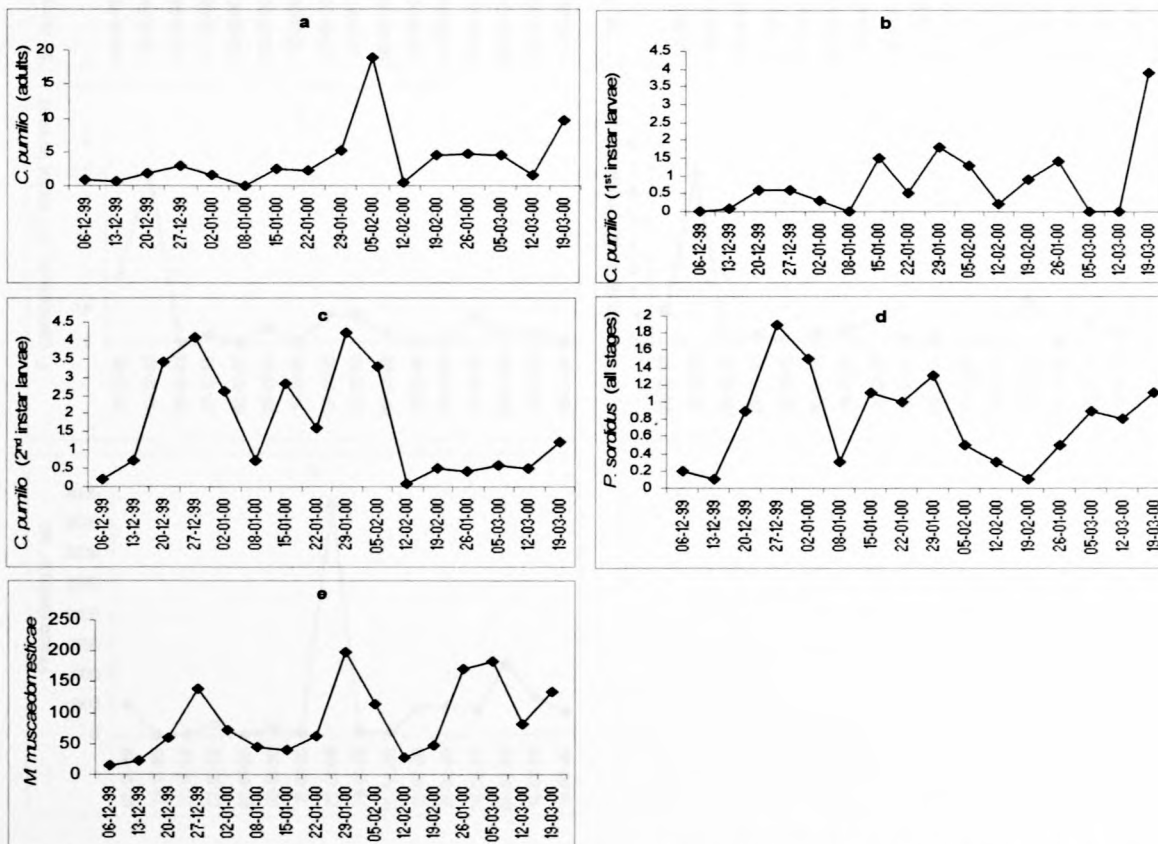


Fig. 2. Mean number of arthropod predators per 0.18 liter core sample collected from University House throughout a three month manure accumulation cycle.

3.2 Arthropod numbers at Rosendal Farm

3.2.1 Prey numbers

The numbers of 1st and 2nd instar larvae of *M. domestica* were generally very low. The 1st instar larvae reached a peak of 3.2 ± 2.98 larvae/core sample (6wks PC) (Fig. 3a). Numbers of the 2nd instar larvae had small peaks at 2, 6 and 15wks PC, reaching a maximum of 3.8 ± 1.67 . The 1st and 2nd instar numbers of *F. canicularis* peaked after 2wks PC at 2.5 ± 2.50 and 6.8 ± 4.24 larvae/core sample respectively, and then declined to low numbers throughout the census period (Figs. 3c, d).

Numbers of *Proctolaelaps* sp. were relatively low after cleanout, peaking only once at 3793.7 ± 2091.59 per core sample during 8wks PC (Fig. 3e).

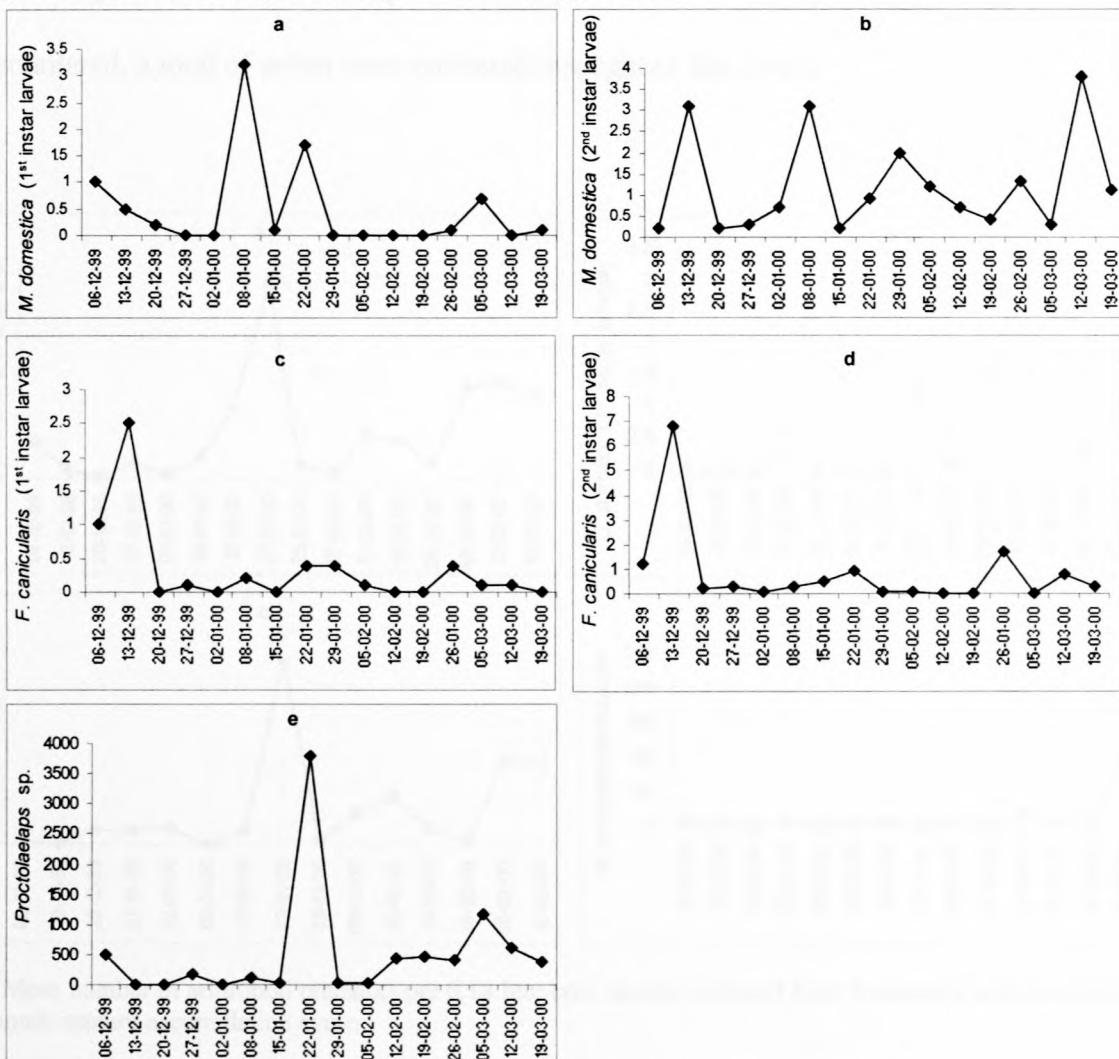


Fig. 3. Mean numbers of arthropod prey per 0.18 litre core sample collected from Rosendal Farm throughout a three month manure accumulating cycle.

3.2.2 Predator numbers

At the Rosendal Farm, the numbers of the adult *C. pumilio* also remained low initially and then increased to reach a major peak of 18.6 ± 6.00 larvae/core sample at 8wks PC, 3 weeks earlier than at the University House (Fig. 4b). The numbers of first instar larvae reached a peak of 3.1 ± 1.36 larvae/core sample at 16wks PC, similar to those at the University (Fig. 4b). The numbers of the 2nd instar larvae peaked also at 5.5 ± 2.0 larvae/core sample, 8wks PC (Fig. 4c) like the adults.

The predatory mite, *M. muscaedomesticae* had low numbers for the greater part of the census season. The numbers started increasing at 14wks PC 92.3 ± 67.83 per core sample when they reached a peak of 202.6 ± 86.10 per core sample a week later (Fig. 4d). *P. sordidus* was rarely encountered, a total of seven were collected throughout the census.

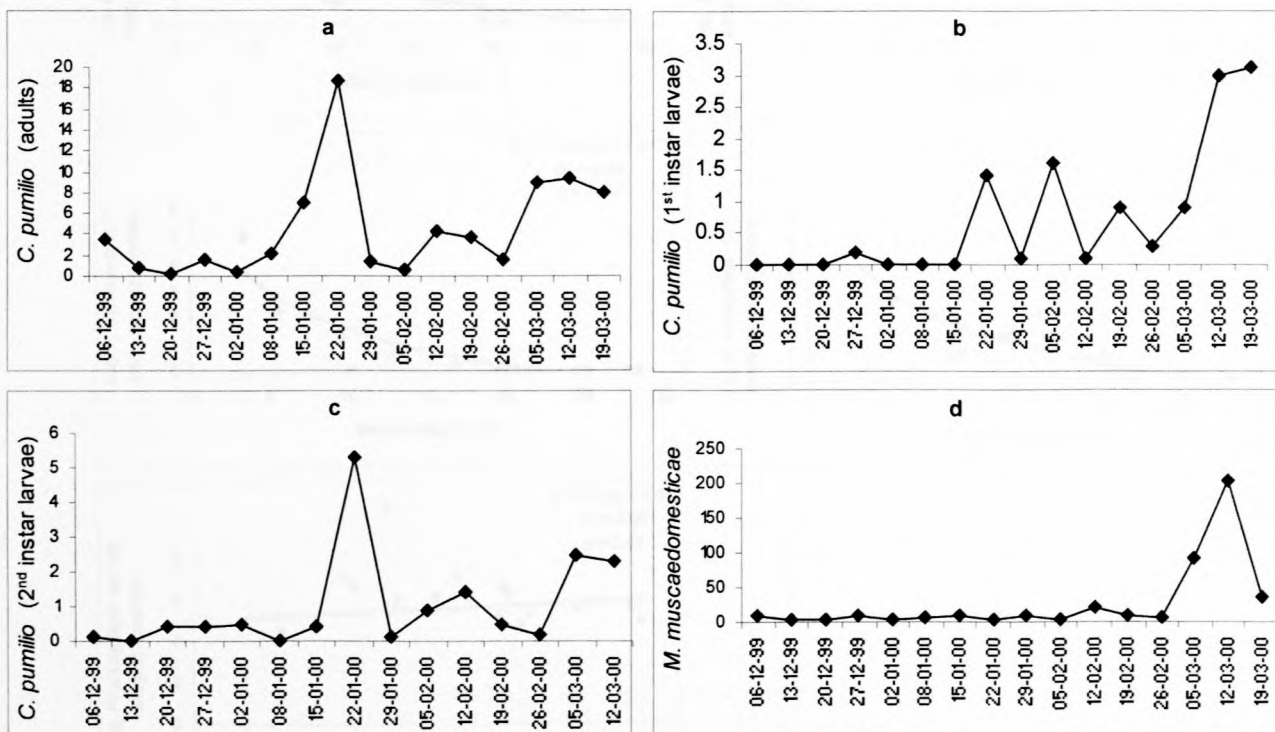


Fig. 4. Mean number of arthropod predators per 0.18 liter core sample collected from Rosendal Farm throughout a three month manure accumulation cycle.

4. Relationship between manure height and arthropod numbers

4.1 University House

4.1.1 Prey numbers

The 1st and 2nd instar larvae of *M. domestica* and *F. canicularis* were negatively correlated with manure height (Fig. 5a, b, c, d). The numbers of *Proctolaelaps* sp. remained relatively high and appeared not to be affected by the increase in manure height (Fig. 5e). The 1st instar larvae of *M. domestica* and 1st and 2nd instar larvae of *F. canicularis* declined to very low numbers at a manure height above 25cm. The height of the manure accumulated at the rate of about 1cm/week (Table 1).

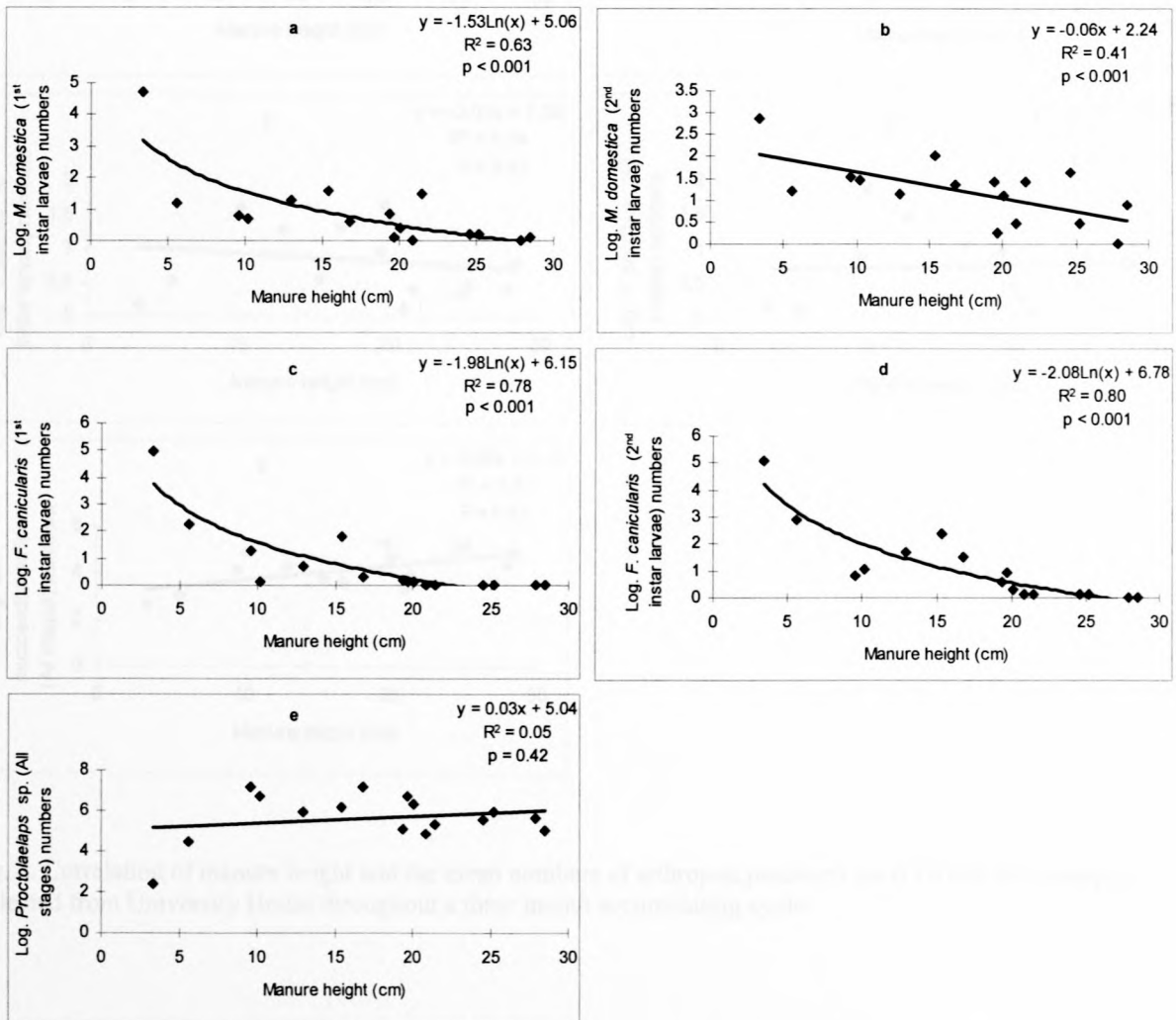


Fig. 5. Correlation of manure height and the mean numbers of arthropod prey per 0.18 litre core sample collected from the University House throughout a three month accumulating cycle.

4.1.2 Predator numbers

The numbers of adults and 1st instar *C. pumilio* larvae were positively correlated with manure height (Fig. 6a, b). As the manure height increased the ratio of adults to larvae of *C. pumilio* increased (Fig. 2a, b, c). Numbers of *P. sordidus* showed no discernible relationship with manure height (Fig. 6d), whilst the numbers of *M. muscaedomesticae* were positively correlated with an increase in manure height (Fig. 6e).

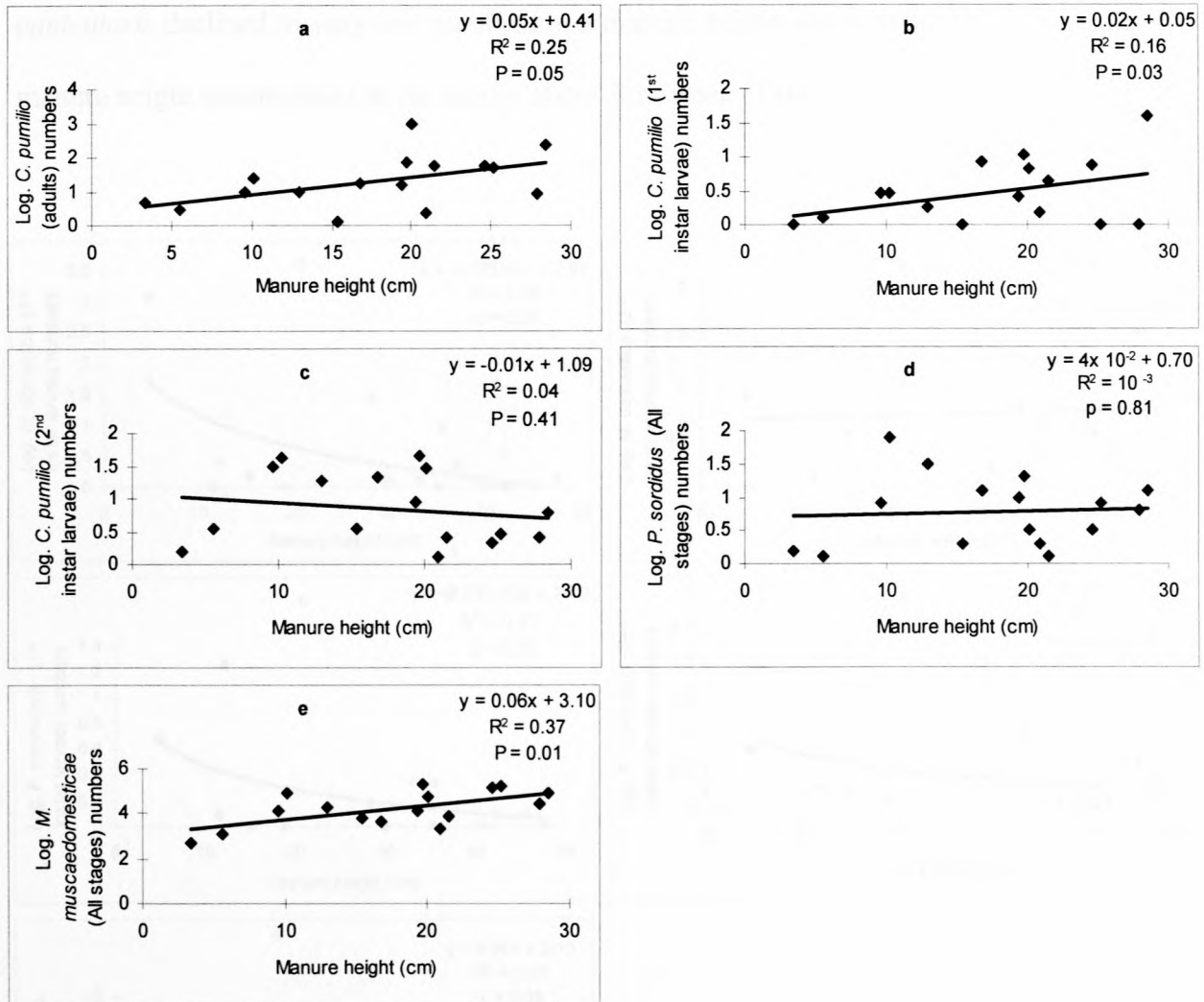


Fig. 6. Correlation of manure height and the mean numbers of arthropod predators per 0.18 litre core sample collected from University House throughout a three month accumulating cycle.

4.2 Rosendal Farm

4.2.1 Prey numbers

The numbers of 1st instar *M. domestica* larvae and 1st and 2nd instar *F. canicularis* were negatively correlated with the increase in manure height (Fig.7a, c, d) whilst those of 2nd instar *M. domestica* and the mite *Proctolaelaps* sp. had no correlation with increase in manure height (Fig. 7b, e). The 1st instar larvae of *M. domestica* and 1st and 2nd instar larvae of *F. canicularis* declined to very low numbers at a manure height above 40cm (Fig. 7a, c, d). The manure height accumulated at the rate of about 3cm/week (Table 1).

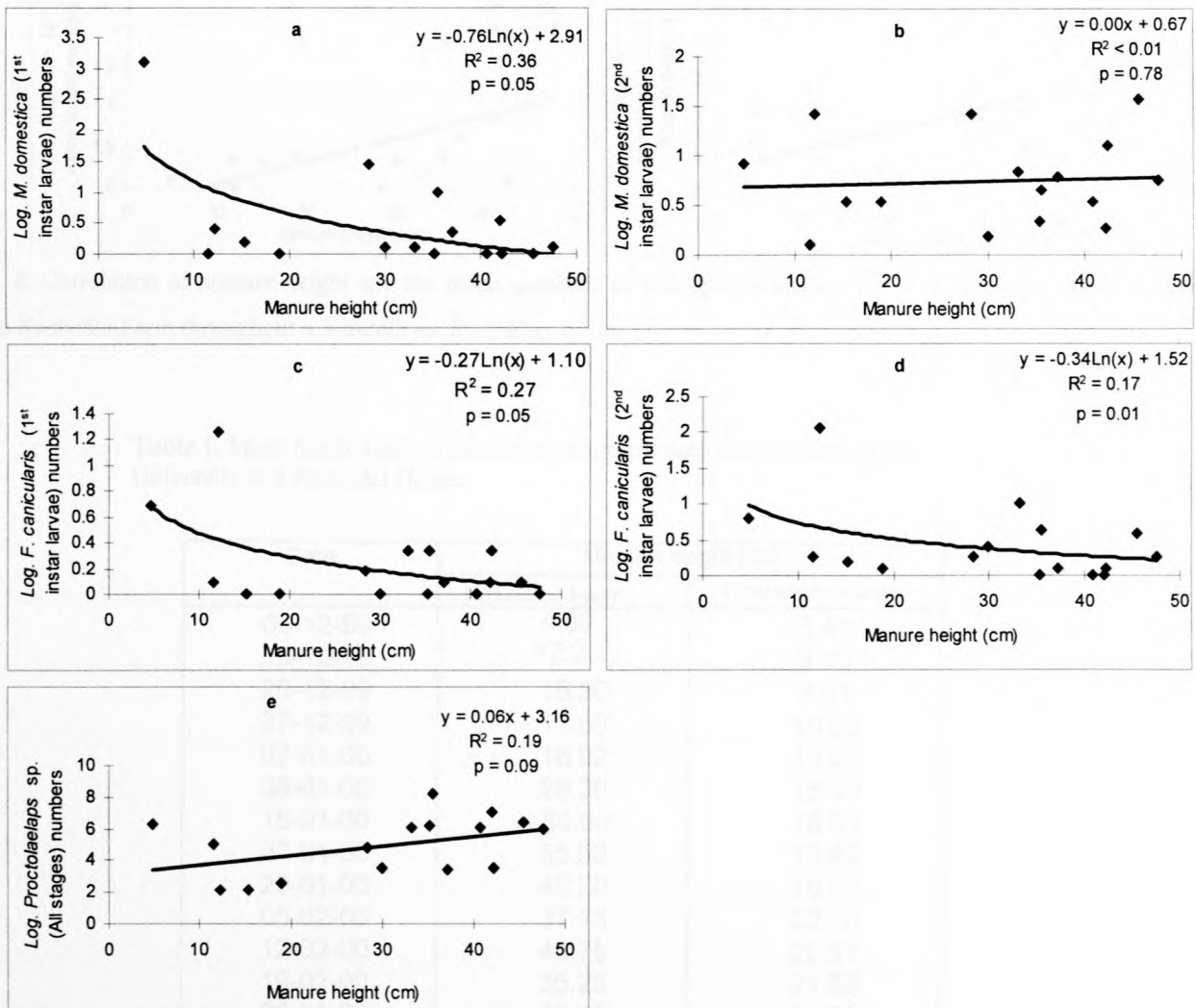


Fig. 7. Correlation of manure height and the mean numbers of arthropod prey per 0.18 litre core sample collected from Rosendal Farm throughout a three month accumulating cycle

4.2.2 Predator numbers

The numbers of *C. pumilio* (adults and larvae) and *M. muscaedomesticae* (all stages) were positively correlated with increase in manure height, and reached high numbers at a manure height above 30cm (Fig. 8). The ratio of adult to larvae of *C. pumilio* was always adult biased throughout the census period (Fig.4).

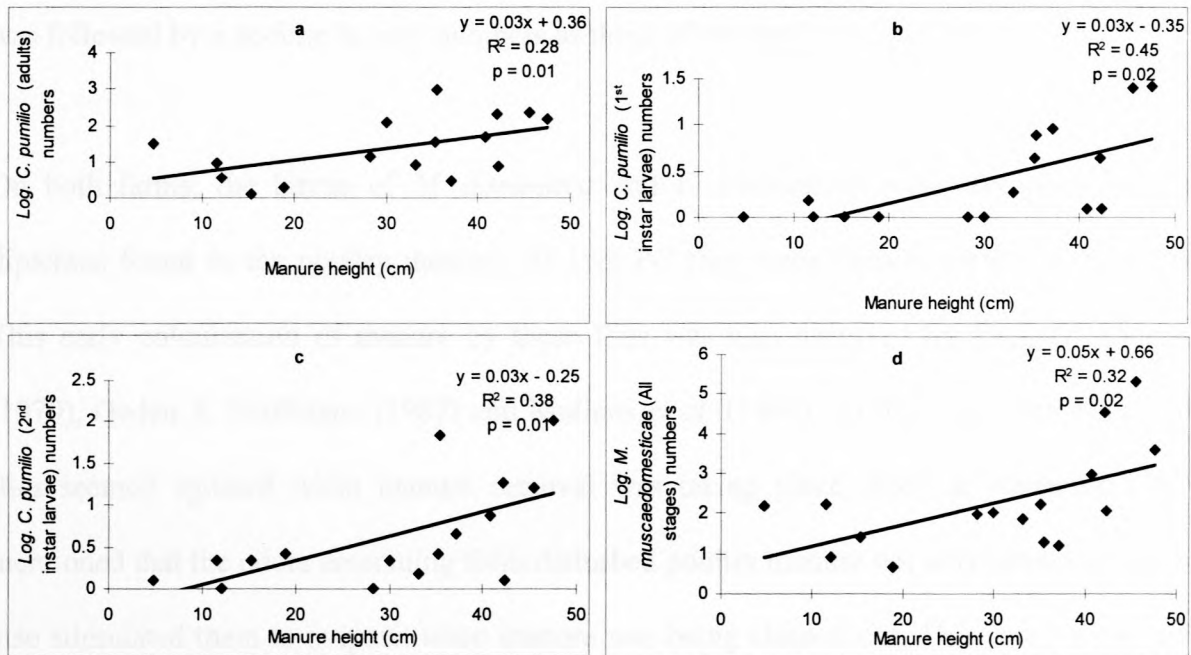


Fig. 8. Correlation of manure height and the mean numbers of arthropod predators per 0.18-litre core sample collected from Rosendal Farm throughout a 3-month accumulating cycle.

Table 1. Mean height (cm) of manure measured at each census week at the University and Rosendal House

| Date | Manure height (cm) | |
|----------|--------------------|------------------|
| | Rosendal Farm | University House |
| 06-12-99 | 4.80 | 3.41 |
| 13-12-99 | 12.20 | 5.60 |
| 20-12-99 | 15.30 | 9.61 |
| 27-12-99 | 11.60 | 10.23 |
| 02-01-00 | 18.92 | 13.01 |
| 08-01-00 | 28.30 | 15.40 |
| 15-01-00 | 30.00 | 16.81 |
| 22-01-00 | 35.50 | 19.40 |
| 29-01-00 | 42.28 | 19.71 |
| 05-02-00 | 37.13 | 20.10 |
| 12-02-00 | 40.75 | 20.91 |
| 19-02-00 | 35.25 | 21.50 |
| 26-01-00 | 33.15 | 24.63 |
| 05-03-00 | 42.11 | 25.21 |
| 12-03-00 | 45.55 | 27.90 |
| 19-03-00 | 47.60 | 28.50 |

5. DISCUSSION.

During the period of the weekly survey, the numbers of the arthropods in the accumulating manure fluctuated widely, which was presumably due to sampling variation. However, the general pattern was that of initial high numbers of prey and low numbers of predator. This was followed by a decline in prey numbers as those of the predators increased.

On both farms, the larvae of *M. domestica* and *F. canicularis* were the most abundant dipterans found in the poultry manure. At 1 wk PC they were already present at both sites. This early colonization of manure by these flies was also observed by Peck & Anderson (1970), Geden & Stoffolano (1987) and Mullens *et al.* (1996). At the University House, the flies seemed agitated when manure removal was taking place. Peck & Anderson (1970) mentioned that the odors emanating from disturbed poultry manure not only attracted flies but also stimulated them to oviposit when manure was being cleaned out. This could account for the high larval numbers encountered at 1 wk PC at the University House.

Although the fly populations had greatly declined by the time the predator numbers attained their peaks, they appeared to be important in the initial establishment of predators in newly accumulating manure. The predatory arthropods *C. pumilio*, *P. sordidus* and *M. muscaedomesticae* appeared to respond to the availability of *M. domestica* and *F. canicularis* as their numbers usually peaked about three weeks after those of the fly larvae.

After the two fly species the mite *Proctolaelaps* sp. was the next species to reach high numbers, attaining a peak two weeks after the peak of the fly numbers at both sites. With the decline in fly populations, the predators, *C. pumilio*, *M. muscaedomesticae* and *P. sordidus*

were apparently sustained by feeding on the large populations of *Proctolaelaps* sp., a phenomenon also observed by Geden & Stofollano (1987). Peaks in the numbers of *Proctolaelaps* sp. preceded those of *C. pumilio* adults and second instar larvae between 4 and 8wks intervals respectively. *Microcheles muscaedomesticae* also appeared to respond to the availability of the *Proctolaelaps* sp. and peaked about 1wk after the peak of the mites.

High numbers of *C. pumilio* adults only occurred from 8 to 10wks PC. This agrees with the work of Peck & Anderson (1970) and Mullens *et al.* (1996) who stated that the repopulation of newly accumulating manure by predatory beetles did not begin until at least 6wks PC. The slow increase in *C. pumilio* adult numbers occurred despite the abundance of prey, which could indicate that the fresh manure might not be attractive to them. Peck & Anderson (1970) stated that histerids preferred older manure whilst Geden (1984) mentioned that fresh manure was relatively not attractive to predators. This delay in colonization could serve as a window for the proliferation of synanthropic flies such as *M. domestica* (see also Chapters 1 and 2). Peck & Anderson (1970) also showed that pest flies increased in numbers while the predatory population was reduced considerably in both weekly and bi-weekly complete manure removals.

The predaceous beetle *P. sordidus* was only present at the University House and then only in low numbers. It was already present 1wk PC, an indication that it was not averse to fresh manure droppings. It attained peak numbers 4wks PC. Peck & Anderson (1970) also found that *P. sordidus* repopulated new manure in significant numbers 4wks PC. *Philonthus sordidus* was the fourth in succession to colonize the fresh accumulating manure attaining peak numbers 3wks after the peak of the early colonizers, the two fly species.

Microcheles muscaedomescae colonized the manure at the University House in significant numbers at 4wks PC, about the same time as *P. sordidus*, but at the Rosendal Farm, it arrived much later. Peck & Anderson (1970) also observed that *M. muscaedomesticae* became abundant in 4wks old manure.

In most cases the mass of the breeding habitat influenced the number of both prey and predatory arthropods. All the predators increased in density with an increase in manure accumulation. This was also described in Chapter 2 and by Peck & Anderson (1969). The trend was generally reversed, however, for the prey on both farms except for *Proctolaelaps* sp. As the manure deposits became higher and aged the number of fly larvae declined. This was also described in Chapter 1 and by Legner *et al.* (1973).

The considerable increase in the numbers of arthropod predators at manure heights above 20 to 30cm seems to suggest that it may be desirable to retain the manure height at least at this level for the benefit of the predators, a suggestion also made by Legner *et al.* (1973). It will be desirable to retain even greater heights for fly control at certain times of the year as was also suggested by Legner *et al.* (1973). In the Western Cape Province, it appears that maximum manure height should be maintained during the October-February season for *M. domestica* and the May-July season for *F. canicularis* when these flies are abundant (Chapter 1). The removal of accumulated manure might best be accomplished in March-April and August-September when maximum heights would be least needed for the reduction of the predominant synanthropic flies.

It was possible that the reduction in the number of fly larvae with accumulating manure was not only due to the increase in predator and possibly parasitoid numbers, but also due to

physico-chemical changes in the manure making it less suitable for fly oviposition and development (Legner & Olton 1970, Legner *et al.* 1973). In this study, manure droppings accumulated at about 1-3cm/wk, as was also observed by Bills (1973). The accumulated manure gradually settled on its own weight due to gravity (Bills 1973), becoming more compact (Legner *et al.* 1973). Such changes render part of the manure cone uninhabitable for flies, but conducive for the development of predators and parasitoids (Peck & Anderson 1969, Legner & Olton 1970).

REFERENCES.

- AXTELL, R. C. 1970. Integrated fly-control program for caged-poultry houses. *Journal of Economic Entomology* **63**: 400-405.
- AXTELL, R. C. 1986. Fly management in poultry production: cultural, biological and chemical. *Poultry Science* **65**: 657-667.
- AXTELL, R. C & ARENDS J. J. 1990. Ecology and management of arthropod pests of poultry. *Annual Review of Entomology* **35**: 101-126.
- BAI, G. M. & SANKARAN, T. 1977. Parasites, predators and other arthropods associated with *Musca domestica* and other flies breeding in bovine manure. *Entomophaga* **22**: 163-167.
- BILLS, G. T. 1973. Biological fly control in deep-pit poultry houses. *British Poultry Science* **14**: 209-212.
- BRADLEY, U. E., MEIFERT, D. W. & LABRECQUE, G. C. 1966. Residual sprays for the control of house flies in field tests. *Journal of Economic Entomology* **59**: 1522-1523.
- CONWAY, J., A. 1973. The micro-fauna of California - system poultry houses in Britain. *British Poultry Science* **14**: 213-216.

- DEANGELIS, D. L. 1992. *Dynamics of nutrients cycling and food webs*. Chapman and Hall, London.
- FATCHUROCHIM, S., GEDEN, C. J. & AXTELL, R. C. 1989. Filth fly (Diptera) oviposition and larval development in poultry manure of various moisture levels. *Journal of Entomological Science* **24**: 224-231.
- GEDEN, C. J. 1984. *Population dynamics, spatial distribution, dispersal behaviour and life history of the predaceous histerid, Carcinops pumilio (Erichson), with observations of other members of the poultry manure arthropod community*. Ph.D. dissertation, University of Massachusetts, Amherst.
- GEDEN, C. J. & STOFFOLANO, J. G. 1987. Succession of manure arthropods at a poultry farm in Massachusetts, USA, with observations on *Carcinops pumilio* (Coleoptera: Histeridae) sex ratios, ovarian condition and body size. *Journal of Medical Entomology* **24**: 212-220.
- HART, S. A. 1963. Fowl fecal facts. *World's Poultry Science Journal* **19**: 262-266.
- HOWARD, J. & WALL, R. 1996. Control of the house fly, *Musca domestica*, in poultry units: current techniques and future prospects. *Agricultural Zoology Review* **7**: 247-265.
- HULLEY, P. E. 1983. A survey of the flies breeding in poultry manure, and their potential natural enemies. *Journal of the entomological Society of southern Africa* **46**: 38-47.
- HULLEY, P. E. 1986. Factors affecting numbers of *Musca domestica* Linnaeus (Diptera: Muscidae) and some other flies breeding in poultry manure. *Journal of the entomological Society of southern Africa* **49**: 19-27.
- HULLEY, P. E. & PFLEIDERER, M. 1988. The Coleoptera in poultry manure-potential predators of the house fly, *Musca domestica* Linnaeus (Diptera: Muscidae). *Journal of the entomological Society of southern Africa* **51**: 18-29.

- KESH, D., SARKAR, A. K. & ROY, A. B. 1977. Succession in a three-species food-chain model. *Ecological Modelling* **96**: 211-219.
- LEGNER, E. F. & OLTON, G. S. 1970. Worldwide survey and comparison of adult predator and scavenger insect populations associated with domestic animal manure where livestock is artificially congregated. *Hilgardia* **40**: 225-266.
- LEGNER, J. H., BOWEN, W. R., MCKEEN, W. D., ROONEY, W. F. & HOBZA, R. F. 1973. Inverse relationships between mass of breeding habitat and synanthropic fly emergence and the measurement of population densities with sticky tapes in California inland valleys. *Environmental Entomology* **2**: 199-205.
- MILLER, R. W., SCHMIDTMANN, E. T., WAUCHOPE, R. D., CLEGG, C. M., HERNER, A. E., & WEBER, H. 1996. Urine delivery of cyromazine for suppressing house and stable flies (Diptera: Muscidae) in outdoor dairy calf hutches. *Journal of Economic Entomology* **89**: 689-694.
- MULLENS, B. A. HINKLE, N. C. & SZIJJ, C. E. 1996. Impact of alternating manure removal schedules on pest flies (Diptera: Muscidae) and associated predators (Coleoptera: Histeridae, Staphylinidae; Acarina: Macrochelidae) in caged-layer poultry manure in Southern California. *Journal of Economic Entomology* **89**: 1406-1417.
- PECK, J. H. & ANDERSON, J. R. 1969. Arthropod predators of immature diptera developing in poultry droppings in Northern California. *Journal of Medical Entomology* **6**: 163-167.
- PECK, J. H. & ANDERSON, J. R. 1970. Influence of poultry-manure removal schedules on various Diptera larvae and selected arthropod predators. *Journal of Economic Entomology* **63**: 82-90.
- PFEIFFER, D. G. & AXTELL, R. C. 1980. Coleoptera of poultry manure in caged-layer houses in North Carolina. *Environmental Entomology* **9**: 21-28.

- RUTZ, D. A. & PATTERSON, R. S. 1990. *Biocontrol of Arthropods Affecting Livestock and Poultry*. Westview Press, Boulder, San Francisco.
- TANADA, Y., HOLDAWAY, F. G. & QUISENBERRY, J. H. 1950. DDT to control flies breeding in poultry manure. *Journal of Economic Entomology* **43**: 30-36.
- TOYAMA, G. M. & IKEDA, J. K. 1976. An evaluation of fly breeding and fly parasites at animal farms on leeward and central Oahu. *Proceedings, Hawaiian Entomological Society* **22**: 353-368.
- WEST, L. S. 1951. *The house fly: its natural history, medical importance and control*. Comstock Publishing Company, Ithaca, New York.
- WILHOIT, L. R., STINNER, R. E. & AXTELL, R. E. 1991. Computer simulation model of house fly management in confined-animal production systems. *North Carolina Agricultural Research Service, Technical Bulletin* **296**:1-81.

1. INTRODUCTION

The house fly, *Musca domestica* L. (Diptera: Muscidae) and the stable fly, *Stomoxys calcitrans* (L.) (Diptera: Muscidae) are important pests in confined animal production systems (Anderson & Fairbairn 1990, Anderson 1973, Toyama & Ikeda 1976, Fuller 1983, 1986, Fuller & Fairbairn 1989, Anderson 1991). Currently they are controlled mostly by the use of insecticides, eg. the organophosphates

CHAPTER 5

BIOLOGY OF *CARCINOPS PUMILIO* (ERICHSON) (COLEOPTERA: HISTERIDAE)

ABSTRACT:

Two larval instars of *Carcinops pumilio* (Erichson) were identified from a frequency distribution of the head capsule measurements. The total developmental time from egg to adult emergence in the laboratory at 30°C was about 20.5 days. The 2nd instar was the longest, accounting for 39% of the total development time. The 1st instar larvae sustained the highest mortality of 26% whilst there was no mortality in the pupal stage. The immature stages sustained about 50% mortality before adult emergence. The adult females of *C. pumilio* can live for 130 days and had a Type I survivorship curve, ie. the rate of survival was high in the young adults but decreased as the beetles aged. Newly emerged adults could survive for about 25 days without feeding. The sex ratio was 0.48 females: 0.52 males. The intrinsic rate of natural increase (r_m) was 0.064943 and the net reproduction rate was (R_0) 20.191.

Key words: *Carcinops pumilio*, life-table, developmental time.

1. INTRODUCTION

The house fly, *Musca domestica* L. (Diptera: Muscidae) and the lesser house fly, *Fannia canicularis* (L.) (Diptera: Muscidae) are important pests in confined poultry and other livestock production systems (Anderson & Poorbough 1964; Axtell 1970, 1985; Conway 1973; Toyama & Ikeda 1976; Hulley 1983, 1986; Hulley & Pfleiderer 1988, Chapter 5). Currently they are controlled mostly by the use of insecticides, eg. the larvicide cyromazine.

These have inherent limitations such as their toxicity to non-target organisms and the possibility of resistance developing.

As an alternative approach, the biological control of these flies using pteromalid parasitoids and predators is becoming more feasible in both developed and developing countries, as our knowledge about them and their commercial availability increase. Political and economic constraints may also influence the funding for bio-control research programmes and the need for and acceptance of bio-control measures (Axtell 1990).

Carcinops pumilio Erichson (Coleoptera: Histeridae), commonly found in poultry manure, is an important predator of house fly eggs and larvae (Pfeiffer & Axtell 1980, Morgan *et al.* 1983, Geden 1984, Geden & Stoffolano 1987, Chapter 2). The predation rates of this species have been determined by Geden *et al.* (1988). The use of this species is considered to be compatible with that of pteromalids such as *Spalangia endius* Walker (Morgan *et al.* 1983), because *C. pumilio* would be seeking fly eggs and larvae and not competing with the parasitoids for the host pupae.

The taxonomic characteristics of *C. pumilio* have been described by Hinton (1945) whilst the studies on its biology have been done on a limited scale by Hinton (1945) and expanded by Smith (1975), Morgan *et al.* (1983) and Geden (1984). No study on its biology has been conducted in South Africa and the present study was therefore aimed at determining its developmental time, fecundity and survival in South Africa. The data obtained were also used to construct a life table for *C. pumilio*.

2. MATERIALS AND METHODS

All experiments were carried out in the laboratory at the University of Stellenbosch, Cape Town (33° 54'S; 18° 57'E) from 20 September 1999 to 21 October 2000, at a controlled temperature of about 30°C.

2.1 Measurement of head capsules to determine the number of larval stages

Newly emerged 1st instar larvae of *C. pumilio* were reared and larvae were taken for measurement every day until pupation. The width and length of the head capsule were measured using a compound microscope equipped with an eyepiece micrometer. The width of the head capsule was measured at the major epicraneal setae. The length was measured from the tip of the mandible to the postoccipital suture. Eighty specimens were measured.

2.2 Developmental time and mortality of immature stages

2.2.1 Egg development

The rate of development from egg deposition to hatch was determined in triplicate. Eggs were obtained by placing about 250 adult beetles of undetermined sex onto the rearing medium (see Chapter 10) in a plastic container of 25 cm x 25 cm x 15 cm in an incubator at 30°C. The container had a lid with an opening of 20.5 cm in diameter which was covered with organdy held in place with glue. After 24 hours the adult beetles were removed from the container and returned to the incubator. At 24 hour intervals the medium was examined and emerged 1st instar larvae removed. In calculating the egg development time, it was assumed that all eggs were laid at the mid-point of the 24 hour adult oviposition interval and emerged at the mid-point between the 24 hour observation times.

To obtain the eggs, several adults were placed into 250cc petri dishes with an abundant supply of refrigerated *M. domestica* eggs and a wet hand paper towel. The later was removed after 12 hours and examined under a dissecting microscope for the eggs.

2.2.2 Larval and pupal development

Forty 1st instar larvae obtained in 2.2.1 were placed singly in petri dishes with moistened tissue paper covered with another petri dish to reduce desiccation. Each larva was supplied daily with about 200 frozen house fly eggs and 10g of *D. melanogaster* rearing medium exposed to adult *D. melanogaster* for two weeks. The 1st instar larval development time was determined by observing the appearance of recently moulted 2nd instar larvae. Similarly, the development time from 2nd instar to pre-pupa, pre-pupa to the formation of a cell around the pupa and cell formation to pupation was determined. The rate of development from pupation to adult emergence was determined by observing the same individuals. The mean proportion of mortality was calculated for every stage by dividing the number that died by the number of immatures per replicate at the beginning of the life stage.

2.3 Life table of *C. pumilio*

A cohort of 100 1st instar larvae, were transferred in batches of 10 into 10 petri dishes with moistened tissue paper and an abundant source of food (frozen fly eggs). They were placed in an incubator at $30 \pm 1^\circ\text{C}$. This allowed for direct observation of individual life stages and monitoring of their mortality. The adults that emerged were separated into males and females to obtain the sex ratio.

Twenty-five gravid females and males of the emerged adults were placed on the combined rearing medium in five containers, each containing a pair of five females and males. After every 24 hours the adults were removed, counted and placed on new breeding medium until

all the adults died. The number of 1st instar larvae that emerged from each container was recorded daily.

Developmental time, fecundity and survival data were used to construct a life table for *C. pumilio*. The net replacement rate (R_0) and the mean generation time (T) were calculated according to Price (1984). These values were then used to obtain an initial estimate of the intrinsic rate of increase (r_m) (Price 1984):

$$r_m = [\ln (R_0)] T^{-1} .$$

The estimates of r_m were then used in the first iteration to solve the equation (Watson 1964):

$$\sum_{x=1}^t e^{-r_m x} l_x m_x = 1, \quad x = 1, 2, 3, \dots, t \text{ days.}$$

where x = age interval in days,

m_x = mean number of female progeny produced during the age interval x ,

l_x = proportion of females alive at age x .

The iterations were continued until the left-hand side of the equation was within 0.0001 of the right- hand side.

Two methods were used to determine the sex of the beetles. In the first, the beetles were chilled for ten minutes at $5 \pm 1^\circ\text{C}$ (this facilitated easy handling and genital extrusion). A beetle was then held between the thumb and fore finger and gently squeezed, extruding the female ovipositor or male aedeagus (Kaufman, pers. comm.). The aedeagus was more curved and brownish in colour than the ovipositor. In the second, pupal cells were opened and sexes differentiated by the examination of the abdominal terminalia (Smith 1975, Geden 1984). The male terminalia have equal urigomphi while those of the female are unequal (Fig. 1).

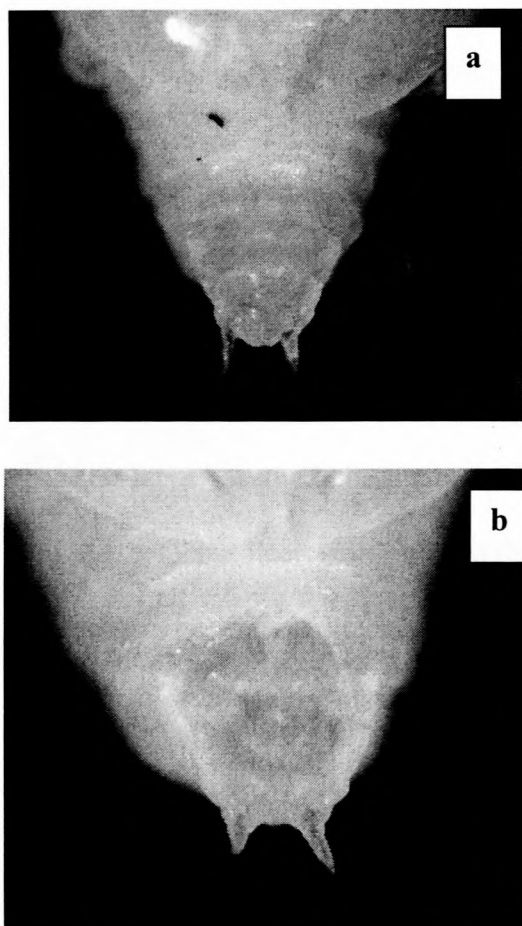


FIG. 1. **a** = Male terminalia with equal urigomphi; **b** = Female terminalia with unequal urigomphi.

2. 4 Effect of prey deprivation on survival of *C. pumilio* adults

To quantify the effect of prey deprivation on the survival of *C. pumilio* adults, 30 well fed F₂ of both sexes which were 60 days old and 30 of F₃ of both sexes of newly emerged and never fed *C. pumilio* adults were collected. They were placed in 100ml plastic containers on wet hand towel papers, covered with organdy and placed in an incubator at 30°C. Containers were checked daily for mortality and the hand towel paper remoistened. Dead beetles were removed and counted daily. The time to 50% mortality was determined.

3. RESULTS

3.1 Life stages

The egg was smooth white to cream in colour, slightly convex, glistening and bluntly tapering at both ends (Fig. 2a). The newly hatched larva was completely cream coloured, with only the head capsule fully pigmented with dark brown colouration (Fig. 2b). The 2nd instar larva which is about twice the size of 1st instar larva, maintained the same colouration of the 1st instar larva (Fig. 2c). The 2nd instar larva became lethargic before pupation. The exarate pupa was entirely creamy white (Fig. 2d, e, f), but later, starting from the head, turned from golden-brown to black. The adult, ovate in shape, emerged from the cell with the cuticle shining and black (Fig. 2g).

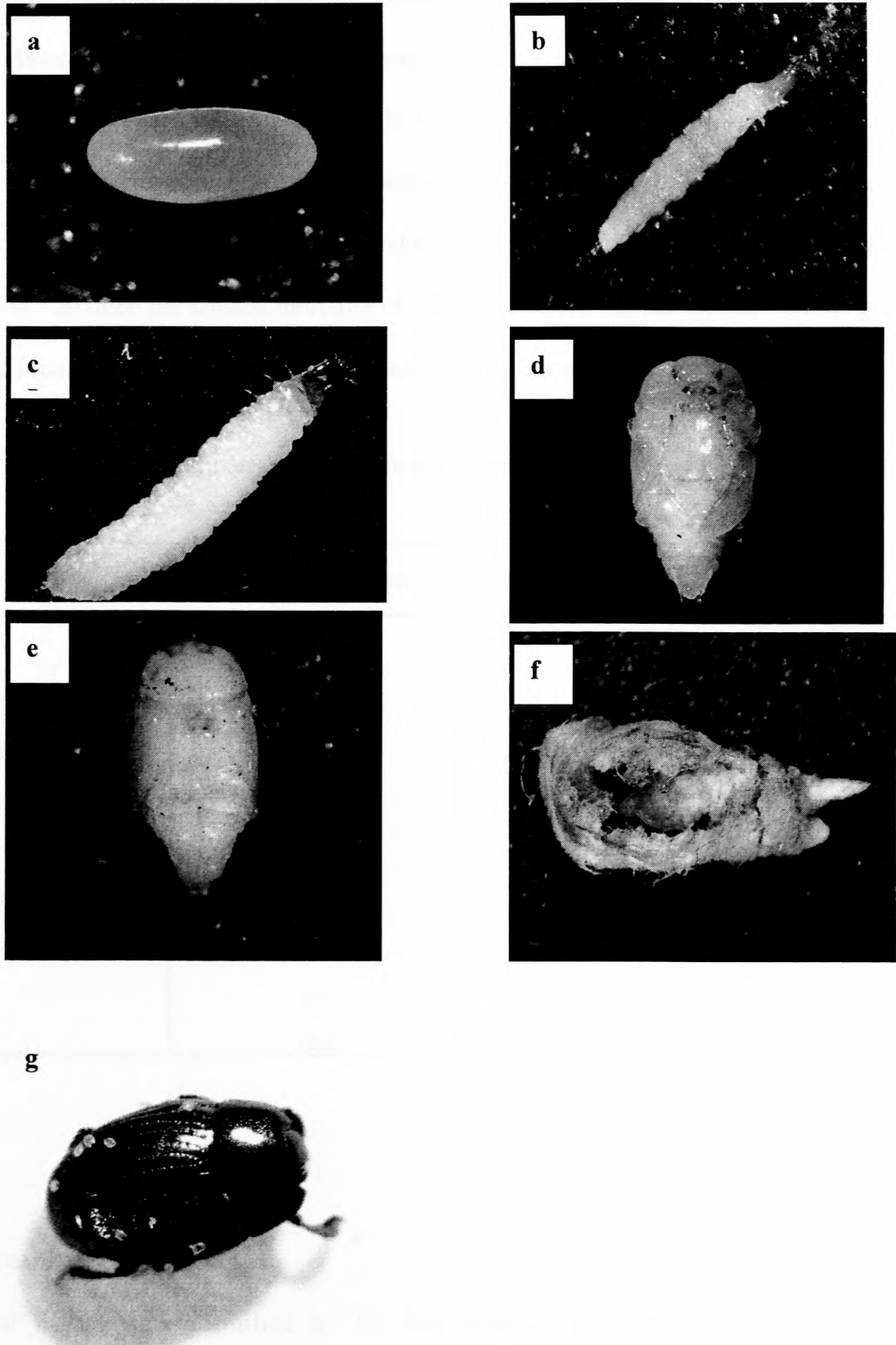


Fig. 2. Various stages of *C. pumilio*. **a** = Egg; **b** = 1st instar larva; **c** = 2nd instar larva; **d** = Ventral side of pupa; **e** = Dorsal side of pupa; **f** = Pupa in cell; **g** = Adult.

3.2 Developmental time and mortality of immatures

The total developmental time for egg, 1st instar, 2nd instar to pupation and pupa stages was 3.5, 3.0, 8.0 and 6.0 days respectively (Table 1). The duration from 2nd instar to pre-pupa, pre-pupa to cell formation and cell formation to pupation was 3.0, 2.0, and 3.0 days respectively. The 2nd instar was the longest, taking 39% of the total development time. The 1st instar larvae sustained the highest mortality of 26% while there was no mortality in the pupal stage. The immature stages sustained 49.8% mortality before adult emergence (Table 1).

Table 1. Developmental times of *C. pumilio* immature stages at 30°C.

| Stage | Developmental time (in days) | % of total developmental time | % mortality |
|--------------------------------------|------------------------------|-------------------------------|-------------|
| Egg | 3.5 | 17.1 | |
| 1 st instar | 3.0 | 14.6 | 26.0 |
| 2nd instar: | | | |
| (2 nd instar to pre-pupa) | 3.0 | 14.6 | 13.2 |
| (pre-pupa to cell formation) | 2.0 | 9.8 | 7.8 |
| (cell formation to pupation) | 3.0 | 14.6 | 2.8 |
| 2nd instar total | 8.0 | 39.0 | |
| Pupa | 6.0 | 29.3 | 0.0 |
| Total | 20.5 | 100.0 | |

3.3 Head capsule

The larval instars were identified by the two different size classes in the frequency distribution of the head capsule measurements. The results showed that *C. pumilio* had two larval instars (Fig. 3).

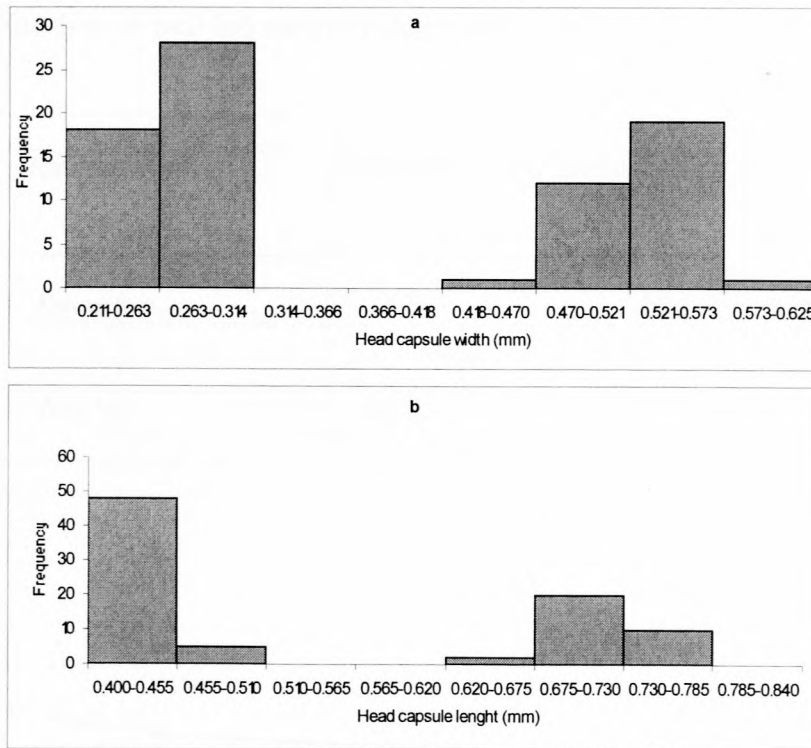


Fig. 3. Frequency distribution of width (a) and length (b) of the head capsule of *C. pumilio* larvae (in mm.).

3.4 Survivorship

When the number of adult survivors over time was plotted on a log scale, which is more instructive (Deevey 1947), a Type I curve (Price 1997) resulted, that is low initially in mortality with the rate of survival decreasing with the age of the beetles. The last mortality occurred after 130 days (Fig. 4).

A comparison of the survivorship of beetles which were well fed for 30 days and those just emerged and never fed showed that the 50% survival time of the fed beetles was about 1.5 times higher than that of those which had just emerged (Table 2). Some of the newly emerged and starved beetles appeared lethargic from day 8 of observation.

Table 2. Survival of well fed and prey-deprived *C. pumilio* adults at 30°C.

| Satiation level | Duration for 50% mortality (in days) | |
|-----------------|--------------------------------------|------|
| | ♀♀ | ♂♂ |
| Never fed | 25.5 | 26.0 |
| Well fed | 38.5 | 37.5 |

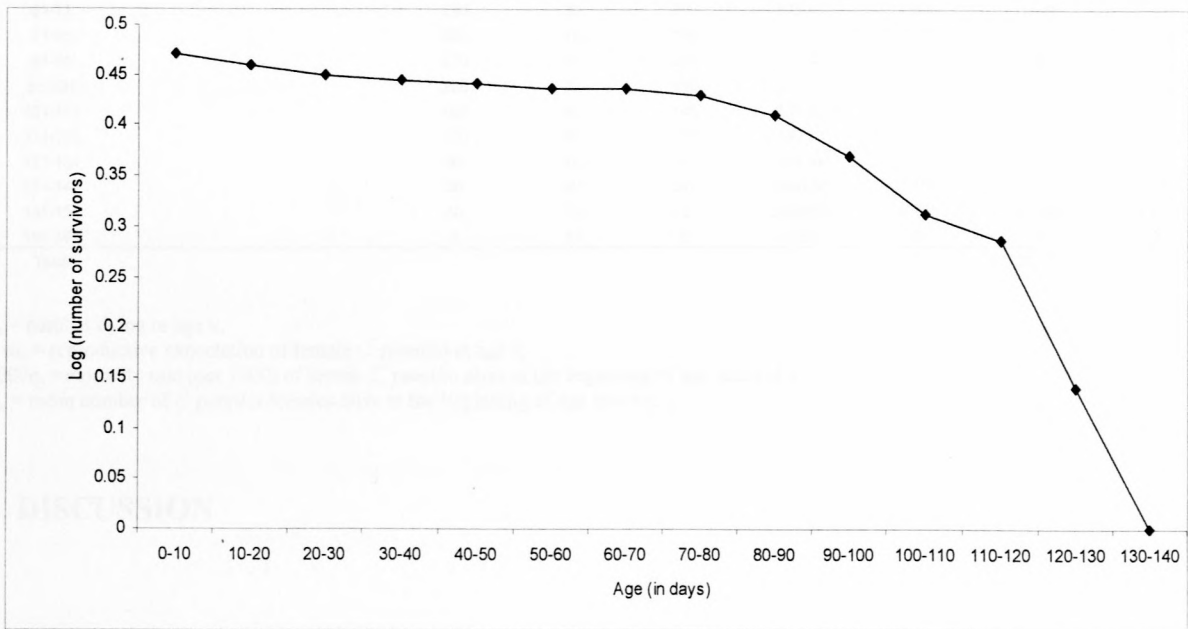


FIG. 4. Survivorship curve of adult *C. pumilio*.

3.5 Life table

The sex ratio of the adults was 0.48 females: 0.52 males. The intrinsic rate of natural increase (r_m) was 0.064943 and the net replacement rate (R_0) was 20.191 (Table 3).

Table 3. A partial life table for *C. pumilio* under laboratory conditions (30° C). Data based on a hypothetical cohort of 1000 newly-hatched L_1 's. Egg mortality was not determined.

| Day (x) | Life stage | l_x | d_x | L_x | $1000q_x$ | m_x | $l_x m_x$ | $l_x m_x x$ |
|---------|--|-------|-------|-------|-----------|--------|-----------|-------------|
| 1-4 | egg | 1000 | 0 | 965 | 0.00 | | | |
| 4-7 | L1 | 930 | 70 | 900 | 75.27 | | | |
| 7-10 | L2 to prepupa | 870 | 130 | 800 | 149.43 | | | |
| 10-12 | Prepupa to cell formation | 730 | 140 | 650 | 191.78 | | | |
| 12-15 | Cell formation to pupation | 570 | 160 | 545 | 280.70 | | | |
| 15-21 | Pupation to adult emergence Adult (250 F:270 M) | 520 | 50 | 260 | 96.15 | | | |
| 21-31 | | 440 | 80 | 405 | 181.82 | 10.922 | 2.425 | 66.254 |
| 31-41 | | 370 | 70 | 350 | 189.19 | 17.03 | 3.654 | 115.531 |
| 41-51 | | 330 | 40 | 325 | 121.21 | 18.252 | 3.563 | 134.831 |
| 51-61 | | 320 | 10 | 305 | 31.25 | 9.346 | 1.904 | 74.745 |
| 61-71 | | 290 | 30 | 285 | 103.45 | 7.556 | 1.486 | 71.356 |
| 71-81 | | 280 | 10 | 275 | 35.71 | 16.999 | 2.572 | 183.786 |
| 81-91 | | 270 | 10 | 245 | 37.04 | 6.799 | 1.341 | 83.092 |
| 91-101 | | 220 | 50 | 190 | 227.27 | 5.762 | 1.034 | 75.332 |
| 101-111 | | 160 | 60 | 145 | 375.00 | 4.099 | 0.712 | 56.595 |
| 111-121 | | 130 | 30 | 110 | 230.77 | 1.037 | 0.341 | 30.295 |
| 121-131 | | 90 | 40 | 60 | 444.44 | 1.01 | 0.308 | 39.108 |
| 131-141 | | 30 | 60 | 20 | 2000.00 | 3.101 | 0.755 | 72.082 |
| 141-151 | | 10 | 20 | 5 | 2000.00 | 0.865 | 0.096 | 8.371 |
| 151-161 | | 0 | 10 | 0 | 0.00 | 0 | 0 | 0 |
| Total | | | | | | | 20.191 | 1011.378 |

d_x = number dying in age x ,

$l_x m_x$ = reproductive expectation of female *C. pumilio* at age x ,

$1000q_x$ = mortality rate (per 1000) of female *C. pumilio* alive at the beginning of age interval x

L_x = mean number of *C. pumilio* females alive at the beginning of age interval x .

4. DISCUSSION

Two larval stages were identified, which agrees with the observations of Smith (1975) and Geden (1984). Three larval stages had previously been noted by Hinton (1945). The late 2nd instar larva constructed a pupal cell from moistened tissue paper or bran which appeared to be “cemented” together, an observation also made by Hinton (1945) and Geden (1984). The pupal cell was resilient or tough when an attempt was made to open it up mechanically. The duration required for immature development to adult emergence in this study was 20.5 days which was similar to the 21.6 and 20.1 days obtained by Geden (1984) and Fletcher *et al.* (1991) respectively. The developmental time of 20.5 days compared favourably with that of the pteromalids *Muscidifurax raptor* Gerault (<http://www.anbp.org/c-mucidifurax.htm>) and

Spalangia endius Walker (<http://www.rinconvitova.com/flycontrol.htm>) which took 18 and 21 days, respectively. The pteromalids are produced by many commercial insectaries for control of house flies in livestock facilities, unlike *C. pumilio* (Geden *et al.* 1992).

The immature stage mortality before adult emergence was about 50%, an observation also made by Geden (1984). The immature stage only forms about 14% of the total survival time of the adult, indicating that in the field larvae might suffer a higher mortality rate than the adults. The pupal stage experienced the least mortality, as was also observed by Geden (1984) and Fletcher *et al.* (1991). This also indicated that the pupal cell conferred on the pupa some degree of protection. In a natural environment some mortality might occur in this stage due to desiccation or predation.

The survival of *C. pumilio* for up to 130 days in this study showed it to be a long-lived species. This was in agreement with findings of Geden (1984), who reported that *C. pumilio* on average could live longer than 100 days at 30°C. The Type I survivorship curve of *C. pumilio* adults indicated a very low death rate of the young and only high mortality when they are very old (Price 1997). The Type I curve obtained in this study was also similar to the work done by Geden (1984), should his data be log transformed. The longevity of the adults and their low reproduction rate explain why the population of *C. pumilio* in a stable habitat later becomes adult biased (Geden 1984, Chapter 2). This could be as a result of newly emerged adults joining the population pool at a rate faster than could be reduced by adult mortality (Poole 1974, Geden 1984).

The value of r_m for the adults was low and this may indicate low rate of increase in nature and would lead to a search for adaptive methods for avoiding mortality (Price 1997). *Carcinops pumilio* displays thagomosis (Crowson 1981). When an adult was touched or startled it

feigned death by withdrawing the head into the prothorax followed by the retraction of the legs beneath the body, an observation also made by Hinton (1945). The eggs were observed in 'bumps' in the tissue paper and often in vertical or horizontal positions, an indication of the female's ability to hide deposited eggs.

The R_0 value of 20.19 reflected an increase in the net replacement rate in the course of a generation (Price 1997), an indication that more young adults enter into the population (Poole 1991), a characteristic of insects with Type I survivorship curve such as *C. pumilio*.

5. REFERENCES

- ANDERSON, J. R. & POORBAUGH, J. H. 1964. Observation on the ethology and ecology of various Diptera associated with Northern California poultry ranches. *Journal of Medical Entomology* **1**: 131-147.
- AXTELL, R. C. 1970. Integrated fly - control program for caged - poultry houses. *Journal of Economic Entomology* **63**: 400-405.
- AXTELL, R. C. 1985. Fly management in poultry production: Cultural, biological and chemical. *Poultry Science* **65**: 657-667.
- AXTELL, R. C. 1990. Potential of biocontrol for livestock and poultry pests. In, Rutz, D. A. & Patterson, R. S. *Biocontrol of arthropods affecting livestock and poultry*, Westview Press, San Francisco.
- CONWAY, J., A. 1973. The micro-fauna of California-system poultry houses in Britain. *British Poultry Science* **14**: 213-216.
- CROWSON, R. A. 1981. *The Biology of the Coleoptera*. Academic Press, New York.
- DEEVEY, E. S., JR. 1947. Life tables for natural populations of animals. *The Quarterly Review of Biology* **22**: 283-314.

FLECTHER, M. G., AXTELL, R. C., STINNER, R. E. & WILHOIT, L. R. 1991.

Temperature-dependent development of immature *Carcinops pumilio* (Coleoptera: Histeridae), a predator of *Musca domestica* (Diptera: Muscidae). *Journal of Entomological Science* **26**: 99-108.

GEDEN, C. J. 1984. *Population dynamics, spatial distribution, dispersal behaviour and life history of the predaceous histerid, Carcinops pumilio (Erichson), with observations of other members of the poultry manure arthropod community*. Ph.D. dissertation, University of Massachusetts, Amherst.

GEDEN, C. J. & STOFFOLANO, J. G. 1987. Succession of manure arthropods at a poultry farm in Massachusetts, USA, with observations on *Carcinops pumilio* (Coleoptera: Histeridae) sex ratios, ovarian condition and body size. *Journal of Medical Entomology* **24**: 212-220.

GEDEN, C. J., STINNER, R. E. & AXTELL, R. C. 1988. Predation by predators of the house fly in poultry manure: effects of predator density, feeding history, interspecific interference, and field conditions. *Entomological Society of America* **17**: 320 - 329.

GEDEN, C. J., SMITH, L., LONG, S. J. & RUTZ, D. A. 1992. Rapid deterioration of searching behaviour, host destruction and fecundity of the parasitoid *Muscidifurax raptor* (Hymenoptera; Pteromalidae) in culture. *Annals of the Entomological Society of America* **85**: 179-187.

HINTON, H. E. 1945. The Histeridae associated with stored products. *Bulletin of Entomological Research* **35**: 309-340.

HULLEY, P. E. 1983. A survey of the flies breeding in poultry manure, and their potential natural enemies. *Journal of the entomological Society of southern Africa* **46**: 38-47.

HULLEY, P. E. 1986. Factors affecting numbers of *Musca domestica* Linnaeus (Diptera: Muscidae) and some other flies breeding in poultry manure. *Journal of the entomological Society of southern Africa* **49**: 19-27.

- HULLEY, P. E. & PFLEIDERER, M. 1988. The Coleoptera in poultry manure potential predators of the house fly, *Musca domestica* Linnaeus (Diptera: Muscidae). *Journal of the Entomological Society of Southern Africa* **51**: 18-29.
- MORGAN, P. B., PATTERSON, R. S. & WEIDHAAS, D. E. 1983. A life-history study of *Carcinops pumilio* Erichson (Coleoptera: Histeridae). *Journal of Georgia Entomological Society* **18**: 353-359.
- PFEIFFER, D. G. & AXTELL, R. C. 1980. Coleoptera of poultry manure in caged-layer houses in North Carolina. *Environmental Entomology* **9**: 21-28.
- POOLE, R. W. 1974. *An introduction to quantitative ecology*. McGraw-Hill, New York.
- PRICE, P. W. 1997. *Insect Ecology*. John Wiley & Sons, Inc., New York.
- SMITH, K. A. 1975. *Observations on the life history, ecology and behaviour of Carcinops pumilio* (Erichson). MSc. Thesis, Department of Entomology, University of New Hampshire, Durham.
- TOYAMA, G. M. & IKEDA, J. K. 1976. An evaluation of fly breeding and fly parasites at animal farms on leeward and central Oahu. *Proceedings, Hawaiian Entomological Society* **22**: 353-368.
- WATSON, T. F. 1964. Influence of host plant condition on population increase of *Tetranychus telarius* (Linnaeus) (Acarina: Tetranychidae). *Hilgardia* **35**: 237-322.

CHAPTER 6

EFFECT OF CROWDING ON FECUNDITY, BODY SIZE, DEVELOPMENTAL TIME, SURVIVAL AND OVIPOSITION OF *CARCINOPS PUMILIO* (ERICHSON) (COLEOPTERA: HISTERIDAE) UNDER LABORATORY CONDITIONS

ABSTRACT

An increase in the density of the histerid beetle, *Carcinops pumilio* (Erichson), had a dampening effect on fecundity. Body size of 2nd instar larvae and weight of 1st and 2nd instar larvae were inversely proportional to density. Developmental time was inversely proportional to body size of 2nd instar larvae and weight of 1st and 2nd instar larvae reared at densities of 5, 10, 15, 20, 30, 40 and 50 pairs of males and females. Survival of 2nd instars decreased with an increase in density but increased with an increase in body size. The rate of oviposition was directly proportional to body size and weight. Density will be a critical factor in any mass rearing programme for this predator of fly larvae.

Key words: Body size, body weight, *Carcinops pumilio*, crowding, developmental time, fecundity.

1 INTRODUCTION

Intraspecific competition may result in the decrease of the population growth rate. It increases with increasing density and often results in increased mortality and decreased natality. This could be due to factors such as limited space for living and breeding and the depletion of food (Pianka 1994, Price 1997).

Bradshaw & Holzapfel (1992) stated that when increased density or decreased food levels, or both, limited resources, individual organisms could not simultaneously maximize all components of fitness. Reduced acquisition of resources translated into reduced fitness and to variable allocation of acquired resources, leading to tradeoffs such as reduction in the number of eggs laid per female. Such tradeoffs could become more apparent when factors such as per-capita resource level, weight or some other index of resource acquisition was taken into account (Bell & Koufopanou 1986). Bradshaw & Holzapfel (1992) added that even at a single combination of food and density, some individuals may acquire more resources than others because of variation in local microhabitat or maternal investment in yolk and would be better off than others. Reduced availability of resources for larvae could result in population decline, long development time and smaller size at metamorphosis among individuals that do pupate (Fisher *et al.* 1990, Bradshaw & Holzapfel 1992).

Smith & Fretwell (1974) postulated that at any point in an organism's life history there was an optimum percentage of available energy that should be diverted to reproduction to maximize the parent's total contribution to future generations. This implied that energy available for reproduction is limited to a finite amount at any given time. Smith & Fretwell (1974) concluded that as the energy expended on individual offspring was increased, the number of offspring that parents could produce was decreased. Also, as the energy expended on individual offspring increased, the fitness of individual offspring increased.

Since *Carcinops pumilio* (Erichson) (Coleoptera: Histeridae) is an important predator of fly larvae breeding in manure and could be used in inundative releases to control flies (Geden 1990), it is important to know more about factors affecting its biotic potential, particularly in mass breeding programmes. The aims of this study were therefore (1) to determine the effects of different densities of *C. pumilio* on female fecundity, body size,

weight and developmental time, (2) the relationship between developmental time, and weight and body size and (3) the relationship between oviposition, and weight and body size. Geden (1984) performed similar experiments, so this study was done in part to ascertain whether similar results would be obtained using *C. pumilio* found in South Africa.

2 MATERIALS AND METHODS

2.1 Rearing of *C. pumilio* at various crowding levels

All experiments were carried out in an incubator set at $30 \pm 1^\circ\text{C}$ in a laboratory of the University of Stellenbosch. Beetles used in the experiments were F_5 progeny collected from a cohort reared in the laboratory. The adults were maintained on the medium used for the rearing of *Musca domestica* and *Drosophila* sp. respectively (see Chapter 5). The medium, prior to the introduction of the adults, had been exposed to *Drosophila* adults for the previous 10 days.

Adults of *Carcinops pumilio* at crowding levels of 5, 10, 15, 20, 30, 40 and 50 pairs of females and males were placed in 2 litre milk containers, containing 1.5 litres of the medium. The top of the container was removed and covered with a piece of an organdy, in the process trapping several laboratory reared *Drosophila* adults. The trapped *Drosophila* adults fed on the medium, oviposited and thus provided a continuous supply of food for the *C. pumilio* adults and emerged larvae. A total of 9 replicates was used for each density level. After 9 days, the contents of each container were placed in a Berlese funnel with a 60W bulb as source of heat to extract the adults and larvae. To reduce the rate of desiccation, the larvae were placed in a 200cc plastic container lined with moist tissue paper, and covered with organdy.

2.2 Fecundity

The eggs of *C. pumilio* are minute, inconspicuous and difficult to find. The fecundity of the adults (progeny/female/day) at each crowding level was therefore determined using the larvae. The mean numbers of 1st and 2nd instar larvae obtained were divided by the number of females introduced at each crowding level. These figures were then divided by the number of days in which oviposition could have occurred to give rise to 1st and 2nd instar larvae by day 9 post adult introduction. Since the eggs take 3.5 days to hatch and the 1st instar larvae 3.0 days to become a 2nd instar (see Chapter 5), any 1st instar larvae found would have developed from eggs laid on or about day 7 only (those from days 8-9 would still be eggs). The figure for the 2nd instar larvae was determined by subtracting development times for eggs (3.5 days) and 1st instars (3.0 days) from the 9 day observation period.

2.3 Weight

The wet weight of 1st and 2nd instar larvae from each crowding level was measured. Twenty 1st and 2nd instar larvae were taken for each crowding level to be weighed, using a Sartorius microbalance which weighed to the nearest 0.1mg.

2.4 Developmental time

2.4.1 Preliminary studies

To avoid unnecessary disturbance in later experiments, preliminary developmental times from 1st to 2nd instar larvae and 2nd instar larvae to adult emergence from the pupa were determined for each crowding level in 2.1. The 1st and 2nd instar larvae used were the progeny at each crowding level. Observations were made daily to obtain the estimates of developmental times at each of the seven crowding levels.

2.4.2 Larval development (1st instar)

The 1st instar larvae used for the larval development study were obtained as described in 2.1 at each crowding level. The medium was prepared as described in 2.1. Three replicates were used for each crowding level of 5, 10, 15, 20, 30, 40 and 50. Prior to the introduction of the larvae, the rearing media were placed in an incubator for 24 hours to be stabilized at 30°C, the temperature at which the experiments were performed. The required number of 1st instar larvae were introduced into the rearing media using a hairbrush and returned to the incubator.

From a day before the estimated time of the 1st instar molt, based on the preliminary experiment described in 2.4.1, the media were examined twice daily for the presence of 2nd instar larvae. To minimize disruption, a rotation method was employed so that an individual larva was disturbed only once before the final examination.

2.4.3 Larval development (2nd instar)

The development rate from 2nd instar to adult emergence from the pupa was determined by observing the 2nd instar larvae obtained in 2.1 above and following the procedure in 2.4.2. The same crowding levels were used as in 2.4.2 above. The percentage survival of the 2nd instar larvae at the various crowding levels was calculated from the formula:

$$\% \text{ survival} = (\bar{x}/\chi) \times 100\%,$$

where \bar{x} = mean number of emerged adults

χ = crowding level of 2nd instar larvae.

2.5 Width and length of head capsule

The width and length of the 2nd instar larvae head capsule were measured as an indication of body size using a compound microscope equipped with an eyepiece micrometer. The width of the head capsule was measured at the major epicraneal setae. The length was measured from the tip of the mandible to postoccipital suture. Twenty specimens of each larval instar were measured.

2.6 Oviposition of F₁ progeny

Five pairs of adult males and females from each crowding level (5, 10, 15, 20, 30, 40 and 50) obtained in 2.4.3 were chosen at random immediately after emergence. They were placed in small plastic containers, 5cm in height and 3cm in diameter. The lid with a hole of 1.5cm in diameter was covered with organdy held in place with glue. Each density level had five replicates. Each pair (male and female) was supplied with *Drosophila* eggs and larvae *ad libitum* together with a small amount of *M. domestica* breeding medium to serve as an oviposition site for the adult *C. pumilio*. After 24 hours, the pair was removed and placed in a new container with medium and a source of food. This routine was followed for 20 days when the first peak in oviposition was expected (see Chapter 5). One week after the first introduction of the adults the media were examined for the presence of larvae and those found were counted. Any male that died during the course of the experiment was replaced. It was assumed that the number of the larvae hatched was equal to the eggs oviposited and that no mortality occurred in the egg stage.

3 ANALYSIS

The effect of beetle density and the relationship between fecundity and body size (width and length) of head capsule, developmental time and survival were analyzed using regression analysis. The developmental times were log transformed. A graph of the mean width and length of the larval head capsule versus number of beetles per container was plotted. Furthermore, the inverse of the developmental time (in days) was plotted against the size (width and length) of head capsule. The figures used in analyzing the crowding data were based on assumptions that (a) adult females began ovipositing immediately following introduction onto the medium (b) that there was no egg mortality and (c) no 1st instar larva mortality.

4 RESULTS AND DISCUSSION

There was a non-linear relationship between the log of the number of progeny and crowding (Fig.1), a phenomenon also observed by Geden (1984) for *C. pumilio*. The decline in female fecundity was an indication of intraspecific competition and supported the finding of Geden (1984) and Wilhoit *et al.* (1991) that fecundity tended to decrease with an increase in density due to an increase in the scramble for food, space and oviposition sites. The dampening effect of an increase in *C. pumilio* adults was also observed in the manure of caged chickens when the adults became more numerous than the larvae during most of the sampling period (Chapter 2). With a decrease in quality and quantity of suitable oviposition sites the adults, which have the ability to fly, may be forced to disperse to new habitats.

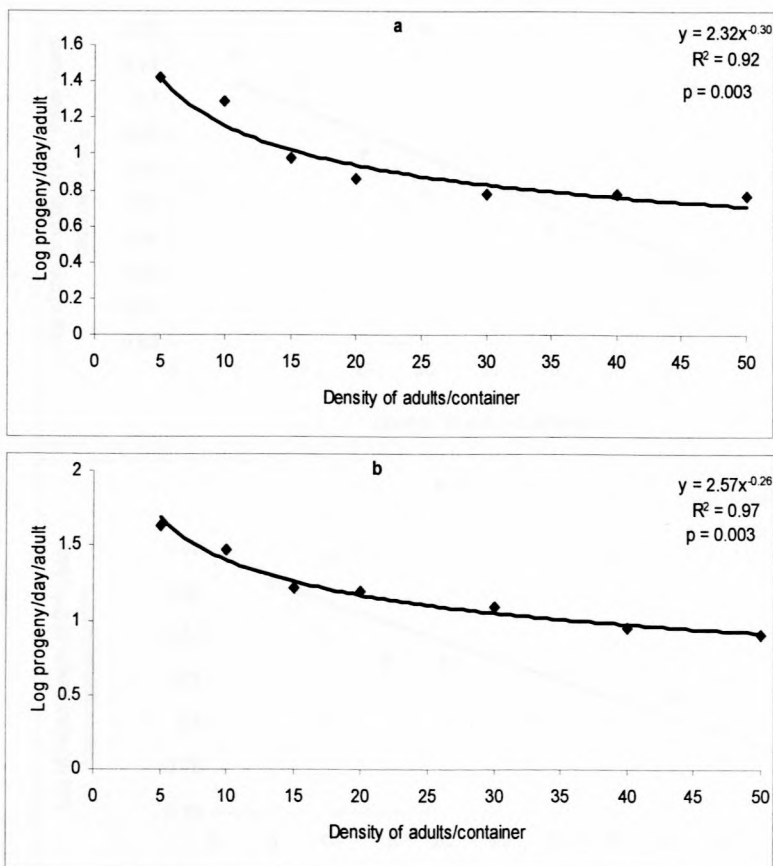


Fig. 1. Relationship between number of beetles/container and the number of **a** = 1st instar larvae; **b** = 2nd instar larvae.

The body size of the larvae, as indicated by the width and length of the head capsule of 2nd instar larvae, was inversely related to adult density, also an indication of intraspecific competition (Fig. 2). Ultimately the adult progeny derived from adults at high density will be smaller. Geden & Stoffolano (1987) observed in their study of *C. pumilio* that smaller adult body size coincided with the time when adult population densities were maximal. When beetle larvae were crowded in the laboratory in a petri dish they spent much of their time fighting one another in the presence of abundant prey, as was also observed by Geden & Staffolano (1987). Thus, energy allocated for growth and development was expended on avoiding and attacking each other, a situation which deteriorated with an increase in crowding as the proximity between individuals decreased.

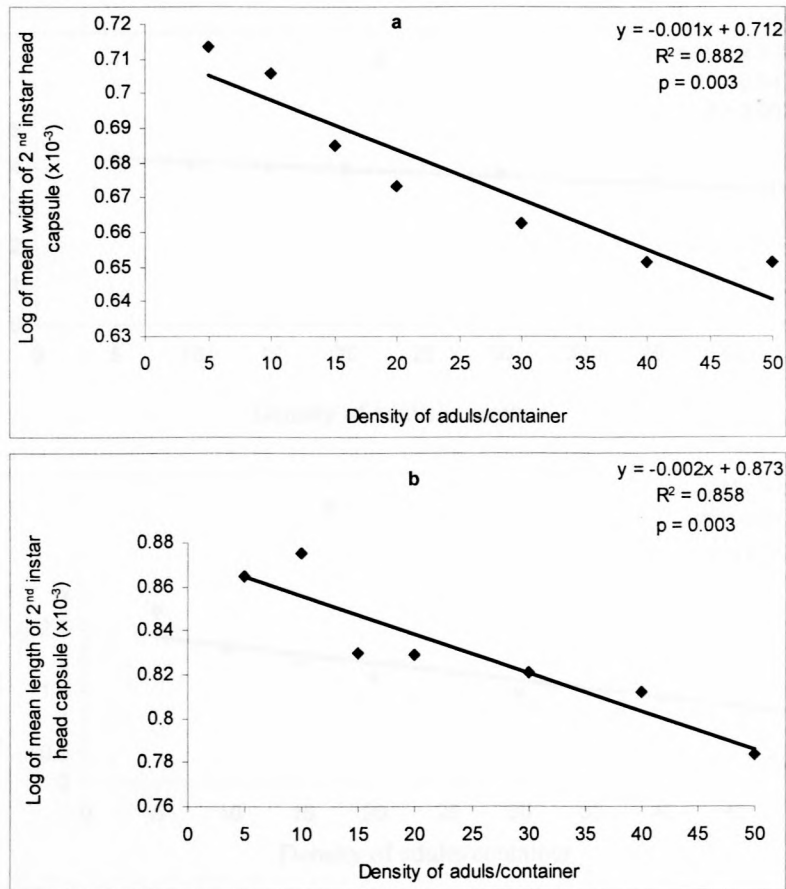


Fig. 2. Relationship between size, **a** = length, **b** = width of 2nd instar larvae head capsule and density of adult *C. pumilio* per container.

There was a linear decrease in weight with increasing density in both 1st and 2nd instar larvae (Fig. 3). The reduction in weight of progeny due to crowding was observed for various insects, eg. by Ashburner (1989), Iba *et al.* (1995), Saunders & Bee (1995) and Hirschberger (1999). Evidently, the increased metabolic activity brought about by larval crowding and gradual depletion of energy reserves led to subsequent loss in weight or the slowing down of the rate of body weight increase.

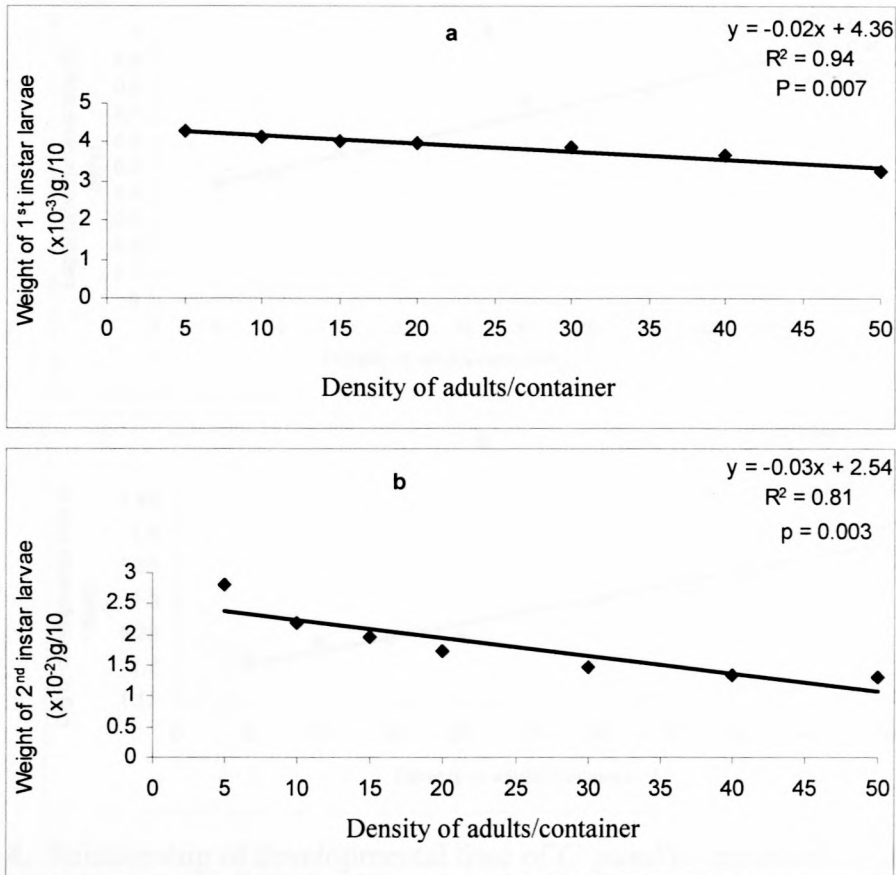


Fig. 3. Relationship between weight of larvae and density of adult *C. pumilio* per container. **a** = 1st instars; **b** = 2nd instars.

The developmental time of both 1st and 2nd instar larvae under crowded conditions was positively correlated with an increase in density (Fig. 4), which suggested that the two parameters were dependent (Huffaker & Gutierrez 1999). This corroborated reports by Price (1997) and Huffaker & Gutierrez (1999) that positive correlations existed between increase in larval density and developmental time for various insects.

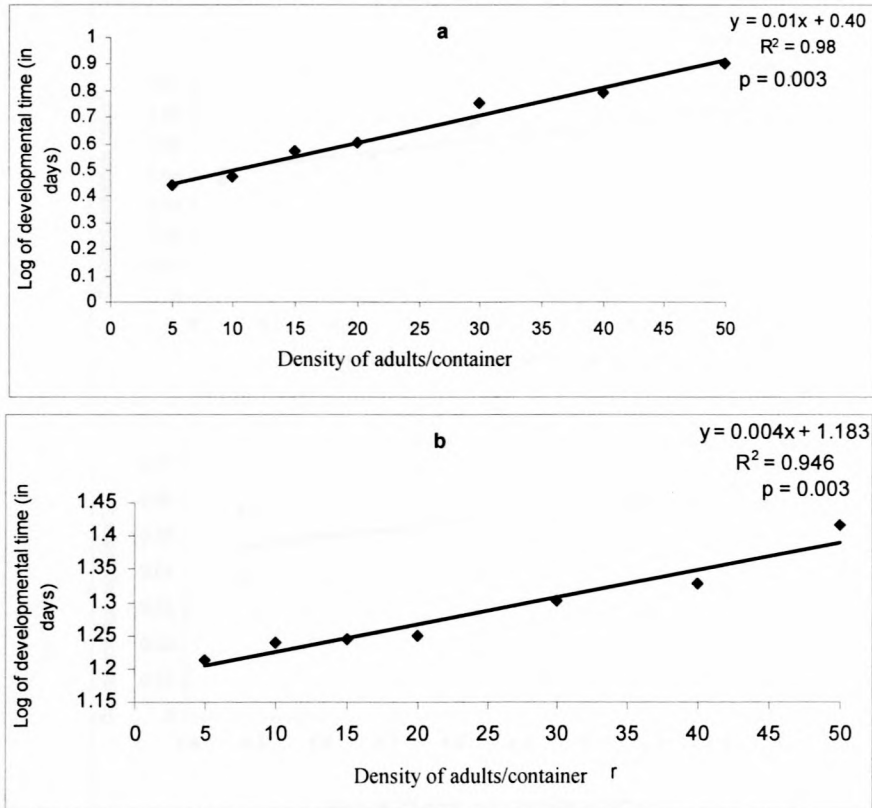


Fig. 4. Relationship of developmental time of *C. pumilio* immatures to density of adults/container. **a** = 1st instar; **b** = 2nd instar.

At high densities relative to the abundance of exploited resources, individual organisms would receive less than they required. This resulted in a negative feedback affecting their growth and development. Size and weight were strongly and positively correlated with rate of development (Figs. 5 & 6). This was an indication that development of larvae depended on body weight, an observation also made by Sibly *et al.* (1991). The drawback of high population density during larval development could be compensated for later during the adult life by those individuals that acquired more resources than others as *C. pumilio* adults could live on the average longer than 12 weeks at 30°C (Geden 1990, see Chapter 5).

Fig. 4. Relationship between the developmental rate and density of immature *C. pumilio*, **a** = 1st instar; **b** = 2nd instar.

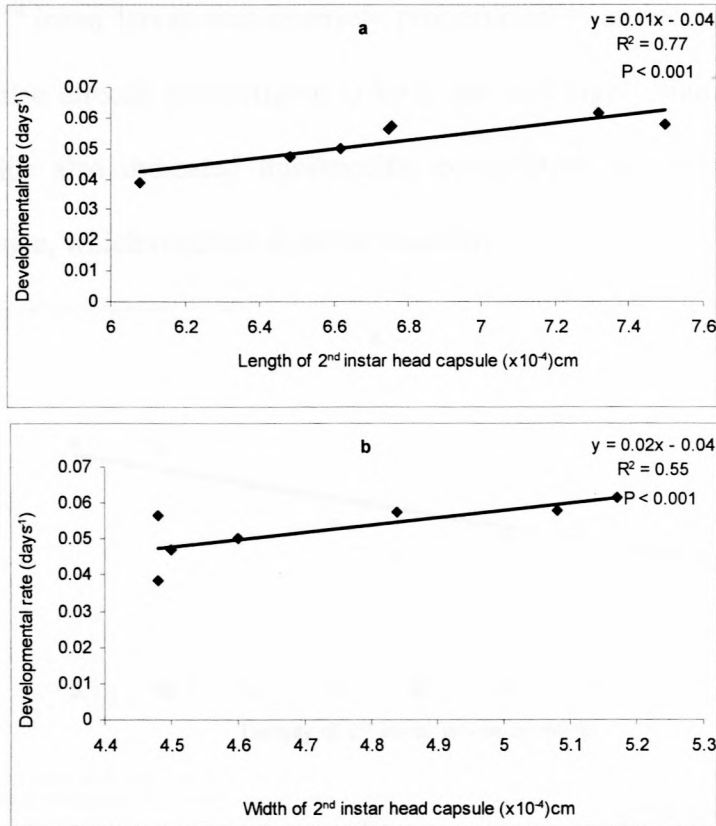


Fig. 5. Relationship between the developmental rate and size, **a** = length, **b** = width of immature *C. pumilio* 2nd instar larvae head capsule.

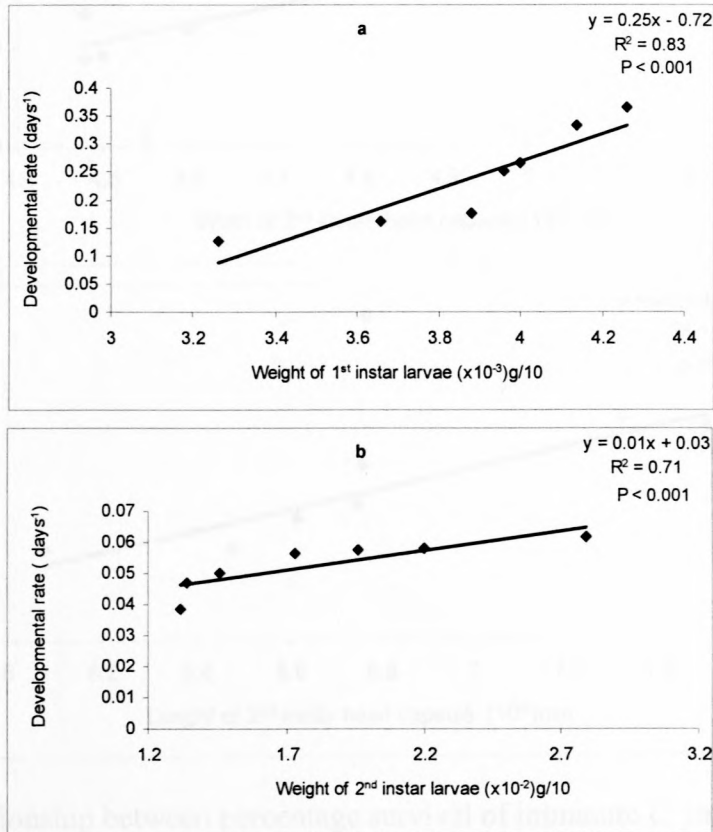


Fig. 6. Relationship between the developmental rate and weight of immature *C. pumilio*, **a** = 1st instars; **b** = 2nd instars.

The survival of 2nd instar larvae was inversely proportional to an increase in larval density (Fig. 7a). It was also directly proportional to body size and highly significant (Figs. 7b, c). These relationships also indicated intraspecific competition for resources and possibly physical interference, which resulted in larval mortality.

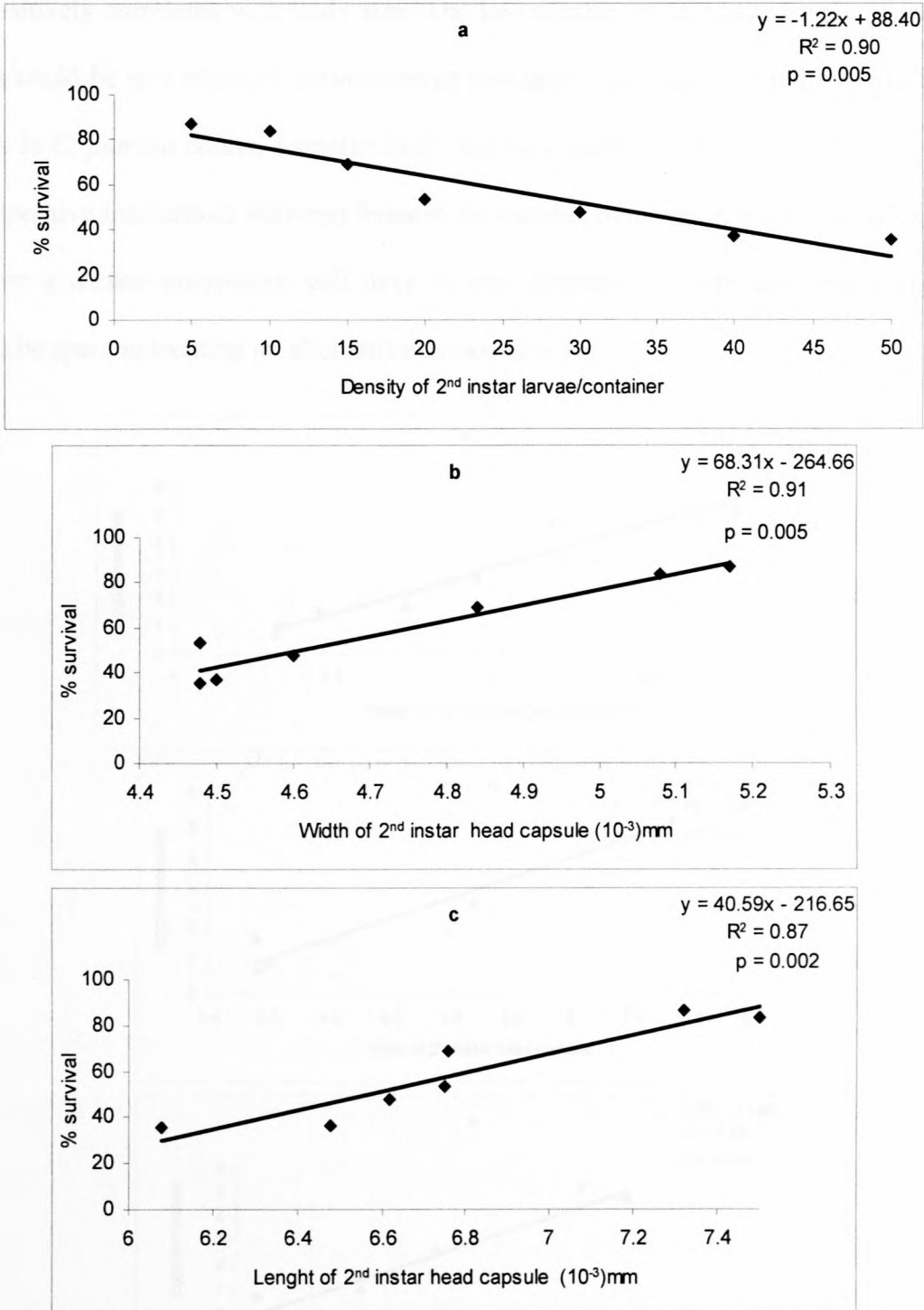


Fig. 7. Relationship between percentage survival of immature *C. pumilio* **a** = density; **b** = width of head capsule; **c** = length of head capsule of 2nd instar larvae.

The average number of eggs per female per day correlated with weight and body size of 2nd instar larvae respectively (Fig. 8) indicating that the effects of crowding on beetle body size most likely translate into *C. pumilio* fitness. This phenomenon corroborated reports of workers such as Hawley (1985), Lawrence (1990) and Hirschberger (1999) that oviposition rate positively correlates with body size. The low number of oviposited eggs of the small beetles could be as a result of limited energy available, as was also stated by Hirschberger (1999). In *C. pumilio* adults, a smaller body size as a result of high density may play a role in competitive interactions between females for suitable oviposition sites. Being small and therefore a weaker competitor will have its own drawbacks: more time and energy will have to be spent in locating an alternative oviposition site.

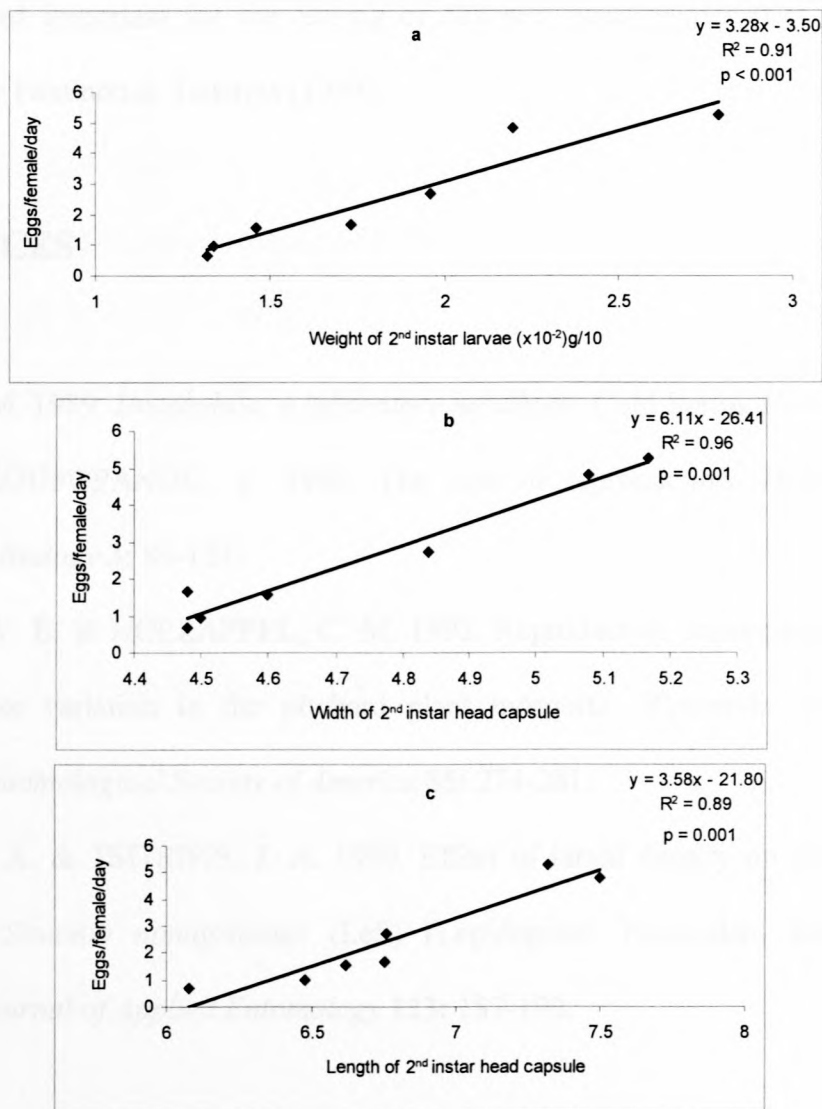


Fig. 8. Relationship of *C. pumilio* oviposition rate with **a** = weight; **b** = width; **c** = length of head capsule of 2nd instar larvae.

The study showed that negative feedback operated to regulate population density. The performance of individual beetles depended on characteristics such as fertility, fecundity, successful oviposition, developmental and mortality rates and other factors. The common trait in the study was that an increase density resulted in a decline in fitness of individuals.

The role of crowding on the development of *C. pumilio* will be an important consideration in the establishment of an efficient mass rearing programme of this predator of fly larvae. The number of adults or larvae per rearing medium per container is a factor that could greatly influence the cost of production and the quality of the adult beetles reared. Therefore, the appropriate number should be determined experimentally. This factor was also considered important for the rearing of *Sesamia nonagrioides* (Lef.) (Lepidoptera: Noctuidae) by Fantinou & Tsitsipis (1999).

REFERENCES

- ASHBURNER, M. 1989. *Drosophila, a laboratory handbook*. Cold Spring Harbor, New York.
- BELL, G. & KOUFOPANOU, V. 1986. The cost of reproduction. *Oxford Surveys in Evolutionary Biology* **3**: 83-131.
- BRADSHAW, W. E. & HOLZAPFEL, C. M. 1992. Reproductive consequences of density-dependent size variation in the pitchard plant mosquito, *Wyeomyia smithii* (Diptera: Culicidae). *Entomological Society of America* **85**: 274-281.
- FANTINO, A. A. & TSITSIPIS, J. A. 1999. Effect of larval density on development and diapause of *Sesamia nonagrioides* (Lef.) (Lepidoptera: Noctuidae) under laboratory conditions. *Journal of Applied Entomology* **123**: 187-190.

- FISHER, I. J., BRADSHAW, W. E. & KAMMEYER, C. 1990. Fitness and its correlates assessed by intra- and interspecific interactions among tree-hole mosquitoes. *Journal of Animal Ecology* **59**: 499-506.
- GEDEN, C. J. 1984. *Population dynamics, spatial distribution, dispersal behaviour and life history of the predaceous histerid, Carcinops pumilio (Erichson), with observations of other members of the poultry manure arthropods community*. Ph.D dissertation, University of Massachusetts, Amherst.
- GEDEN, C. J. & STOFFOLANO, J. G. 1987. Succession of manure arthropods at a poultry farm in Massachusetts, USA, with observations on *Carcinops pumilio* (Coleoptera: Histeridae) sex ratios, ovarian condition and body size. *Journal of Medical Entomology* **24**: 212-220.
- GEDEN, C. J. 1990. Coleoptera and acarine predators of house fly immatures in poultry production system *In: Rutz, D. A. and Patterson, R. S. Biological control of arthropods affecting livestock and poultry*. Westview Press, Oxford.
- HAWLEY, W. A. 1985. A high-fecundity Aedine: Factors affecting egg production of the western treehole mosquito, *Aedes sierrensis* (Diptera: Culicidae). *Journal of Medical Entomology* **22**: 220-225.
- HIRSCHBERGER, P. 1999. Larval population density affects female weight and fecundity in the dung beetle *Aphodius ater*. *Ecological Entomology* **24**: 316-322.
- HUFFAKER, C. B. & GUTIERREZ, E. 1999. *Ecological Entomology*. (2nd Ed.). John Wiley & Sons, Inc. New York.
- IBA, M., NAGAO, T. & URANO, A. 1995. Effects of population density on growth, behaviour and levels of biogenic amines in the cricket, *Gryllus bimaculatus*. *Zoological Science* **12**: 695-702.

- LAWRENCE, W. S. 1990. Effects of body size and repeated matings on female milkweed beetle (Coleoptera: Cerambycidae) reproductive success. *Annals of the Entomological Society of America* **83**: 1096-1100.
- PIANKA, E. R. 1994. *Evolutionary Ecology*. Harper Collins, New York.
- PRICE, P. W. 1997. *Insect Ecology*. (3rd Ed.) John Wiley & Sons, Inc. New York.
- SAUNDERS, D. S. & BEE, A. 1995. Effects of larval crowding on size and fecundity of the blow fly, *Calliphora vicina* (Diptera: Calliphoridae). *European Journal of Entomology* **92**: 615-622.
- SIBLY, R. M., SMITH, R. H. & MOELLER, H. 1991. Evolutionary demography of a bruchid beetle. IV. Genetic trade-off, stabilizing selection and a model of optimal body size. *Functional Ecology* **5**: 594-601.
- SMITH, C. C. & FRETWELL, D. S. 1974. The optimal balance between size and number of offspring. *The American Naturalist* **108**: 499-506.
- WILHOIT, L. R., STINNER, R. E. & AXTELL, R. E. 1991. Computer simulation model of house fly management in confined-animal production systems. *North Carolina Agricultural Research Service, Technical Bulletin* **296**: 1-18.

CHAPTER 7

FOOD, TEMPERATURE, AND CROWDING MEDIATED LABORATORY DISPERSAL OF *CARCINOPS PUMILIO* (ERICHSON) (COLEOPTERA: HISTERIDAE), A PREDATOR OF HOUSE FLY (DIPTERA: MUSCIDAE) EGGS AND LARVAE

ABSTRACT

The dispersal potential of natural enemies is critical to the success of biological control by mass release. Factors studied were the effects of satiation level, temperature and crowding on the dispersal of the predatory beetle *Carcinops pumilio* (Erichson) under laboratory conditions. Adults with access to sufficient prey were less reluctant to disperse. Starved individuals had higher dispersal rates during the first 2 days. *Cacinops pumilio* dispersion was more pronounced at 30°C than at 20°C. The absence of food was a greater driving force to initiate dispersal than an increase in temperature. No flight dispersal was observed after 7 days of starving, which could be associated with depletion in energy reserves. A crowding level of 50 *C. pumilio* adults per 200ml container resulted in the least dispersal and did not exceed 2.5% per day as compared with up to 24% at a crowding level 400. No significant sexual differences were found in the effects of the different parameters (food, temperature and crowding) on dispersal.

Key words: Dispersal, *Carcinops pumilio*, food, crowding, temperature.

1. INTRODUCTION

High density production of livestock creates a number of problems, including the presence of a number of fly species such as *Musca domestica* L. and *Fannia canicularis* (L.) (Diptera:

Muscidae). These flies are often a major concern for commercial poultry farmers. Fly populations may create public health hazards, resulting in poor community relations and threats of litigation. Most pest control measures rely almost exclusively on pesticides to keep populations below economic injury levels or nuisance thresholds. Since threshold levels are not well defined, control practices are generally carried out arbitrarily. Extensive or improper use of pesticides results in the destruction of biological control agents and the development of pesticide resistance, which in turn results in larger pest populations, increased pesticide use and higher control costs (Scott *et al.* 2000).

Beneficial insects such as the predaceous beetle *Carcinops pumilio* (Erichson) (Coleoptera: Histeridae) and the mite *Macrocheles muscaedomesticae* (Scopoli) (Acarina: Macrochilidae) usually appear with the accumulation of poultry manure. Geden (1984) and Geden & Stoffolano (1987) considered *C. pumilio* an important predator of *M. domestica* eggs and larvae in poultry facilities.

Augmentation of biological control agents for fly control in poultry facilities using pteromalid parasitoids has been practiced for many years (Kaufman *et al.* 2001). Commercial releases of predatory beetles such as *C. pumilio* lag behind those of parasitoids and producers generally rely on naturally occurring populations (Kaufman *et al.* 2001). Geden & Staffolano (1987) and Chapter 4 reported on successional establishment of *C. pumilio* and other predators in New England, USA and South African poultry facilities, respectively.

The role of temperature, food availability and crowding on the dispersal of *C. pumilio* has not been investigated. The aim was therefore to undertake a laboratory study of these factors on the

dispersal of *C. pumilio* adults in the laboratory and to examine the possibility of considering dispersal in *C. pumilio* adults in augmentative releases for the biological control of flies dwelling in poultry manure.

2. MATERIALS AND METHODS

All experiments were carried out in an incubator set at $25 \pm 1^\circ\text{C}$ at a University of Stellenbosch laboratory ($33^\circ 54'\text{S}$; $18^\circ 57'\text{E}$). Adults of *C. pumilio* used in the experiments were of undetermined age from a cohort reared in the laboratory.

The dispersal chambers used were 9.5 liter plastic containers. The cover of the container had a circular opening with a diameter of 21cm. The opening was covered with a transparent white organdy cloth held in place with glue. Inside the 9.5 liter container a 200ml plastic cup was filled to two-thirds of its volume with house fly breeding medium, a 1:2.9 ratio of bran and water (w/v) at 60–70% moisture content. The inside of the remaining top third of the 200ml container was smeared with baby talcum powder to prevent the beetles from crawling up on the side and coming out. Beetles dispersing from the inner container were trapped in 150ml of water that surrounded it. The dispersal chambers were placed in the incubator without light throughout the experiment. For each experiment, 50 adult beetles previously kept acclimatized in the incubator at 25°C were placed on the surface of the moistened house fly breeding medium and the dispersal chamber was covered with the lid. Beetles that were trapped in the water were collected, separated according to sex and counted, every 24 hours for 15 days. Because beetles were unable to climb out of the inner container, dispersal was thus by flight only.

Kaufman (2000) states that 50 adult *C. pumilio* consume 100mg refrigerated dead house fly eggs per day. With this in mind and to determine the effect of food availability on the dispersal behaviour of *C. pumilio*, the density of prey was manipulated. Different quantities of food were offered to the beetles inside the 200ml container: A = no eggs added, B = 50mg of eggs ($\frac{1}{2}x$), C = 100mg of eggs ($1x$) and D = 200mg of eggs ($2x$). The source of food was a once-off supply. There were three replicates for each treatment at each level of food.

To examine the effect of temperature on the dispersal of *C. pumilio*, two sets each in triplicate, were assigned to one of three temperatures levels: 20°C, 25°C and 30°C. In the first set, the 50 *C. pumilio* adults were supplied with once-off feeding of 100mg frozen house fly eggs whilst in the second set, which served as control, they were offered 100mg per container daily.

The effect of crowding was examined at incremental levels of 50, 100, 200 and 400 *C. pumilio* adults per container. The dispersal chamber was used in triplicate for each crowding level. A once off feeding of 200mg of frozen house fly eggs per beetle was supplied.

3. Analysis

Data were analyzed using statistical analysis software (STATISTICA MICROSOFT). The number of dispersed *C. pumilio* individuals at the three different temperatures of 20°C, 25°C and 30°C were $\log(x + 1)$ transformed, whilst the arithmetic means were used in the rest of the graphs plotted. Factorial analyses of variance were used to determine the effect of day (D), gender (G), food (F), crowding (N) and temperature (T) plus interactions on *C. pumilio*.

4. RESULTS AND DISCUSSION

4.1 Food mediated dispersal

Adults that were starved had a higher dispersal rate during days 1 and 2 than all the groups that were fed (Fig. 1a). This resulted in the significant interaction between day (D) and food (F) (Table 1). It was also observed by Kaufman *et al.* (2000) who found that starved *C. pumilio* had a significantly higher dispersal rate during days 1 to 3 than fed ones. All the fed ones only dispersed from day 3. Adults supplied with the 1x and 2x levels of food had much slower dispersal rates than those provided with the ½x level of house fly eggs (Fig.1b, c, d). Similar observations were made by Kaufman *et al.* (2000) who also found that beetles with lower amounts of food dispersed in greater numbers than those with more abundant food. There was a delayed response of 2 to 3 days to starvation by *C. pumilio* in this study (Fig.1b, c, d), as compared to 3 days reported by Geden *et al.* (1987). These results indicated that the absence of food could initiate dispersal in *C. pumilio* adults, and conversely that this could be averted by the presence of sufficient numbers of eggs from houseflies or other prey species. Geden *et al.* (1987) and Kaufman *et al.* (2000) reported that it was possible to reverse the dispersal phase of *C. pumilio* by the presence of dipteran prey. In light of this producers should be discouraged from controlling small dung flies like sphaerocerids, which are generally not pests, as they may serve as an alternative food source for the beetles and other beneficial arthropods (see Chapter 1).

The interaction between day (D) and food (F) (Table 1), indicated that dispersal took place on different days with different amounts of food, supporting the above observations (Fig. 1). Gender did not affect dispersal (Table 1), indicating that dispersal by males and females was the same.

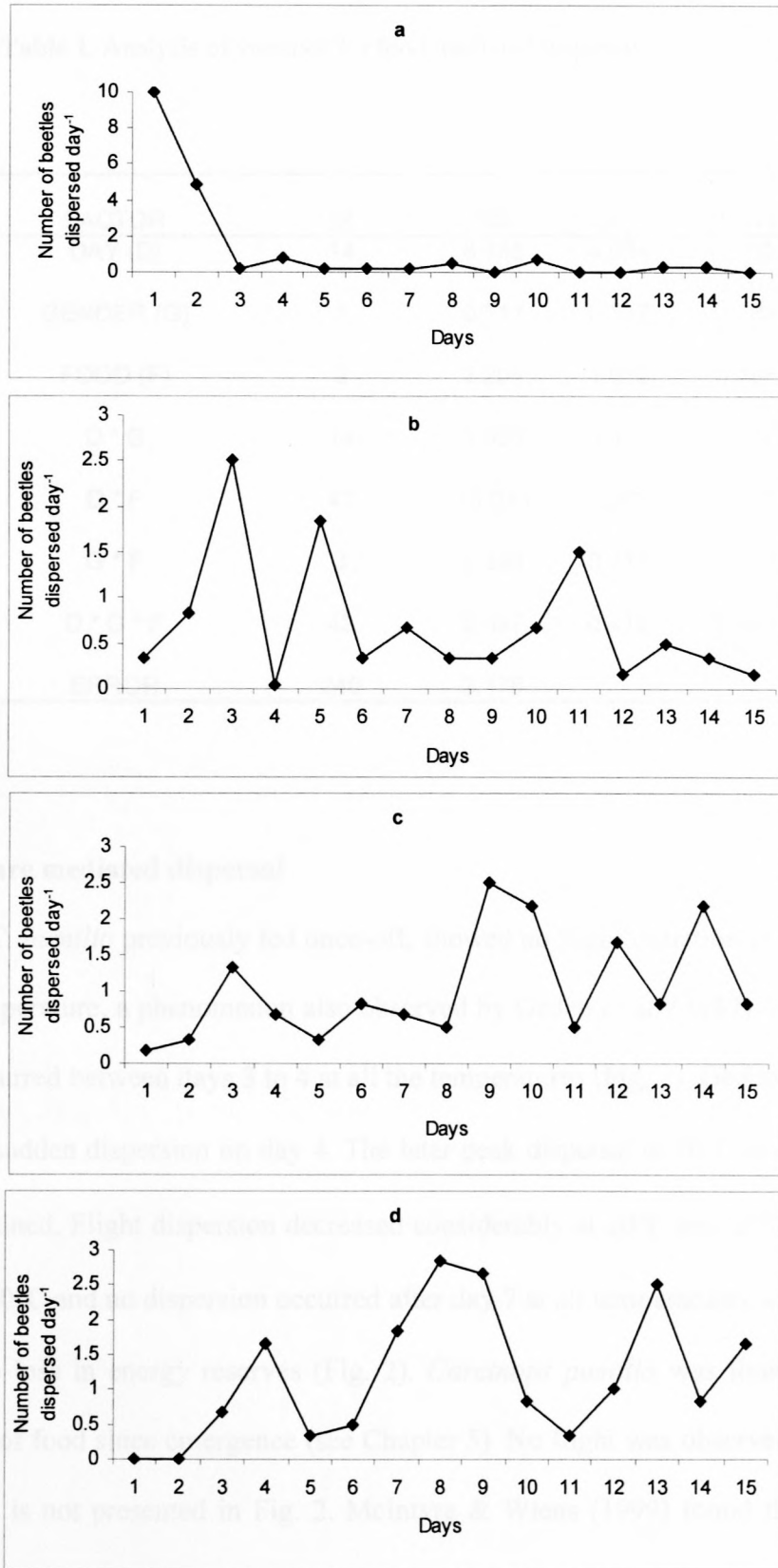


Fig. 1. Dispersal response of *C. pumilio* to absence/presence of food. **a** = starved; **b** = 1/2x; **c** = 1x; **d** = 2x. x = 100mg frozen house fly eggs.

Table 1. Analysis of variance for food mediated dispersal.

| FACTOR | Df | MS | F | P-level |
|------------|-----|--------|-------|---------|
| DAY (D) | 14 | 8.785 | 4.034 | < 0.001 |
| GENDER (G) | 1 | 0.711 | 0.327 | 0.568 |
| FOOD (F) | 3 | 2.204 | 1.012 | 0.388 |
| D * G | 14 | 1.806 | 0.829 | 0.637 |
| D * F | 42 | 16.033 | 7.362 | < 0.001 |
| G * F | 3 | 1.556 | 0.714 | 0.544 |
| D * G * F | 42 | 0.897 | 0.412 | 0.995 |
| ERROR | 240 | 2.178 | | |

4. 2 Temperature mediated dispersal

Prey deprived *C. pumilio* previously fed once-off, showed no flight initiation in the first 2 days in response to temperature, a phenomenon also observed by Geden *et al.* (1987). A sudden increase in dispersal occurred between days 3 to 4 at all the temperatures (Fig. 2). Geden *et al.* (1987) also observed their sudden dispersion on day 4. The later peak dispersal at 30°C was unexpected and cannot be explained. Flight dispersion decreased considerably at 20°C and 25°C on day 4, a day earlier than at 30°C and no dispersion occurred after day 7 at all temperatures which in part could be attributed to loss in energy reserves (Fig. 2). *Carcinops pumilio* was found to be lethargic when deprived of food since emergence (see Chapter 5). No flight was observed among prey-fed controls, which is not presented in Fig. 2. McIntyre & Wiens (1999) found that food-deprived

beetles, *Eleodes extricata* Say, moved more slowly and over shorter distances than did fed beetles.

The number of beetles dispersed varied significantly with day and temperature (Table 2). The interaction of D * T was highly significant. This was probably due to the later peak in dispersion at 30°C (day 4) than at 20°C and 25°C (day 3) (Fig. 2).

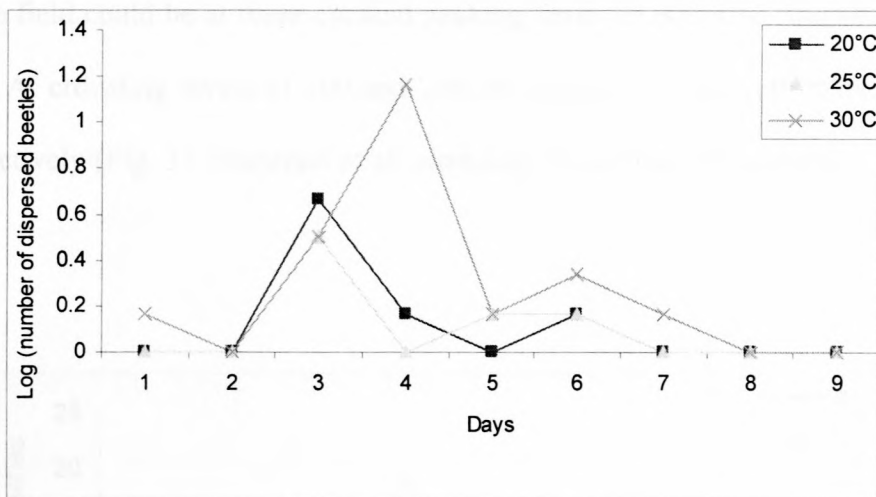


Fig. 2. Dispersal of *C. pumilio* adults at three different temperatures.

Table 2. Analysis of variance for temperature mediated dispersal.

| FACTOR | Df | MS | F | P-level |
|-----------------|-----|--------|--------|---------|
| DAY (D) | 8 | 60.917 | 58.221 | < 0.001 |
| TEMPERATURE (T) | 2 | 36.750 | 35.124 | < 0.001 |
| GENDER (G) | 1 | 0.003 | 0.003 | 0.956 |
| D * T | 16 | 16.326 | 15.604 | < 0.001 |
| D * G | 8 | 0.628 | 0.600 | 0.777 |
| T * G | 2 | 0.040 | 0.038 | 0.962 |
| D * T * G | 16 | 0.436 | 0.477 | 0.977 |
| ERROR | 216 | 1.046 | | |

4.3 Crowding mediated dispersal

At a crowding level of 50 adults per 200ml container, dispersal of *C. pumilio* was lowest, not exceeding 2.5%, whilst at a density of 400 dispersal was highest, sometimes reaching 24% (Fig. 3). At the highest crowding level, there was a cyclical pattern of dispersion with peaks at 3-day intervals. Kaufman *et al.* (2002) also observed a cyclic pattern in both laboratory and field dispersal of *C. pumilio* adults. This seemed to suggest that the best time to collect dispersing beetles in the field could be at these cyclical peaking times, as was also suggested by (Kaufman *et al.* 2002). At crowding levels of 100 and 200 the beetles only actively dispersed on days 13 and 14 respectively (Fig. 3). Dispersal at all crowding levels was considerably reduced after day 15 (Fig. 3).

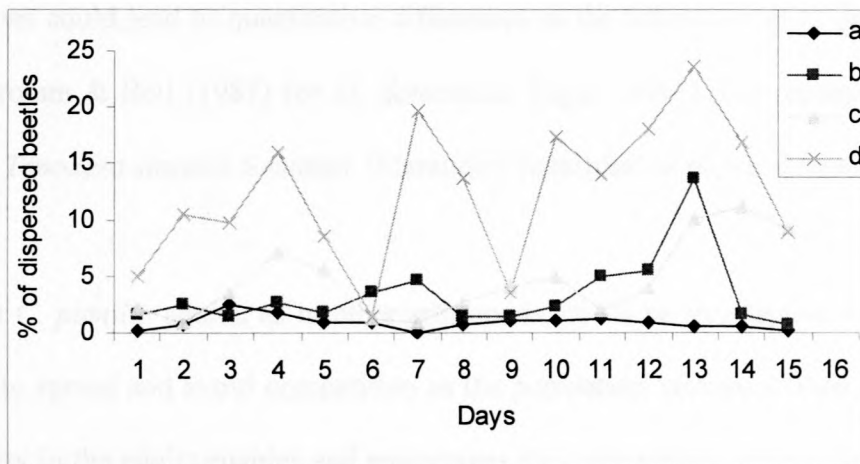


Fig. 3. The percentage of *C. pumilio* adults that dispersed on a particular day at four different crowding levels. **a** = 50; **b** = 100; **c** = 200; **d** = 400

The number of beetles dispersed varied significantly with day and crowding levels (Table 3). The interaction of D * N was highly significant confirming that crowding affected the days on which dispersal of *C. pumilio* occurred (Table 3).

Table 3. Analysis of variance for crowding mediated dispersal.

| FACTOR | Df | MS | F | P-level |
|------------|-----|----------|--------|---------|
| DAY (D) | 14 | 159.705 | 6.194 | < 0.001 |
| NUMBER (N) | 3 | 2216.855 | 85.980 | < 0.001 |
| GENDER (G) | 1 | 0.803 | 0.031 | 0.860 |
| D * N | 42 | 71.224 | 2.762 | < 0.001 |
| D * G | 14 | 0.922 | 0.036 | 1.000 |
| N * G | 3 | 4.899 | 0.190 | 0.903 |
| D * N * G | 42 | 1.050 | 0.041 | 1.000 |
| ERROR | 240 | 25.783 | | |

High densities could lead to quantitative differences in the behaviour of *C. pumilio* as was also found by Fromm & Bell (1987) for *M. domestica*. Fagan (1997) also reported a higher rate of dispersal in *Tenodera sinensis* Saussure (Mantodea: Mantidae) at higher densities.

Dispersal in *C. pumilio* adults, as in other arthropods, could be an adaptive feature that permits individuals to spread and avoid competition as the population increases (Bell 1990, Price 1997). Such mobility in the adults enables and encourages the colonization of new habitats (Price 1997, Jones *et al.* 1999). Furthermore, the dispersal of the reproductive individuals would result in genetic distribution between populations, which will create a diverse gene pool that would adjust better to the environment (Price 1997, Jones *et al.* 1999).

No significant sexual differences were found in the effects of the different parameters (food, temperature and crowding) on dispersal. Similar observations were made by Geden *et al.* (1987)

who also detected no differences between the sex ratio of dispersing and non-dispersing *C. pumilio* adults.

The implication for biological control of flies using *C. pumilio* is that newly released satiated adults would not disperse for at least 3 days depending on the temperature. Unfed *C. pumilio* should be given preference if quick dispersal is a critical factor, as they dispersed on day 1 and also survived for at least 25 days (Geden 1984, Chapter 5) (Fig.1a).

Kaufman *et al.* (2000) found that *C. pumilio* could enter into a dispersal mode starting in late spring in USA, and suggested that farmers could collect beetles in large numbers and release them into recently cleaned houses on the same farm, thus providing a cheaper on-farm source of biological control agents. Since dispersal was least at 20°C, it would be appropriate to introduce the beetles collected in case of South Africa in winter, allowing their population to built up before the onset of warm spring temperatures at which time numbers of *Musca domestica* would have started increasing (see Chapter 1). This is in line with a suggestion made by Kaufman *et al.* (2002).

The results of this study are consistent with those of other studies cited which showed that *C. pumilio* adults could disperse under certain conditions in the laboratory. However, additional studies are needed in natural settings to provide a more complete picture of their dispersal behaviour in South Africa.

REFERENCES

- BELL, W. J. 1990. Searching behaviour patterns in insects. *Annual Review of Entomology* **35**: 447-467.
- FROMM, J. E. & BELL, W. J. 1987. Search orientation of *Musca domestica* in patches of sucrose drops. *Physiological Entomology* **12**: 297-307.
- FAGAN, W. F. 1997. Introducing a "boundary-flux" approach to quantifying insect diffusion rates. *Ecology* **78**: 579-587.
- GEDEN, C. J. 1984. *Population dynamics, spatial distribution, dispersal behaviour and life history of the predaceous histerid, Carcinops pumilio (Erichson), with observations of other members of the poultry manure arthropod community*. Ph.D. dissertation, University of Massachusetts, Amherst.
- GEDEN, C. J. & STOFFOLANO, J. G. JR. 1987. Succession of manure arthropods at a poultry farm in Massachusetts, USA, with observations on *Carcinops pumilio* (Coleoptera: Histeridae) sex ratios, ovarian condition and body size. *Journal of Medical Entomology* **24**: 212-220.
- GEDEN, C. J., STOFFOLANO, J. G. JR & ELKINTON, J. S. 1987. Prey-mediated dispersal behaviour of *Carcinops pumilio* (Coleoptera: Histeridae). *Environmental Entomology* **16**: 415-419.
- JONES, C. J., ISARO, S. A. & CORTINAS, M. R. 1999. Dispersal of synanthropic Diptera: Lessons from the past and technology for the future. *Annals of the Entomological Society of America* **92**: 829-839.

- KAUFMAN, P. E., LONG, S. J., RUTZ, D. A. & GLENISTER, C. S. 2000. Prey and density-mediated dispersal in *Carcinops pumilio* (Coleoptera: Histeridae), a predator of house fly (Diptera: Muscidae) eggs and larvae. *Journal of Medical Entomology* **37**: 929-932.
- KAUFMAN, P. E., LONG, S. J., RUTZ, D. A. & GLENISTER, C. S. 2001. Larval production from field-collected *Carcinops pumilio* (Coleoptera: Histeridae) following three starvation periods. *Journal of Medical Entomology* **38**: 278-281.
- KAUFMAN, P. E., RUTZ, D. A. & WALDRON, J. K. 2002. Seasonal variation in *Carcinops pumilio* (Coleoptera: Histeridae) dispersal and potential for suppression of dispersal behaviour. *Journal of Medical Entomology* **39**: 106-111.
- MCINTYRE, N. E. & WIENS, J. A. 1999. Interactions between landscape structure and animal behavior: the roles of heterogeneously distributed resources and food deprivation on movement patterns. *Landscape Ecology* **14**: 437-447.
- PRICE, P. W. 1997. *Insect Ecology*. John Wiley & Sons, Inc., New York.
- SCOTT, J. G., ALEFANTIS, T. G., KAUFMAN, P. E. & RUTZ, D. A. 2000. Insecticide resistance in house flies from caged-layer facilities. *Pest Management Science* **56**: 1-7.

CHAPTER 8

POTENTIAL PREDATORS OF *MUSCA DOMESTICA* L. (DIPTERA: MUSCIDAE) AND OTHER POULTRY MANURE FILTH FLIES IN THE WESTERN CAPE PROVINCE, SOUTH AFRICA

ABSTRACT

Laboratory experiments on the feeding preferences of the potential predators of *Musca domestica* (L.) indicated that *Philonthus sordidus* (Gravenhorst) consumed all immature stages of *M. domestica* whilst *Carcinops pumilio* (Erichson), *C. troglodytes* (Paykull), *Oxytellus sculptus* (Gravenhorst), *Alphitobius diaperinus* (Panzer) and *Macrocheles muscaedomesticae* (Scopoli) fed on the eggs and 1st instar larvae of *M. domestica*. The predators could be important in the natural control of house flies. Predation rates over a range of predator densities varied considerably within and between species. The consumption of *M. domestica* immatures per predator per day were: *C. pumilio* adults, from 19 to 50; *C. pumilio* 2nd instar larvae, from 13 to 29; and *M. muscaedomesticae* adults, from 15 to 32. Predation rates decreased with increase in predator density. At densities of five and 20 beetles per container they were 46.89 ± 4.75 and 19.23 ± 0.13 per predator per day respectively. Adult *C. pumilio* starved for nine days consumed significantly more *M. domestica* immatures than those fed for nine days, 75.27 ± 0.51 and 15.67 ± 2.96 per beetle per day respectively. The predation rate of the beetles increased with an increase in starvation. Starvation and feeding treatments had no significant effect on predation rate of *M. muscaedomesticae*.

Key words: *Carcinops pumilio*, *Microcheles muscaedomesticae*, *Musca domestica*, poultry manure, predation.

1. INTRODUCTION

High density confinement production systems of poultry are becoming increasingly more common in South Africa. Whilst such systems provide greater efficiency in livestock production, they create problems such as the need for manure disposal and flies breeding in the manure, eg. the house fly, *Musca domestica* L. (Diptera: Muscidae) (Axtell 1986). House fly population outbreaks present economic and social problems for farmers. An effective pest management program is therefore necessary to avoid economic losses and to reduce nuisance levels (Howard & Wall 1996). The use of insecticides in house fly management programs is becoming more costly and less effective because of resistance problems in the target pest population (Geden *et al.* 1992).

Arthropod predators in poultry manure could have a substantial effect in regulating populations of filth flies. Under proper conditions they can maintain populations of pest fly species at nearly zero levels (Geden & Axtell 1988, Geden 1990). The two most important cosmopolitan predators of immature stages of house flies in poultry manure are *Carcinops pumilio* (Erichson) (Coleoptera: Histeridae) and *Macrocheles muscaedomesticae* (Scopoli) (Acarina: Macrochelidae) (Peck 1969, Axtell 1970, Legner *et al.* 1975, Geden *et al.* 1988). They are also found in South Africa (Hulley & Pfeleiderer 1988, Chapter 2).

The studies of predatory beetles from poultry manure lag behind those of the pteromalid parasitoids (Pfeiffer & Axtell, 1980). The few studies done on the beetles were mostly carried out in North America (Hulley & Pfeleiderer, 1988), while Legner

& Olton (1968) stated that little is known of the beetles breeding in poultry manure in the Afrotropical Region.

In earlier chapters various aspects of the biology and ecology of the predators in poultry manure, particularly *C. pumilio* were studied. In this study the objectives were to gain more information in the laboratory on (1) the feeding behaviour of some predators encountered in the poultry manure, (2) the predation rates at varying predator densities and (3) the effect of starvation on fly predation by *C. pumilio*. Such information would be useful in evaluating the predation of various species encountered as biological control agents.

2. MATERIALS AND METHODS

2.1 Food preferences

All experiments were carried out at a University of Stellenbosch laboratory (33° 54'S; 18° 57'E). The food preference of some adult putative fly predators found in the poultry manure was determined by observing predator-prey and other interactions in 25cc glass vials, covered with nylon mesh held in place with a rubber band.

The various stages of *M. domestica* and *Fannia canicularis* (L.) were obtained from colonies reared at the Department of Entomology and Nematology, Stellenbosch University, South Africa. They were placed on moist tissue paper in the vials to avoid desiccation, and thereupon offered to the predators. About 5g each of Pro-Plex[®] (albumin powder) and poultry manure were also offered. The trials were carried out at $22 \pm 2^\circ\text{C}$. Each glass vial was observed continuously for the first hour and then at one-hour intervals for a further 16 hrs. Preference was measured as elapsed time until

a particular item was first fed upon (Hulley & Pfeleiderer 1988). The predators were used immediately after collection from poultry manure.

2.2 Predation rates at varying predator densities

Predators used in the experiments were the progeny of adults collected from a cohort reared in the laboratory. Predators were held without food for 24 hrs before being offered prey. A house fly breeding medium (see Chapter 5) with about 60-65% moisture content was prepared. About 1.5 litres of this medium was placed in a 2 l milk container for each predatory density level. Predators at densities of 5, 10, 15, 20 and 25 for *M. muscaedomesticae* adults, *C. pumilio* adults (males and females) and 2nd instar larvae, were transferred to the medium. There were five replicates in each experiment. The precise age of the predators was undetermined. About 500 three hour old house fly eggs were pipetted onto the surface of the medium in each milk container. Milk containers with medium and the same number of fly eggs were used as controls. The number of eggs used per container was estimated volumetrically from the mean counted previously. The containers were held at $27 \pm 2^{\circ}\text{C}$ in an incubator for 20 days and emerged *M. domestica* adults counted.

The mortality of *M. domestica* due to predation was calculated from the formula:

$$\text{mortality} = [(T - t) / T],$$

where T = mean number of eggs introduced and

t = mean number of flies that emerged.

The correction factor for mortality in each milk container with predators was made using Abbott's formula (Abbott 1925), $(W-w)/(1-w)$, where

W = proportion of dead flies in the treatment and w = proportion of dead flies in the control. This was then multiplied by 100 to obtain percentage mortality.

The rate of predation per predator per day was obtained by firstly multiplying the corrected mortality in each container by 500, the number of *M. domestica* eggs introduced, to give the total number of flies destroyed. This figure was then divided by the number of predators present in each container and the number of days that the house fly immatures were vulnerable to predation. The prey vulnerability period was taken to be about one day for both beetles and mite predators since only eggs and 1st instar larvae are preyed upon.

2.3 Effect of satiation on predation

The satiation effect of predators on predation rates was studied by subjecting the adults of *C. pumilio* (both sexes) and *M. muscaedomesticae* to the following five feeding treatments: fed on abundant *Drosophila melanogaster* (Meig.) eggs and larvae for 9, 5, 3 and 1 day(s), or deprived of food for 1, 3, 5, 7 and 9 day(s). The medium described in section 2.2 was prepared and placed in 2 l milk containers for each satiation level in triplicate. About 500 freshly laid *M. domestica* eggs were pipetted onto the surface of the medium. Five *C. pumilio* adults and 20 *M. muscaedomesticae* at each satiation level were added to the containers. The control (without predators) was also in triplicate with about 500 freshly laid *M. domestica* eggs. Containers were held at $27 \pm 1^\circ\text{C}$ for 20 days and the numbers of emerged flies were counted. Predation rates were calculated as described in 2.2 above.

2.4 Analysis

Predation rates were analyzed using one-way analysis of variance (ANOVA) and significance differences ($P < 0.05$) among the means of each species was determined using Fisher's (LSD).

3. RESULTS

3.1 Food preferences

Table 1 shows the feeding preferences of some selected species of manure dwelling arthropods. Adult *Philonthus sordidus* (Gravenhorst) (Coleoptera: Staphylinidae) consumed eggs, 1st and 2nd instar larvae of *M. domestica* and *F. canicularis* 1st and 2nd instar larvae. *Oxytellus sculptus* Gravenhorst (Coleoptera: Staphylinidae) fed on eggs and 1st instar of *M. domestica* and 2nd instar of *F. canicularis* and attempted to feed on albumin powder. *Dactylosternum abdominale* (Fabricius) (Coleoptera: Hydrophilidae) fed exclusively on manure whilst *Alphitobius diaperinus* (Panzer) (Coleoptera: Tenebrionidae) also fed on manure, eggs, 1st instar larvae of *M. domestica* and as well as *F. canicularis* 1st instar larvae. *C. pumilio* adults were avid feeders on *M. domestica* eggs and 1st instar larvae and also fed on *F. canicularis* 1st instar larvae. *Carcinops pumilio* attempted to feed on the albumin powder but had difficulty holding on with the mandibles. *Carcinops troglodytes* (Paykull) (Coleoptera: Histeridae) like *M. muscaedomesticae* fed on eggs and 1st instar larvae of *M. domestica* and 1st instar larvae of *F. canicularis*.

Table 1. Laboratory observation of feeding preferences of some putative predators found in poultry manure.

| Species | N* | <i>Musca domestica</i> | | | | <i>Fannia canicularis</i> | | | Other item | | |
|---|----|------------------------|------------------------|------------------------|------------------------|---------------------------|------------------------|------------------------|------------|-----------|-----|
| | | Egg | 1 st instar | 2 nd instar | 3 rd instar | 1 st instar | 2 nd instar | 3 rd instar | manure | PRO-PLEX™ | |
| Histeridae | | | | | | | | | | | |
| <i>Carcinops pumilio</i> (Erichson) | 3 | 5 | +++ | +++ | - | - | ++ | - | - | - | +++ |
| <i>Carcinops troglodytes</i> (Payle) | 3 | 2 | + | +++ | - | - | +++ | - | - | - | +++ |
| Staphylinidae | | | | | | | | | | | |
| <i>Philonthus sordidus</i> (Gravenhorst) | 3 | 5 | + | +++ | +++ | - | ++ | ++ | - | - | - |
| <i>Oxytelus sculptus</i> Gravenhorst | 3 | 5 | ++ | +++ | - | - | ++ | - | - | - | ++ |
| Tenebrionidae | | | | | | | | | | | |
| <i>Alphitobius diaperinus</i> (Panzer) | 3 | 3 | + | ++ | - | - | + | - | - | + | - |
| Cerylonidae | | | | | | | | | | | |
| <i>Euxestus phalacroides</i> Wallaston | 3 | 3 | ++ | ++ | - | - | + | - | - | - | + |
| Hydrophilidae | | | | | | | | | | | |
| <i>Dactylosternum abdominale</i> (Fabricius) | 3 | 3 | - | - | - | - | - | - | - | +++ | - |
| Macrochelidae | | | | | | | | | | | |
| <i>Macrocheles muscaedomesticae</i> (Scopoli) | 5 | 5 | ++ | + | - | - | + | - | - | - | - |

+++ = Specimen presented eaten within 5 minutes.

++ = Specimen presented eaten within 5 to 15 minutes.

+ = Specimen presented eaten within 16 to 60 minutes.

* = Number of replicates; number of individuals per replicate.

3.2 Predation rate at varying predator densities

Mean predation by male and female *C. pumilio* was similar (Table 2). Predation/beetle/day decreased as the predator density increased (Table 2). The predation rate was about twice as high at 10 *C. pumilio* adults (both sexes) per container as at 25 beetle adults per container (Table 2). The 2nd instar larvae of *C. pumilio* consumed significantly fewer prey per larva per day as compared to adults. The predation rate of five 2nd instar larvae per container was twice for 20 2nd instar larvae per container.

Machrocheles muscaedomesticae adults had higher predation rate of five adults per container than 20 and 25 per container respectively (Table 2).

Predator density had effect on predation rates of all predators (Table 2).

TABLE 2. Rate of predation (prey per predator per day) for *M. domesticae*, *C. pumilio* and *M. muscaedomesticae*.

| Predator (sex) | Prey | 10 | 20 | 25 |
|---------------------------|--------------|------|------|------|
| <i>C. pumilio</i> (adult) | 1st instar | 0.12 | 0.06 | 0.04 |
| <i>C. pumilio</i> (adult) | 2nd instar | 0.15 | 0.07 | 0.05 |
| <i>C. pumilio</i> (adult) | 3rd instar | 0.18 | 0.09 | 0.06 |
| <i>C. pumilio</i> (adult) | 4th instar | 0.21 | 0.10 | 0.07 |
| <i>C. pumilio</i> (adult) | 5th instar | 0.24 | 0.12 | 0.08 |
| <i>C. pumilio</i> (adult) | 6th instar | 0.27 | 0.14 | 0.09 |
| <i>C. pumilio</i> (adult) | 7th instar | 0.30 | 0.16 | 0.10 |
| <i>C. pumilio</i> (adult) | 8th instar | 0.33 | 0.18 | 0.11 |
| <i>C. pumilio</i> (adult) | 9th instar | 0.36 | 0.20 | 0.12 |
| <i>C. pumilio</i> (adult) | 10th instar | 0.39 | 0.22 | 0.13 |
| <i>C. pumilio</i> (adult) | 11th instar | 0.42 | 0.24 | 0.14 |
| <i>C. pumilio</i> (adult) | 12th instar | 0.45 | 0.26 | 0.15 |
| <i>C. pumilio</i> (adult) | 13th instar | 0.48 | 0.28 | 0.16 |
| <i>C. pumilio</i> (adult) | 14th instar | 0.51 | 0.30 | 0.17 |
| <i>C. pumilio</i> (adult) | 15th instar | 0.54 | 0.32 | 0.18 |
| <i>C. pumilio</i> (adult) | 16th instar | 0.57 | 0.34 | 0.19 |
| <i>C. pumilio</i> (adult) | 17th instar | 0.60 | 0.36 | 0.20 |
| <i>C. pumilio</i> (adult) | 18th instar | 0.63 | 0.38 | 0.21 |
| <i>C. pumilio</i> (adult) | 19th instar | 0.66 | 0.40 | 0.22 |
| <i>C. pumilio</i> (adult) | 20th instar | 0.69 | 0.42 | 0.23 |
| <i>C. pumilio</i> (adult) | 21st instar | 0.72 | 0.44 | 0.24 |
| <i>C. pumilio</i> (adult) | 22nd instar | 0.75 | 0.46 | 0.25 |
| <i>C. pumilio</i> (adult) | 23rd instar | 0.78 | 0.48 | 0.26 |
| <i>C. pumilio</i> (adult) | 24th instar | 0.81 | 0.50 | 0.27 |
| <i>C. pumilio</i> (adult) | 25th instar | 0.84 | 0.52 | 0.28 |
| <i>C. pumilio</i> (adult) | 26th instar | 0.87 | 0.54 | 0.29 |
| <i>C. pumilio</i> (adult) | 27th instar | 0.90 | 0.56 | 0.30 |
| <i>C. pumilio</i> (adult) | 28th instar | 0.93 | 0.58 | 0.31 |
| <i>C. pumilio</i> (adult) | 29th instar | 0.96 | 0.60 | 0.32 |
| <i>C. pumilio</i> (adult) | 30th instar | 0.99 | 0.62 | 0.33 |
| <i>C. pumilio</i> (adult) | 31st instar | 1.02 | 0.64 | 0.34 |
| <i>C. pumilio</i> (adult) | 32nd instar | 1.05 | 0.66 | 0.35 |
| <i>C. pumilio</i> (adult) | 33rd instar | 1.08 | 0.68 | 0.36 |
| <i>C. pumilio</i> (adult) | 34th instar | 1.11 | 0.70 | 0.37 |
| <i>C. pumilio</i> (adult) | 35th instar | 1.14 | 0.72 | 0.38 |
| <i>C. pumilio</i> (adult) | 36th instar | 1.17 | 0.74 | 0.39 |
| <i>C. pumilio</i> (adult) | 37th instar | 1.20 | 0.76 | 0.40 |
| <i>C. pumilio</i> (adult) | 38th instar | 1.23 | 0.78 | 0.41 |
| <i>C. pumilio</i> (adult) | 39th instar | 1.26 | 0.80 | 0.42 |
| <i>C. pumilio</i> (adult) | 40th instar | 1.29 | 0.82 | 0.43 |
| <i>C. pumilio</i> (adult) | 41st instar | 1.32 | 0.84 | 0.44 |
| <i>C. pumilio</i> (adult) | 42nd instar | 1.35 | 0.86 | 0.45 |
| <i>C. pumilio</i> (adult) | 43rd instar | 1.38 | 0.88 | 0.46 |
| <i>C. pumilio</i> (adult) | 44th instar | 1.41 | 0.90 | 0.47 |
| <i>C. pumilio</i> (adult) | 45th instar | 1.44 | 0.92 | 0.48 |
| <i>C. pumilio</i> (adult) | 46th instar | 1.47 | 0.94 | 0.49 |
| <i>C. pumilio</i> (adult) | 47th instar | 1.50 | 0.96 | 0.50 |
| <i>C. pumilio</i> (adult) | 48th instar | 1.53 | 0.98 | 0.51 |
| <i>C. pumilio</i> (adult) | 49th instar | 1.56 | 1.00 | 0.52 |
| <i>C. pumilio</i> (adult) | 50th instar | 1.59 | 1.02 | 0.53 |
| <i>C. pumilio</i> (adult) | 51st instar | 1.62 | 1.04 | 0.54 |
| <i>C. pumilio</i> (adult) | 52nd instar | 1.65 | 1.06 | 0.55 |
| <i>C. pumilio</i> (adult) | 53rd instar | 1.68 | 1.08 | 0.56 |
| <i>C. pumilio</i> (adult) | 54th instar | 1.71 | 1.10 | 0.57 |
| <i>C. pumilio</i> (adult) | 55th instar | 1.74 | 1.12 | 0.58 |
| <i>C. pumilio</i> (adult) | 56th instar | 1.77 | 1.14 | 0.59 |
| <i>C. pumilio</i> (adult) | 57th instar | 1.80 | 1.16 | 0.60 |
| <i>C. pumilio</i> (adult) | 58th instar | 1.83 | 1.18 | 0.61 |
| <i>C. pumilio</i> (adult) | 59th instar | 1.86 | 1.20 | 0.62 |
| <i>C. pumilio</i> (adult) | 60th instar | 1.89 | 1.22 | 0.63 |
| <i>C. pumilio</i> (adult) | 61st instar | 1.92 | 1.24 | 0.64 |
| <i>C. pumilio</i> (adult) | 62nd instar | 1.95 | 1.26 | 0.65 |
| <i>C. pumilio</i> (adult) | 63rd instar | 1.98 | 1.28 | 0.66 |
| <i>C. pumilio</i> (adult) | 64th instar | 2.01 | 1.30 | 0.67 |
| <i>C. pumilio</i> (adult) | 65th instar | 2.04 | 1.32 | 0.68 |
| <i>C. pumilio</i> (adult) | 66th instar | 2.07 | 1.34 | 0.69 |
| <i>C. pumilio</i> (adult) | 67th instar | 2.10 | 1.36 | 0.70 |
| <i>C. pumilio</i> (adult) | 68th instar | 2.13 | 1.38 | 0.71 |
| <i>C. pumilio</i> (adult) | 69th instar | 2.16 | 1.40 | 0.72 |
| <i>C. pumilio</i> (adult) | 70th instar | 2.19 | 1.42 | 0.73 |
| <i>C. pumilio</i> (adult) | 71st instar | 2.22 | 1.44 | 0.74 |
| <i>C. pumilio</i> (adult) | 72nd instar | 2.25 | 1.46 | 0.75 |
| <i>C. pumilio</i> (adult) | 73rd instar | 2.28 | 1.48 | 0.76 |
| <i>C. pumilio</i> (adult) | 74th instar | 2.31 | 1.50 | 0.77 |
| <i>C. pumilio</i> (adult) | 75th instar | 2.34 | 1.52 | 0.78 |
| <i>C. pumilio</i> (adult) | 76th instar | 2.37 | 1.54 | 0.79 |
| <i>C. pumilio</i> (adult) | 77th instar | 2.40 | 1.56 | 0.80 |
| <i>C. pumilio</i> (adult) | 78th instar | 2.43 | 1.58 | 0.81 |
| <i>C. pumilio</i> (adult) | 79th instar | 2.46 | 1.60 | 0.82 |
| <i>C. pumilio</i> (adult) | 80th instar | 2.49 | 1.62 | 0.83 |
| <i>C. pumilio</i> (adult) | 81st instar | 2.52 | 1.64 | 0.84 |
| <i>C. pumilio</i> (adult) | 82nd instar | 2.55 | 1.66 | 0.85 |
| <i>C. pumilio</i> (adult) | 83rd instar | 2.58 | 1.68 | 0.86 |
| <i>C. pumilio</i> (adult) | 84th instar | 2.61 | 1.70 | 0.87 |
| <i>C. pumilio</i> (adult) | 85th instar | 2.64 | 1.72 | 0.88 |
| <i>C. pumilio</i> (adult) | 86th instar | 2.67 | 1.74 | 0.89 |
| <i>C. pumilio</i> (adult) | 87th instar | 2.70 | 1.76 | 0.90 |
| <i>C. pumilio</i> (adult) | 88th instar | 2.73 | 1.78 | 0.91 |
| <i>C. pumilio</i> (adult) | 89th instar | 2.76 | 1.80 | 0.92 |
| <i>C. pumilio</i> (adult) | 90th instar | 2.79 | 1.82 | 0.93 |
| <i>C. pumilio</i> (adult) | 91st instar | 2.82 | 1.84 | 0.94 |
| <i>C. pumilio</i> (adult) | 92nd instar | 2.85 | 1.86 | 0.95 |
| <i>C. pumilio</i> (adult) | 93rd instar | 2.88 | 1.88 | 0.96 |
| <i>C. pumilio</i> (adult) | 94th instar | 2.91 | 1.90 | 0.97 |
| <i>C. pumilio</i> (adult) | 95th instar | 2.94 | 1.92 | 0.98 |
| <i>C. pumilio</i> (adult) | 96th instar | 2.97 | 1.94 | 0.99 |
| <i>C. pumilio</i> (adult) | 97th instar | 3.00 | 1.96 | 1.00 |
| <i>C. pumilio</i> (adult) | 98th instar | 3.03 | 1.98 | 1.01 |
| <i>C. pumilio</i> (adult) | 99th instar | 3.06 | 2.00 | 1.02 |
| <i>C. pumilio</i> (adult) | 100th instar | 3.09 | 2.02 | 1.03 |
| <i>C. pumilio</i> (adult) | 101st instar | 3.12 | 2.04 | 1.04 |
| <i>C. pumilio</i> (adult) | 102nd instar | 3.15 | 2.06 | 1.05 |
| <i>C. pumilio</i> (adult) | 103rd instar | 3.18 | 2.08 | 1.06 |
| <i>C. pumilio</i> (adult) | 104th instar | 3.21 | 2.10 | 1.07 |
| <i>C. pumilio</i> (adult) | 105th instar | 3.24 | 2.12 | 1.08 |
| <i>C. pumilio</i> (adult) | 106th instar | 3.27 | 2.14 | 1.09 |
| <i>C. pumilio</i> (adult) | 107th instar | 3.30 | 2.16 | 1.10 |
| <i>C. pumilio</i> (adult) | 108th instar | 3.33 | 2.18 | 1.11 |
| <i>C. pumilio</i> (adult) | 109th instar | 3.36 | 2.20 | 1.12 |
| <i>C. pumilio</i> (adult) | 110th instar | 3.39 | 2.22 | 1.13 |
| <i>C. pumilio</i> (adult) | 111th instar | 3.42 | 2.24 | 1.14 |
| <i>C. pumilio</i> (adult) | 112th instar | 3.45 | 2.26 | 1.15 |
| <i>C. pumilio</i> (adult) | 113th instar | 3.48 | 2.28 | 1.16 |
| <i>C. pumilio</i> (adult) | 114th instar | 3.51 | 2.30 | 1.17 |
| <i>C. pumilio</i> (adult) | 115th instar | 3.54 | 2.32 | 1.18 |
| <i>C. pumilio</i> (adult) | 116th instar | 3.57 | 2.34 | 1.19 |
| <i>C. pumilio</i> (adult) | 117th instar | 3.60 | 2.36 | 1.20 |
| <i>C. pumilio</i> (adult) | 118th instar | 3.63 | 2.38 | 1.21 |
| <i>C. pumilio</i> (adult) | 119th instar | 3.66 | 2.40 | 1.22 |
| <i>C. pumilio</i> (adult) | 120th instar | 3.69 | 2.42 | 1.23 |
| <i>C. pumilio</i> (adult) | 121st instar | 3.72 | 2.44 | 1.24 |
| <i>C. pumilio</i> (adult) | 122nd instar | 3.75 | 2.46 | 1.25 |
| <i>C. pumilio</i> (adult) | 123rd instar | 3.78 | 2.48 | 1.26 |
| <i>C. pumilio</i> (adult) | 124th instar | 3.81 | 2.50 | 1.27 |
| <i>C. pumilio</i> (adult) | 125th instar | 3.84 | 2.52 | 1.28 |
| <i>C. pumilio</i> (adult) | 126th instar | 3.87 | 2.54 | 1.29 |
| <i>C. pumilio</i> (adult) | 127th instar | 3.90 | 2.56 | 1.30 |
| <i>C. pumilio</i> (adult) | 128th instar | 3.93 | 2.58 | 1.31 |
| <i>C. pumilio</i> (adult) | 129th instar | 3.96 | 2.60 | 1.32 |
| <i>C. pumilio</i> (adult) | 130th instar | 3.99 | 2.62 | 1.33 |
| <i>C. pumilio</i> (adult) | 131st instar | 4.02 | 2.64 | 1.34 |
| <i>C. pumilio</i> (adult) | 132nd instar | 4.05 | 2.66 | 1.35 |
| <i>C. pumilio</i> (adult) | 133rd instar | 4.08 | 2.68 | 1.36 |
| <i>C. pumilio</i> (adult) | 134th instar | 4.11 | 2.70 | 1.37 |
| <i>C. pumilio</i> (adult) | 135th instar | 4.14 | 2.72 | 1.38 |
| <i>C. pumilio</i> (adult) | 136th instar | 4.17 | 2.74 | 1.39 |
| <i>C. pumilio</i> (adult) | 137th instar | 4.20 | 2.76 | 1.40 |
| <i>C. pumilio</i> (adult) | 138th instar | 4.23 | 2.78 | 1.41 |
| <i>C. pumilio</i> (adult) | 139th instar | 4.26 | 2.80 | 1.42 |
| <i>C. pumilio</i> (adult) | 140th instar | 4.29 | 2.82 | 1.43 |
| <i>C. pumilio</i> (adult) | 141st instar | 4.32 | 2.84 | 1.44 |
| <i>C. pumilio</i> (adult) | 142nd instar | 4.35 | 2.86 | 1.45 |
| <i>C. pumilio</i> (adult) | 143rd instar | 4.38 | 2.88 | 1.46 |
| <i>C. pumilio</i> (adult) | 144th instar | 4.41 | 2.90 | 1.47 |
| <i>C. pumilio</i> (adult) | 145th instar | 4.44 | 2.92 | 1.48 |
| <i>C. pumilio</i> (adult) | 146th instar | 4.47 | 2.94 | 1.49 |
| <i>C. pumilio</i> (adult) | 147th instar | 4.50 | 2.96 | 1.50 |
| <i>C. pumilio</i> (adult) | 148th instar | 4.53 | 2.98 | 1.51 |
| <i>C. pumilio</i> (adult) | 149th instar | 4.56 | 3.00 | 1.52 |
| <i>C. pumilio</i> (adult) | 150th instar | 4.59 | 3.02 | 1.53 |
| <i>C. pumilio</i> (adult) | 151st instar | 4.62 | 3.04 | 1.54 |
| <i>C. pumilio</i> (adult) | 152nd instar | 4.65 | 3.06 | 1.55 |
| <i>C. pumilio</i> (adult) | 153rd instar | 4.68 | 3.08 | 1.56 |
| <i>C. pumilio</i> (adult) | 154th instar | 4.71 | 3.10 | 1.57 |
| <i>C. pumilio</i> (adult) | 155th instar | 4.74 | 3.12 | 1.58 |
| <i>C. pumilio</i> (adult) | 156th instar | 4.77 | 3.14 | 1.59 |
| <i>C. pumilio</i> (adult) | 157th instar | 4.80 | 3.16 | 1.60 |
| <i>C. pumilio</i> (adult) | 158th instar | 4.83 | 3.18 | 1.61 |
| <i>C. pumilio</i> (adult) | 159th instar | 4.86 | 3.20 | 1.62 |
| <i>C. pumilio</i> (adult) | 160th instar | 4.89 | 3.22 | 1.63 |
| <i>C. pumilio</i> (adult) | 161st instar | 4.92 | 3.24 | 1.64 |
| <i>C. pumilio</i> (adult) | 162nd instar | 4.95 | 3.26 | 1.65 |
| <i>C. pumilio</i> (adult) | 163rd instar | 4.98 | 3.28 | 1.66 |
| <i>C. pumilio</i> (adult) | 164th instar | 5.01 | 3.30 | 1.67 |
| <i>C. pumilio</i> (adult) | 165th instar | 5.04 | 3.32 | 1.68 |
| <i>C. pumilio</i> (adult) | 166th instar | 5.07 | 3.34 | 1.69 |
| <i>C. pumilio</i> (adult) | 167th instar | 5.10 | 3.36 | 1.70 |
| <i>C. pumilio</i> (adult) | 168th instar | 5.13 | 3.38 | 1.71 |
| <i>C. pumilio</i> (adult) | 169th instar | 5.16 | 3.40 | 1.72 |
| <i>C. pumilio</i> (adult) | 170th instar | 5.19 | 3.42 | 1.73 |
| <i>C. pumilio</i> (adult) | 171st instar | 5.22 | 3.44 | 1.74 |
| <i>C. pumilio</i> (adult) | 172nd instar | 5.25 | 3.46 | 1.75 |
| <i>C. pumilio</i> (adult) | 173rd instar | 5.28 | 3.48 | 1.76 |
| <i>C. pumilio</i> (adult) | 174th instar | 5.31 | 3.50 | 1.77 |
| <i>C. pumilio</i> (adult) | 175th instar | 5.34 | 3.52 | 1.78 |
| <i>C. pumilio</i> (adult) | 176th instar | 5.37 | 3.54 | 1.79 |
| <i>C. pumilio</i> (adult) | 177th instar | 5.40 | 3.56 | 1.80 |
| <i>C. pumilio</i> (adult) | 178th instar | 5.43 | 3.58 | 1.81 |
| <i>C. pumilio</i> (adult) | 179th instar | 5.46 | 3.60 | 1.82 |
| <i>C. pumilio</i> (adult) | 180th instar | 5.49 | 3.62 | 1.8 |

TABLE 2. Rate of predation (prey per predator per day) on *M. domestica* immatur stages at varying densities of *C. pumilio* and *M. muscaedomesticae*

| Predator / stage | Predator density level | | | | | |
|---|------------------------|------------------------|-----------------------|------------------------|--------------------------|---------------------|
| | Control | 5 | 10 | 15 | 20 | 25 |
| <i>C. pumilio</i> adult females | | | | | | |
| mean (\pm SE) no. of fly mortality | 99.20 \pm 11.18 a | 333.640 \pm 38.20 b | 413.80 \pm 6.76 c | 448.00 \pm 5.00 d | 485.40 \pm 1.93 e | 492.20 \pm 2.56 e |
| mean (\pm SE) % mortality ^k | 19.84 \pm 2.24 a | 58.49 \pm 3.61 b | 78.49 \pm 1.35 c | 87.03 \pm 1.05 d | 96.26 \pm 0.39 e | 98.05 \pm 0.51 e |
| mean (\pm SE) predation ^m | — | 46.89 \pm 4.72 a | 31.46 \pm 0.88 b | 23.25 \pm 0.43 c | 19.29 \pm 0.13 d | 15.72 \pm 13 d |
| <i>C. pumilio</i> adult males | | | | | | |
| mean (\pm SE) no. of fly mortality. | 100.80 \pm 8.55 a | 335.00 \pm 7.40 b | 416.80 \pm 6.66 c | 445.00 \pm 6.30 d | 482.40 \pm 1.86 e | 491.80 \pm 1.36 e |
| mean (\pm SE) % mortality ^k | 20.16 \pm 1.71 a | 58.67 \pm 1.48 b | 79.16 \pm 1.38 c | 86.22 \pm 1.26 d | 95.59 \pm 0.37 e | 97.95 \pm 0.27 e |
| mean (\pm SE) predation ^m | — | 46.84 \pm 5.03 a | 31.60 \pm 9.01 b | 22.95 \pm 8.52 c | 19.08 \pm 2.52 d | 15.64 \pm 1.84 d |
| <i>C. pumilio</i> 2 nd instar larvae | | | | | | |
| mean (\pm SE) no. of fly mortality | 121.00 \pm 3.59 a | 230.60 \pm 3.20 b | 296.60 \pm 6.07 c | 307.20 \pm 5.97 c | 341.60 \pm 8.05 d | 366.20 \pm 7.77 e |
| mean (\pm SE) % mortality ^k | 24.20 \pm 1.21 a | 28.92 \pm 0.64 b | 46.33 \pm 1.21 c | 49.13 \pm 1.19 c | 58.21 \pm 1.61 d | 64.7 \pm 1.55 e |
| mean (\pm SE) predation ^m | — | 21.92 \pm 0.85 e | 17.6 \pm 0.80 d | 12.41 \pm 0.53 c | 11.03 \pm 0.53 a,b | 9.81 \pm 0.41 a |
| <i>M. muscaedomesticae</i> adult | | | | | | |
| mean (\pm SE) no. of fly mortality | 105.60 \pm 3.84 a | 232.20 \pm 16.05 b,c | 273.20 \pm 8.80 c,d | 309.60 \pm 10.33 c,d | 342.20 \pm 10.78 b,c,d | 395.20 \pm 4.87 e |
| mean (\pm SE) % mortality ^k | 21.12 \pm 0.98 a | 32.10 \pm 4.13 b,c | 42.49 \pm 2.29 c,d | 51.72 \pm 2.67 c,d | 59.99 \pm 2.77 b,c,d | 73.43 \pm 1.11 e |
| mean (\pm SE) predation ^m | — | 25.32 \pm 4.07 c | 16.80 \pm 1.12 b | 13.60 \pm 0.87 a,b | 11.83 \pm 0.68 a | 11.58 \pm 0.25 a |

^k = Corrected for control mortality^m = Number of house fly immatures destroyed per predator per dayFigures with the same letters in a row are not significantly different ($P < 0.05$)

3.3 Influence of satiation on predation

Carcinops pumilio adults (both sexes) fed for nine days consumed significantly fewer *M. domestica* immatures per predator per day (15) compared to those for nine days (45) (Table 3).

Both fed and starved *M. muscaedomesticae* consumed a consistent number (9-10) *M. domestica* immatures per day. Satiation levels in *M. muscaedomesticae* had no effect on the predation of the *M. domestica* immature stages (Table 3).

Table 3. Numbers of immatures *M. domestica* consumed by fed and starved predators of *C. pumilio* and *M. muscaedomesticae*

| Predator | Predator satiation level (number of days fed) | | | | | | | * P-value | |
|--|--|------------------|------------------|------------------|------------------|--------------------|-----------------------|-----------------|-------|
| | Gender | Control | Fed 9 d | Fed 7 d | Fed 5 d | Fed 3 d | Fed 1 d | | |
| <i>C. pumilio</i> adult (5 per cup) mean (± SE) no. of fly mortality | M | 120 ± 12.81 j | 197.33 ± 7.88 i | 345.0 ± 3.60 h | 387.0 ± 4.61 g | 480.0 ± 0.58 c, d | 486.33 ± 8.29 a, b, c | | |
| | F | 120 ± 12.81 j | 198.34 ± 8.11 i | 343.67 ± 3.20 h | 380.33 ± 6.39 g | 479.33 ± 2.73 c | 485.67 ± 9.84 b, c | | |
| | M | - | 20.35 ± 1.58 a | 59.21 ± 0.72 b | 70.26 ± 0.92 c | 94.74 ± 0.12 e | 96.32 ± 1.66 f, g | | |
| | F | - | 20.62 ± 1.62 a | 58.86 ± 0.67 b | 68.51 ± 1.28 c | 94.56 ± 0.55 e | 96.23 ± 1.97 f, g | | |
| | M | - | 15.47 ± 0.09 a | 45.00 ± 1.63 b | 53.40 ± 0.25 c | 72.00 ± 0.33 f | 73.20 ± 2.36 g | < 0.001 | |
| | F | - | 15.67 ± 2.96 a | 44.73 ± 1.96 b | 52.07 ± 2.31 c | 71.87 ± 0.67 f | 73.13 ± 2.55 g | < 0.001 | |
| <i>M. muscaedomesticae</i> adults (20 per cup) mean (± SE) no. of fly mortality | F | 145.67 ± 17.95 a | 315.00 ± 4.16 b | 317.33 ± 3.28 b | 325.00 ± 11.37 b | 332.33 ± 9.26 b | 338.67 ± 6.69 b | | |
| | | 26.67 ± 2.23 a | 51.32 ± 0.68 b | 51.93 ± 1.04 b | 53.95 ± 0.71 b | 55.88 ± 1.12 b | 57.54 ± 1.63 b | | |
| | | - | 9.72 ± 0.24 a | 9.87 ± 0.41 a | 10.18 ± 0.37 a | 10.46 ± 0.25 a | 10.51 ± 0.40 a | 0.160 | |
| | | | | | | | | | |
| <i>C. pumilio</i> adult (5 per cup) mean (± SE) no. of fly mortality | M | 120 ± 12.81 j | 344.67 ± 1.45 h | 423.33 ± 2.96 f | 451.67 ± 0.88 e | 487.67 ± 6.57 a, b | 496.33 ± 2.03 a, b | | |
| | F | 120 ± 12.81 j | 346.0 ± 3.48 h | 423 ± 3.79 f | 451.67 ± 1.45 e | 488.33 ± 8.0 a, b | 495.67 ± 1.20 a | | |
| | M | - | 59.12 ± 0.29 b | 79.82 ± 0.59 c | 87.28 ± 0.18 e | 96.76 ± 1.31 f, g | 99.03 ± 0.41 g | | |
| | F | - | 59.47 ± 0.70 b | 79.74 ± 0.76 c | 87.28 ± 0.29 e | 96.93 ± 1.60 f, g | 98.86 ± 0.24 g | | |
| | M | - | 44.93 ± 1.22 b | 60.67 ± 1.44 d | 66.33 ± 0.67 e | 73.53 ± 1.70 g | 75.27 ± 0.51 h | < 0.001 | |
| | F | - | 45.20 ± 1.45 b | 60.60 ± 1.43 d | 66.33 ± 0.39 e | 73.67 ± 2.26 g | 75.13 ± 0.30 h | < 0.001 | |
| | <i>M. muscaedomesticae</i> adults (20 per cup) mean (± SE) no. of fly mortality | F | 145.67 ± 17.95 a | 332.67 ± 10.97 b | 340.67 ± 9.84 b | 343.67 ± 5.81 b | 345.77 ± 3.76 b | 347.00 ± 4.58 b | |
| | | | 26.67 ± 2.23 a | 52.78 ± 1.63 b | 55.03 ± 0.82 b | 55.88 ± 1.00 b | 56.47 ± 0.87 b | 56.82 ± 0.42 b | |
| | | | - | 9.35 ± 0.58 a | 9.75 ± 0.29 a | 9.90 ± 0.35 a | 10.01 ± 0.31 a | 10.07 ± 0.15 a | 0.160 |
| | | | | | | | | | |

^a = Corrected for control mortality
^b = Number of house fly immatures destroyed per predator per day
 Figures with the same letters in a row not significantly different (P < 0.05)

4. Discussion

The staphylinid *P. sordidus* was the most voracious and aggressive predator tested. It fed on all stages of *M. domestica* except 3rd instar larvae (Table 1). This observation was also made by Peck (1969) and Hulley & Pfeiderer (1988) who found *Philonthus* sp. to be avid feeders on essentially all stages of *M. domestica*. Hulley & Pfeiderer (1988) also stated that *Philonthus* sp. had the greatest affinity for *M. domestica* immature stages even in the presence of other living insects offered. Legner & Olton (1968) found *P. sordidus* to be one of the principal predators in California, USA. Hulley & Pfeiderer (1988) found that *Philonthus* sp. was numerous in poultry manure in Eastern Cape Province, South Africa, which was not the case in the Western Cape, South Africa (see Chapter 2). Peck (1969) found them to be “pugnacious” and cannibalistic. This could exert strong density-dependent regulation on their population in the poultry manure. This might explain the low numbers found in the Western Cape, although this obviously does not happen to the same extent in the Eastern Cape. These characteristics do not render *P. sordidus* as a good candidate for mass rearing and inundative releases in IPM (Peck 1969). Two other beetle species *Oxytelus sculptus* and *Euxestus phalacroides*, which fed on eggs and 1st instar larvae of *M. domestica*, were only occasionally encountered in the manure and as such may probably not be of much importance.

The adult lesser mealworm, *Alphitobius diaperinus*, behaved as an omnivore, feeding as a predator on immature *M. domestica* and as a scavenger on manure. Legner & Olton (1968), Despins *et al.* (1988) and Geden (1990) also considered it as both a predator and scavenger, whilst Pfeiffer & Axtell (1980), Axtell (1986) and Paterson &

Rutz (1986) grouped it among the principal predators of *M. domestica* immature stages found in poultry manure. Although beneficial as a predator it could create problems by tunneling in and destroying the insulation in poultry houses (Safrit & Axtell 1984, Axtell 1986, Geden & Axtell 1987, Axtell & Arends 1990). Axtell & Arends (1990) stated that this results in greater heating costs as well as lowered feeding conversion efficiency of the birds due to lack of adequate temperature control in the houses. There was also the cost involved in replacing damaged insulating polystyrene panels (Turner 1986, Despins *et al.* 1988). *Alphitobius diaperinus* can also become a serious nuisance to humans as they tend to move or fly to nearby houses when poultry manure containing beetles is spread on fields (Axtell & Arends, 1990). Despins *et al.* (1988) and Geden (1990) mentioned that *A. diaperinus* promoted aeration and drying of accumulated manure by their tunneling activities in the manure, thus reducing opportunities for fly breeding. The potential of *A. diaperinus* as a biological control agent against *M. domestica* was overridden by its destructive tendencies in poultry houses. It was therefore not a suitable candidate for mass rearing for biological control of house flies (Safrit & Axtell 1984), unless a suitable means to limit their destructive activities is developed (Despin *et al.* 1988, Geden 1990).

Carcinops troglodytes was predaceous on *M. domestica* immatures but was scarcely encountered (see Chapter 2). This was in direct contrast to Hulley & Pfeleiderer (1988) who found *C. troglodytes* to be the most numerous histerid in poultry manure in the Eastern Cape Province, South Africa. *C. pumilio* was observed by many workers to be a predator of *M. domestica* immatures, eg. Peck (1969), Bills (1973), Geden (1984) and Hulley & Pfeleiderer (1988). It was the most common histerid found in poultry manure throughout much of the world and was considered to be the most important predator of fly immatures (Geden 1990).

The mite, *Macrocheles muscaedomesticae* fed on *M. domestica* eggs and 1st instar larvae in this study, an observation also made by Axtell (1961) and Willis & Axtell (1968). They occurred in high numbers at the University House and Rosendal Farm respectively (see Chapter 2). Patterson & Rutz (1986) considered *M. muscaedomesticae* to be a major fly predator in poultry manure and Chyi-Chen Ho *et al.* (1990) developed a method to mass produce this species.

At 27°C the vulnerability period of *M. domestica* immature stages to *C. pumilio* was about one day, (Geden *et al.* 1988, Geden & Axtell 1988). Thus the developing *M. domestica* immature stages destroyed by *C. pumilio* would essentially be the egg and 1st instar larvae. The predation rate of *C. pumilio* adults at 5 beetles per container was 47 fly immature stages per predator per day. This was similar to the results obtained by Geden *et al.* (1988) who found that *C. pumilio* destroyed 49 fly immature stages per day at densities of 5 beetles per container. The results in this study further showed that attack rates of *C. pumilio* on *M. domestica* immatures were unaffected by beetle crowding at 20 or higher densities that might be typical of field populations, a suggestion also made by Geden (1990). The predation rates of *C. pumilio* adults and larvae decreased with increasing predator densities, a phenomenon also observed by Geden *et al.* (1988). The decrease in predation was in tandem with a declining prey to predator ratio as was also observed by (Geden & Axtell 1988). The lower predation rates at higher predator densities might also have been due to intra-specific competition and in the case of the larvae, spending more time fighting each other than on searching for prey (see Chapter 6).

The predation rate of *C. pumilio* increased with a decrease in satiation level, a phenomenon also observed by Geden *et al.* (1988). The increase in predation with

increase in starvation might have resulted from the beetles' need to replenish the decrease in their energy reserves. The predation rate ranged from an average of about 15 fly immatures consumed per predator per day with *C. pumilio* fed for nine days to about 75 for beetles when starved for nine days. The low predation rate may not occur often in nature as beetles may not be satiated constantly in the field (Geden *et al.* 1988). The highest predation rate may only occur briefly when starved predators encountered prey after dispersal. Starved beetles may also choose to feed on an alternative prey rather than to stay hungry (Geden & Stoffolano 1987, Geden 1990, see Chapter 4).

The results obtained from the laboratory-derived predation rates provide baseline data for future investigations into other factors that affect the effectiveness of predators in regulating house fly and other pests found in poultry manure, a suggestion also made by Geden *et al.* (1988). Furthermore, additional research should be done to determine in what combinations the predators could be released to be effective and to develop cost-effective rearing methods for these beneficials.

REFERENCES.

- ABBOTT, W. S. 1925. A method for computing the effectiveness of an insecticide. *Journal of Economic Entomology* **18**: 265-267.
- AXTELL, R. C. 1961. New records of North American Macrochelidae (Acarina: Mesostigmata) and their predation rates on the house fly. *Entomological Society of America* **54**: 748.
- AXTELL, R. C. 1970. Integrated fly-control program for caged-poultry houses. *Journal of Economic Entomology* **63**: 400-405.
- AXTELL, R. C. 1986. *Fly control in confined livestock and poultry production*. Technical Monograph. CIBA-GEIGY Corporation, N. Carolina, USA.
- AXTELL, R. C. 1986. Fly management in poultry production: cultural, biological and chemical. *Poultry Science* **65**: 657-667.
- AXTELL, R. C & ARENDS J. J. 1990. Ecology and management of arthropod pests of poultry. *Annual Review of Entomology* **35**: 101-126.
- BILLS, G. T. 1973. Biological fly control in deep pit poultry houses. *British Poultry Science* **14**: 209-212.
- CHYI-CHEN HO, CROMROY, H. L. & PATTERSON, R. S. 1990. Mass production of the predaceous mite, *Macrocheles muscaedomesticae* (Scopoli) (Acarina: Macrochelidae), a predator of the house fly. In: Rutz, D. A. and Patterson, R. S. *Biological control of arthropods affecting livestock and poultry*. Westview Press, Oxford.
- DESPINS, J. L., VAUGHAN, J. A. & TURNER, C. E. JR. 1988. Role of the lesser mealworm, *Alphitobius diaperinus* (Panzer) (Coleoptera: Tenebrionidae), as a

- predator of the house fly, *Musca domestica* L. (Diptera: Muscidae), in poultry houses. *The Coleopterists Bulletin* **42**: 211-216.
- GEDEN, C. J. 1984. *Population dynamics, spatial distribution, dispersal behaviour and life history of the predaceous histerid, Carcinops pumilio (Erichson), with observations of other members of the poultry manure arthropod community*. Ph.D. dissertation, University of Massachusetts, Amherst.
- GEDEN, C. J. & AXTELL, R. C. 1987. Factors affecting climbing and tunneling behaviour of the lesser mealworm, *Alphitobius diaperinus* (Coleoptera: Tenebrionidae). *Journal of Economic Entomology* **80**: 1197-1204.
- GEDEN, C. J. & STOFFOLANO, J. G. 1987. Succession of manure arthropods at a poultry farm in Massachusetts, USA, with observations on *Carcinops pumilio* (Coleoptera: Histeridae) sex ratios, ovarian condition and body size. *Journal of Medical Entomology* **24**: 212-220.
- GEDEN, C. J. & AXTELL, R. C. 1988. Predation by *Carcinops pumilio* (Coleoptera: Histeridae) and *Macrocheles muscaedomesticae* (Acarina: Macrochelidae) on the house fly (Diptera: Muscidae): Functional response, effects of temperature and availability of alternative prey. *Environmental Entomology* **17**: 739-744.
- GEDEN, C. J., STINNER, R. E. & AXTELL, R. C. 1988. Predation by predators of the house fly in poultry manure: effects of predator density, feeding history, interspecific interference, and field conditions. *Entomological Society of America* **17**: 320-329.
- GEDEN, C. J. 1990. Coleoptera and acarine predators of house fly immatures in poultry production system *In*: Rutz, D. A. and Patterson, R. S. *Biological control of arthropods affecting livestock and poultry*. Westview Press, Oxford.

- GEDEN, C. J., RUTZ, D. A., SCOTT, J. G. & LONG, S. J. 1992. Susceptibility of house flies (Diptera: Muscidae) and five pupal parasitoids (Hymenoptera: Pteromalidae) to Abamectin and seven commercial insecticides. *Entomological Society of America* **85**: 435-440.
- HOWARD, J. & WALL, R. 1996. Control of the house fly, *Musca domestica*, in poultry units: current techniques and future prospects. *Agricultural Zoology Review* **7**: 247-265.
- HULLEY, P. E. & PFLEIDERER, M. 1988. The Coleoptera in poultry manure-potential predators of house flies, *Musca domestica* Linnaeus (Diptera: Muscidae). *Journal of the entomological Society of southern Africa* **51**: 18-29.
- LEGNER, E. F. & OLTON, G. S. 1968. The biological method and integrated control of house and stable flies in California. *California Agriculture* **22**: 2-4.
- LEGNER, E. F., OLTON, G. S., EASTWOOD, R. E. & DIETRICK, E. J. 1975. Seasonal density, distribution and interactions of predatory and scavenger arthropods in accumulating poultry wastes in coastal and interior southern California. *Entomophaga* **20**: 269-283.
- PATTERSON, R. S. & RUTZ, D. A. 1986. Biological control of Muscoid flies. *Entomological Society of America Miscellaneous Publication* **61**: 88-100.
- PECK, J. H. 1969. Arthropod predators of immature Diptera developing in poultry droppings in northern California. Part II. Laboratory studies on feeding behaviour and predation potential of selected species. *Journal of Medical Entomology* **6**: 168-171.
- PFEIFFER, D. G. & AXTELL, R. C. 1980. Coleoptera of poultry manure in caged-layer houses in North Carolina. *Environmental Entomology* **9**: 21-28.
- SAFRIT, R. D. & AXTELL, R. C. 1984. Evaluation of sampling methods for darkling

beetles (*Alphitobius diaperinus*) in the litter of turkey and broiler houses. *Poultry Science* **63**: 2368-2375.

TURNER, E. C. JR. 1986. Structural and litter pests. *Poultry Science* **65**: 644-648.

WILHOIT, L. R., STINNER, R. E. & AXTELL, R. E. 1991. Computer simulation model of house fly management in confined - animal production systems. *North Carolina Agricultural Research Service, Technical Bulletin* **296**:1-81.

WILLIS, R. R. & AXTELL, R. C. 1968. Mite predators of the house fly: a comparison of *Fuscuropoda vegetans* and *Macrocheles muscaedomesticae*. *Journal of Economic Entomology* **62**: 1669-1676.

1. INTRODUCTION

Rearing insects on artificial diets has many advantages over natural food, particularly in the case of parasitoids and predators which do not feed on natural prey. This should reduce the cost of production, one of the problems limiting the use of parasitoids and predators in inundative releases (Lappala 1986, Thompson 1990). This is overcome such problems and meet the demands for large numbers of insects reared for

CHAPTER 9

THE REARING OF *CARCINOPS PUMILIO* (ERICHSON) (COLEOPTERA: HISTERIDAE) ON AN ARTIFICIAL DIET

ABSTRACT

A number of concentrations of PRO-PLEX™ were incorporated into an artificial diet to determine its effect on the predatory beetle, *Carcinops pumilio* (Erichson). The impact of this host-free artificial diet on developmental time, larval weight, oviposition and mortality was assessed. When *C. pumilio* is fed on a host-free diet, the total development of egg to adult was prolonged in comparison with those reared on natural diet by an average of 3.95 ± 0.17 days. The number of stadia was not affected by the artificial diet. The increase in weight of both 1st and 2nd instar larvae was highly significantly and strongly correlated with the concentration of PRO-PLEX™ in the artificial diet ($P < 0.001$). Adults fed on the artificial diet laid eggs, but significantly less than on the natural diet ($P < 0.05$). *Carcinops pumilio* larvae reared on a natural diet had a significantly faster rate of oviposition, shorter developmental time and lower mortality as compared to those fed on the artificial diet.

Key words: Artificial diet, body weight, *Carcinops pumilio*, developmental time, mortality, natural diet.

1. INTRODUCTION

Rearing insects on artificial diets has many advantages over natural food, particularly in the case of parasitoids and predators where the need to provide prey is eliminated. This should reduce the cost of production, one of the problems limiting the use of insect parasitoids and predators in inundative releases (Leppla 1996, Thompson 1999). Thus to overcome such problems and meet the demands for large numbers of insects required for

fundamental research in the fields of physiology, ecology, genetics and insect control techniques such as male sterilization and IPM programs, the use of artificial diets for rearing insects has generated great interest since the 1950's (Singh 1977). Mass reared insects on an artificial diet could also serve as a cheap source of food for animals in zoos and birds, eg. poultry. Endangered insect species could be reared on an artificial diet in the laboratory and later released into their own natural habitat (Singh 1977). The artificial diet could also be used as a dietary supplement over periods when natural prey is scarce or unavailable for rearing, a suggestion also made by Hattingh (1991).

The first known example of mass rearing an insect on an artificial diet was the larvae of the blowfly, *Cochliomyia hominivorax* (Coquerel) in 1936. This was a hallmark, which facilitated suppression of screwworm by genetic means (Knipling 1984). Excellent artificial diets are now available for rearing many phytophagous arthropods, but are generally lacking for entomophagous arthropods (House 1977, Singh 1977). The house fly is an unsuitable prey source for mass production of its predators such as *Carcinops pumilio* (Erichson) (Geden 1990, Chapter 5), because larvae that escape predation disrupt the substrate and interfere with pupating *C. pumilio* larvae. However, alternative prey can be used, such as sphaerocerid flies (Geden 1984), *Drosophila repleta* (Wallaston) (Fletcher *et al.*1991) and *Drosophila melanogaster* (Meigen) (see Chapter 5). Geden (1990) stated that cost-effective *C. pumilio* production must await the development of artificial diets and methods of handling that will minimize the effects of cannibalism in culture.

Musca domestica L. is cosmopolitan and a serious pest found on poultry farms. Poultry farmers employ various techniques to control them but rely heavily on the use of chemicals which constitutes a significant production expense (Lazarus *et al.* 1989). Such heavy reliance on insecticides for pest suppression has the serious drawback of the target pest becoming resistant (Rutz & Scott 1990, Howard & Wall 1996) and the possible destruction of beneficial insects (Theilling & Croft 1988). This could create new secondary pests and a later resurgence of damaging population levels of the primary pest (Metcalf & Luckmann 1975). One way of overcoming such problems is to develop an IPM program with emphasis on biological control. In such a programme the availability of an artificial medium for rearing the principal predator, *C. pumilio*, would be of great advantage. However, an economical mass rearing method on an artificial diet is yet to be developed for *C. pumilio*.

In an attempt to find an artificial diet for *C. pumilio* it was supplied with PRO-PLEX™, a protein rich food additive used by body builders. *Carcinops pumilio*, when supplied with PRO-PLEX™ powder attempted to consume it but could not hold on with the mandibles. The powder adhered to the body or it got entangled in the melted powder (see Chapter 8). It was therefore decided to investigate the possibility of formulating PRO-PLEX™ powder in another form that will enhance the ability of *C. pumilio* to feed on it. The objectives of this study were therefore: (1) to formulate an artificial diet devoid of any prey material using PRO-PLEX™ and (2) to determine the nutritional and the physical adequacy of the diet formulation using (a) developmental time, (b) mortality rate and (c) oviposition rate.

2. MATERIALS AND METHODS

2.1 Insects

The adults of *C. pumilio* used in this study were from a population maintained in the laboratory originating from samples obtained from Stellenbosch University Experimental Poultry Farm, Elsenburg, Western Cape Province, South Africa (33° 51'S; 18° 50'E). All experiments were carried out in an incubator set at $30 \pm 1^\circ\text{C}$ at a Stellenbosch University Laboratory (33° 54'S; 18° 57'E). Beetles used in the experiment were F₆ progeny.

2.2 Diet composition

The dietary composition of the PRO-PLEX™, designated as “protein” in this study is listed in Table 1.

Table 1. Components of PRO-PLEX™ in mg/100gm

| Nutritional information* | unit |
|--------------------------|----------|
| Vitamin A, B & C | 0.06 |
| Nicotinamide | 0.71 |
| Calcium pantothenate | 1.90 |
| Phosphorus | 171.00 |
| Calcium | 78.00 |
| Magnesium | 84.00 |
| Copper sulphate | 0.16 |
| Sodium | 1279.00 |
| Pottasium | 1183.00 |
| Protein (Albumin) | 83000.00 |
| Aspartame | 400.00 |
| Essential amino acids | unit |
| L - Histidine | 2403 |
| L - Isoleucine | 2929 |
| L - Leucine | 6833 |
| L - Lysine | 5869 |
| L - Methionine | 3672 |
| L - Phenylalanine | 5009 |
| L - Threonine | 3927 |
| L - Tryptophan | 1196 |
| L - Valine | 4142 |

* Obtained from PRO - PLEX™ Manufacturer : California Pharma®

2.3 Diet preparation

Diets were prepared using protein and agar in various ratios (W/W) so that diets with 30, 40, 50, 60, and 70% protein were obtained. Each mixture was blended for 60 seconds and brought to boil for 5 to 10 minutes whilst continuously stirring. After it had boiled for 5 minutes, 1.5g Na-methylhydroxy benzoate dissolved in 2ml alcohol was added to each mixture to prevent fungal growth in the medium. After preparation, while the diet which had a rather smooth texture was still hot, it was poured into 1 litre plastic containers. The containers were left open for 10 minutes to allow some moisture to evaporate, to cool down and solidify. The top of the solidified medium was then covered with Parafilm[®]. The open portion of the container was later covered with organdy held in place with a rubber band. It was then placed in a cool room at $5 \pm 1^{\circ}\text{C}$ until use. On the day of use, several pieces of about 10gm of diet were transferred into each rearing container. The shelf life of the diet was not determined but used diet stored for 30 days in similar experiments gave similar results to those of fresh diet.

2.4 Developmental time

2.4.1 Preliminary experiments

In order to reduce the disturbance of the different stages during the final observations on development, preliminary development times were determined for the stages from egg to hatch, 1st instar larva to 2nd instar larva and 2nd instar larva to adult emergence from the pupa, at each protein concentration level from 30 to 70%. To obtain eggs, freshly emerged adult beetles were placed on the artificial diet for 10 days at each of the different

concentration levels. Several pieces of the artificial diet at each protein concentration level were mixed with 1 litre of moistened bran. The bran to water ratio was 1: 2.9 (W/W) which produced about 60-65% moisture content. The mixture was then transferred into 2 litre milk containers. The newly emerged adult beetles that were kept on the artificial diet were put on the bran and protein mixture for 24 hours. They were then removed to prevent them from eating their eggs. Five replicates were used. The 2 litre container with the top removed was covered with organdy held in place with a rubber band. The preliminary tests were observed daily to obtain estimates of the above developmental periods for each concentration level. Similar procedures were also followed for *C. pumilio* fed on *Drosophila melanogaster* as a source of natural diet (see Chapter 5).

2.4.2 Developmental times of stages

The developmental times of egg to 1st instar larva, 1st instar to 2nd instar larva and 2nd instar larva to adult emergence from the pupa were determined. The media and the procedure of rearing described in 2.4.1 were used in 5 replicates for each protein concentration. After 24 hours, the adults were removed and the media of each replicate was divided into 20 test tubes to facilitate easier counting of the larvae. The test tubes, covered with a plastic lid with small holes pierced into it using an office pin, were placed in an incubator at $30 \pm 1^\circ\text{C}$. From two days before the estimated time of egg hatch, based on the preliminary experiment described in 2.4.1, the media were examined for the presence of 1st instar larvae.

The 1st instar larvae removed from each test tube were introduced into new medium with the appropriate protein concentration. Two days before the appearance of the 2nd instar larvae was expected, the test tubes were examined at 24hr intervals to detect their presence.

The developmental time of the 2nd instar larvae to adults was determined by observing the same individuals used in the 1st instar larvae studies. All test tubes were observed for adults as described above, except that a rotational method was used to reduce the disturbance of the pupae.

The data for developmental time (days) of various stages was analyzed using ANOVA. The means were separated at $p < 0.05$ level by Fisher's LSD.

2.5 Weight measurement

The wet weight of ten 1st and 2nd instar larvae from each protein concentration level of individuals obtained in 2.4.2 was measured using a Sartorius microbalance which weighed to the nearest 0.01mg. The larvae were weighed at the beginning of each stage.

The effects of diet concentration on weight of 1st and 2nd instar larvae were analyzed by regression.

2. 6 Mortality rates

To determine the mortality of 1st instar larvae, five newly hatched larvae were transferred onto the medium in test tubes described in 2.4 using a fine wet camel's hair brush. There were 20 replicates for each protein concentration of 30, 40, 50, 60 and 70%. Individual 2nd instar larvae obtained from surviving 1st instar larvae were used to determine the mortality rate from 2nd instar to adult emergence. Five 2nd instar larvae per test tube and ten replicates for each concentration level were used.

The percentage mortality from 1st to 2nd instar larva and 2nd instar larva to adult emergence was calculated as $[\bar{x} \text{ number dead} \div \text{number of larvae per container}] \times 100$.

2. 7 Oviposition

The adults reared on the artificial diet at different concentrations in 2.6 were used to determine oviposition rate. Two pairs of adult males and females from each protein concentration levels of 30, 40, 50, 60 and 70% were selected immediately after emergence and were placed in a small plastic container of 5 cm in height and 3 cm in diameter. The lid had a hole of 1.5cm in diameter and this was covered with organdy, held in place with glue. This was replicated five times for each concentration. The adults were supplied with artificial diet *ad libitum*, with a small amount of moistened bran to serve as an oviposition site. After 24 hours, they were removed and placed in a new container with fresh medium and source of food. This routine was followed for ten days.

Six days after the first introduction of the adults the media were examined for the presence of larvae and those found were counted. In this study it was assumed that the number of larvae hatched was equal to the eggs oviposited and that no mortality occurred in the egg stage.

The data for oviposition rates was analyzed using ANOVA. The means were separated at $P < 0.05$ level by Fisher's LSD.

3. RESULTS

3.1 Developmental time

Developmental times of the various stages differed significantly between the artificial diet and natural diet ($P < 0.05$) (Table 2). *Carcinops pumilio* reared on the artificial diet developed more slowly than those reared on natural diet. The developmental time from 1st to 2nd instar larva in relation to the protein concentration or natural diet followed no particular pattern. The developmental time from the 2nd instar larvae to adult stage was also significantly shorter on the natural diet as compared to larvae fed on artificial diet. The total developmental time from egg to adult of *C. pumilio* fed on artificial diet was longer than that for *C. pumilio* fed on natural diet (Table 2). The number of stadia was not affected by the artificial diet.

Table 2. Developmental time of various stages of *C. pumilio* fed on natural and artificial diets.

| %protein in artificial diet | Developmental period (days) (mean \pm SE)* | | | Total developmental time |
|-----------------------------|--|---|--------------------------------|--------------------------|
| | Egg - 1 st instar larva | 1 st instar - 2 nd instar larva | 2 nd instar - adult | |
| 30 | 5.2 \pm 0.09 b | 4.70 \pm 0.16 a | 13.50 \pm 0.17 b | 23.40 \pm 0.16 b |
| 40 | 5.0 \pm 0.01 b | 5.30 \pm 0.11 b | 13.85 \pm 0.31 b | 24.15 \pm 0.21 b |
| 50 | 5.1 \pm 0.07 b | 4.55 \pm 0.11 a | 15.95 \pm 0.44 c | 25.60 \pm 0.27 c |
| 60 | 5.0 \pm 0.06 b | 5.40 \pm 0.11 b | 16.60 \pm 0.78 c | 27.00 \pm 0.34 c |
| 70 | 5.0 \pm 0.09 b | 4.40 \pm 0.11 a | 15.70 \pm 0.50 c | 25.10 \pm 0.30 c |
| Natural diet | 3.8 \pm 0.02 a | 5.10 \pm 0.10 b | 11.30 \pm 0.15 a | 20.10 \pm 0.11 a |

*Figures followed by the same letters are not significantly different. $P < 0.05$

3. 2 Effect of artificial diet on larval weight

The 1st instar larvae that emerged from eggs of adult *C. pumilio* fed on the artificial diet at the higher protein concentrations were heavier than those fed on natural diet (Fig. 1). However, the 1st instar larvae of adults fed on the natural and artificial diet with a protein concentration of 30% were the same weight. The 2nd instar larvae fed on 70% protein were also heavier than those fed on the natural diet. At the lower protein concentrations the differences were not significant except at the lowest concentration (30%) where the larvae were significantly lighter. The increase in weight of both 1st and 2nd instar larvae were highly significantly and strongly correlated with the protein concentration in the artificial diet ($P < 0.001$) (Fig. 1).

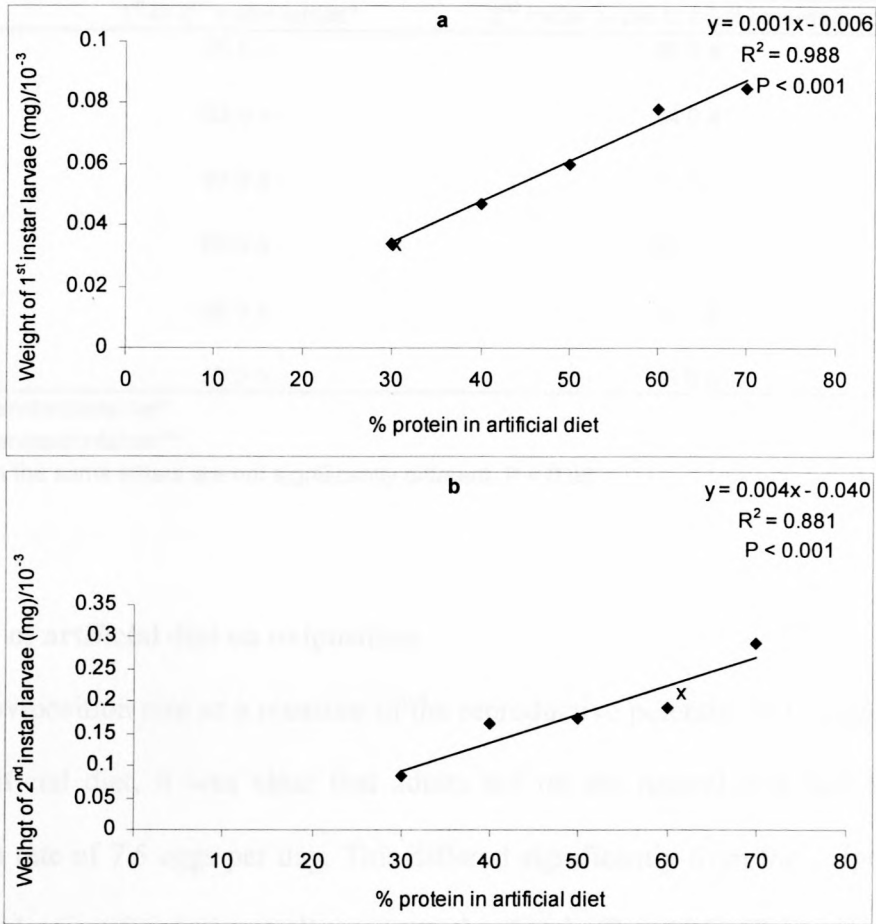


Fig. 1. Mean weight of **a** = 1st instars; **b** = 2nd instars reared on five different protein concentration levels of artificial diet. **X** = weight of larvae fed on natural diet.

3. 3 Effect of artificial diet on mortality

The mortality of 1st and 2nd instar larvae reared on the artificial diet was extremely high, exceeding 85% and 65% respectively, whilst the mortality of larvae reared on natural diet was comparatively low at 22% and 16% respectively. The mortality of both 1st and 2nd instar larvae reared on artificial diet was four times more than those reared on natural diet (Table 3).

Table 3. Mortality rates of *C. pumilio* on an artificial and natural diet

| % protein | % mortality | |
|--------------|---|--|
| | 1 st to 2 nd instar larvae* | 2 nd instar larvae to adult emergence** |
| 30 | 95.5 a | 96.0 a |
| 40 | 92.0 a | 94.0 a |
| 50 | 92.5 a | 76.0 a |
| 60 | 89.0 a | 66.0 a |
| 70 | 86.0 a | 70.0 a |
| Natural diet | 22.0 b | 16.0 b |

N = 10, 5 larvae/container*

N = 10, 5 larvae/container**

Figures with the same letters are not significantly different. $P < 0.05$

4. DISCUSSION

3. 4 Effect of artificial diet on oviposition

From the oviposition rate as a measure of the reproductive potential of *C. pumilio* reared on the artificial diet, it was clear that adults fed on the natural diet had the highest oviposition rate of 7.5 eggs per day. This differed significantly from the oviposition rate of adults fed on artificial diet at all concentration levels ($P < 0.05$) (Table 4). There was no significant difference in the rate of oviposition between the various protein concentrations.

Table 4. Oviposition rates (eggs/female/day) of *C. pumilio* on an artificial and natural diet

| % artificial diet * | Oviposition (mean \pm SE.)** | Oviposition day ⁻¹ /female |
|---------------------|--------------------------------|---------------------------------------|
| 30 | 0.9 \pm 0.41 a | 0.09 |
| 40 | 2.7 \pm 0.50 a | 0.27 |
| 50 | 1.5 \pm 0.50 a | 0.15 |
| 60 | 2.0 \pm 0.49 a | 0.2 |
| 70 | 1.0 \pm 0.30 a | 0.1 |
| Natural diet | 7.5 \pm 0.70 b | 1.5 |

*N = 10. **Figures with the same letters are not significantly different. P < 0.05.

4. DISCUSSION

The developmental time for an insect reared on an artificial diet is often prolonged, as was the case with *C. pumilio*. This was, for example, also found by De Clercq & Degheele (1992) and Wittmeyer & Coudron (2001) for *Podisus maculiventris* (Say), a generalist stinkbug predator, and Carpenter & Greany (1998) and Gelman *et al.* (2000) for *Diapetimorpha introita* (Cresson), a parasitoid wasp. The prolongation of the developmental time of *C. pumilio* was most pronounced during the last stadium. This information provides direction for future research on improving this artificial diet to reduce developmental time. Furthermore, there were a small number of individuals that developed faster than others, indicating they adapted more quickly to the diet. From such fast developers a strain could be selected that are more suited to the artificial diet formulated, a suggestion also made by Wittmeyer & Coudron (2001) for *P. maculiventris*.

At certain protein concentrations, the weight of the 1st and 2nd instar larvae was similar or higher than those fed on natural diet, indicating that they developed adequately on the artificial diet. Adult females that developed from larvae reared on the artificial diet also had a significantly lower rate of oviposition than those reared on the natural diet. From the weight alone, one would have expected the females from the artificial diet to produce similar or higher numbers of eggs, as heavier females usually produce greater quantities of eggs Lawrence (1990), Trudel *et al.* (1994), Hirschberger (1999), and Chapter 6. However, they had a longer developmental time and higher mortality. Larvae reared on the natural diet had a significantly higher rate of oviposition, shorter developmental time and a lower mortality rate. The protein concentration in the artificial diet had no effect on the rate of oviposition as it remained low at all concentrations. This indicated that the poor performance of *C. pumilio* on the artificial diet might have been due to an inappropriate balance or lack of nutrient(s). Clancy (1992) also reported that the poor performance of an artificial diet for rearing western spruce budworm could be attributed to inappropriate balances of one or more minerals in the diet. Similar observations were also made by VanderSar (1978), who found that *Pissodes strobi* Peck appeared to feed normally on an artificial diet, but did not lay the expected number of eggs and attributed this to feeding and oviposition stimulants being different from the natural diet.

The low oviposition of *C. pumilio* fed on the artificial diet showed the need to improve the diet for better results. It is therefore suggested that chemical analyses of the eggs and/or 1st instar larvae *M. domestica* or *Drosophila melanogaster* (Meig.), which serve as natural prey, be done. This will help to identify both the qualitative and quantitative

nutritional requirements of *C. pumilio*. Brewer & Lindig (1984) and Hattingh (1991) also recommend that the ratios of various chemical constituents of the artificial diet and those obtained from the analysis of the natural prey should be used to help to formulate the artificial diet.

The most positive aspects of the results were that *C. pumilio* completed its development on the artificial diet and that both the F₁ and F₂ generations fed on an artificial diet were able to lay eggs. This could be the first step towards finding an artificial diet that would allow continuous rearing of *C. pumilio* ensuring its availability at all times for utilization in the biological control of houseflies.

REFERENCES

- BREWER, F. D. & LINDIG, O. 1984. Ingredients for insect diets. *In*: King, E. G. & Leppla, N. C. *Advances and challenges in insect rearing*. USDA, Agricultural Research Service, New Orleans.
- CARPENTER, J. E. & GREANY, P. D. 1998. Comparative development and performance of artificially reared versus host-reared *Diapetimorpha introita* (Cresson) (Hymenoptera: Ichneumonidae) wasps. *Biological Control* **11**: 203-208.
- CLANCY, K. M. 1992. Response of western spruce budworm (Lepidoptera: Tortricidae) to increased nitrogen in artificial diets. *Environmental Entomology* **21**: 331-344.

- DE CLERCQ, P. & DEGHEELE, D. 1992. A meat-based diet for rearing the predatory stinkbugs *Podisus maculiventris* and *Podisus sagitta* (Heteroptera: Pentatomidae). *Entomophaga* **37**: 149-157.
- FLETCHER, M. G., AXTELL, R. C., STINNER, R. E. & WILHOIT, L. R. 1991. Temperature-dependent development of immature *Carcinops pumilio* (Coleoptera: Histeridae), a predator of *Musca domestica* (Diptera: Muscidae). *Journal of Entomological Science* **26**: 99-108.
- GEDEN, C. J. 1984. *Population dynamics, spatial distribution, dispersal behaviour and life history of the predaceous histerid, Carcinops pumilio (Erichson), with observations of other members of the poultry manure arthropod community*. Ph.D. dissertation, University of Massachusetts, Amherst.
- GEDEN, C. J. 1990. Coleoptera and acarine predators of house fly immatures in poultry production system *In: Rutz, D. A. & Patterson, R. S. Biological control of arthropods affecting livestock and poultry*. Westview Press, Oxford.
- GELMAN, D. B., CARPENTER, J. E. & GREANY, P. D. 2000. Ecdysteroid levels/profiles of the parasitoid wasp, *Diapetimorpha introita*, reared on its host, *Spodoptera frugiperda* and on an artificial diet. *Journal of Insect Physiology* **46**: 457-465.
- HATTING, V. 1991. Development of artificial diets for entomophagous coccinelids. *In: The problems of insect rearing in South Africa and possible solutions. 2nd national insect rearing workshop*, Bloemfontein, South Africa.
- HIRSCHBERGER, P. 1999. Larval population density affects female weight and fecundity in the dung beetle *Aphodius ater*. *Ecological Entomology* **24**: 316-322.

- HOUSE, H. L. 1977. Nutrition of natural enemies. *In*: Ridgeway, R. L. & Vinson, S. B. (eds.), *Biological Control by Augmentation of Natural Enemies*. Plenum Press, New York.
- HOWARD, J. & WALL, R. 1996. Control of the house fly, *Musca domestica*, in poultry units: current techniques and future prospects. *Agricultural Zoology Reviews* **7**: 247-265.
- KNIPLING, E. F. 1984. Forward. *In*: King, E. G. & Leppla, N. C. *Advances and challenges in insect rearing*. USDA, Agricultural Research Service, New Orleans.
- LAWRENCE, W. S. 1990. Effects of body size and repeated matings on female milkweed beetle (Coleoptera: Cerambycidae) reproductive success. *Annals of the Entomological Society of America* **83**: 1096-1100.
- LAZARUS, W. F., RUTZ, D. A., MILLER, R. W. & BROWN, D. A. 1969. Cost of existing and recommended manure management practices for house fly and stable fly (Diptera: Muscidae) control on dairy farms. *Journal of Economic Entomology* **82**: 1145-1151.
- LEPPLA, N. C. 1996. Global applications and requirements for artificially reared parasitoids and predators. *XX International Congress of Entomology, Proceedings, Florence, Italy*.
- METCALF, R. L. & LUCKMAN, W. H. 1975. *Introduction to insect pest management*. John Wiley & Sons, New York.
- RUTZ, D. A. & SCOTT, J. G. 1990. Susceptibility of muscoid fly parasitoids to insecticides used in dairy facilities. *In*: Rutz, D. A. & Patterson, R. S. *Biological control of arthropods affecting livestock and poultry*. Westview Press, Oxford.
- SINGH, P. 1977. *Artificial diets for insects, mites and spiders*. Plenum Press, New York.
- THEILING, K. M. & CROFT, B. A. 1988. Pesticide side effects on arthropod natural enemies: a data base summary. *Agricultural Ecosystems and Environment* **21**: 191-218.

CHAPTER 10

- THOMPSON, S. N. 1999. Nutrition and culture of entomophagous insects. *Annual Review of Entomology* **44**: 561-592.
- TRUDEL, R., LAVALLÉE, R., BAUCE, É. CABANA, J. & GUERTIN, C. 1994. Variations in ground white pine bark concentration in artificial diet in relation to egg laying, feeding and mortality of *Pissodes strobi* (Peck) (Coleoptera: Curculionidae). *Journal of Economic Entomology* **87**: 96-100.
- VANDERSAR, T. J. D. 1978. Resistance of white pine to feeding and oviposition by *Pissodes strobi* Peck in western Canada. *Journal of Chemical Ecology* **4**: 641-647.
- WITTMAYER, J. L. & COUDRON, T. A. 2001. Life table parameters, reproductive rate, intrinsic rate of increase, and estimated cost of rearing *Podisus muculiventris* (Heteroptera: Pentatomidae) on an artificial diet. *Journal of Economic Entomology* **94**: 1344-1352.

1 INTRODUCTION

During the study on the survey of arthropods in poultry houses, *Podisus muculiventris* was the basic, *Carduopsis pusilla* (L.) was considered as a major predator in the suppression of house flies in poultry houses in the USA (Legner 1971, Tindan & Swift 1987) and in Britain (1976, 1978, 1980). In order to study the biology of this important species in the laboratory, a suitable rearing method became essential. Such a rearing method could also lead to the development of mass rearing techniques which would be a prerequisite for utilizing *P. muculiventris* as a biological control agent against house flies.

CHAPTER 10

REARING *CARCINOPS PUMILIO* (ERICHSON) (COLEOPTERA: HISTERIDAE) USING EGGS AND LARVAE OF *DROSOPHILA MELANOGASTER* (MEIGEN) (DIPTERA: DROSOPHILIDAE) AS PREY

ABSTRACT:

A method was successfully developed for rearing *Carcinops pumilio* (Erichson) (Coleoptera: Histeridae) on *Drosophila melanogaster* (Meigen) (Diptera: Drosophilidae) in the laboratory.

Key words: *Carcinops pumilio*, *Drosophila melanogaster*, rearing.

1 INTRODUCTION

During the study on the survey of arthropods in poultry manure (Chapters 1 & 2), the key fly predator was the beetle, *Carcinops pumilio* (Erichson) (Coleoptera: Histeridae). It is also considered as a major predator in the suppression of synanthropic flies in poultry houses in the USA (Legner 1971, Geden & Stoffolano 1987) and in Britain (Bills 1973, Conway 1973). In order to study the biology of this important species in the laboratory, finding a suitable rearing method became essential. Such a rearing method could also lead to the development of mass rearing techniques which would be a prerequisite for utilizing *C. pumilio* as a biological control agent against house flies.

An earlier attempt to breed *C. pumilio* using *M. domestica* as source of prey proved to be unsuccessful, a result also obtained by other workers such as Smith (1975) and Geden (1984). Geden (1984) observed that the glut of older larvae, which escaped predation, disrupted histerid pupation and oviposition sites. Furthermore, only the egg and 1st instar stages are readily fed on by *C. pumilio*, with the result that astronomical numbers of house flies would have to be reared to provide them with these stages in mass rearing, which would make it economically unviable (Geden 1984).

In the course of taking samples for arthropods in the poultry manure, *Drosophila* sp. was encountered (see Chapter 1). Since Geden (1984) and Fletcher *et al.* (1991) mass bred *C. pumilio* on colonized *Coproica hirtula* (Rondani) and *Drosophila repleta* (Wallaston) respectively, it was decided to attempt utilizing *Drosophila melanogaster* (Meig.) (Diptera: Drosophilidae) in the same way.

The aims of this study were therefore to colonize *D. melanogaster* on a medium other than poultry manure and then to exploit it as prey for *C. pumilio*.

2 MATERIALS AND METHODS

All experiments were carried out in a laboratory at the University of Stellenbosch, Cape Town (33° 54'S; 18° 57'E) from 20 September 1999 to 21 October 2000, at an ambient temperature of about 22°C.

2.1 Colonization of *Drosophila melanogaster*

One litre house fly medium made up of wheat bran (0.5kg.), milk powder (75.0g), yeast (5.0g), Na-methyl hydroxybenzoate (1.5g) and water (820ml), was placed in 2 litre milk

containers, which had their tops removed. A number of *D. melanogaster* individuals collected from a progeny bred at the Genetics Department, Stellenbosch University, South Africa were then introduced. After 5 days all the adults were removed using a 60W light source to attract them. The container without adults was placed in a small house fly cage. Cages were placed in a room with natural lightening. Adults appeared after 11 days. The fly medium was remoistened every 5 days, maintaining it at about 60-75% moisture.

The flies were reared through five generations on house fly medium but thereafter on *Drosophila* sp. medium formula obtained from the Genetics Department. The constituents of the medium were water (550ml), sugar (10.0g), agar (4.0g), maize meal (75.0g), yeast (6.0g), methylium (0.5g) and alcohol (2.0ml). This change in rearing medium became necessary as a result of fungal growth in the house fly rearing medium, the need to remoisten it and the subsequent fermentation scent emanating from it which caused inconvenience to other workers in the same building. An attempt was made to rectify the fungal growth by applying the method of Geden (1984), who mechanically agitated the fly rearing medium on day 2 and 3 post-preparation to disrupt the mycelia mats and aerate the medium, yet there was still fungal growth. The dense fungal growth accelerated the drying of the medium. Both the adult and especially larvae could not move freely due to masses of mycelia and hyphae of the fungi, which subsequently had a deleterious effect on the fecundity of *D. melanogaster*. A high fecundity rate was observed after switching from the housefly to *Drosophila* rearing medium, with the subsequent advantage that remoistening was no longer required and fungi did not appear.

2.2 Mass-rearing of *Drosophila melanogaster* in the laboratory

Ten milk containers (2 litres) with the tops removed were filled with 1 litre of prepared *Drosophila* rearing medium and exposed to adult *D. melanogaster* for 5 days in a cage. The

containers were then transferred to a new cage whereupon adult flies emerged after another 6 days. In 20 days, there were many *D. melanogaster*, which the 1litre medium could support for a period of four weeks of continuous reproduction of the flies. Newly prepared *D. melanogaster* medium was introduced every four weeks. The freshly prepared medium was cooled for 24 hours before exposing it to adult *D. melanogaster*.

When there was the need to increase the population in a cage the adults, which are positively phototactic, could be extracted from another cage by illuminating a bottle with a 60W light source. The mouth of the bottle was inserted into the opening of the cage, and light shone from the bottom of the bottle. After enough *D. melanogaster* adults had been extracted, the mouth was quickly covered and the flies transferred to a new cage. To obtain adults of the same age several milk containers with *Drosophila* rearing medium were exposed to the adult flies for 24 hours and transferred into a new cage.

2.3 Colonization of *Carcinops pumilio*

2.3.1 Beetle collection

Carcinops pumilio adults were collected from the University Farm at Elsenburg (33° 51'S; 18° 50'E) on 21st September 1999. A liter of manure was collected just below the tip of the manure cone and placed in a 5 litre tin container. It was then filled with water and stirred. The *C. pumilio* adults that floated and those that moved on the inside of the container were removed with a camel's hair brush and quarantined for 10 days to clear them from the mite, *Macrocheles muscaedomesticae* (Scopoli) (Acarina: Macrochelidae). Wade & Rodriguez (1961) mentioned that the life span of this mite was 7-10 days. This was done prior to introducing them to the *Drosophila* rearing medium in order to avoid contamination and subsequent feeding by the mite on the *C. pumilio* eggs, as was observed by Smith (1975). The

quarantined *C. pumilio* adults were kept in containers with wet tissue throughout the 10 days to avoid dehydration. Even though these precautions were taken, problems involving the invasion of the mite still occurred, a situation also encountered by Smith (1975) and Geden (1984).

A chemical means of 'demiting' the beetles was attempted, using 0.3g tricyclotin (Peropal[®]) dissolved in 250ml of water in a beaker. *Carcinops pumilio* adults were placed in the solution for one minute and strained. They were then dried in a hand paper towel and later transferred to 75% alcohol for one minute and strained and dried again. Mortality that occurred during this procedure was so high (>75%) that it was considered not feasible, as even those which did not die became lethargic coupled with irregular movements.

A further attempt was made to 'demite' the beetles by applying Geden's (1984) method in which beetles were first shaken in talc baby powder for one minute, transferred to 70% ethanol for 30 sec., and then allowed to dry. After two additional talc-alcohol treatments, beetles were placed in containers with water saturated dental wick and held for three days. Mortality among beetles was higher than 60%, compared to Geden (1984) who had more than 40% mortality following this process. This procedure was also discarded in view of the high mortality.

To reduce mite contamination, cultural methods such as dividing the different rearing activities in space and time, cleaning of containers and rearing spaces regularly before handling another culture were instituted. Isolation was also created between cultures by placing them on blocks which in turn were placed in a tray of water were then employed. These methods reduced the population of mites considerably, resulting in an increase of the numbers of *C. pumilio* larvae.

2.3.2 Rearing method

Ten pairs of both sexes of adult *C. pumilio* were added to each of ten 2 litre milk containers with 400ml of *Drosophila* rearing medium previously exposed to adult *D. melanogaster* for two weeks. About 150ml of *M. domestica* rearing medium which was to provide a place for egg laying and a refuge for the adults (also exposed to the adult *D. melanogaster* for seven days), was added on top of the *Drosophila* medium with the adult beetles. The contents were left for 15 days for the emergence of 1st and 2nd instar larvae after which the adult *C. pumilio* parents were removed manually by sieving to prevent overstocking and cannibalism. The contents were then returned to the cage containing *D. melanogaster* adults which provided a continuous source of prey. By day 20 after the beetles were introduced, large numbers of both 1st and 2nd instar *C. pumilio* larvae could be seen. The adult *C. pumilio* were often found in the *M. domestica* rearing medium whilst *C. pumilio* 1st and 2nd instar larvae were mostly found in the interface of the two media. The *D. melanogaster* 1st and 2nd instar larvae were mostly found in the *Drosophila* rearing medium. Meanwhile the adult *D. melanogaster* moved in and out of the milk container to feed and lay their eggs. By day 30, the ten 2 litre containers were transferred to an open 21.5 litre rectangular plastic container which was covered with organdy. At this stage most or all the *C. pumilio* larvae were in their 2nd instar or pre-pupa stage and did not require a lot of prey.

The contents of the containers were monitored for the emergence of adult beetles, which happened around day 50. After the first appearance they were left for a further five days before extraction by sieving. The sieved contents with *C. pumilio* larvae were returned to the 21.5 litre container and left for a further five days for the last extraction of adults by sieving.

3 RESULTS AND DISCUSSION

The two sievings yielded about 600 *C. pumilio* adults, proving that the species can successfully be reared on *D. melanogaster* as prey.

Drosophila melanogaster appears to be an ideal candidate as a source of prey for mass rearing *C. pumilio* due to its short developmental time of about ten days as was observed by Ashburner (1989). It is inexpensive and easy to breed, and has a very high biotic potential. Furthermore, it can be maintained on a substrate other than poultry manure which tends to emanate bad odour. Also due to its small size almost all stages of their life cycle are readily fed on by 2nd instars and adults of *C. pumilio*.

However, from 100 female beetles only about 600 progeny were obtained in a period of about 50 days, indicating a low rate of increase. This was possibly due to the low temperature experienced during the duration of rearing. An increase in temperature to 30°C would increase the rate of oviposition and reduce the rearing time by about 60% (Geden 1984, Chapter 5). The adults can also be prevented from feeding on the eggs by placing adults in rearing medium and removing and re-introducing them onto new medium every day.

Since the rearing medium successfully supported all stages of *C. pumilio* it could form the basis for the continuous rearing of this major predator, an essential requirement for using this species in the development of an IPM programme for filth flies found in poultry manure.

REFERENCES

ASHBURNER, M. 1989. *Drosophila*. Cold Spring Harbour Laboratory Press, New York.

CONWAY, J., A. 1973. The micro-fauna of California-system poultry houses in Britain.

British Poultry Science **14**: 213-216.

BILLS, G. T. 1973. Biological fly control in deep pit poultry houses. *British Poultry Science*

14: 209-212.

FLETCHER, M. G., AXTELL, R. C., STINNER, R. E. & WILHOIT, L. R. 1991.

Temperature-dependent development of immature *Carcinops pumilio* (Coleoptera: Histeridae), a predator of *Musca domestica* (Diptera: Muscidae). *Journal of Entomological Science* **26**: 99-108.

GEDEN, C. J. 1984. *Population dynamics, spatial distribution, dispersal behaviour and life*

history of the predaceous histerid, Carcinops pumilio (Erichson), with observations of other members of the poultry manure arthropod community. Ph.D. dissertation, University of Massachusetts, Amherst.

GEDEN, C. J. & STOFFOLANO, J. G. 1987. Succession of manure arthropods at a poultry

farm in Massachusetts, USA, with observations on *Carcinops pumilio* (Coleoptera: Histeridae) sex ratios, ovarian condition and body size. *Journal of Medical Entomology* **24**: 212-220.

LEGNER, E. F. 1971. Some effects of the ambient arthropod complex on the density and

potential parasitization of muscoid Diptera in poultry wastes. *Journal of Economic Entomology* **64**: 111-113.

SMITH, K. A. 1975. *Observations on the life history, ecology and behaviour of Carcinops*

pumilio (Erichson). MSc. Thesis, Department of Entomology, University of New Hampshire, Durham.

WADE, C. F. & RODRIGUEZ, J. G. 1961. Life history of *Macrocheles muscaedomesticae*

(Acarina: Macrochelidae), a predator of the house fly. *Annals of the Entomological Society of America* **54**: 776-781.

GENERAL CONCLUSIONS

The study focused primarily on the arthropods breeding in accumulating poultry manure and the biotic and abiotic factors affecting them, with particular emphasis on the most common predator *Carcinops pumilio* (Erichson). The study of arthropods in poultry manure at two sites indicated that the most common pest species were *Musca domestica* L., and *Fannia canicularis* (L.) (Chapter 1).

In South Africa, chemicals including the insect growth regulator cyromazine (Larvadex[®]) are extensively used to control synanthropic flies on poultry farms. This might lead to the development of resistance by the flies to these insecticides and the danger of devastating the populations of beneficial arthropods that regulate their numbers. Alternative methods are therefore required to manage fly numbers.

General observations indicated that their numbers could be reduced considerably if certain management practices are followed, such as allowing the manure to fall onto a well drained porous substrate and preventing accumulation of excess water leakage from the drinking water system. Good ventilation and airflow facilitate faster drying of the manure and must therefore be incorporated into building designs to maximize this factor. The building design should also make provision for water drainage away from the house. The results of a survey in this study showed that fly numbers are low or absent in dry manure while it harbours relatively high numbers of predators.

The majority of the predators (eg. *C. pumilio*) were dispersed below the crest of the manure cone, whilst the prey, (eg. *M. domestica* and *F. canicularis*) were found in high numbers in

the crest. It is therefore suggested that farmers should remove only the upper portions of the manure as a fly management strategy. This will not only save time but also money. It will also prevent the total depletion of the predator population that occurs with complete removal of manure. The protection of predators will also be aided by the removal of alternate rows of manure and leaving the manure, especially the bottom part, in the poultry house for extended periods (up to a year or more).

The study of manure height in relation to arthropod numbers indicated that predatory arthropod numbers such as *C. pumilio* increased with increase in manure height whilst the prey numbers such as *M. domestica* and *F. canicularis* decreased. Thus the manure could be left for one to two years and only the portions that overflow onto the walkways removed. Farmers should retain manure height at least at 25cm for the benefit of predators. They could even retain greater heights for fly control at the times of the year when flies are abundant, i.e. during October to February and May to July for *M. domestica* and *F. canicularis*, respectively.

Farmers should use simple methods of monitoring fly numbers, for example the use of spot cards. This would help in decision making as to when to institute any IPM measure(s) that might be necessary.

Carcinops pumilio, *P. sordidus* and *M. muscaedomesticae* could be used to complement one another in regulating fly numbers in poultry manure. The release of these predators in augmentative or inoculative programs could be conducted in two phases as *C. pumilio* prefers aged manure and *P. sordidus* and *M. muscaedomesticae* prefer fresh manure. *Philonthus sordidus* and *M. muscaedomesticae* could be released after 1wk PC and *C.*

pumilio, 6wks PC. *Philonthus sordidus* in particular could be released in winter since they prefer lower temperatures (15 to 18°C) (Chapter 3) to combat *F. canicularis* which occurs in high numbers during winter (Chapter 1).

The release of *C. pumilio* should be synchronized with the right state of satiation of the adults, manure temperature and moisture. The predation rate of the beetles increased with an increase in starvation whilst the number of beetles that dispersed varied significantly with temperature (Chapter 7). The implication for biocontrol of flies using *C. pumilio* is the possibility that newly released satiated adults would not disperse. However, if the preference is for quick dispersal, then unfed beetles should be used as newly emerged adults can survive for at least 25 days without food (Chapter 5). The dispersal of *C. pumilio* was impeded below 20°C, therefore any releases for augmentative or inoculative purposes should be done at low temperatures.

The pteromalid parasitoids such as *Muscidifurax raptor*, *Spalangia endius* and *Nasonia vitripennis* could be used to supplement *C. pumilio*, *P. sordidus* and *M. muscaedomesticae* and other key predators. The pteromalids attack mature fly larvae and fly pupae whilst the predators consume the immature stages of the flies, thus they do not compete directly.

Carcinops pumilio, as shown in this study, could have a regulatory effect on fly numbers. Therefore, developing a rearing technique for it is essential for augmentative or inoculative releases for biocontrol as part of an IPM programme. Evidence is presented in this study that it is possible to mass breed *C. pumilio* by exploiting *Drosophila melanogaster* as the source of prey for colonization (Chapter 10), while progress has been made in developing an artificial rearing medium (Chapter 9).

A model for the number of *C. pumilio* per bird or a given volume of manure that could provide adequate fly control should be developed. However this requires census data for several successive seasons. It would also be desirable to have further work on the commercial viability of *C. pumilio* production and its efficacy in the field when released augmentatively for fly control.

The work will hopefully contribute to a better understanding of the biology, ecology and management of filth flies and their main predators on livestock farms. It is also hoped that the poultry industry in particular will benefit from the results of this study.