ASPECTS OF THE BIOLOGY, BEHAVIOR, BIONOMICS, AND CONTROL OF IMMATURE STAGES OF THE CAT FLEA *Ctenocephalides felis felis* (Bouché) (SIPHONAPTERA: PULICIDAE) IN THE DOMICILIARY ENVIRONMENT

by

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ASPECTS OF THE BIOLOGY, BEHAVIOR, BIONOMICS, AND CONTROL OF IMMATURE STAGES OF THE CAT FLEA Ctenocephalides felis felis (Bouché) (SIPHONAPTERA: PULICIDAE) IN THE DOMICILIARY ENVIRONMENT

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(ABSTRACT)

The larval stage of the cat flea, Ctenocephalides felis felis (Bouché), was found to exhibit behaviors that were conducive to its security in carpet. Larvae exhibited positive geotactic, and negative phototactic behaviors. This resulted in the larvae spending greater than 80% of their time at the base of the carpet pile. Cat flea larvae also exhibited a positive hygrotaxis, and appeared to exhibit undirected movements when foraging. Larva were observed to respond to disturbances by coiling their body longitudinally.

Cat flea hatched and unhatched eggs, and larval exuviae were found to be dispersed in a contagious fashion within carpet. The spatial pattern of the immature stages and remains was influenced by the habits of the pet host within a given room. First-instar larvae do not move far, if at all, from the location of eclosion.

The movement of the larval stage is influenced by biotic and abiotic factors in the environment. Areas of high pedestrian or pet traffic are not conducive to successful eclosion from the egg or for successful larval development.

Various methods of control exist for controlling an indoor infestation including both non-chemical and chemical tactics. A method for the physical control of immature stages in carpet is vacuuming. A beater-bar vacuum removes about 50% of the eggs but less than 30% of the larvae from a carpet. Chemical control tactics indoors are normally conducted using a compressed-air sprayer. Pressure within the application system is critical for creating spray patterns which can be overlapped to allow even insecticide coverage of the substrate. A compressed-air application system is not capable of delivering pesticides in a manner that will completely penetrate the carpet substrate to reach the base of the carpet. No significant differences in carpet penetration were observed over a range of 20 to 70 psi. Regardless of pressure, more than 93% of the solution applied to carpet was deposited in the upper third (6 mm) of the carpet.

Pet owners were surveyed about their knowledge and perceptions of household infestations of the cat flea, and also about financial expenditures and their willingness to pay for a flea-free environment. The importance and the pest status of flea infestations were determined to be based on physical, psychological, and economic impacts on homeowners. Respondents' perceptions of infestations on their pet were associated with infestation levels in the house. The respondents were willing to pay more for flea control in July, the onset of the flea season, than they were at the peak or decline of the season. They were also willing to pay more as their perception of the intensity of the problem on the pet or in the home increased. Household income was not shown to affect a respondent's actual financial expenditures or his willingness to pay for flea control on the pet or in the home.

DEDICATION

There are a number of people who have had a significant impact on my life. I have very special fellings for these people and hereby wish to dedicate this dissertation to them. I can in no way place their value in order of importance so I will address each form a standpoint of my life's chronicle.

My family; , has always been and will continue to be a source of inspiration to me. Their constant support and advice has helped to get me where I am today and will, without a doubt, help me to get where I need to go for the rest of my life, thank God. I thank you all for your influence on my life.

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uniquely affected my life. From , I learned that challenges, whether on the river or in the classroom, are the precursors to success. These lessons were and still are applicable to nearly every facet of life that I have experienced. I thank you for your influence on my life.

. was my undergraduate advisor at Clemson University. God has taken , but memories of the time we shared will live forever.

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Last, but definitely first in reality, thanks go to my wife, . She is an inspiration to all spouse's of graduate students. I especially thank her for her skillfull hand which has illustrated and created most of the graphics contained within this dissertation.

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CHAPTER I

LITERATURE REVIEW AND OBJECTIVES

1.1 PHYLOGENY

The phylogenetic placement of the Siphonaptera is thought to be close to the nematocerous Diptera. Larval fleas are morphologically and behaviorally similar to these flies (Harwood and James 1979). However, some authors have suggested a lineage from a mecopteran-like ancestor (Hinton 1958, Rothschild and Schlein 1975, Kunitskaya 1960, Schlein 1977). Hinton (1958) suggested this placement on the basis of morphological similarities in larval characters. The secretion of resilin in the pleural arch of fleas and the wing base of a mecopteran genus Boreus is similar. The mode of secretion of resilin among other orders of insects is different (Rothschild and Schlein 1975). Only two orders of insects have both panoistic and polytrophic ovaries, these orders are the Mecoptera and the Siphonaptera (Kunitskaya 1960). Schlein (1977) reported morphological similarities in skeletal structures between mecopterans and siphonapterans. He concluded that the phylogenetic lineage of fleas stemmed from a mecopteran, Boreus-like, ancestor.

1.2 TAXONOMY

The North American Siphonaptera are classified into seven families (Lewis 1972-1975, Hopkins and Rothschild 1953,1962). The superfamily, Pulicoidea, contains two families; Tungidae and Pulicidae. These two closely related families

can be distinguished by the presence or absence of a row or patch of spiniform bristles located on the inner side of the hind coxae. The Pulicidae possess them while the Tungidae lack them.

Differences are also found on the sensilium, a sensory plate dorsally located just posterior to the 8th abdominal tergite and anterior to the anus. The tungids have 8 pits on each side, while in the pulicids there are 14.

The genus Ctenocephalides Stiles and Collins is considered to be the most important genus of domiciliary fleas worldwide (Rust 1986). There are 11 species in the genus, but of primary importance is the cat flea, Ctenocephalides felis felis (Bouché). The nomenclature of C. felis felis is addressed by Hopkins and Rothschild (1953).

Four subspecies of C. felis exist, three of which are much less widely distributed than C. felis felis. C. felis strongylus Jordan has been introduced to Europe from Africa on domestic dogs and cats (Hopkins and Rothschild 1953). C. felis damarensis Jordan exists in southwest Africa, and C. felis orientis Jordan occurs in Sri Lanka and portions of India (Hopkins and Rothschild 1953, Jordan 1965, Joseph 1981).

1.3 DISTRIBUTION AND HOST RANGE

The cat flea is suspected to have originated in the Ethiopian zoogeographic region. The cat flea has become a cosmopolitan species, and is well established in all six zoogeographical regions. In the Nearctic Region two principle flea species infest domestic dogs and cats: the cat flea and the dog flea, C. canis (Curtis). C. canis is primarily, but not exclusively, limited to hosts in the vertebrate family Canidae. It is much less adaptable than the cat flea in terms of environmental limitations and host selection. This has limited its establishment and resultant pest status to man and

associated domestic animals (Amin 1976, Ebeling 1978, Joseph 1981). The cat flea has more than 50 homeothermic hosts, including Canis familiaris Linnaeus (Hopkins and Rothschild 1953, Jordan 1965, Muller and Kirk 1976). C. canis has only 12 known hosts, including Felis catus Linnaeus (Hopkins and Rothschild 1953, Jordan 1965, Muller and Kirk 1976). When the cat flea and the dog flea occur together, the cat flea is usually more prevalent (Rust and Reierson 1985).

1.4 MEDICAL SIGNIFICANCE

The medical importance of C. felis is based on its habits of infesting and feeding on domestic animals and man, and from its potential as a disease vector (Holland 1949). All known cases involving fleas as disease vectors involve mechanical transmission or pathogens within the digestive tract of the flea. There are no known instances of vertebrate pathogens developing beyond the flea's alimentary canal to infect salivary glands or other tissues with respect to pathogen transmission (Bibikova 1977).

1.4.1 Plague

The most significant disease causing agent vectored by fleas is Yersinia pestis (Lehmann and Neumann), a bacillus which causes plague. Campestral plague exists at endemic levels in partially resistant rodents and their fleas. On a global basis, 220 rodent species have been shown to harbor the plague bacillus (Dubos and Hirsch 1965). Pollitzer (1960) demonstrated the ability of C. felis to vector plague bacilli. The cat flea is of minor importance in plague transmission because of its affinity for a single host for the duration of the adult stage. However, the wide host range of this species provides for the potential of vectoring plague in urban areas.

Gohen (1966) demonstrated that only adenine containing nucleotides, such as ATP, elicited feeding responses of many species of fleas. When a host dies, dephosphorylation of the nucleotides occurs, resulting in a decomposition of the phagostimulant. The adult flea will abandon the deceased host and seek a living host, possibly a domestic dog or cat. It is under these conditions, that C. felis could transfer campestral plague in the urban/suburban environment.

Domestic carnivores, particularly pet cats, play a significant role in the transmission of diagnosed plague cases (Poland and Barnes 1979, Rust et al. 1971). In the 1970's 3% of human plague cases in the U. S. were transmitted by contact with domestic cats (Kaufman et al. 1980).

1.4.2 Typhus

The cat flea can vector Rickettsia typhi (Wolbach and Todd), the causative agent of murine or endemic typhus (Irons et al. 1944). Rubbing or scratching flea feces into the wound caused by puncture of the mouthparts of the adult flea is the principle mode of transmission. Approximately 50 recognized typhus cases occur annually in the U. S., primarily along the southeastern and gulf coast and extending up the Mississippi river drainage basin (Adams et al. 1970). In the Los Angeles, California area the opposum, Didelphis marsupialis Linnaeus, maintains the pathogen with C. felis serving as the vector to man (Adams et al. 1970).

1.4.3 Cestodes

Helminth parasites can be vectored by the cat flea. The double-pored dog tapeworm, Dipylidium caninum (L.), uses the cat flea as an intermediate host (Harwood and James 1979). Flea larvae ingest tapeworm eggs which are eliminated in the feces of the animal. When infected fleas are ingested by a dog, cat, or human

the cysticercoids in the body cavity of the flea are liberated and develop into tapeworms in the digestive tract of the definitive host. Children are frequently infested by ingesting parasitized fleas following close contact with the pet cats and dogs (Jellison 1959). Other tapeworms found in C. felis include, Taenia taeniaeformis Verster, Echinococcus multilocularis Leuckart, and the rat tapeworm, Hymenolepis diminuta Rudolphi.

1.4.4 Allergies and Dermatitis

Cat fleas can become abundant in situations where domestic dogs and cats are associated and within the confines of human dwellings. The host pet is irritated by the feeding habits of the adult fleas. In severe instances animals can develop flea induced pruritus and dermatitis. These conditions stem from allergic reactions or hypersensitivity.

Flea allergy dermatitis is the most common hypersensitivity skin disorder in dogs and cats (Baker and O'Flanagan 1975, Halliwell 1979). This dermatitis is popularly termed "summer eczema" and for years had been considered a skin disorder with unknown cause. Its frequency of occurrence initiated investigation and it was found that summer eczema was a symptomological result of self-inflicted trauma. The bite of the flea was considered to be the primary etiological agent responsible for the inception and continuation of the disease (Kissileff 1962). The etiopathogenesis of parasitic hypersensitivity caused by flea bites has been extensively studied in guinea pigs, dogs, and cats (Benjamini et al. 1963, Kieffer and Kristensen 1979, Kristensen and Kieffer 1978). Flea saliva contains many potential antigenic substances including polypeptides, amino acids, aromatic compounds, and fluorescent materials (Young et al. 1963, Feingold et al. 1968). The allergenic substance(s) were demonstrated to be haptens (i.e. there must be combination with an adjuvant before

sensitization occurs). It was demonstrated that dermal collagen appeared to be a cutaneous adjuvant for the flea saliva haptens (Benjamini et al. 1963, Michaeli 1965, Michaeli et al. 1966).

The host animal in close association with the human inhabitants of the dwelling permits transfer of C. felis from pet to human. Humans may also react to flea bites by exhibiting hypersensitivity. Depending on human sensitivity, the symptoms of the bite may vary from a transient wheal to prolonged vesicular skin lesions (Hewitt et al. 1971).

1.5 ECONOMIC SIGNIFICANCE

The pest status of the cat flea is based on both medical and psychological factors. The direct human association with the cat flea and an empathetic concern for the family pet almost always results in a willingness to pay to alleviate the discomfort.

There are approximately 99 million pet dogs and cats in the U. S.; 45 million households have at least one (Anonymous 1986). The documentation of the economic importance of C. felis in the United States has only recently been investigated. The Insect Detection, Evaluation and Prediction Committee of the Southeastern Branch of the Entomological Society of America estimated that in 1982 in nine southeastern states, $102.7 million had been spent for control and rectifying the resultant damage or losses from flea infestations*. The same report estimated that only $46 million had been spent for control of Heliothis virescens (Fabr.), the tobacco budworm.

* Hamer, J. L., Ed. 1985. Southeastern Insect Detection, Evaluation and Prediction Report 1983. Insect Detection, Evaluation and Prediction Committee, Southeastern Branch of the Entomological Society of America, July 1985, 8. 44 pp.

In 1983 in Virginia estimates of the total revenue for pest control operators servicing flea accounts was $2.5 million (Dodson and Robinson 1986). Virginia homeowners reported that they were willing to spend $13 per month (ca. $82 per year) for flea control services. In Atlanta, Georgia local veterinary hospitals reported as much as 50% of their income was derived from treating flea infested animals and flea-related maladies. Local veterinarians in the area earn 1/4 to 1/3 of their annual incomes by treating fleas on pets (Lauterbach 1982). It was estimated that in 1981 dog and cat owners paid $6-8 million to vets in the Atlanta area for handling pet flea problems. This figure is exclusive of over-the-counter purchases of pesticide products and professional pest control services (Lauterbach 1982).

Data on the economic impact of C. felis from countries other than the U. S. is lacking, except for Denmark. The Danish Pest Infestation Laboratory (DPIL) has monitored the incidence of C. felis infestations over the past 15 years. Kristensen et al. (1978) estimated that one-third of the dogs and cats in Denmark are infested by the cat flea yearly. Skovmand (1983) monitored the incidence of cat flea inquiries to the DPIL. In 1970 less than 2% of DPIL cases were in reference to cat fleas. This rose to more than 9% in 1975 and exceeded 16% of total inquiries to the facility in 1982.

1.6 BIOLOGY, BEHAVIOR, AND BIONOMICS

The relative medical and economic importance of the cat flea clearly demonstrates a need for a complete understanding of the biology, behavior, and bionomics of this pest.

1.6.1 Adult Feeding and Oviposition

Both male and female cat fleas feed exclusively on blood taken from a warm-blooded host. Joseph (1976) observed adult C. felis orientis feeding behavior and reported that males fed for an average of 4.4 min and females for 7.4 min per feeding bout. The volume of blood taken during feeding bouts, ca. 18% of the female's body weight, and ca. 33% of the male's, resulted in the production of copious amounts of fecal material. The feces is eliminated as 8 - 10 droplets of partially or undigested fecal blood, which then dry and fall to the host or the substrate. The nutritional value of the blood meal is considered important for successful oogenesis in female fleas. However, Jordan (1965) stated that newly emerged females could begin laying eggs before taking a blood meal. He hypothesized that enough nutritional material could be carried over from the feeding of the larval stage to provide for the development of a number of eggs.

Egg production occurs about two days after the first blood meal, and peaks around the fourth day (Osbrink and Rust 1984). Adult females lay eggs singly while on the host (Karandikar and Munshi 1950). An average adult female enters three gonadotrophic cycles daily, resulting in an average of 13.5 eggs per day with a maximum number observed of 22.3 (Osbrink and Rust 1984). Karandikar and Munshi (1950) reported that a female cat flea laid over 800 eggs in her adult life span. However, Osbrink and Rust (1984) reported that the average total number of eggs per female to be 150 with a maximum of 432 observed.

1.6.2 Egg Development

The opalescent eggs are about 300 u long and oval in shape. The smooth chorion facilitates the dislodging of the eggs from the host to the substrate (Mallis 1982, Karandikar and Munshi 1950). Eggs of C. felis hatch within 2 - 4 days

following oviposition (Karandikar and Munshi 1950). Silverman et al. (1981) reported that the incubation period of eggs was temperature dependent. They reported that temperature and relative humidity were important factors of egg mortality. Increased temperatures (32^0 C) and relative humidities below 50% prevented egg hatching (Silverman et al. 1981). Their research indicate that environmental factors such as ultraviolet light, moisture, and controlled environments, such as heating and air-conditioning in homes can greatly effect egg survival.

1.6.3 Larvae

Patten and Evans (1929) described the morphological characteristics of C. felis larvae. The vermiform larva has prognathous mouthparts, lacks ocelli and compound eyes, but has small cylindrical antennae (Karandikar and Munshi 1950). The larvae move by means of wriggling motions aided by a pair of anal struts, and by segmental setae (Busvine 1951). The larval stage consists of 3 stadia. The developmental rate and survival of each is dependent on temperature and relative humidity (Bruce 1948, Silverman et al. 1981, Silverman and Rust 1983). Larvae could not survive below 50% relative humidity when held at 27^o C, nor at any temperature, when relative humidity was 33% or below (Silverman et al. 1981).

A limiting factor to larval development is food quality and availability. Larval food requirements include, adult flea fecal excrement and assorted organic debris (Ebeling 1978, Bruce 1948, Fox 1968, Muller and Kirk 1976, Karandikar and Munshi 1950). Bruce (1948) studied the effects of nutritional as well as environmental requirements of cat flea larvae and reported that a diet consisting of 2 parts dried beef blood to 1 part brewer's yeast by weight yielded the best growth and survival.

Strenger (1973) reported that adult flea excrement is the only necessary source of larval nourishment. Rust and Reierson (1985) reported that eggs broadcast into areas not containing any adult fecal material will not successfully develop.

Larval feeding behavior was reported to be undirected or random (Bruce 1948). With less food per unit area, the larval maturation period was increased nearly two-fold with the larvae spending more time in search of the food required to reach the prepupal size. Developing larvae appear to be limited to areas where the host, which harbors a major portion of the adult flea population, frequents (Rust and Reierson 1985).

Joseph (1981) reported larval behaviors of C. felis orientis as negatively phototactic and positively geotactic. Third instar larvae when disturbed remained motionless for a few seconds and then actively burrowed into the substrate (debris) and "hide away from the light" (Joseph 1981). Joseph (1981) noted gregarious tendencies which continued from the larval stage through and included cocoon formation.

When larvae complete development through the third stadium, which takes between 9 and 26 days, the contents of the alimentary canal are purged (Silverman et al. 1981, Karandikar and Munshi 1950). This stage, termed the active prepupa, appears pale white. Joseph (1981) reported that the active C. felis orientis prepupa migrated to undisturbed locations away from light. The active prepupa folds longitudinally and spins a silken cocoon around itself from salivary secretions. Both C. felis and C. felis orientis larvae reared under laboratory conditions have been observed to spin loose networks of silk to support the cocoons of other active prepupae (Karandikar and Munshi 1950, Joseph 1981).

The movement of the active prepupa within the cocoon during its construction facilitates the adhesion of particles and debris from the substrate giving the finished cocoon a camoflauge with its surroundings (Karandikar and Munshi 1950, Joseph 1981). Once the cocoon is completed, the prepupa becomes inactive in preparation for pupation. The process of voiding the gut contents through cocoon formation normally takes between 36 and 48 hours (Joseph 1981). The inactive prepupa undergoes ecdysis within the cocoon to produce the exarate pupa.

1.6.4 Pupae

The inactive prepupa is second only to the exarate pupa with regards to resistance to dessication when compared to the other immature stages (Silverman et al. 1981). Tolerance of the pupa to cold temperatures was equivalent to that of the larva. Both stages were more tolerant than the prepupa (Silverman 1981, Silverman and Rust 1983).

1.6.5 Pre-emerged Adults

The duration of the pupal stage is 7 - 10 days (Joseph 1981, Karandikar and Munshi 1950). After this period the pupa molts into the imago within the cocoon. The quiescent adult may remain in the cocoon until some stimulus(i) triggers its emergence (Bacot 1914, Karandikar and Munshi 1950, Silverman and Rust 1985). This stage is the most resilient to environmental factors such as temperature and relative humidity, and its decreased respiratory demands enables it to to survive considerably longer than emerged adults (Silverman and Rust 1985).

Joseph (1981) reported that C. felis orientis adults emerge within 10 days by vibrational stimuli caused by an animal, and that none remain within the cocoon for long periods. Silverman and Rust (1985) reported that stimuli of direct pressure on

the cocoon or increased ambient temperatures stimulated emergence. They also demonstrated that the pre-emerged adult would remain quiescent within the cocoon from 4 to 140 days waiting for emergence stimuli.

1.6.6 Emerged Adults

Adult females emerge between 1 and 3 days earlier than males (Joseph 1981, Silverman et al. 1981, Silverman and Rust 1985). Rust and Reierson (1985) stated that the biological significance of the early female emergence is unknown. However, Joseph (1981) reported that female sex organs develop before males, resulting in their earlier emergence.

Host finding behaviors were investigated under laboratory conditions by Osbrink and Rust (1985b). They reported that stationary heated targets evoked orientation and locomotory responses and that light, CO_2, and air movements stimulated only locomotion. They concluded that visual cues, such as the contrast of a dark target against a light background, and thermal cues were the primary stimuli evoking orientation and attraction, and that the addition of air currents could elicit an oriented-jumping response.

Emerged adults that fail to acquire a host live for approximately 7 - 10 days, with unfed females living slightly longer than unfed males (Joseph 1981, Silverman et al. 1981). Unfed females also live longer than females which have taken a single blood meal (Joseph 1981). Osbrink and Rust (1984) reported that the on-host longevity of females (mean = 11.2 days; observed maximum = 37 days) was significantly longer than that of males (mean = 7.2 days; observed maximum = 25 days).

Environmental parameters affect the duration and mortality of the adult stage. Silverman et al. (1981) reported that adult longevity increased with increasing

relative humidity and decreasing temperature. The overall life-cycle of the cat flea from egg to adult can last from 16 days to 18 - 20 months (Karandikar and Munshi 1950).

1.7 CONTROL STRATEGY

Control of domiciliary cat flea infestations is normally initiated after a member of the household has experienced flea bite(s), flea sightings, or by visible signs of an irritated family pet. Treatment strategies for the control or elimination of established flea infestations usually consists of a number of tactics, involving insecticide treatment of the animal and the indoor environment, and to areas outdoors (Pratt and Wiseman 1962, Ebeling 1975, Bledsoe et al. 1982).

1.7.1 Pet Tactics

The health and age of the host animal can greatly affect the population of adult cat fleas in its pelage. Marshall (1981) reported that a direct relationship existed between the host's ability to groom and the incidence and intensity of ectoparasitism. Haas (1966) noted that unhealthy mongooses harbored considerably more C. felis adults than did healthy ones. The age of the host cat was shown by Osbrink and Rust (1985a) to influence the number of adult cat fleas infesting the host. They found more C. felis adults (mean = 17.7) on young cats than older cats (mean = 4.7) and attributed this to the host's experience with respect to effectiveness and frequency of grooming.

Direct control can be achieved by using insecticidal or inert (silica aerogel and diatomaceous earth) dusts. Dusts are safer to use than spray insecticides because of the absence of chemical propellants which can irritate the derma or be accidentally misapplied to eyes, mouth, and the nostril areas of the pet (Ebeling 1975). Aerosol

sprays are often used to control adult cat fleas on pets. These contain either synthetic or botanical insecticides such as pyrethrum, rotenone, or d-limonene (Hink and Fee 1986, WHO 1980, Arther and Young 1985). Insecticidal dips and shampoos normally formulated for water compatibility are available with more than a dozen active insecticidal ingredients (WHO 1980). Insecticidal flea treatments are available with metered release activity and these include insecticide impregnated collars (Bedford 1980), and systemic insecticides such as cythioate, tiguvon, and fenthion (Bledsoe et al. 1982, Hill et al. 1963, Hopkins and Baldock 1984, Everett et al. 1986, Arther and Cox 1985, Rubensomn 1982).

1.7.2 Indoor Tactics

There are a number of insecticides registered for indoor use for flea control (Muller et al. 1983, Bledsoe et al. 1982, WHO 1980). The insecticides are normally formulated as a water- or oil-based spray. Aerosol formulations exist, and dichlorvos impregnated resin strips have also been incorporated in indoor flea control strategies (Olsen et al. 1982). Insect growth regulators, such as methoprene and fenoxycarb are available in total release aerosols and water based emulsifiable formulations (Rust and Reierson 1985, Chamberlain 1983, Rust and Reierson 1983).

Areas to be treated include; pet bedding areas, carpeted areas, under rugs, cracks and crevices in floors, and corners where floors adjoin walls (Osbrink et al. 1986).

1.7.2.1 Equipment

Equipment used to apply pesticides in the indoor environment includes manual and CO_2 compressed-air sprayers. Frazer (1958) investigated the physical aspects of droplet production from hydraulic-energy nozzles. The droplets produced varied

considerably in size and volume. A normal spectrum of droplets produced by a hydraulic nozzle may have large droplets with volumes a million times that of the smallest (Matthews 1979). The smallest droplets pose hazards of drift, and contamination of non-target organisms and substrates. Excessively large droplets result in over-application, and wasted pesticide. Frazer (1958) recognized the need for alternative nozzles and/or application equipment.

There is an optimal droplet size for a particular application target which minimally contaminates the environment (Himel 1969, Brett 1974). The optimum droplet size for impacting on small flying insects, such as mosquitoes is 10 - 20 u (Latta et al. 1947, Mount 1970, Mount et al. 1975, Lofgren et al. 1973).

Other technologies exist for pesticide application such as controlled droplet application (CDA). CDA technology for application equipment used indoors can be found on centrifugal-energy nozzles (spinning discs) (Bals 1975, Matthews 1979). Spinning disc application equipment is used in the United Kingdom and Europe for indoor flea control. This method of application is not used in the U. S. because of costs of individual units, and claims of equipment breakdown. The application of a carbamate insecticide, Ficam W (bendiocarb) is now recommended with spinning disc application equipment (Anonymous 1984).

1.7.3 Outdoor Tactics

Silverman and Rust (1983) investigated the effects of ambient, outdoor environmental factors such as temperature, relative humidity, and soil moisture on the development and survival of the cat flea in the southwestern U. S. They reported that life stages of the cat flea particularly the larval stages, can survive in protected microhabitats. Daniel (1973) investigated adult overwintering of Ctenophthalmus

agyrtes agyrtes Haller in a field experiment and reported the percentage survival of adults increased from 0% to 41% as the depth of containment chambers went from ground surface to 30 cm subsurface.

In the eastern U. S. the spring, summer, and fall temperatures and relative humidities in exposed and protected microhabitats could be conducive to the survival of outdoor populations of cat fleas within the limitations reported by Silverman et al. (1981) and Silverman and Rust (1983).

1.8 OBJECTIVES

The effective development of a pest management strategy as described by Geier (1966) involves three general areas of knowledge; 1) determining methods to modify the life system of a pest to reduce its numbers below a tolerable threshold, 2) understanding biological characteristics to achieve the desired modification, and 3) developing pest control tactics which are available given current technology and compatible with both economic and environmental aspects. Using Geier's (1966) description as a set of basic pest management principles, the purpose of the research presented here was to develop information and increase the data base on household flea infestation biology and habits, and control to move towards a management strategy for indoor cat flea infestations. The specific objectives were to:

1) determine the behaviors of cat flea larvae within carpet in the laboratory and to relate these behavioral responses to control tactics;
2) develop a field sampling procedure for flea larvae and eggs;
3) determine spatial patterns of indoor populations of flea larvae with regards to biotic and abiotic factors of the environment;

4) determine the efficacy of vacuuming as a non-chemical control tactic;

5) evaluate the effectiveness of application equipment to apply insecticides to the indoor environment;

6) survey pet owner knowledge, perceptions, and willingness to pay for control to better determine the needs of the target audience.

CHAPTER II

LARVAL CAT FLEA BEHAVIORS AND THEIR IMPACT ON CONTROL TACTICS

2.1 INTRODUCTION

Effective pest management strategies are based on a sound knowledge of target pest biology. A crucial component in Geier's (1966) description of pest management was the application of knowledge of the target pest biology to the design of control tactics and strategies. Chemical control is the primary control tactic for cat flea infestations. The intent of pesticide use is to deliver a toxin to a target pest. The efficiency of a pesticide application is directly related to the spatial and temporal habits of the target species (Matthews 1979). Defining the target requires an understanding of all life stages of the pest species. The behavior of a given life stage will determine its location in both space and time.

The management and control of cat flea populations emphasizes the importance of a knowledge of the biology and behavior of a pest species. The hematophagous adults are the damaging stage, yet larvae are the target stage for insecticides applied to carpeted surfaces. Larval biology has been investigated with respect to longevity and survival, and its interrelationship to environmental parameters (Bruce 1948, Silverman et al. 1981, Silverman and Rust 1983). Food requirements of C. felis larvae have also been investigated (Bruce 1948, Fox 1968, Karandikar and Munshi 1950, Strenger 1973, Rust and Reierson 1985). However, there have been few investigations of the behaviors of the larval stages of the cat flea.

The objectives of the research reported here were to investigate larval cat flea behaviors within carpet, and determine how they may impact on existing control tactics. Specific objectives were to determine: 1) foraging, 2) hygrotactic, 3) geotactic, and 4) phototactic behaviors.

2.2 MATERIALS AND METHODS

2.2.1 Larval Flea Rearing

Cat flea eggs were collected and reared under laboratory conditions to the larval stage. Eggs were acquired by placing a domestic cat in a 5.33 cubic foot cage with a slotted floor. A black cloth was placed beneath the cage under the slotted floor. The cat was confined within the cage for 2 to 4 hours. To collect cat flea eggs, the cloth was vacuumed using a 7.4 amp portable vacuum cleaner. The hose of the vacuum cleaner was modified by the insertion of a tight-weaved muslin catch-bag to collect the eggs. The catch-bag was then removed from the hose and turned inside out and brushed. The eggs collected were transferred to a 100 x 20 mm petri dish.

Rearing media added to petri dishes consisted of 100 mg of powdered lyophilized beef-blood and 50 mg of pulverized dog-food containing a minimum of 25% crude protein and 8% crude fat with a maximum of 5% crude fiber and 12% moisture. The dishes containing eggs and rearing media were placed in a controlled environment chamber maintained at $27^{o} \pm 2^{o}C$ and $70\% \pm 5\%$ relative humidity, and an illumination regimen of 12 hr : 12 hr (light : dark).

2.2.2 Foraging Behavior

Ten second- and third-instar flea larvae were randomly extracted from the petri dish cultures and placed in an empty petri dish. Following an acclimation period of

30 min, small pieces of lyophilized beef blood were scattered throughout the 100 x 20 mm petri dish. Larvae were then observed for a period of approximately 30 min, and foraging behaviors recorded.

2.2.3 Hygrotactic Behavior

Five second- and third-instar flea larvae were randomly extracted from petri dish cultures and placed in the center of 95 mm diameter carpet discs (pile height = 10 mm) which were within 100 x 20 mm petri dishes. Eight replicates in new carpet discs in petri dishes were conducted.

The larvae were allowed to disperse for a period of 30 min. Following dispersal a 10 x 4 mm microvial (100 ul) filled with distilled water was placed at the periphery of the carpet, with the base of the microvial located down at the base of the carpet pile. This set up resulted in the upper 1 mm of the top of the glass vial being exposed above the carpet pile. The dish was then observed every 15 min to record larval location within the carpet disc in relation to the water vial. Two hr after the test began, the vial was moved to the opposite edge of the carpet disc. Larvae in the dish were observed every 15 min, and their location recorded.

2.2.4 Geotactic Behavior

Two separate experiments were conducted to observe geotactic behaviors in cat flea larvae. In the first experiment three replicates of 5 larvae each were removed from the stock cultures and placed onto carpet discs within petri dishes as described in Section 2.2.3. Larvae were allowed to disperse throughout the carpet both vertically and horizontally for 4 hours. The dishes were then carefully inverted (lid down) so as not to dislodge any larvae from the carpet. The experiment was

conducted in an environmental chamber ($27^{o} \pm 2^{o}$ C; 70% ± 5% RH) with an illumination regimen of 0 hr : 24 hr (light : dark). The carpets were checked at 12 hr, and the location of the larvae recorded.

In the second study six replicates of 5 larvae each were placed into the center of carpet discs which were mounted in petri dishes that were oriented on an angled plane 30 degrees off level. The experiment was conducted in an environmental chamber with an illumination regimen of 0 hr : 24 hr (light : dark). The location of larvae was recorded 4 hr after the larvae were placed onto the carpet surface.

2.2.5 Phototactic Behavior

Five second- and third-instar flea larvae were randomly taken from stock cultures and placed onto carpets as described in Section 2.2.3. The larvae were allowed to disperse for a period of 30 min then a half-blackened petri dish lid was placed onto the dish. After 1 h the lid was removed, and the location of the larvae with respect to the orientation of the lid and also on the vertical axis within the carpet pile was recorded. Eleven replicates in new carpet discs in petri dishes were conducted.

2.2.6 Data Analysis

Chi square tests were used to observe for significance of association between behavioral responses of the flea larvae. For all analyses, an alpha level for significance was set at 0.05.

2.3 RESULTS AND DISCUSSION

Cat flea larvae locate themselves near the base of carpet as a result of behavioral responses. Combining all the experiments in terms of the data collected

on vertical location, 83% of the larvae were located at the base of the carpet pile. This information strengthens the findings of the investigations of geotactic behaviors presented in Section 2.3.3 which demonstrated that cat flea larvae exhibit a positive geotaxis.

2.3.1 Foraging Behavior

The C. felis larvae appeared to exhibit a random and undirected foraging behavior. Larvae usually travelled in straight paths, and were observed to pass within 2 to 3 mm of the food particles yet exhibit no observable changes in movement patterns. In close proximity to the food particle there was no turning toward the food. Feeding did occur on numerous occasions but only following direct contact with one of the food particles. The encounter often resulted in what appeared to be feeding for a variable period of time ranging from only seconds to more than 5 minutes. Larvae were also observed to grasp food particles with thier mouthparts and carry them to locations away from the location of first contact. Larvae fed or displayed what appeared to be a resting type of behavior in which they remained adjacent to a food particle. The larvae often began locomotory activity, leaving the particle of food behind without any feeding taking place after resting adjacent to it.

Foraging behaviors were not recorded while larvae were in carpet, because of the difficulty in locating and observing larval fleas within carpet for any length of time. The carpet environment would probably restrict movement compared to that in a bare petri dish and this could result in an increase in what could be considered as a searching behavior. Under natural conditions in household carpet food may be more abundant than that supplied in this experiment. The frequency of encountering food particles might be greater in carpet, and may result in variation

from that observed in the dishes in terms of the period of time between food-particle encounters. Bruce (1948) hypothesized that "the feeding behavior of C. felis larvae was a chance occurrence" yet did not report on methods of investigation to support this idea.

The ancestral animal lair environment of larval cat fleas was suitable in terms of food abundance. The localization of food into a confined nest area and the nutritional requirements of larval fleas may not have necessitated the development of specialized sensory receptors or organs to elicit directed foraging responses or behavioral search patterns.

2.3.2 Hygrotactic Behavior

The larvae of C. felis exhibited a positive hygrotactic behavioral response, following the addition of a microvial of water to the carpet. Significantly more larvae (84%) were found within a 10 mm radius of the vial than at other locations on the carpet disc within 60 to 90 minutes (X^2 = 19.60; df = 1; $P < 0.005$). The movement of the water vial to the opposite side of the carpet resulted in a slightly lower proportion (72%) of larvae at the new location. The number at the new location was significantly greater than those which were not drawn to within 10 mm radius of the vial placement (X^2 = 8.10; df = 1; $P < 0.005$). The time required for larvae to locate and move to the new source of moisture was 75 to 105 minutes. This was slightly longer than the time required for movement to the original location of the microvial.

The decrease in the hygrotactic response following repositioning of the moisture source might be attributable to a microclimatic effect, and may explain the increase in response time. The relative humidity at the original vial location and in the

immediate surroundings might have been increased to a level which was sufficiently attractive to inhibit or delay the movement of larvae to the new location of the moisture source.

The behavioral response to moisture in larval cat fleas appears to be of a tropotactic or possibly a kinetic nature (Schöne 1984). Cat flea larvae lack ocelli and compound eyes, but possess a pair of small, bilaterally- located antennae. Silverman et al. (1981) reported the importance of conducive relative humidities for the survival and development of cat flea larvae. It would be an adaptive advantage for the larvae to possess some mode of stimulus reception on a moisture gradient to increase the chances of survival. Various sensory receptors may exist on the antennae and possibly on other parts of the body to detect moisture gradients within the environment.

2.3.3 Geotactic Behavior

Cat flea larvae exhibited a positive geotactic behavioral response. In the first study of geotactic behavior described in Section 2.2.4 the hypothesis was that a positive geotactic response of the larvae would result in their moving to the inverted tips of the carpet fibers, continue the downward locomotion, and fall from the fiber to the lid of the petri dish below. Following the 12 hr period for larval dispersal, 53% of the larvae were found in the lid of the dish. These results were indicative of a positive geotaxis ($X^2 = 8.53$; df = 1; $P < 0.005$). The remaining 47% of the larvae that did not release from the carpet fibers were all found at the distal portions of the fiber surface.

The second study was not as supportive of a positive geotaxis ($X^2 = 1.20$; df = 1; $P > 0.250$). Sixty-one percent (61%) of the larvae were found on the lower half of the carpet disc which had been elevated on one end. Of the larvae which had

dispersed to the upper half, 70% of these were found at the base of the fiber matrix. The angle of incline that was used in the study might not have been sufficiently steep to cause larvae to move down the incline to the lower end. The fact that most (70%) of those that did not move to the lower half of the carpet disc were found at the base of the pile indicates that carpet is a substrate well suited to larval fleas with respect to their geotactic and phototactic behavior, described in Section 2.3.4.

Joseph (1981) described C. felis orientis larvae as being positively geotactic. In the present investigation, larvae of the cat flea, C . felis felis, also exhibited a positive geotaxis.

2.3.4 Phototactic Behavior

Cat flea larvae exhibited a negative phototaxis. Significantly more larvae (67%) moved to the side of the carpet that was beneath the darkened half of the petri dish lid ($X^2 = 6.56$; df = 1; $P < 0.025$). Of the remaining 33% of the larvae (located beneath the non-darkened half of the lid), 85% were found at the base of the carpet pile.

Crumb et al. (1974) reported that C. felis adults exhibited a positive phototaxis. They reported that unfed adults were positively phototactic toward wavelengths within a range of 300 to 700 nm. This adaptive behavior is advantageous to ensure that newly emerged adults acquire a host to begin the process of feeding and reproduction. Jordan (1981) reported that C. felis orientis larvae were negatively phototactic. The combined effect of a positive geotaxis described in Section 2.3.3 and the negative phototaxis is that larvae of the cat flea spend most of their time at the base of the carpet substrate.

Carpet is the usual substrate of the larval cat flea in a household situation. The original environment of the cat flea was probably the lair of a mammal. The present

lair of domestic pets, a carpeted house, may have similar characteristics to that of their ancestors. The vertical dimension of carpet and the food material which collects at its base may be similar to the mat of bedding material and the organic matter that collected within the matrix of the a mammal's resting or nesting location. Larval food reaching the carpet would eventually sift to the lower portion of this substrate. This area of the substrate would exist as the optimal environment for larval fleas, and they have adapted by developing behavioral responses to gravity and light. The interface between bedding in the lair and soil might also have been conducive to a moisture gradient, getting more humid closer to the soil than at the surface of the bedding. A gradient of food availability may also have existed with more food material sifting through the bedding to lie near the soil-bedding interface. The behavioral adaptations that may have developed by cat flea larvae in mammal lairs prior to the advent of carpet appear to be conducive to survival in either environment.

2.3.5 Larval Responses to Disturbances

Two responses to the disturbance were observed, and each depended on the intensity of disturbance to the flea larva. A larva responded to direct contact by ceasing any movement and coiling its body longitudinally. A stimulus was from a nearby disturbance, i.e. moving adjacent carpet fibers within 4 to 5 mm, caused the larva to increase locomotion, normally in a downward direction if the larva was not already at the base of the carpet pile. If the larva was at the base, the locomotion still occurred but on a horizontal plane. Disturbed larvae were never observed to move upward.

2.4 CONCLUSIONS

The larvae of C. felis exhibit positive hygrotactic, positive geotactic, and negative phototactic behavioral responses in a carpet environment. A great portion of the larval development period is spent at the base of carpet. Larvae appear to exhibit undirected foraging behaviors. Specialized receptor cells or organs may exist to control locomotory behaviors while feeding. The trichobothria located on the sensilium and the antennae of adult cat fleas have been shown to support both chemo- and mechanoreceptors (Amrine and Jerabek 1983, Slifer 1980).

The results of this investigation of cat flea larval behavior suggests ways to improve a number of existing control tactics. Specifically, the location of larvae at the base of carpet raises questions about the equipment used to apply insecticides to carpet, and the ability of the insecticide spray to penetrate to the larval habitat. The results of this investigation also indicate that vacuuming as a method of controlling an infestation may not be successful in removing larvae from carpet. The coiling behavior elicited by larvae when disturbed, along with morphological characterstics such as the presence of long setae on each body segment may inhibit their removal from carpet.

Addtional studies on biology and behavior are needed to improve and understand more about control of larval cat fleas. Further research should include 1) the degree of insecticide repellency and the resulting behaviors elicited by larvae, 2) behavior of cat flea larvae in indoor environments other than carpet, and 3) the behavior of larvae outdoors. The incorporation of behavioral and biological information into tactics for the control of pest species could lead to improved pest management strategies.

CHAPTER III

INVESTIGATION OF THE DISTRIBUTION OF THE IMMATURE STAGES OF THE CAT FLEA IN THE HOUSEHOLD ENVIRONMENT

3.1 INTRODUCTION

The life stages of the cat flea indoors are located in two different habitats. Adults are found on homeothermic hosts, and the immature stages are primarily located in carpets or crevices in smooth-surface flooring. To ensure successful development, cat flea larvae require blood or blood components in their diet (Bruce 1948). Larval food requirements have been investigated by Bruce (1948), Karandikar and Munshi (1950), and Strenger (1973). Aspects of the abiotic environment, such as temperature and relative humidity, that are conducive and/or detrimental to development of the immature stages have also been investigated (Bruce 1948, Silverman et al. 1981, Silverman and Rust 1983). The abiotic and nutritional requirements of the adult stage of the cat flea have been reported by Joseph 1981, and Silverman et al. 1981.

The distribution of adult fleas on cat hosts has been investigated by Osbrink and Rust (1985a). They reported that adult cat fleas showed no preference for location on the cats they observed. Osbrink et al. (1986) reported that higher populations of adult fleas were found in those rooms in which residents indicated the pet(s) spent the most time.

Control strategies for indoor infestations of the cat flea are primarily directed at controlling the immature stages including the eggs, and larvae. These stages are primarily located in carpet. The objectives of the research presented here were to determine the spatial patterns of flea larvae, and eggs in carpets within homes, and to assess the effects of biotic and abiotic factors on the spatial patterns.

3.2 MATERIALS AND METHODS

3.2.1 Study Site

An 1800 ft^2 residence was selected for the study based on a history of moderate to severe flea infestations during the study year and for the previous 3 years. A single dog, Canis familiaris Linnaeus, (ca 12 kg) was the only pet which had inhabited the home for more than 3 years. Two rooms within the house, the family-room and a bedroom, were selected as study sites based on the frequency of occupancy by the dog.

All articles within the rooms including furniture, doors, windows, plants, and any other semi-permanent or permanent articles which were located on the floors were recorded on maps for each of the rooms. Family members were then questioned about the normal behavior patterns and habits of the pet within the two rooms.

3.2.2 Sampling

The rooms were completely emptied of all furniture and other articles located on the carpeted floor. The room was then measured and delineated into 40.64 x 40.64 cm (16 x 16 in) sample units, the boundaries of which were marked using chalk. Each sample unit was vacuumed for 1 min using a 4.0 amp beater-bar vacuum cleaner (Eureka: model 1425). A tight-weave muslin bag was affixed to the effluent

tube of the vacuum to collect the sample of extracted material. A clean bag was used for each sample. Samples were labelled and stored in plastic bags prior to microscopic analysis.

3.2.3 Sample Analysis

Carpet debris was removed from the muslin bags into a 230 μ seive and gently shaken to separate fine particles from the larger debris in the extraction sample. The portion of the sample unable to pass throught the mesh was analyzed with a dissecting microscope. Immature stages of the cat flea including, hatched eggs, unhatched eggs (dead), and first- and second-instar larval exuviae, were tallied and recorded for each sample. Actual larvae were unable to be vacuumed from the carpet.

3.2.4 Data Analysis

Sample data for each developmental stage and remnant of life stages taken from the two different rooms were plotted with Surface II, a computer graphics program (Sampson, 1978). These plots were visually analyzed by comparison of the samples from each room. Variance to mean ratios were calculated for each life stage or remnant of a life stage for each of the two rooms.

3.3 RESULTS AND DISCUSSION

3.3.1 Methods Validation

The fine debris small enough to pass through the 230 μ seive was analyzed for ten samples to ensure that eggs or larval exuviae could not escape detection. One

small portion of a larval exuvia which consisted of three segments, and a portion of a hatched egg had passed through the mesh in the ten portions (11.23 g) of fine debris which was microscopically analyzed.

A series of vacuum time intervals was tested to determine the vacuum extraction efficiency so that as much of the material as possible could be collected from each sample location. Four times were tested; 15, 30, 60, and 120 seconds. The 60 sec time interval was the most efficient time for percentage removal of eggs, both hatched and unhatched, and larval exuviae. A separate vacuum extraction study, described in Chapter IV, demonstrated that larvae could not be extracted from carpet. For this reason, larval exuviae were tallied from the samples in this investigation and used as an index of larval location.

3.3.2 Family-Room

The immature stages and remnants in the family-room were not randomly or uniformly dispersed, but showed a contagious spatial pattern. The posted tally data for the hatched eggs, unhatched eggs, and the larval exuviae are depicted in Appendicies A-1, A-2, and A-3, respectively. Associated contour maps with the room map overlayed of these life stages are found in Apendices A-4, A-5, and A-6, respectively.

3.3.2.1 Hatched Eggs

Three areas of very large numbers of hatched eggs in the family-room included the pet's bedding area, the doorway to the kitchen and perpendicularly to the outside, and around the perimeter of a reclining chair (Figure 3.1). The homeowner

indicated that the dog spent considerable amounts of time in each of these three areas. The dispersion of hatched eggs in the family room yielded a variance to mean ratio of 89.98 indicating a contagious distribution.

3.3.2.2 Unhatched Eggs

The occurrence and frequency of the unhatched eggs observed within the family-room was similar to that for the hatched eggs (Figure 3.2). The variance to mean ration was 22.19. The numbers of unhatched eggs are largest in the three locations that the hatched eggs were largest. This may indicate that natural mortality factors exist within the indoor environment with respect to percentage eclosion from the egg. Another explanation for the similarity in location of both hatched and unhatched eggs is that areas of pet or pedestrian activity within the room may physically destroy the eggs dropped in a particular location.

One distinctive feature of the distribution of the unhatched eggs within the family-room is the abrupt decrease in their numbers directly adjacent to the windows. This phenomenon can be seen in the data presented in Figure 3.2 and also in Appendices A-2 and A-5. An explanation for this phenomenon is that the environment, particularly sunlight, had an affect on the success of eclosion from the egg. There was a 1 foot (30 cm) rise from the floor to the window which sheltered a 14 in (36 cm) area directly adjacent to the wall from direct sunlight. Rust and Reierson (1985) reported that cat flea eggs will not hatch in dry (<50% RH) microhabitats. They further reported that eggs laid in summer months and deposited in sunlit areas with these same low relative humidities will not hatch.

3.3.2.3 Larval Exuviae

The variance to mean ratio for the larval exuviae was 23.01. There was a large overall reduction in the number of larval exuviae found in the family-room with respect to the number of hatched eggs. The locations that contained large numbers of larval exuviae were locations that had large numbers of hatched eggs. Blood or blood components are essential components of the larval diet to ensure development (Bruce 1948, Strenger 1973). Larval distribution within a room is expected to be closely associated with that of eggs, because of the feeding and egg-laying habits of the adult fleas on the pet. Both eggs and adult flea feces fall from the pet. Rust and Reierson (1985) reported that eggs broadcast into areas without a source of blood do not successfully develop to adults. They concluded that the survival of flea larvae is limited to areas frequented by the pet.

There were very few larval exuviae located in the doorways that accessed the kitchen, and the outdoors from the family-room. This area had had moderately high numbers of hatched eggs, but also a moderate number of unhatched eggs. This may indicate that heavily traveled areas are not conducive to successful larval development. Similar low numbers of larval exuviae were observed throughout the majority of the family-room, with the exception of those locations where the pet spent the majority of its time (Figure 3.3).

3.3.3 Bedroom

The immature stages of the cat flea located in the bedroom of the house under investigation did not show a random or uniform spatial pattern. Contagious patterns were apparent for all of the life-stages investigated.

The posted tally data for the hatched eggs, unhatched eggs, and combined first- and second-instar larval exuviae are depicted in Appendices B-1, B-2, and B-3, respectively. The associated contour maps with the room map overlayed of these life stages are found in Appendices B-4, B-5, and B-6, respectively. Countour maps with room-map overlays for first-instar larval exuviae, and second-instar larval exuviae are included and are depicted in Appendices B-7, and B-8, respectively.

3.3.3.1 Hatched Eggs

There was a definite contagious pattern of the hatched eggs (variance/mean ratio = 151.57) within the bedroom. There was a definite clump located both around and beneath the bed (Figure 3.4). There was only one side of the bed that contained large numbers of hatched eggs. The dog slept on the bed, usually at the foot of the bed, nearly every night. The dog could fit beneath the bed. The location of the door in reference to the bed provided a viable explanation to the differences of hatched egg counts on either side of the bed. The largest number of hatched eggs from any single sample was 516 (Appendix B-4). This location was directly next to the foot of the bed were the dog probably contacted the floor most frequently when coming down from or jumping up onto the bed. The force of impact when the dog reached the floor or that or leaving the floor was such that eggs laid in the pelage were dislodged onto the floor in that location. Adult flea feces were probably also dislodged from the dogs pelage in this location.

3.3.3.2 Unhatched Eggs

The dispersion of the unhatched eggs had a variance to mean ratio of 29.61 (Figure 3.5). The majority of the unhatched eggs located in the bedroom were in

areas of moderate to heavy pedestrian and pet traffic as described by the tenant. This may indicate that heavily traveled areas could be one cause of mortality on the egg stage.

3.3.3.3 Combined Larval Exuviae

The the variance to mean ratio of 51.55 indicates a contagious spatial pattern of the combined first- and second-instar exuviae (Figure 3.6). The spatial pattern of the larval exuviae almost mirrors that of the hatched eggs (Figure 3.4). The coincidence of large numbers of larval exuviae with that of hatched eggs (R^2 = 0.85) appears to have been directly related to the depostion of eggs and adult flea feces from the pet. This similarity of spatial pattern of both hatched eggs and larval exuviae substantiates the observations of Rust and Reierson (1985) that flea larvae will successfully develop to in areas that the pet frequents. These results also suggest that larvae do not travel far from the location of eclosion. This observation supports the findings of Bruce (1948) and Strenger (1973) that larvae must have a source of blood or blood components in their diet to successfully develop.

3.3.3.4 Separation of First-and Second-Instar Larval Exuviae

The spatial pattern of the first-instar larval exuviae (variance/mean = 36.22) (Figure 3.7) closely resembles that of the hatched eggs (Figure 3.4). When the spatial pattern of the second-instar larval exuviae (variance/mean = 20.72) is compared to that of the first-instar, some inferences can be made about larval movement. First-instar larvae apparently do not survive to become second-instars in areas of high pedestrian, and possibly pet traffic. This appears to be the case in the location directly adjacent to the foot of the bed that had a large number of first-

instar exuviae (Figure 3.7). The second-instar larvae could have moved from this location to other areas that had less disturbance or pedestrian traffic, or they could have been killed.

The region directly against the wall behind the door on Figure 3.8 depicts the presence of second-instar larval exuviae, but this region has few if any first-instar exuviae (Figure 3.7). The sharp rise in the corner of the room (Figure 3.8) are those second-instars that had migrated to an area behind the door. This area would have provided an undisturbed location for development. This indicates that the second-instar larvae had moved to areas of less disturbance (i.e. traffic) to complete development.

Comparing the spatial patterns of both first- (Figure 3.7) and second-instar (Figure 3.8) larval exuviae beneath the bed, it appears that the second-instar larvae had dispersed themselves more evenly than the first-instars. This may indicate that there is some competition for dietary resources or other factors involved with successful larval development.

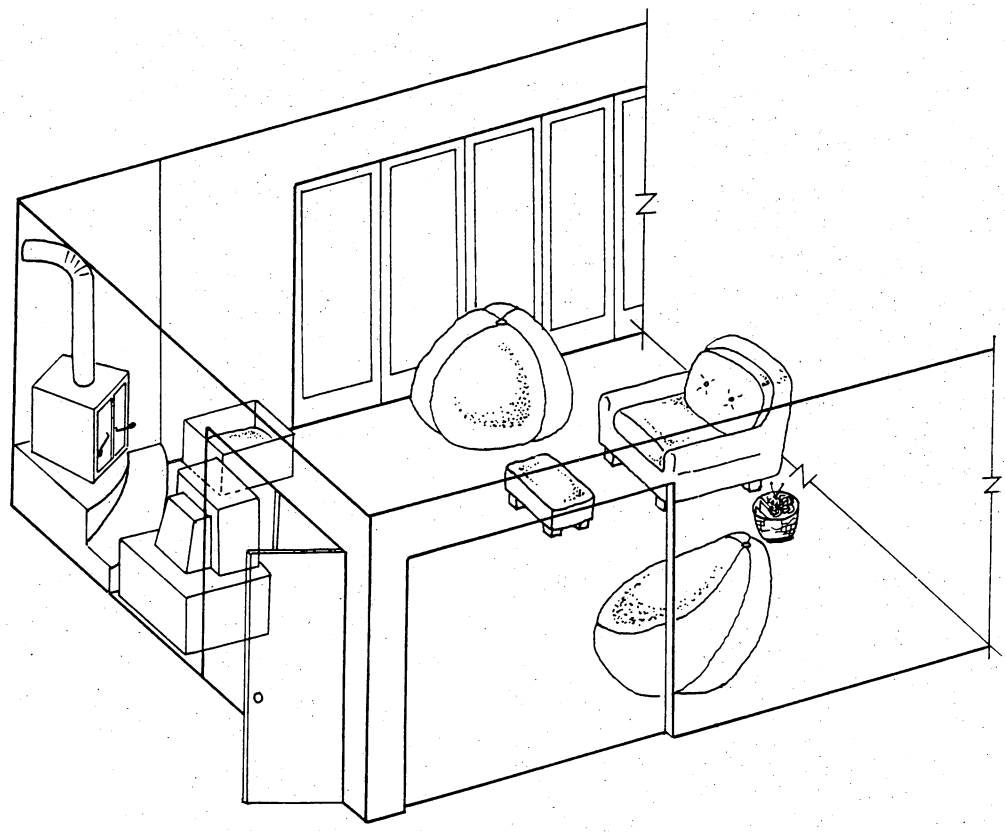
3.4 CONCLUSIONS

The spatial patterns of the immature stages of the cat flea in specific rooms appeared to be contagious. The deposition and location of hatched eggs, unhatched eggs, and first-instar larval exuviae were all directed by the habits of the pet animal within the given room. It was apparent that first-instar larvae do not move far, if at all, from the location of eclosion. This confirms the findings of Rust and Reierson (1985) that locations where the pet frequents are most conducive to successful larval development. Their conclusions on larval location within a domicile were based on the findings of Bruce (1948) and Strenger (1973) that the larval diet must contain a source of blood or blood components to successfully develop. The blood source for

cat flea larvae is adult flea feces which is dislodged from the pelage of the host animal in locations that the animal frequents. Eggs are dislodged from the pelage of the host along with the feces. This places developing larvae in close proximity to this necessary dietary component.

It also appeared that the distribution of immature stages is influenced by abiotic and biotic factors in the environment. Areas of high pedestrian or pet traffic seem to increase the numbers of unhatched eggs in those locations, and also decrease the numbers of second-instar larvae. It appeared that abiotic factors of increased temperatures and decreased relative humidities increased the number of unhatched eggs compared to the number of hatched eggs in the same locations. These findings confirm those of Rust and Reierson (1985) that eggs will not hatch in dry microhabitats.

The dispersion of the immature stages of the cat flea are directly controlled by the habits of the host. As the immature stages are the primary target when insecticides are applied to carpeted areas, the habits of the pet should be known, when designing and implementing control strategies. Particular attention should be paid to those areas frequented by the pet and should result in more effective control with respect to both chemical and non-chemical control tactics.



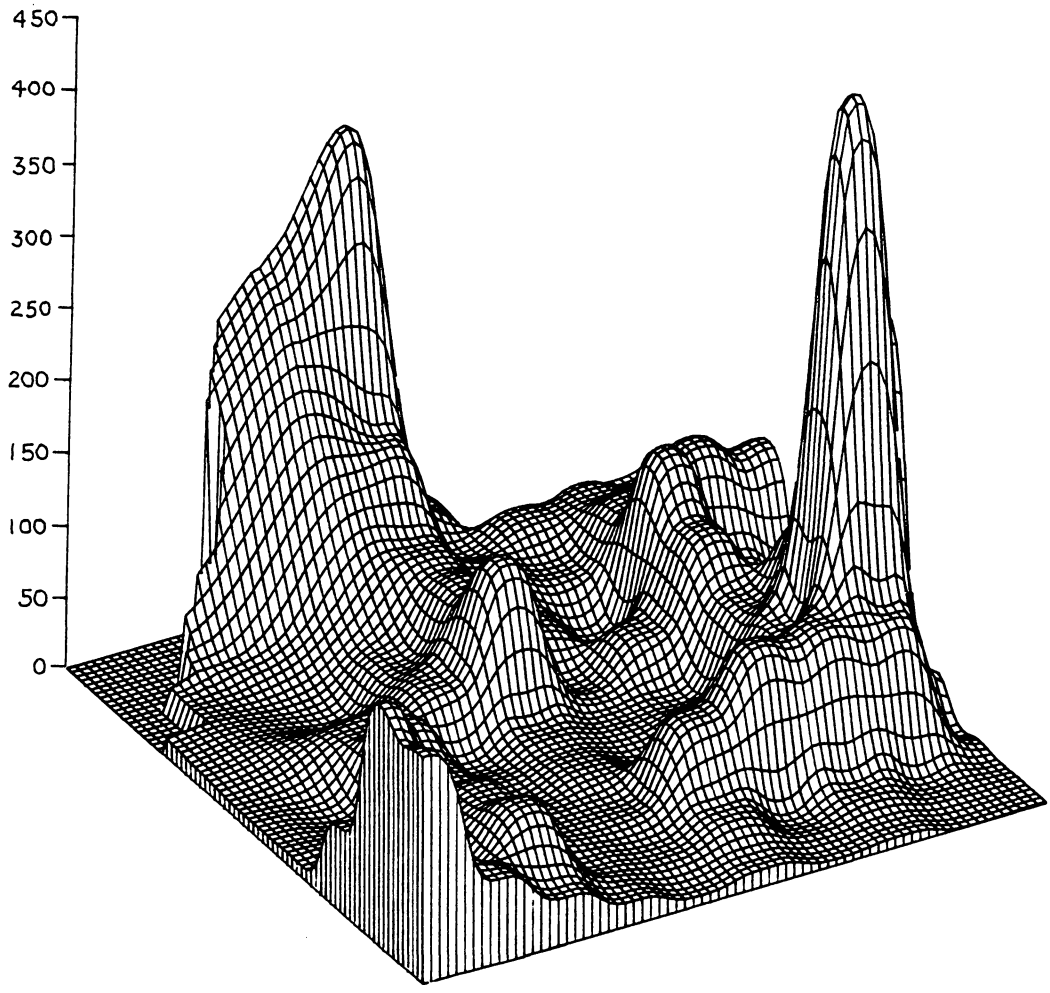


Figure 3.1: Transect surface plot of hatched eggs from family-room.

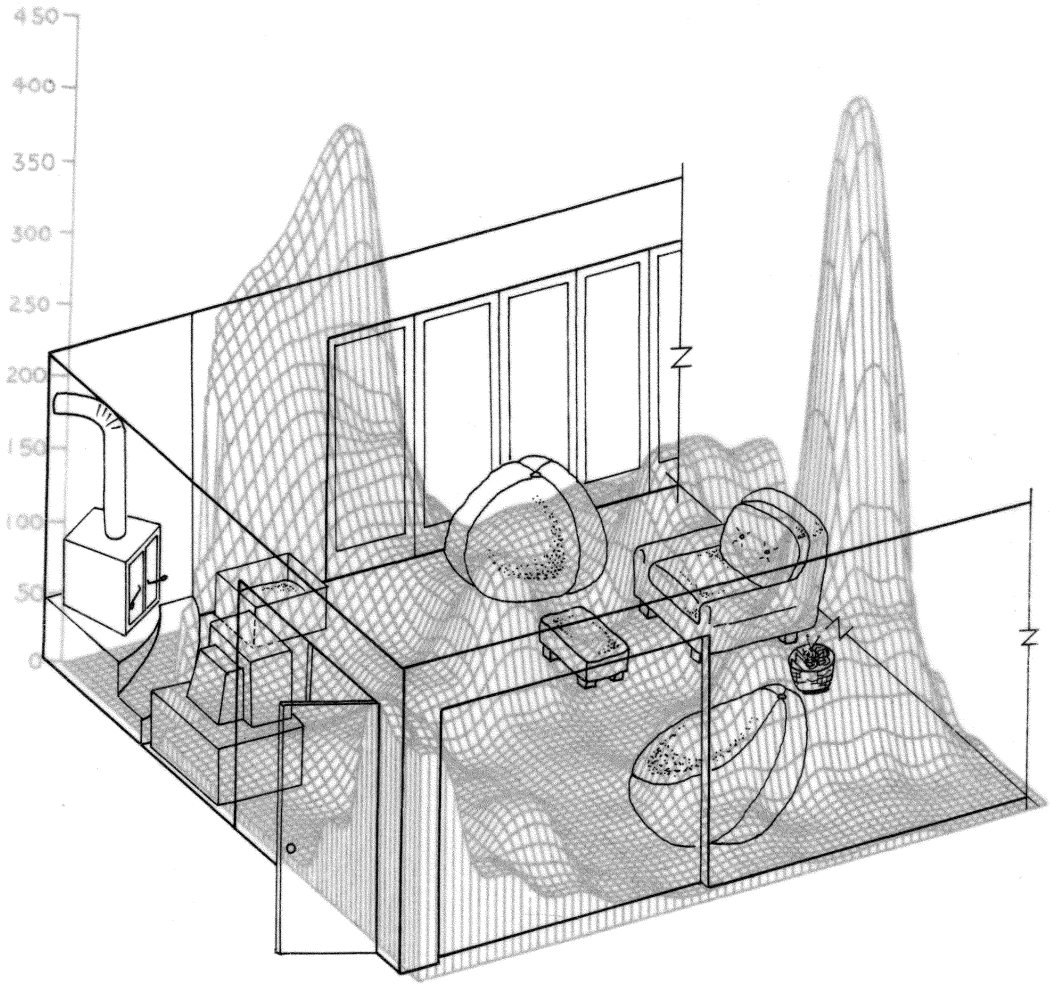
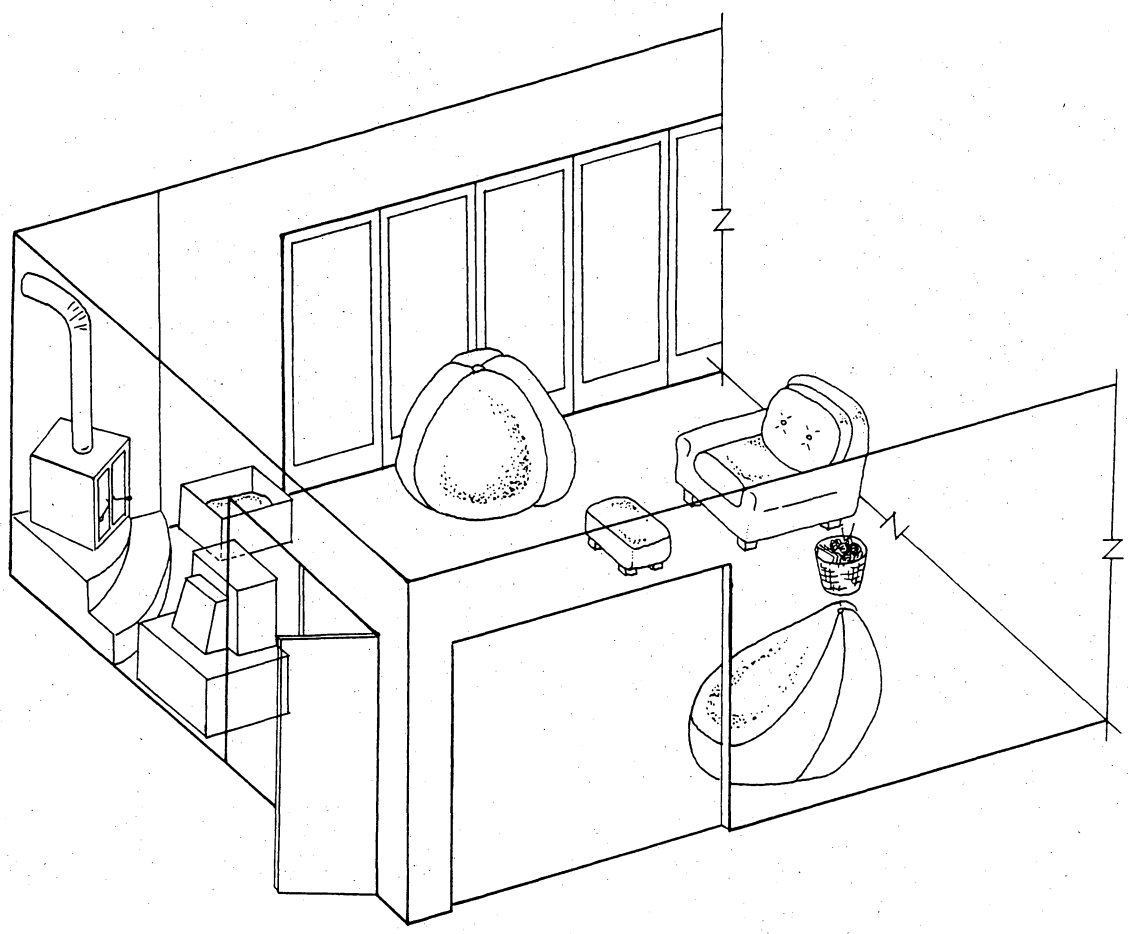


Figure 3.1: Transect surface plot of hatched eggs from family-room.



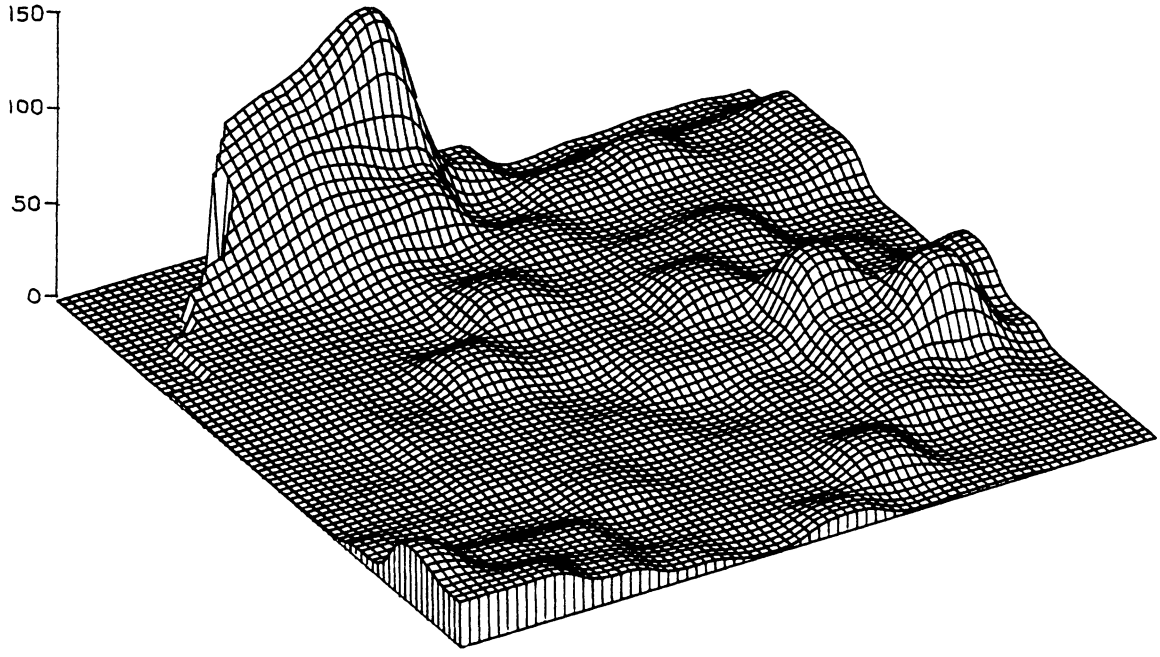


Figure 3.2: Transect surface plot of unhatched eggs from family-room.

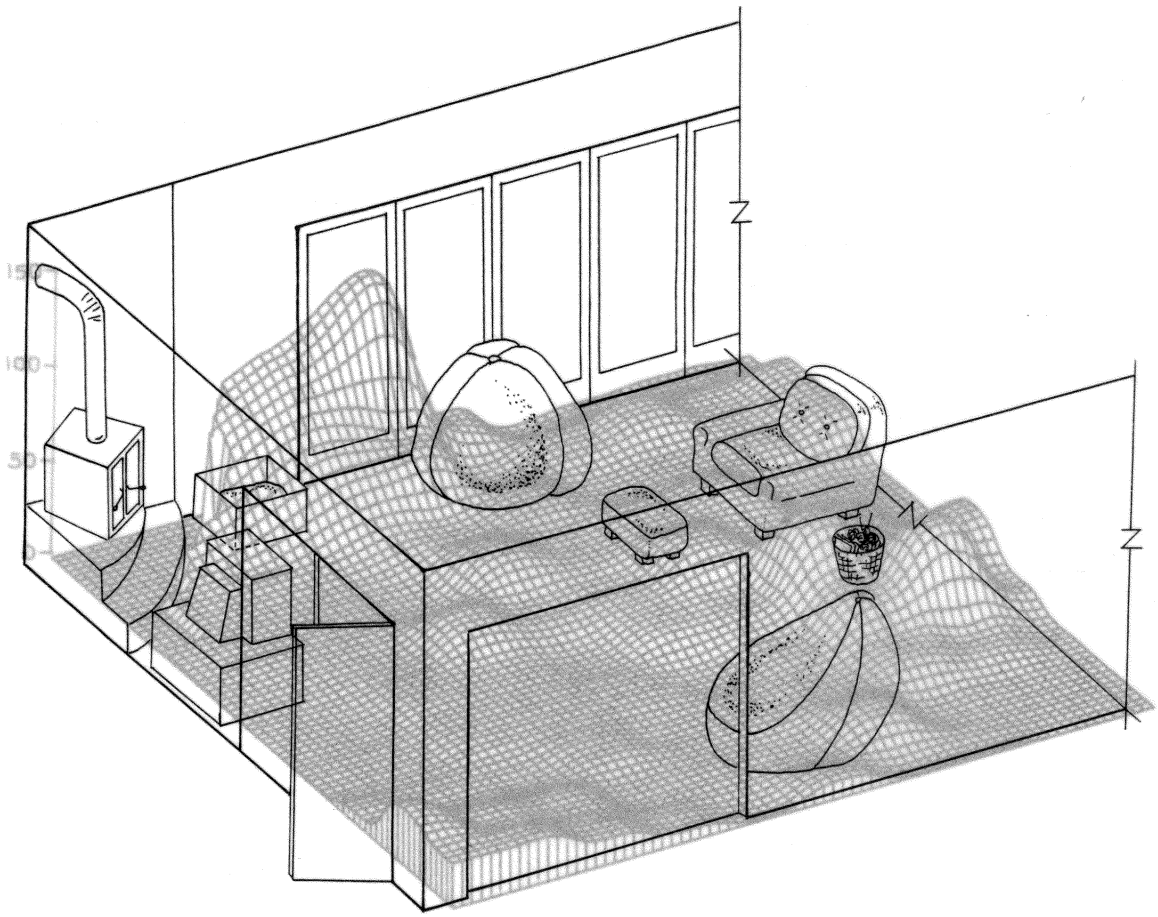
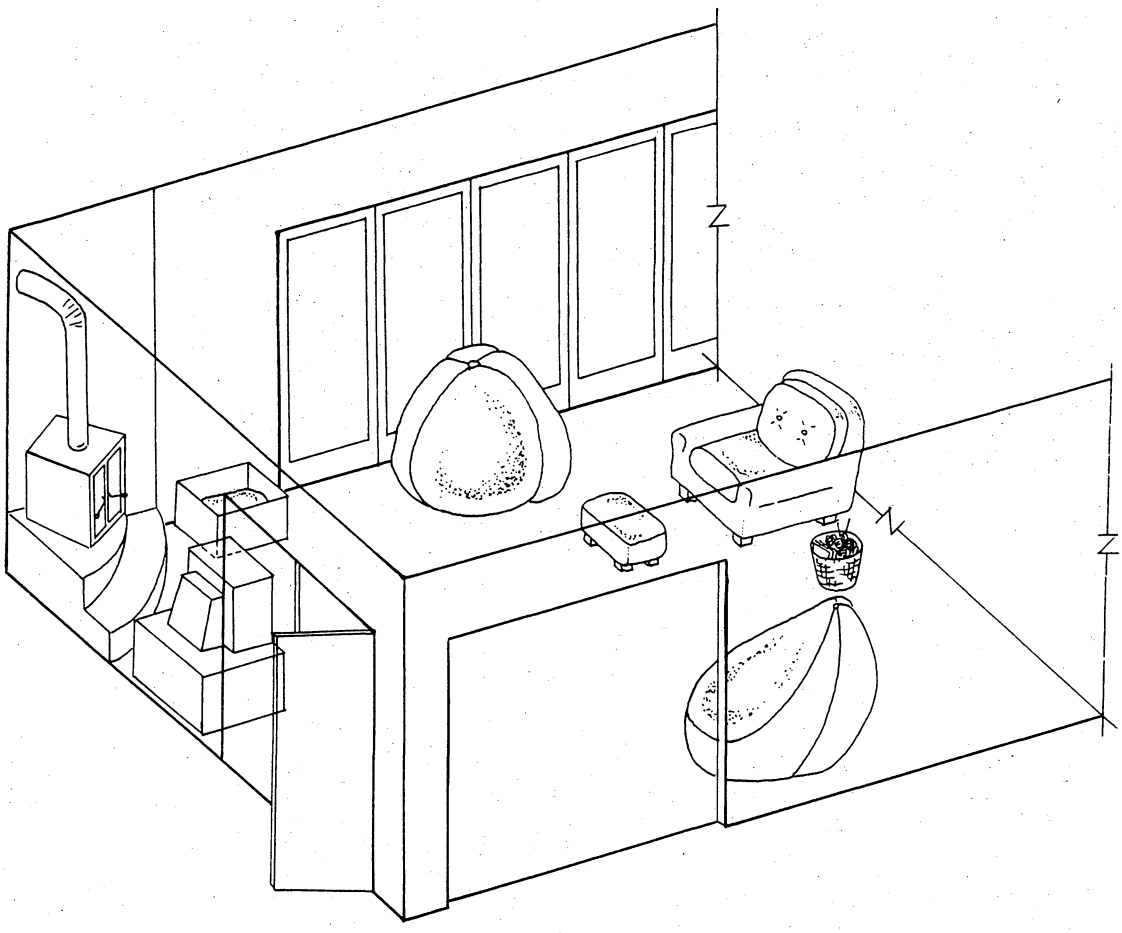


Figure 3.2: Transect surface plot of unhatched eggs from family-room.



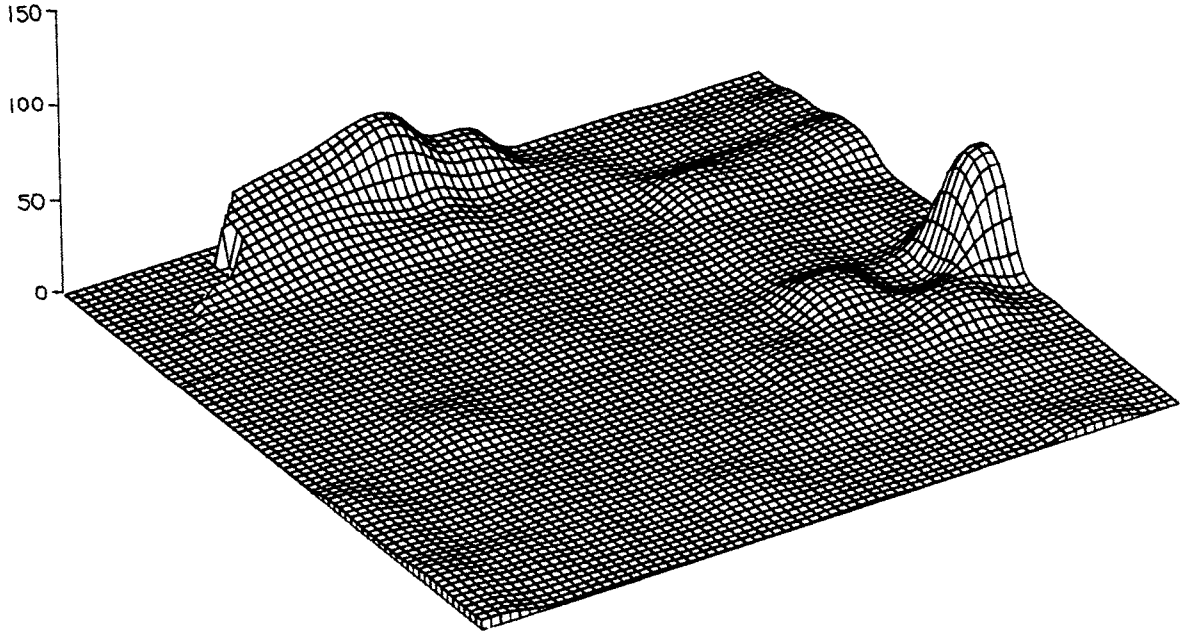


Figure 3.3: Transect surface plot of larval exuviae from family-room.

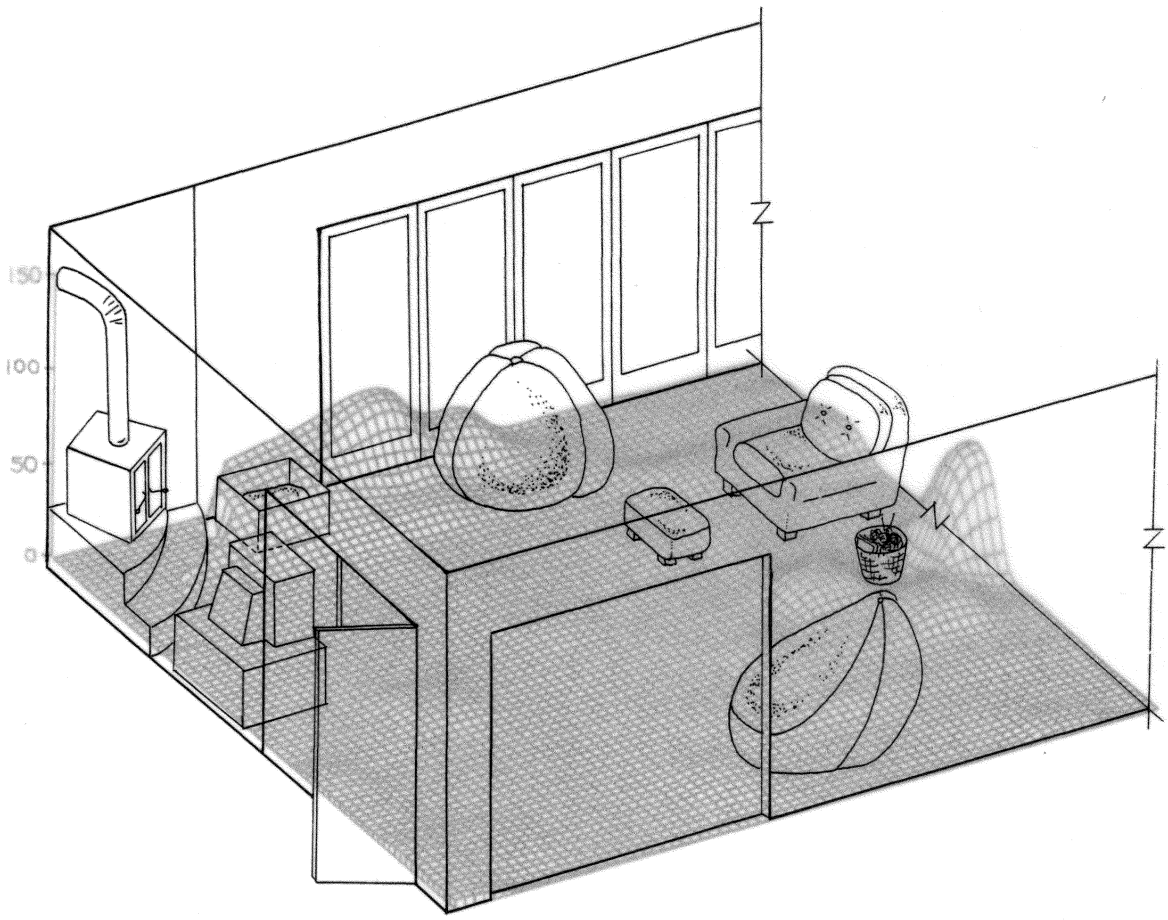
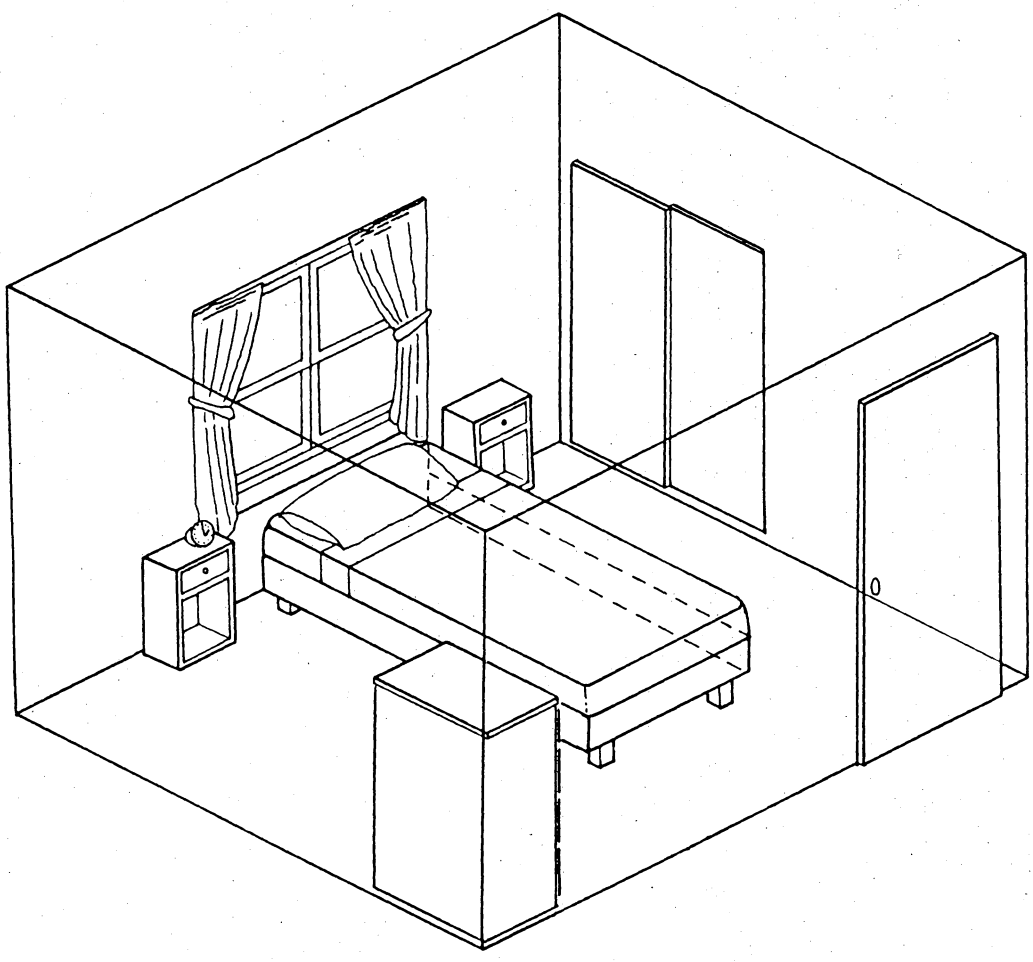


Figure 3.3: Transect surface plot of larval exuviae from family-room.



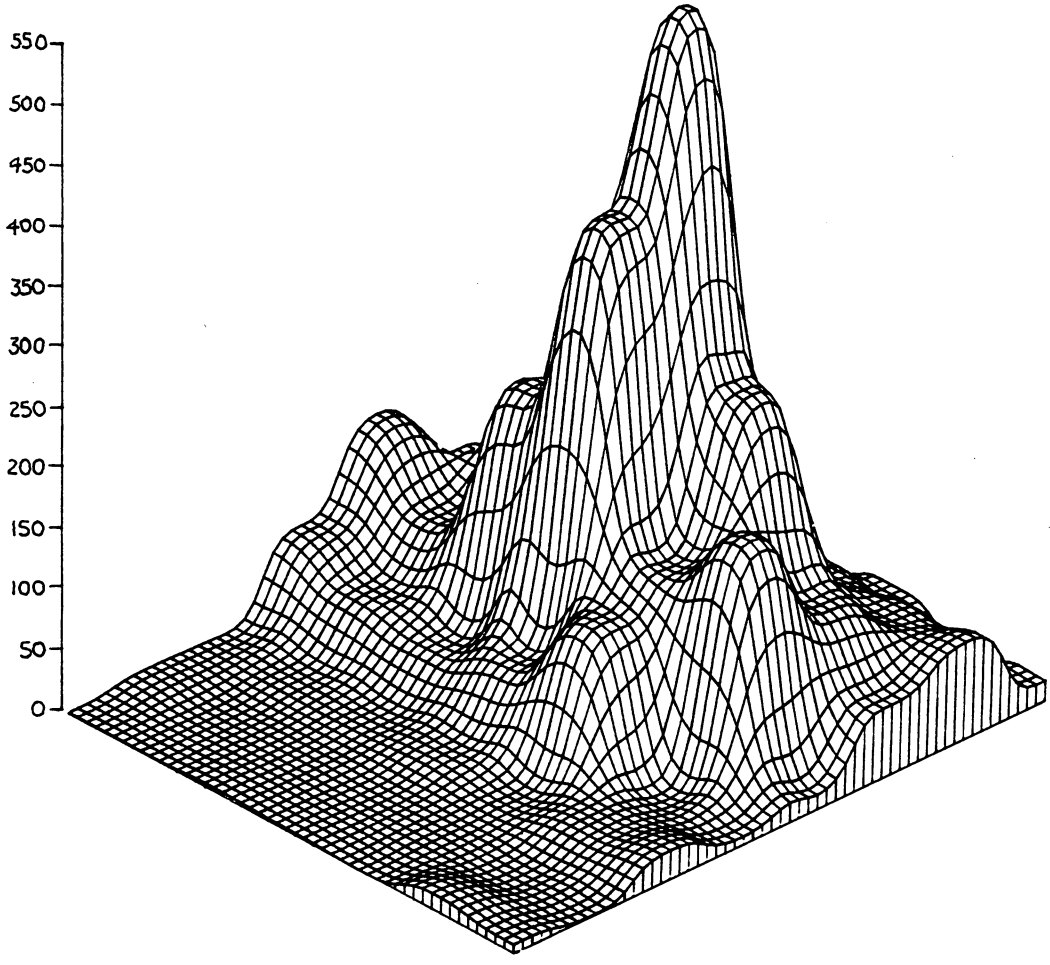


Figure 3.4: Transect surface plot of hatched eggs from bedroom.

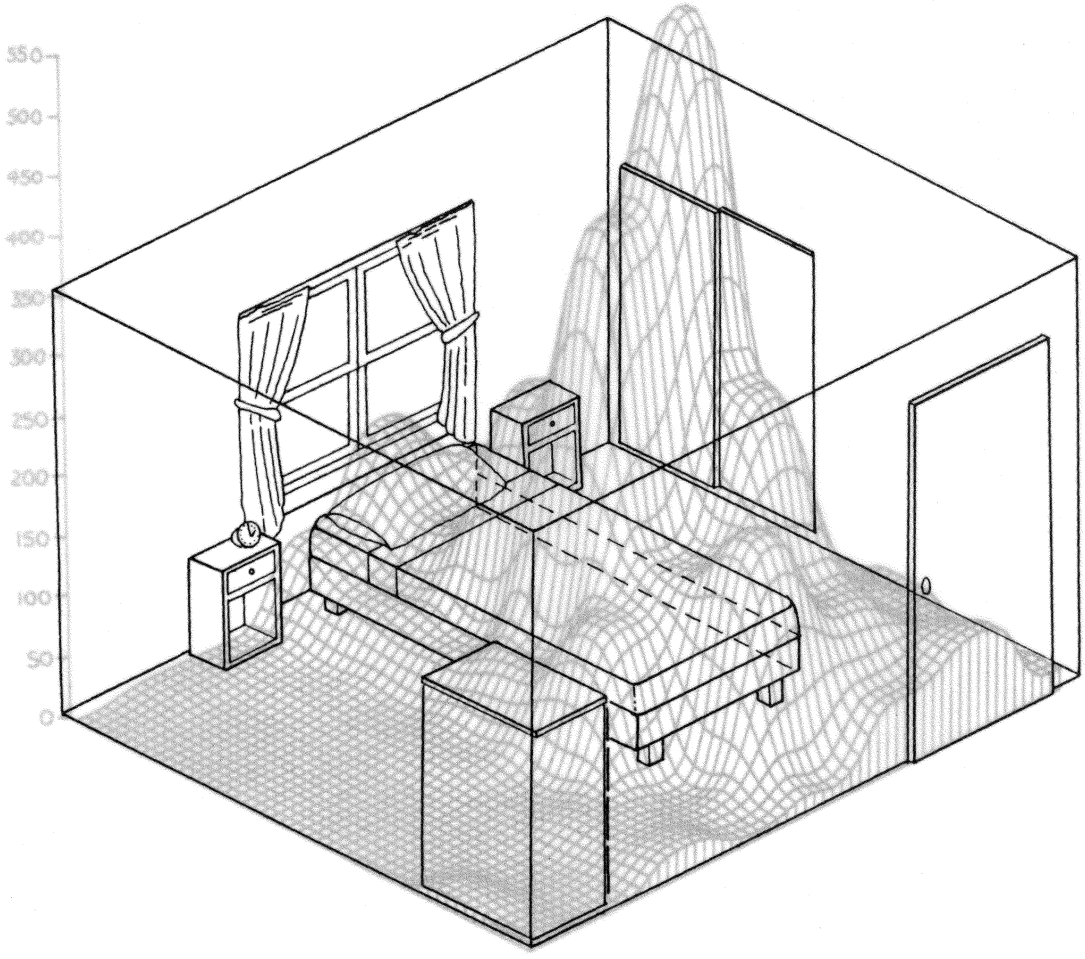
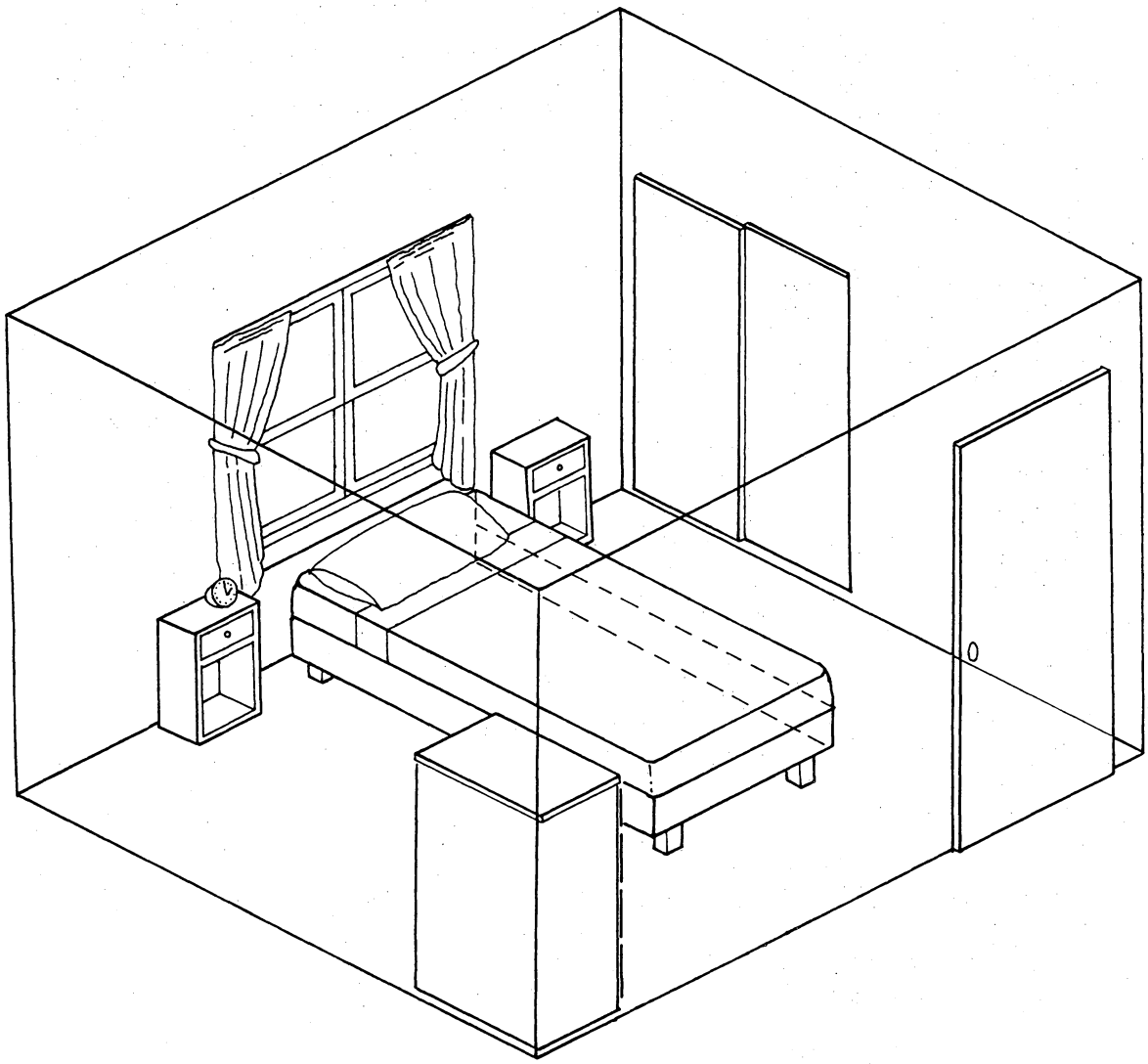


Figure 3.4: Transect surface plot of hatched eggs from bedroom.



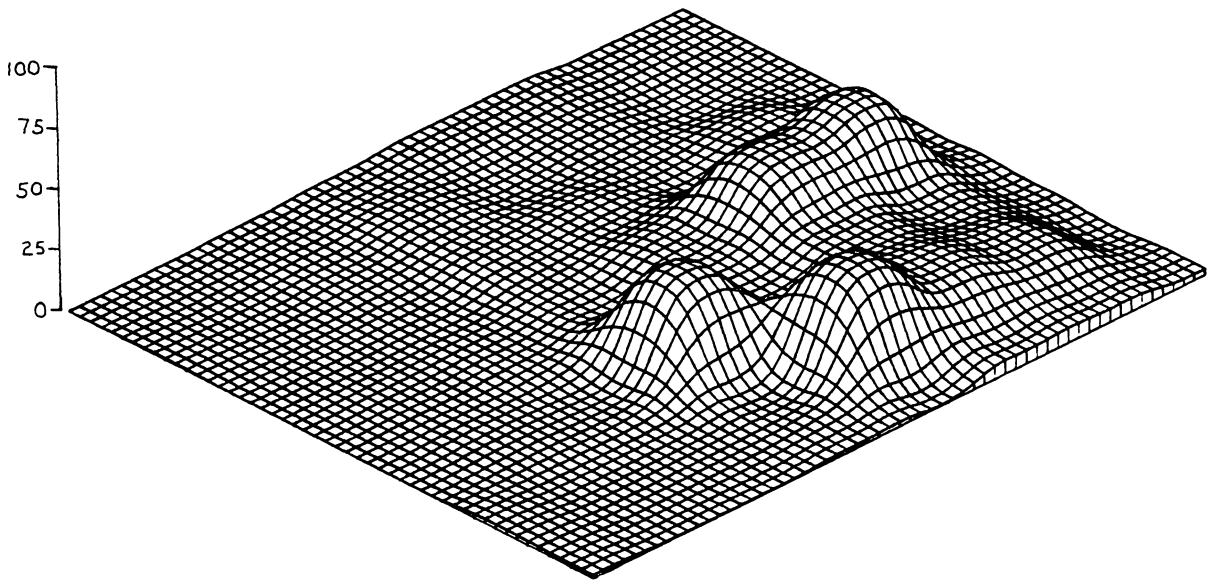


Figure 3.5: Transect surface plot of unhatched eggs from bedroom.

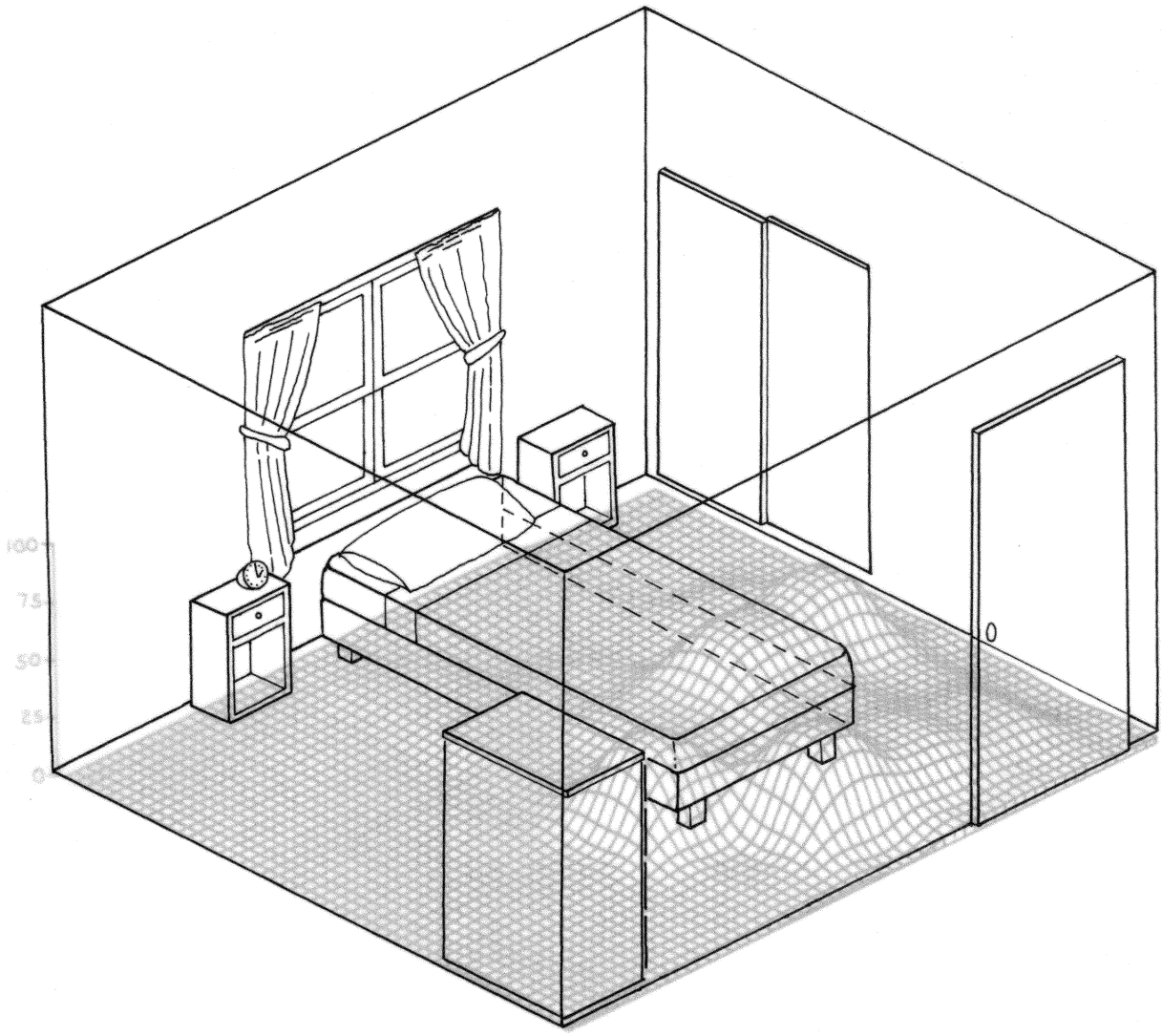
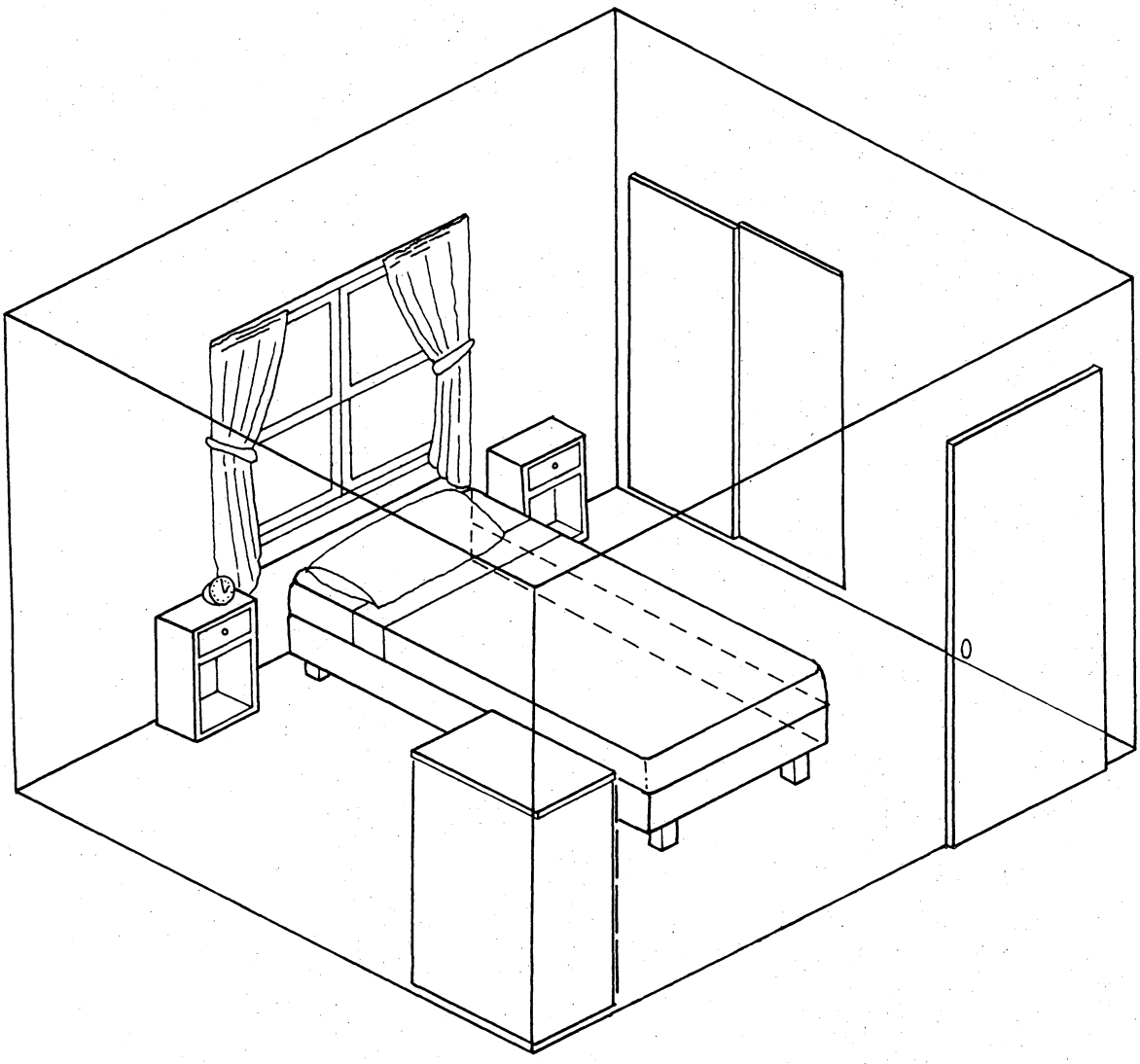


Figure 3.5: Transect surface plot of unhatched eggs from bedroom.



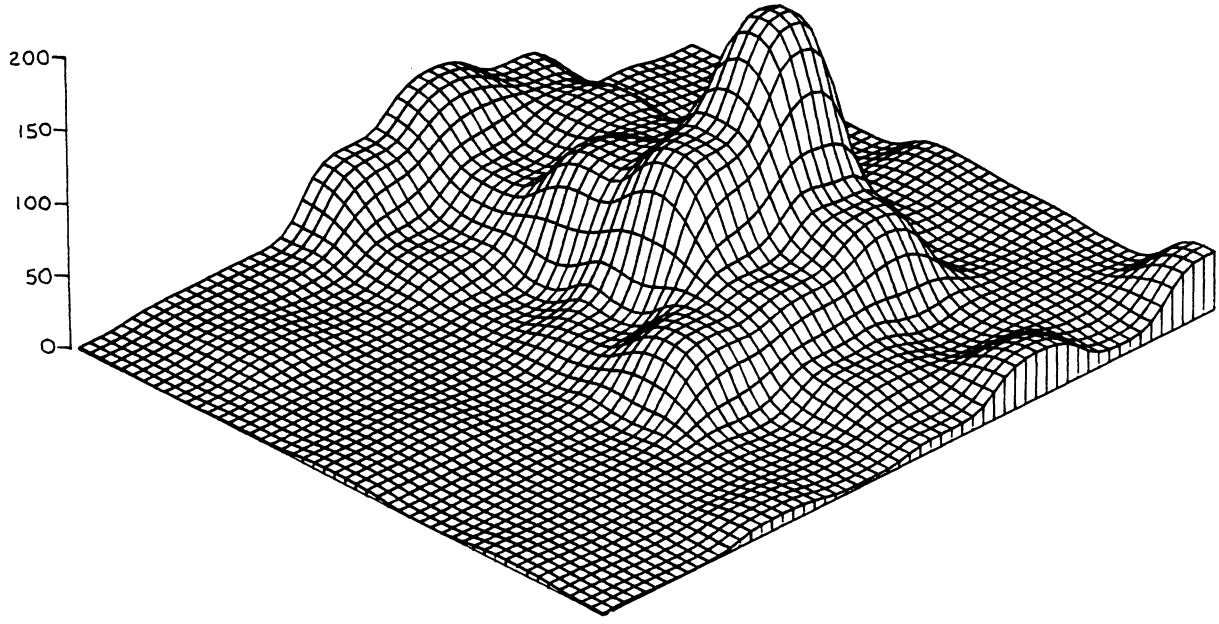


Figure 3.6: Transect surface plot of combined first- and second-instar larval exuviae from bedroom.

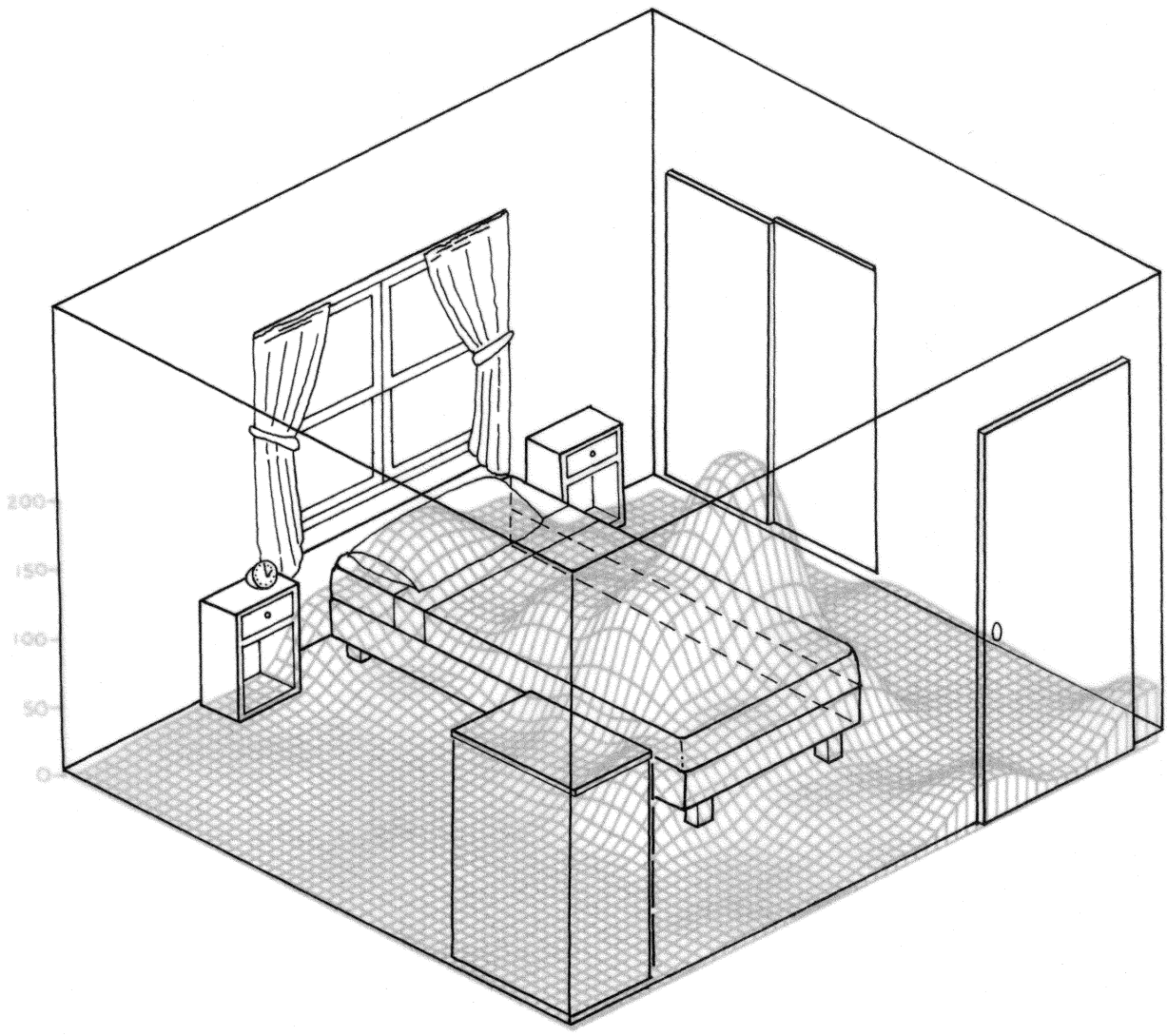
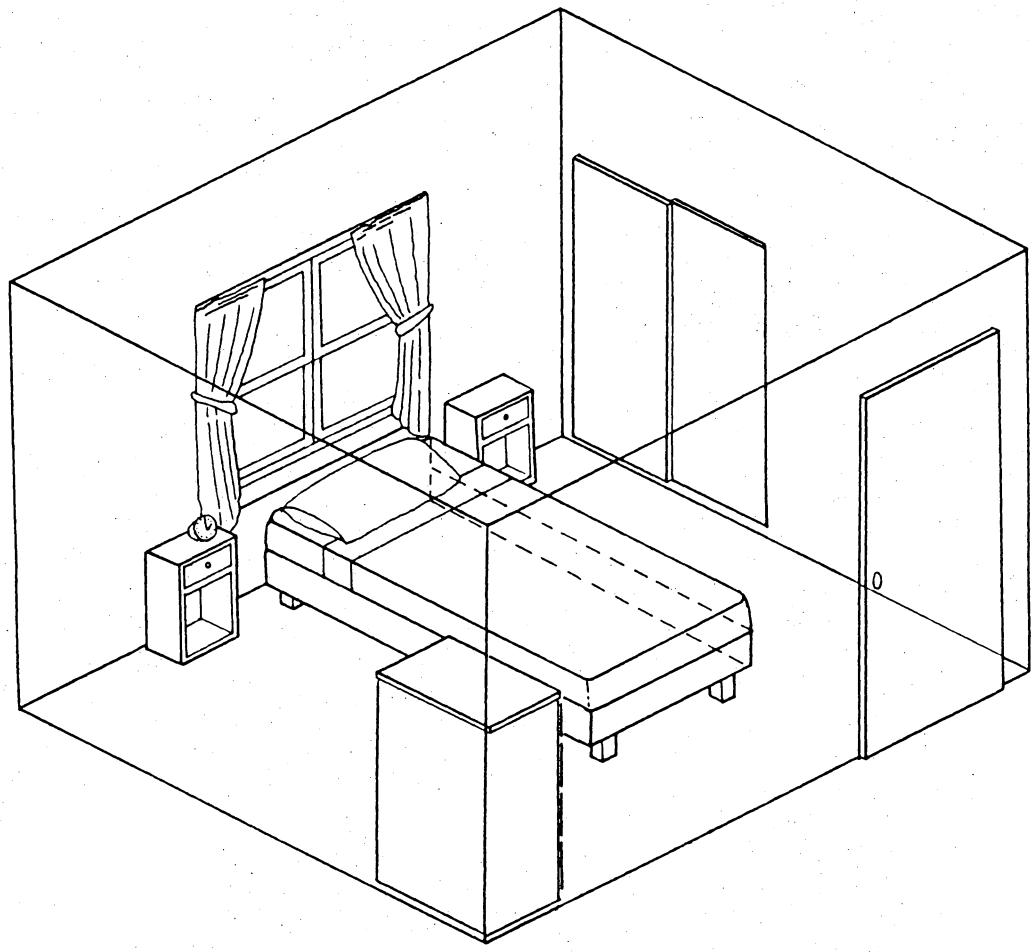


Figure 3.6: Transect surface plot of combined first- and second-instar larval exuviae from bedroom.



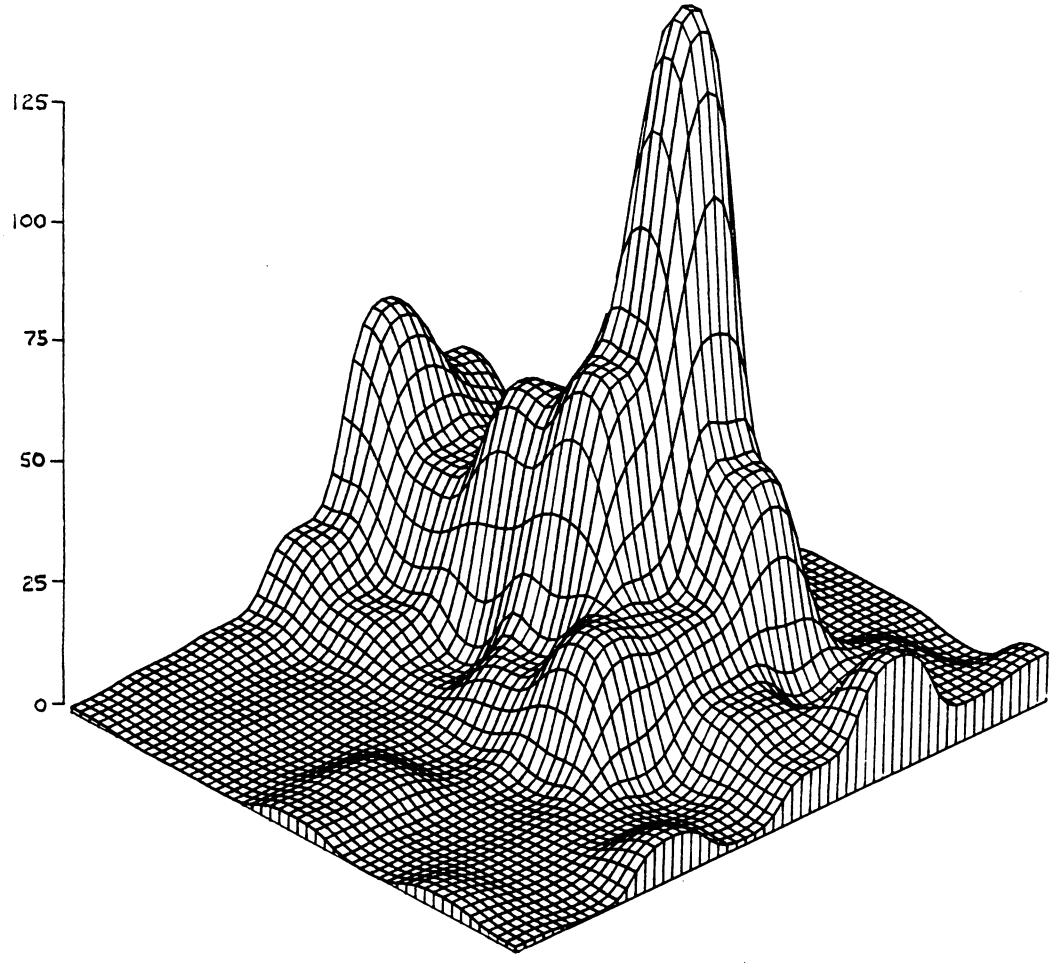


Figure 3.7: Transect surface plot of first-instar larval exuviae from bedroom.

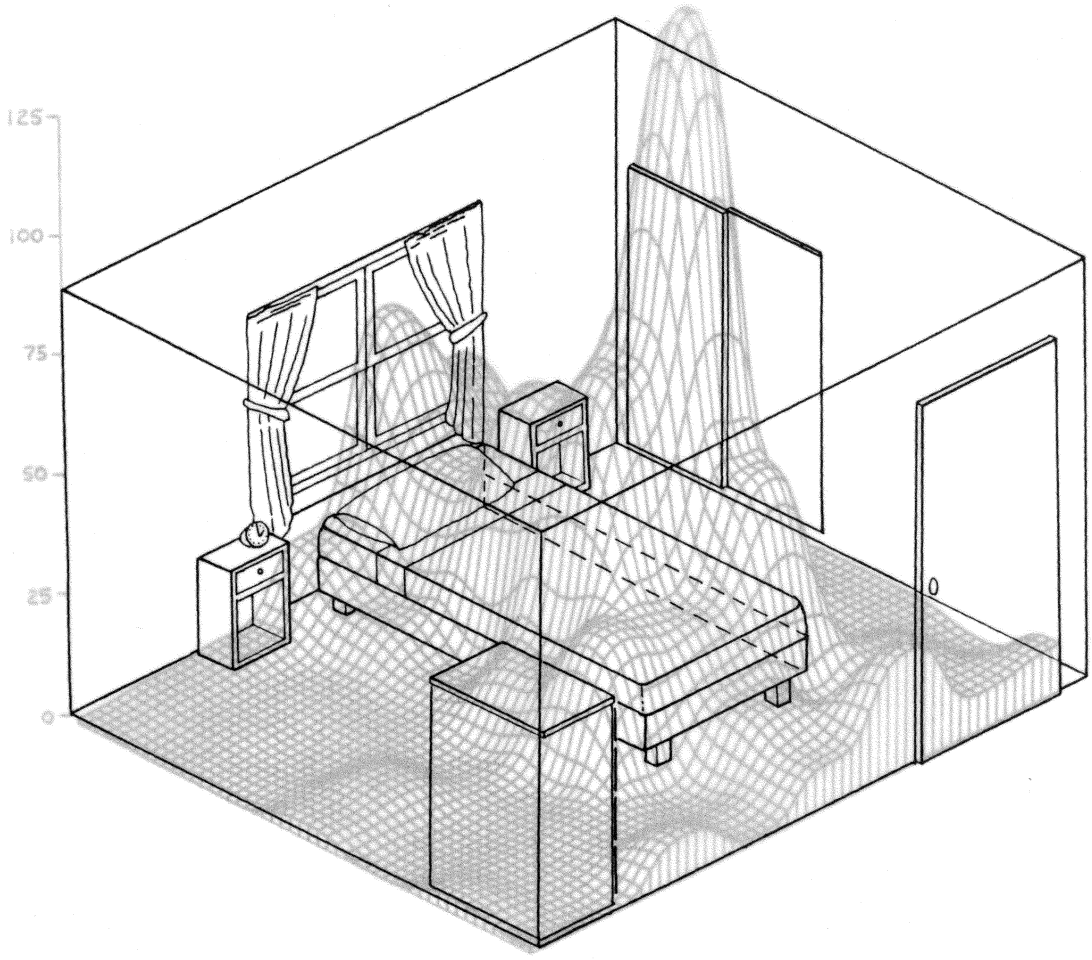
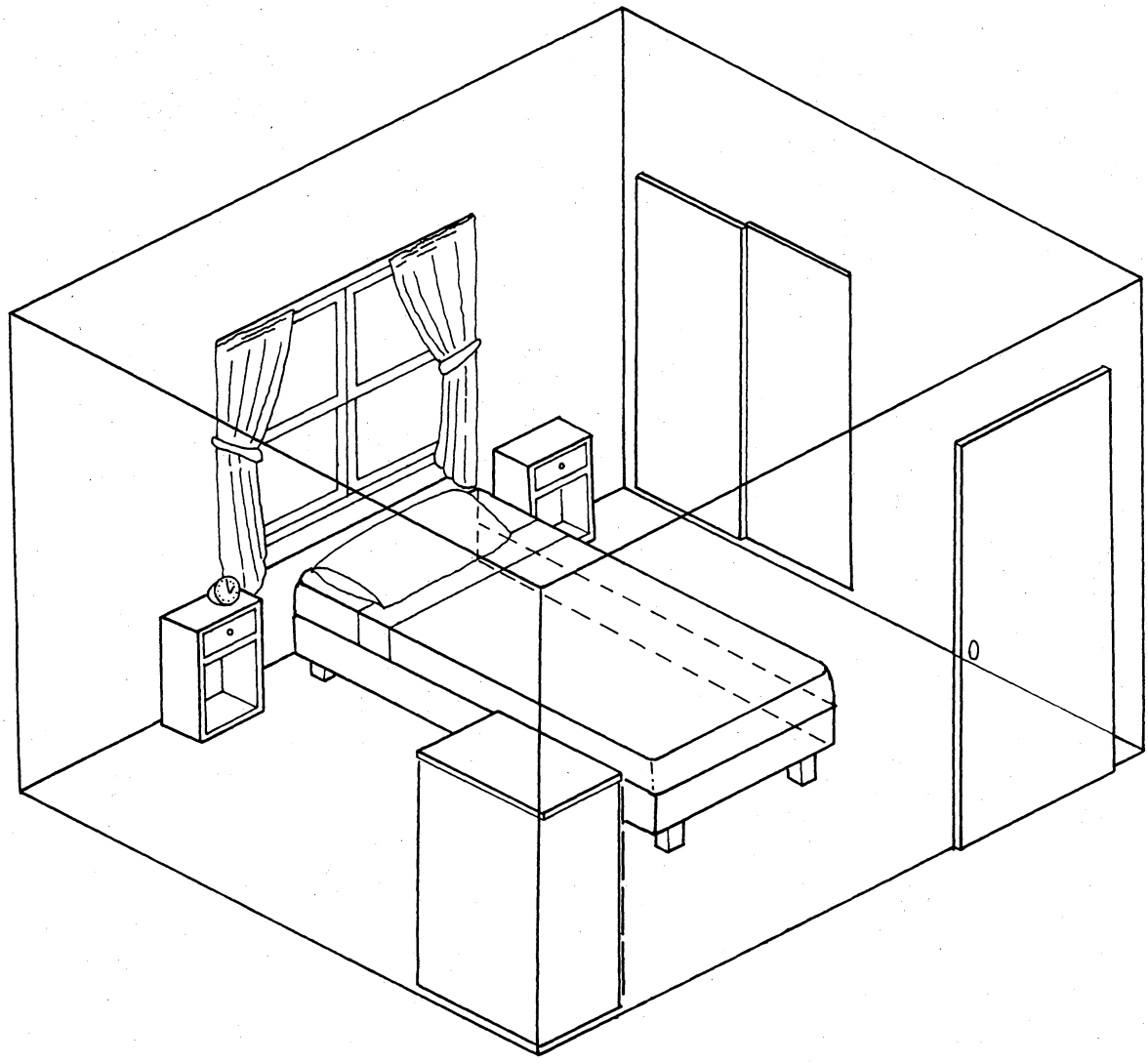


Figure 3.7: Transect surface plot of first-instar larval exuviae from bedroom.



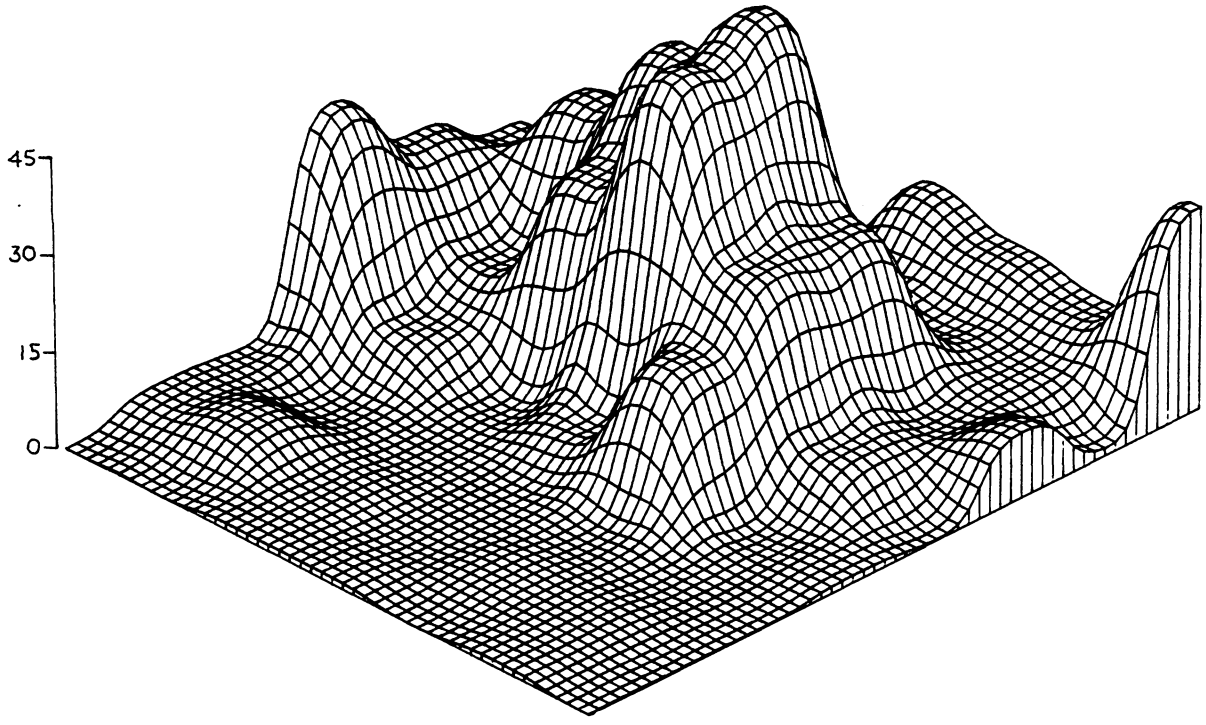


Figure 3.8: Transect surface plot of second-instar larval exuviae from bedroom.

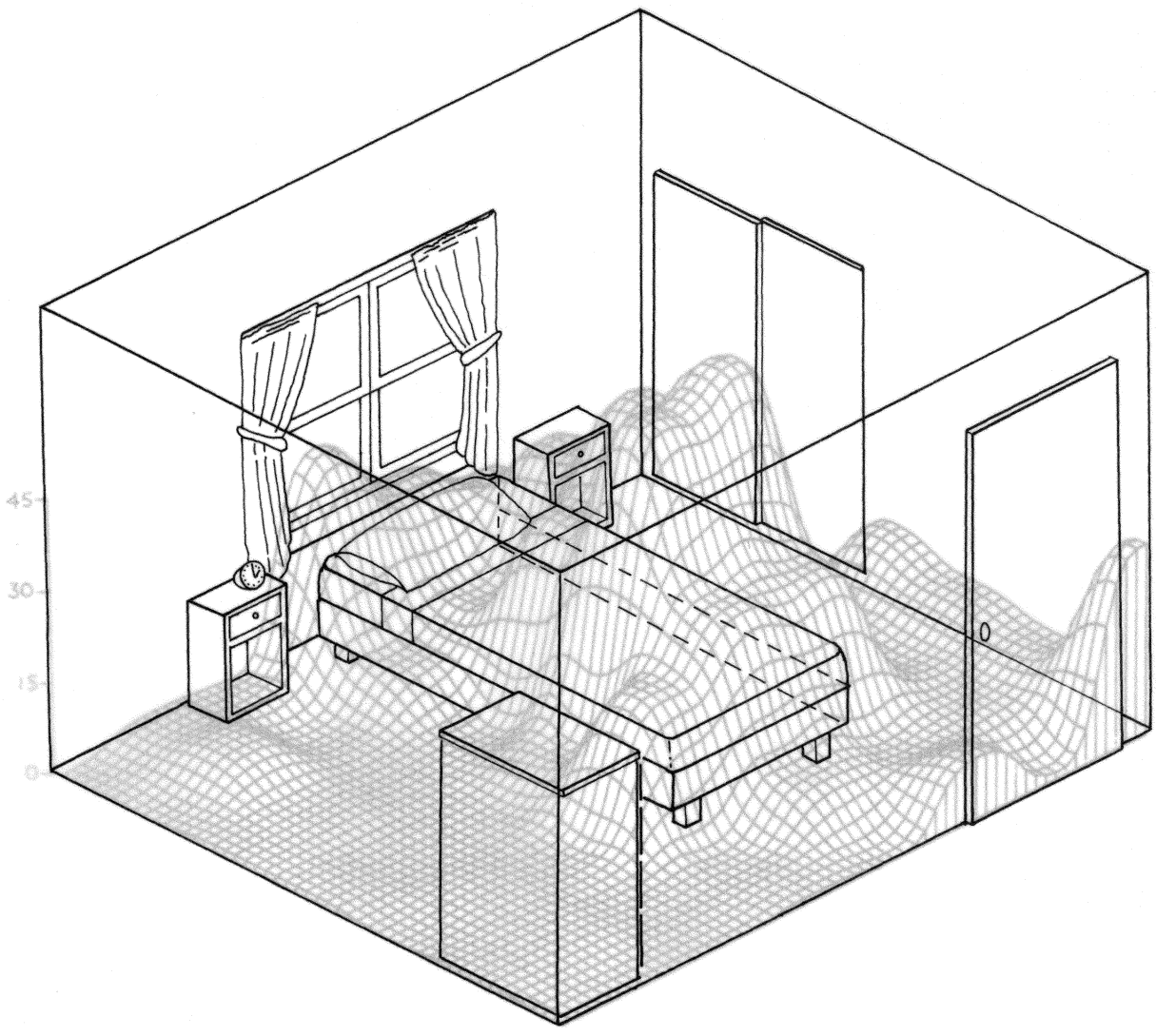


Figure 3.8: Transect surface plot of second-instar larval exuviae from bedroom.

CHAPTER IV

ASSESSMENT OF VARIOUS FEATURES OF EXISTING CONTROL TACTICS AGAINST THE IMMATURE STAGES OF THE CAT FLEA

4.1 INTRODUCTION

The management of a domiciliary infestation of the cat flea is an optimal situation for an integrated pest management approach. The primary control tactic used is chemical control. Broadcast insecticide treatments within a structure are often coupled with perimeter, spot, and broadcast insecticide treatment outside of the structure (Pratt and Wiseman 1962, Bledsoe et al. 1982). In addition, pet animals are treated with insecticides to control adult fleas. The types of insecticides used within and on the exterior of structures, and on pet animals, include synthetic insecticides, growth regulating chemicals, and natural compounds (WHO 1980, Bledsoe et al. 1982, Hink and Fee 1986).

Cultural control tactics involving the elimination of potential harborage sites attractive to stray dogs and cats, feral rodents or wildlife, such as raccoons, skunks, and opossums, can be used. Biological control tactics have received little evaluation. Silverman et al. (1982) reported on the effectiveness of an entomogenous nematode, Neoaplectana carpocapsae Weiser, to control cat flea larvae in a laboratory situation. Physical tactics include washing pet bedding, combing or brushing the animal to remove adult fleas and eggs laid within the pelage, and vacuuming carpeted and other surfaces to remove immature stages of the cat flea.

The manipulation of indoor climate (temperature and relative humidity) could also be considered a form of physical control. However, Skovmand (1983) reported that it was not possible to practically manipulate indoor climate to eliminate an infestation of the cat flea.

The cat flea is a unique pest species with respect to control strategies. The hematophagous adult is the stage which causes the physical, psychological, or economic damage. However, current integrated pest management strategies are designed to control the non-damaging larval stage when carpet is insecticidally treated. Vacuuming carpeted surfaces to eliminate immature stages of the cat flea has been and continues to be a recommended tactic for management of an indoor infestation. However, there has been little or no evaluation of the effectiveness of this tactic.

The following investigation was designed to examine control tactics for integrated management of the cat flea that are most frequently carried out by homeowners and pest control practitioners. The objectives were to; 1) assess the effectiveness of vacuuming carpet for the removal of immature stages of the cat flea, 2) investigate the system most frequently used for indoor application of insecticides, and specifically to assess characteristics (system pressure loss over time, droplet sizing, and pattern production) of the hydraulic nozzles associated with the system.

4.2 MATERIALS AND METHODS

4.2.1 Vacuum Extraction

Separate experiments were conducted to assess the extraction efficiency of a beater-bar vacuum-cleaner (Eureka upright; Model 1425; 4.0 amps) on cat flea eggs and on cat flea larvae in carpet. All experimentation was conducted from July to September of 1985 at V.P.I. & S.U. Cat flea larvae and eggs used in this

investigation were acquired and reared according to the procedures described in Section 2.2.1. The extraction procedure was conducted in four different qualities of carpet (Table 4.1). All carpet sections were vacuumed at a rate of one min per 0.093 m^2 (1 ft^2) prior to experimentation.

4.2.1.1 Larvae

Twenty cat flea larvae (first- through third-instar) were randomly removed from petri dish cultures and placed onto 0.093 m^2 carpet samples. Larvae were distributed evenly over the entire surface of the carpet within 10 cm of the sample boundaries, and confined to the test area by embedding a 29 x 29 cm wooden frame into the carpet pile. The bottom edge of the frame was beveled to a 45^o angle to provide a tight closure at the base of the carpet pile. A 7.3 kg weight was placed on top of the frame to seal the lower edge against the base of the carpet. Larvae were confined for 1 hr to allow for distribution prior to vacuuming. Five replicates of 20 larvae were conducted for each carpet quality, and each on a different section of carpet.

4.2.1.2 Eggs

Twenty eggs were removed from petri dish cultures and examined to ensure viability (observation of larva within egg). Eggs were evenly distributed over the carpet surface and confined with the wooden frame and weight as described above. Agitation which might occur in a field situation causing the eggs to fall into the nap of the carpet pile was simulated by gently rapping on the sides of the wooden frame 20 times per side. Five replicates of 20 eggs were conducted for each carpet quality, and each on different sections of carpet.

4.2.1.3 Vacuuming

A 7.6 x 11.4 cm tight-weave, muslin catch-bag was secured to the effluent of the vacuum cleaner to collect all extracted material. The weight and wooden frame were removed from the carpets, and the samples containing larvae and those containing eggs were vacuumed for 15 sec each. All carpets were vacuumed on the lowest possible setting of the vacuum equipment. Collected material was removed from the muslin bags and extracted larvae and eggs were counted.

4.2.1.4 Post-Vacuum Nourishment and Containment

All of the 40 carpet samples subjected to the vacuum experiment were retained for six weeks to record adult emergence. A food of lyophilized beef blood (0.50 gm) and pulverized dog chow (0.25 gm) was evenly distributed over the surface of each carpet sample. The food was introduced into the nap of the carpet by gently pulling a four dram glass vial over the surface of the carpet until the food material was out of sight.

To contain emerged adult fleas, all of the carpet samples were placed carefully into glass battery jars (3.4 l). A four dram vial of distilled water with a sponge wick was placed into the jar. All jars were covered with porous paper, and sealed with tape.

Six controls of the same carpet were set up. Three of the carpets contained 20 larvae each, and the other three contained 20 eggs each. Preparation of the carpets and their containment in jars was as described in the above sections. The control carpets were not vacuumed. All jars were provided with fresh water vials approximately every third day. Adult emergence was observed for the next 11 wk.

4.2.1.5 Data Analysis

Extraction results for eggs and larvae were converted to percentages and transformed using a square-root arcsin transformation. Transformed percentages were analyzed using analysis of variance procedures to observe effects due to carpet type (Sokal and Rohlf 1981). Mean transformed percentages for eggs were compared using Duncan's New Multiple Range procedures as were the those of the larvae. All analyses were conducted using Statistical Analysis System (SAS 1985).

4.2.2 Application System Technology

The experiments on application systems technology, and nozzle characteristics were conducted in 1985 at the Formulations and Applications Laboratory of FBC Ltd. at the Chesterford Park Research Station, Saffron Walden, Essex, England. The work was continued at the Urban Entomology Research Laboratory of V.P.I. & S.U in 1986 and 1987.

The application equipment used in this investigation was B&G Equipment Company's (Plumsteadville, PA) one gallon, stainless steel, compressed-air sprayer (Model N124-S) (Figure 4.1), and a Multee-Jet nozzle housing, containing four nozzle tips, including a pin-stream, fine-fan, and a coarse-fan orifice, and also an orifice for the insertion of a crack-and-crevice tip assembly (Figure 4.2). The technical specifications of the nozzle orifices on the Multte-Jet nozzle housing are given in Table 4.2. The nozzle housing is manufactured by Spraying Systems Co. (Wheaton, IL).

4.2.2.1 System Pressure-Loss Over Time

The application equipment used in this investigation was fitted with an effluent pressure gauge. The one-gallon B&G N124-S holds a maximum volume of 4.875 l.

The number of full-length compressions of the pump unit with resulting pressure increases was examined. The loss in pressure in the spray system over time was measured for two nozzles tips, the 800067 and 50015. Two initial volumes, 2 and 4 liters were used for each of the two nozzles to assess the effect of starting fluid volume and resultant pressurized air-space in the tank on the rate of pressure increase and decline. Two replicates of each volume-nozzle combination were executed.

4.2.2.2 Droplet Sizing

The effluent droplets of distilled/deionized water from Spraying Systems Company's 80015 and 800067 nozzles were measured using a Malvern 2600HSD LASER particle sizer (Malvern, England). The system functions on the principles of Fraunhofer diffraction when the beam of the 2 mW Helium Neon LASER is interrupted. A scaffold-like structure was constructed onto the rigid optical bench so that the spray was directed downward to intersect the path of the analyzer beam (Figure 4.3). This permitted accurate readings at distances greater than 10 cm (from source to beam), and avoided lens contamination. The effluents from the nozzles were passed above the analyzer beam so that the fan-like configuration of the droplets exiting from the flat-fan nozzles was perpendicular to the beam. The nozzle was passed over a 60 cm rod which was a portion of the scaffold structure. The rod could be adjusted to any given height. The nozzle was slid back-and-forth across the rod two times so that all regions of the fan from one edge to the other passed through the beam 4 times.

The particle sizer was used with a Fourier transform lens with a focal length of 800 mm. The scanning receiver of the analyzer beam was programmed to conduct 500 sweeps which permitted approximately 6 sec of analysis time on any given test

run. The computer software associated with the detection equipment computes a mass median diameter, mmd, value for the particular test run. The mmd is an extrapolation computed by calculating the percentage of the total spray into each of 16 size groupings which passes through the analyzer beam. The beam reciever determines into which of 16 separate size groups (15 μ to 1503 μ; unequal divisions) individual droplets fit, and the percentages of the total in each size group are then analyzed to arrive at the mmd for that particular test run.

Droplet spectra were collected at 3 heights (35, 45, 55 cm) over a range of 6 pressures (137.9, 206.9, 275.8, 344.8, 413.7, 482.7 kPa; {20, 30, 40, 50, 60, 70 psi}) which were held constant throughout the duration of the readings. Three replicates of each of the 18 pressure/height treatments were conducted for both nozzles. Temperature and relative humidity during the entire series of test readings were nearly constant.

4.2.2.3 Spray Patternation of Nozzles

In all patternations a solution of 0.1% Erio Floxine 2GN dye (Ciba Geigy, Manchester, England) in distilled/ deionized water was used. The dye enhanced photovisualizing capabilities. The 800067 and 80015 were patternated using a spray table with 50 knife-edged channels (2.5 cm each) and associated collection cylinders. The nozzles used in the investigations were always fitted with a screen to prevent clogging or aberrations due to particulate matter.The nozzles were subjected to the same pressure and height regimens described in Section 4.2.2.2. One liter was sprayed for each patternation.

4.3 RESULTS AND DISCUSSION

4.3.1 Vacuum Extraction

The maximum mean recovery of eggs from any of the carpets tested was 59% ± 0.03 (mean ± SEM) and the recovery of larvae was 27% ± 0.07 using the beater-bar vacuum (Figure 4.4). There were no significant differences between mean recovery of eggs and quality of carpet ($F = 1.66$; $P < 0.215$). Carpet quality (Table 4.1) significantly affected the recovery of flea larvae ($F = 15.63$; $P < 0.0001$). The mean percentage recovery of larvae from the lowest quality of carpet was significantly higher than any of the other carpets tested. The three higher qualities were not significantly different from each other with respect to mean larval recovery (Figure 4.4).

Olsen (1982) examined the success of vacuuming as a means of controlling a flea infestation and reported that larvae were much more difficult to remove than eggs. She reported that it was not possible to eradicate flea larvae by vacuuming piled carpets.

The results from the present investigation are consistent with those of Olsen (1982). Flea larvae are not easily removed from piled carpet by vacuuming. The morphological characteristics of the larval cat flea help to prevent removal from a carpet. The segmental setae and the streamline shape permit it to secure itself within the substrate. The coiling behaviors of cat flea larvae elicited in response to disturbances described in Section 2.3.5 also help to secure it in the carpet.

The mean percentage of egg extraction from the carpets indicate that this stage could be suppressed through vacuuming. By removing the egg from the environment on a regular basis (vacuum every two days) prior to eclosion a flea population within a domicile could be maintained below levels were human inhabitants are affected by adult populations. Karandikar and Munshi (1950) reported that cat flea eggs

hatched in 2 - 4 days. Regular vacuuming, every other day beginning when the ambient temperature and relative humidity are conducive to flea development, should limit population growth of an indoor infestation.

There are five advantages to incorporating vacuuming into a control strategy for an indoor infestation of the cat flea. Vacuuming reduces populations of egg and larval stages in the carpet environment. Vacuuming should remove a portion of the available larval food from the carpet, making it more difficult for larvae to locate food, resulting in increased developmental time and larval mortality due to starvation. Vacuuming may remove adult fleas from the carpet environment. Rust and Reierson (1985) advocate vacuuming following insecticide application to induce emergence of pre-emerged adults. This stage is often unaffected by insecticidal treatment. Pretreatment vacuuming could cause these pre-emerged adults to emerge and contact insecticides applied to the carpet. Vacuuming appears to reduce matting of carpet fibers to allow for maximal penetration of the insecticide into the carpet. This can increase the probability that the insecticide and the target stage, the larvae, will be in the same location.

Of the remaining 555 eggs and larvae from the treatment carpets, as well as, all of the 120 eggs and larvae in the control carpets, no adult fleas emerged in 11 weeks under the environmental conditions provided ($23^{o} \pm 7^{o}C$; 70% $\pm$ 15% RH). The post-vacuum nourishment and containment of the carpet samples was conducted to observe any lethal effects the beating action of the beater-bar of the vacuum had on the immature stages of the cat flea. The percentage adult emergence was to be added to the extracted percentage to acquire a total percent control by utilizing a beater-bar vacuum.

A possible explanation of no adult emergence from the carpets following vacuum treatment could be the chemistry of new carpet. Fibers and the carpets that are made from them are treated with a variety of compounds by the manufacturer, retail distributors, and the carpet service industry. The properties of these compounds are designed to enhance the anti-microbial, anti-static, odor control, stain resistance, and fiber durability characteristics of the finished product. These compounds include quaternary ammonium compounds and other classes of chemicals that enhance anti-microbial as well as anti-static properties of the carpet. Compounds such as silicon and fluorocarbons are used to prevent staining and control the build-up of odors in the carpet. All of these chemicals could be lethal to any given stage of the cat flea, but the insecticidal activity eventually diminishes to a point where the immature stages of the cat flea can survive in the carpet.

4.3.2 System Pressure-Loss Over Time

The number of full-length compression strokes of the pump in the one-gallon sprayer described in Section 4.2.2, and the resulting system pressure increases are presented in Figure 4.5. The initial fluid volume in the tank was 2 or 4 liters. The mean ($\pm$ SEM) number of compression strokes to bring the system pressure to 60 psi for the initial volume of 2 l was 30.83 $\pm$ 2.75 and was 88.75 $\pm$ 1.98 for the 4 l volume. The regression line describing the relationship of number of pump depressions on the resulting psi calculated for the 2 l volume was $Y = 1.50X - 5.19$ ($r^2 = 0.986$) and the slope for the line was significantly different ($t = 219.71$; $P < 0.005$) from that for the 4 l volume of $Y = 0.53X - 1.16$ ($r^2 = 0.992$). This demonstrates that the 2 l volume requires significantly more pump depressions to acquire any given pressure as compared to the 4 l volume.

The results of loss in pressure from the system upon actuation of the release valve at the 2 and 4 liter initial volumes, and for both the 800067 and the 50015 orifices are presented in Figure 4.6. The nozzle tips were designed to be used at 40 psi. At this pressure the 800067 discharges 0.067 gal/min, and the 50015 discharges 0.15 gal/min. The increased constriction of the 800067 orifice resulted in a slower release of pressure than that of the 50015 when both were at the 2 l starting volume. The increased pressurized air-space afforded by the 2 l versus the 4 l initial volume resulted in a decreased rate of pressure loss for the larger nozzle orifice (50015) at 2 l than for the more constricted 800067 at the 4 liter starting volume.

The initial pressure in the system combined with the 50015 nozzle orifice resulted in the total discharge of the 2 l in 3.3 min. The 800067 nozzle orifice discharged the 2 l volume in 7.6 minutes. The spray system containing 4 l of water, the 50015 nozzle, and starting at 60 psi, required approximately 22 min to lose all pressure. The system containing 4 l of water, the 800067 nozzle, starting at 60 psi was empty before the system pressure reached zero.

The B&G Equipment Company's spray equipment was selected for this investigation because their equipment line has acquired approximately 94% of the U.S. market share in the pest control industry (B&G Equipment Co., personal comm.). In this investigation a pressure gauge was used to monitor increasing pressure due to pump compressions and decreasing pressures due to actuation of the release valve. The importance of monitoring pressure, especially that of pressure decline, when applying pesticides is crucial. The combination of pressure and nozzle characteristics affects the final deposition of pesticide. The importance of pressure in the overall accuracy and precision of pesticide application is paramount.

4.3.3 Spray-Nozzle Droplet Sizing

Mean values of replicates of the mass median diameters (mmd) for the 800067 and 80015 nozzles over all of the pressure/height treatments are depicted in Figures 4.7 and 4.8, respectively. Use of the 800067 nozzle orifice produces a gradual reduction in the mmd as the pressure is increased from 20 psi to 70 psi (Figure 4.7). There is also a nearly consistent decrease in the mean value for mmd at any given pressure when the spray height is decreased. The mean values of the mmd of the droplet spectra decreased with corresponding increases in the system pressure, due to the increased velocity of the liquid. The disintegration of the edge of the sheet of liquid leaving the nozzle tip increased as pressure was increased, resulting in a decrease in the overall size of the droplets produced.

The increase in the mean values of the mmd of the droplet spectra when the height was increased is directly related to effects of the surrounding environment on the water droplets. The very small sized droplets ($<20\ \mu$) that were produced probably evaporated before reaching the analyzer beam in tests conducted at spray heights of 45 and 55 cm. The loss of these droplets shifted the calculated mmd to a value higher than that for the spray height of 35 cm.

Droplets are formed when liquid is forced, under pressure, through the orifice of a hydraulic-energy nozzle. The pressure creates sufficient velocity of the liquid to cause it to spread, forming a thin sheet proximally to the point of effluence. The degree of spread and eventual disintegration of the sheet depends on the pressure forcing the liquid through the constricted opening and physical properties of the liquid, such as surface tension, density, and viscosity. Droplets of liquid are formed at the distal most portions of the sheet as they are torn away due to the velocity of

the liquid exiting the orifice, impaction with the air, and to the physical properties of the liquid, especially that of surface tension. Droplets produced from hydraulic-energy nozzles are not uniform in size (Matthews 1979).

Matthews (1979) reported that the mean size of droplets will increase when they are produced by liquid passing through a larger nozzle orifice. The flow rate of the 80015 at 40 psi is more than twice that of the 800067 at the same pressure. The spray angle of 80^{o} is the same at equal pressures. The mean values of the mmd produced by the 80015 are all higher than those produced by the 800067 when subjected to similar pressure/height treatments.

The mean mmd produced by the 80015 over the 20 - 70 psi pressure and 35 - 55 cm height regimen diverges from the expected gradual decline (Figure 4.8). The mean mmd increased as spray height increased at equivalent pressure. When the 80015 was subjected to 50 psi drastic increases in the mean mmd occurred. These increases continued when 60 and 70 psi were used. Unexpected increases also occurred at the 45 cm height when pressure was increased above 50 psi. The reasons for these aberrations are unknown.

There is an optimum insecticide droplet size for a particular target pest or substrate, and it is based on effective contact with the target, and minimal contamination of non-target organisms and surfaces (Himel 1969, Brett 1974). Small droplets (ca $< 50\,\mu$) can create hazards from drift, resulting in contamination of non-target areas. Rogers et al. (1973) suggested that the 800067 nozzle be used at 20 psi to avoid contamination of the applicator and splattering or drift of particles to non-target surfaces. Heath and Spittler (1985) examined the dermal exposure to insecticides while using the various nozzles housed on the Multee-Jet. They concluded that the lowest dermal exposure rates were associated with low pressure, close range applications using the pin-stream or equivalent nozzles.

The results from the present investigation demonstrate that the hydraulic-energy nozzles investigated produce a wide range of droplet sizes. Safe and effective pesticide application can be achieved by combining the monitoring of system pressure and spray height along with nozzle selection, and accurate use of the equipment.

4.3.4 Spray Patterns of Nozzles

Photographs of all 36 patterns created by subjecting both the 80015 and the 800067 nozzles to the various pressure/height treatments are found in Figures 4.9, 4.10, and 4.11. Figure 4.9 consists of those patterns created by the 80015 and the 800067 over all pressures at 35 cm. Figure 4.10 and Figure 4.11 consist of those patterns created at 45 and 55 cm respectively.

The 80015 and the 800067 were designed to be used at 40 psi to achieve the expected fan angle of 80^{o} and the corresponding flow rates of 0.15 and 0.067 gal/min, respectively. This pressure permits the formation of a pattern that is nearly bilaterally symmetric, and uniformly declines on each side (Figure 4.9, 4.10, and 4.11).

A system pressure of 20 psi causes the resulting pattern to have a "central peak", and also causes the formation of lateral "shoulders". The achievement of evenly distributed insecticide over a substrate using pressures of 20 psi or less is essentially unattainable. To ensure even and thorough coverage, the spray swaths must be overlapped to achieve uniform coverage of the substrate.

The spray height greatly affects the swath width or width of the pattern (Figure 4.9, 4.10, and 4.11). The size of the nozzle orifice also affects the swath width. At the same pressures the 80015 with the larger orifice allows the liquid to more evenly distribute than that of the 800067. The leveling of the central region of the pattern

occurs sooner with the 80015 than with the 800067 (Figures 4.11b, 4.11h, 4.10b, and 4.10h). The wider, more level patterns are much more conducive to proper spray-swath overlapping and permit even and uniform coverage of a substrate.

The goal of insecticide application to carpeted surfaces for the control of a flea infestation is thorough and even coverage of the entire substrate. Overapplication is wasteful and could result in violation of label recommendations. Underapplication in other areas can leave those regions with sublethal dosages of insecticide which could limit control, and lead to insecticide-induced resistance in the population.

The results from this investigation indicate that when a spray system is used at lower pressures (i.e. < 30 psi); the correct nozzle would be the 80015. This will enable proper overlapping and uniform coverage. With this larger orifice the production of small droplets prone to drift which could contaminate non-target organisms and substrates would also be less than that for the more constricted orifice of the 800067.

4.4 CONCLUSIONS

The control or management of indoor infestations of the cat flea involves a number of important chemical and non-chemical tactics. Vacuuming with a beater-bar vacuum removes about 50% of the eggs and less than 30% of the larvae from a carpet. Vacuuming may also remove adults, and portions of the larval food from carpeted substrate. It may be effective for causing pre-emerged adults to eclose from the cocoon, and become exposed to insecticides. Vacuuming could aid in the preparation of the carpet pile to receive an application of pesticide by permitting maximal penetration into the nap.

The application system most frequently used for indoor flea control is a compressed-air sprayer with coarse- and fine-fan nozzle orifices. The system is pressurized by compression strokes with a pump unit and the increase in pressure is a linear function of the number of compressions of the pump. Pressure decline occurs when the release valve is actuated. The more constricted 800067 orifice released pressure more slowly than did the 50015. The increased pressurized air-space afforded by the initial volume of 2 l resulted in a decreased rate of pressure loss for the larger (50015) nozzle orifice than that for the 800067 at the 4 l initial volume.

The importance of monitoring the system pressure is crucial because pressure affects the overall effectiveness of insecticide application (Figure 4.12). The system pressure which forces the liquid through a nozzle orifice creates a characteristic flow rate and spray angle. The combination of the flow rate, spray angle, and the spray height yield characteristic patterns. These patterns must be considered for overlapping to achieve uniform coverage. Lower pressures can be used to reduce the amount of small-droplet drift (Rogers et al. 1973, Heath and Spittler 1985). However, lower pressures can create aberrant spray patterns. These patterns are difficult to properly overlap to achieve uniform coverage of the substrate.

Proper concentrations of insecticides, and the application of recommended rates (as specified by label instructions) must be considered along with the flow rates to enable proper calculations of application speeds for the proper distribution of pesticide according to the label. The correct application speed and scheme of pattern overlapping are necessary goals of proper pesticide application. Proper application should result in effective control of an indoor infestation of the cat flea.

Ebeling (1975) and Wilson et al. (1957) have reported that lack of control of cat flea infestations following application of insecticides can sometimes be attributable to faulty or misapplication of the insecticides.

Table 4.1: Technical specifications of four carpets used in vacuum extraction investigation for immature stages of the cat flea.

English Units

Number	Pile Height (inches)	Tufts/in^2	Face Weight (oz fiber/yd^2)	Density (oz/yd^3)
1	0.500	28	24.5	----
2	0.500	81	32.0	2,050
3	0.625	81	42.0	2,200
4	0.625	100	53.0	2,350

Metric Equivalents

Number	Pile Height (cm)	Tufts/cm^2	Face Weight (gm fiber/m^2)	Density (gm/m^3)
1	1.270	4.35	830.71	----
2	1.270	12.55	1085.01	75,960
3	1.588	12.55	1424.08	81,518
4	1.588	15.50	1797.05	87,076

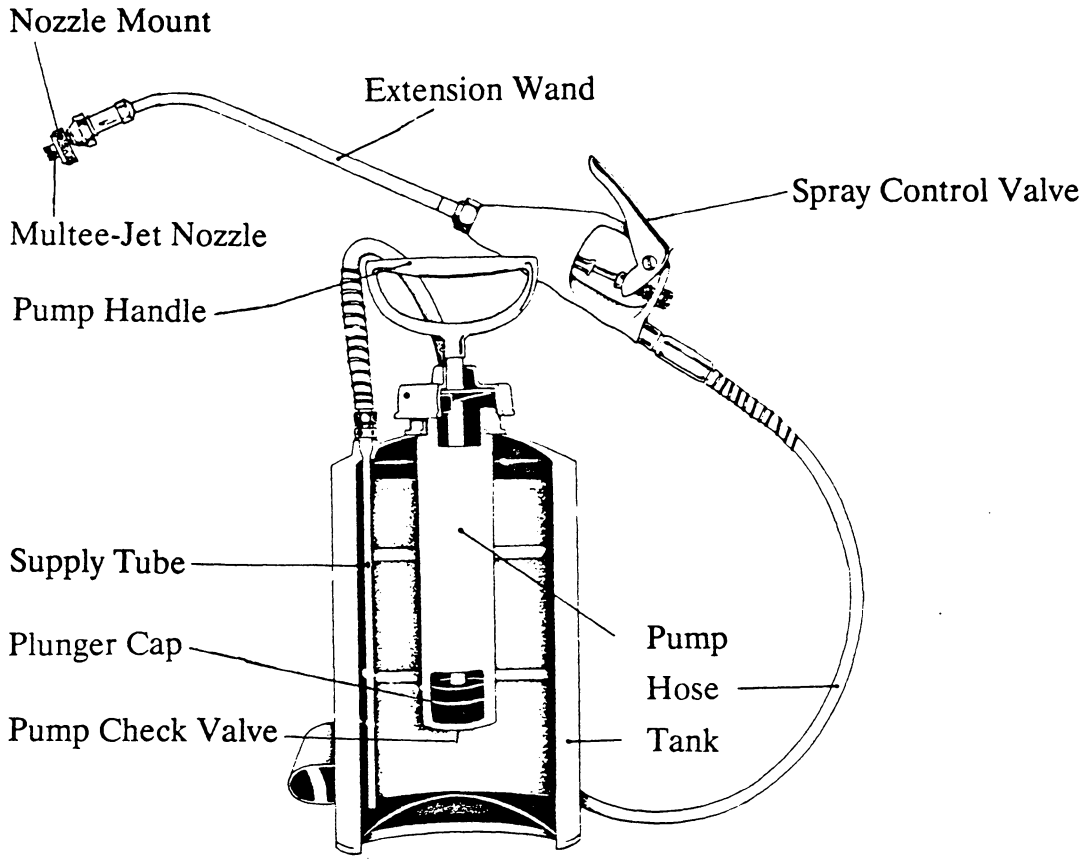


Figure 4.1: Diagram of the N124-S, 1-gallon, compressed-air sprayer manufactured by B&G Equipment Company (Plumsteadville, PA).

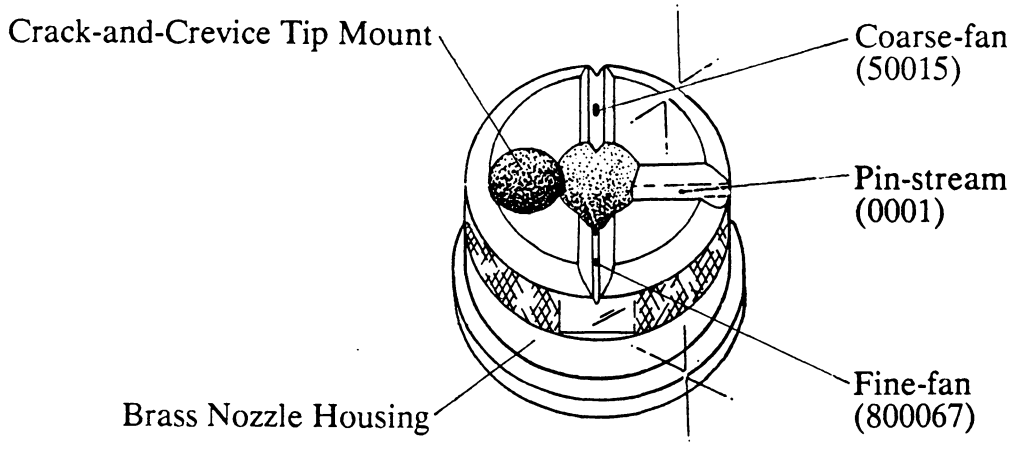


Figure 4.2: Diagram of the Multee-Jet nozzle housing containing four nozzle tips manufactured by spraying Systems Company (Wheaton, IL).

Table 4.2: Technical specifications of three nozzle orifices which are on the Multeejet nozzle housing manufactured by Spraying Systems Co. for use on the Model N124-S stainless steel, compressed-air sprayer manufactured by B&G Equipment Company.

Pattern	Tip No.	Fan Angle (radian degrees)	Flow Rate* (gal/min -- l/min)
Pin-stream	0001	0	0.01 -- 0.038
Fine-fan	800067	80	0.067 -- 0.254
Coarse-fan	50015	50	0.15 -- 0.568

* Data is based on a sytem pressure of 275.8 kPa (40 psi).

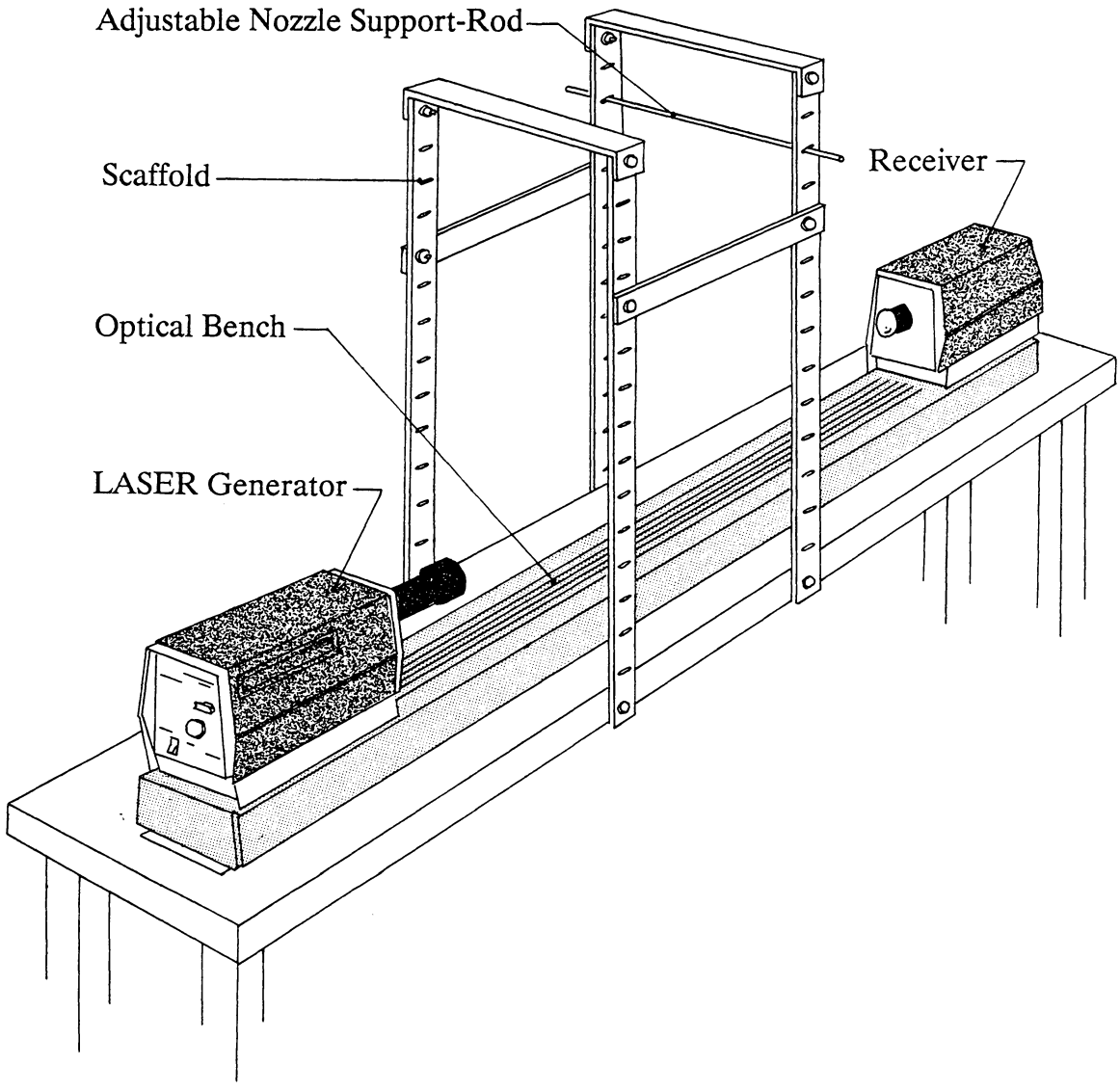


Figure 4.3: Diagram of Malvern 2600HSD LASER particle sizer including scaffold structure for support of nozzle.

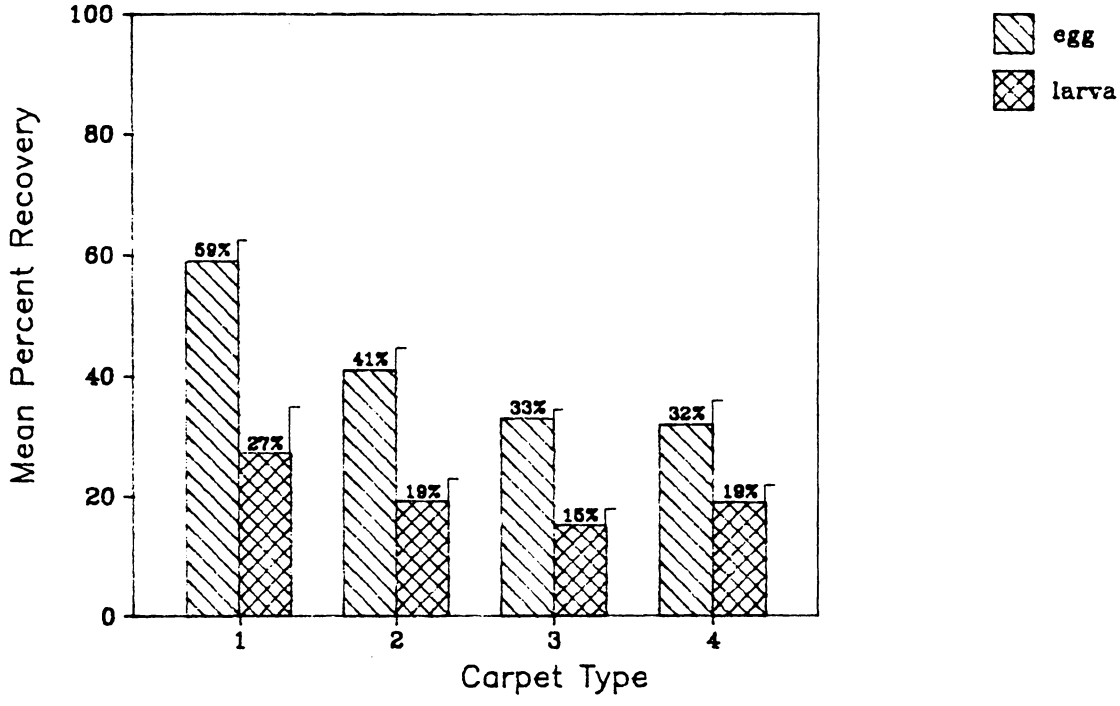


Figure 4.4: Mean percentage recovery (+ SEM) of cat flea eggs and larvae from four qualities of carpet (Table 4.1) when using a 4.0 amp upright beater-bar vacuum.

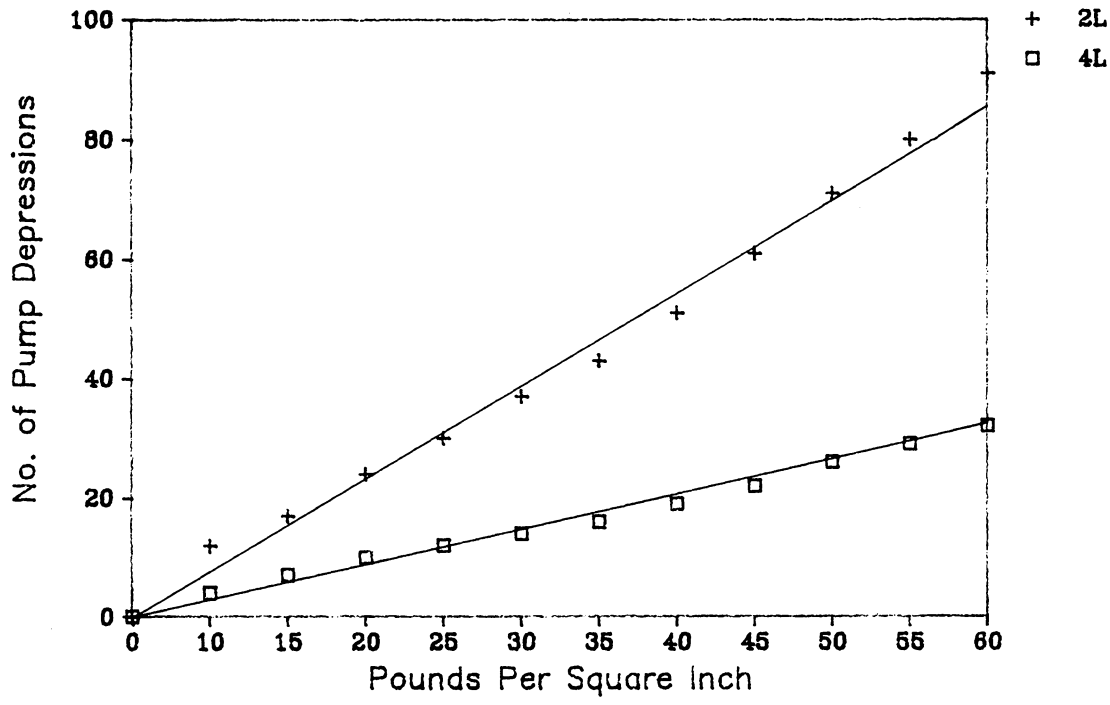


Figure 4.5: Mean number of full-length pump-strokes versus system pressures between 0 and 60 psi in a 1-gallon compressed-air sprayer at initial volumes of two and four liters.

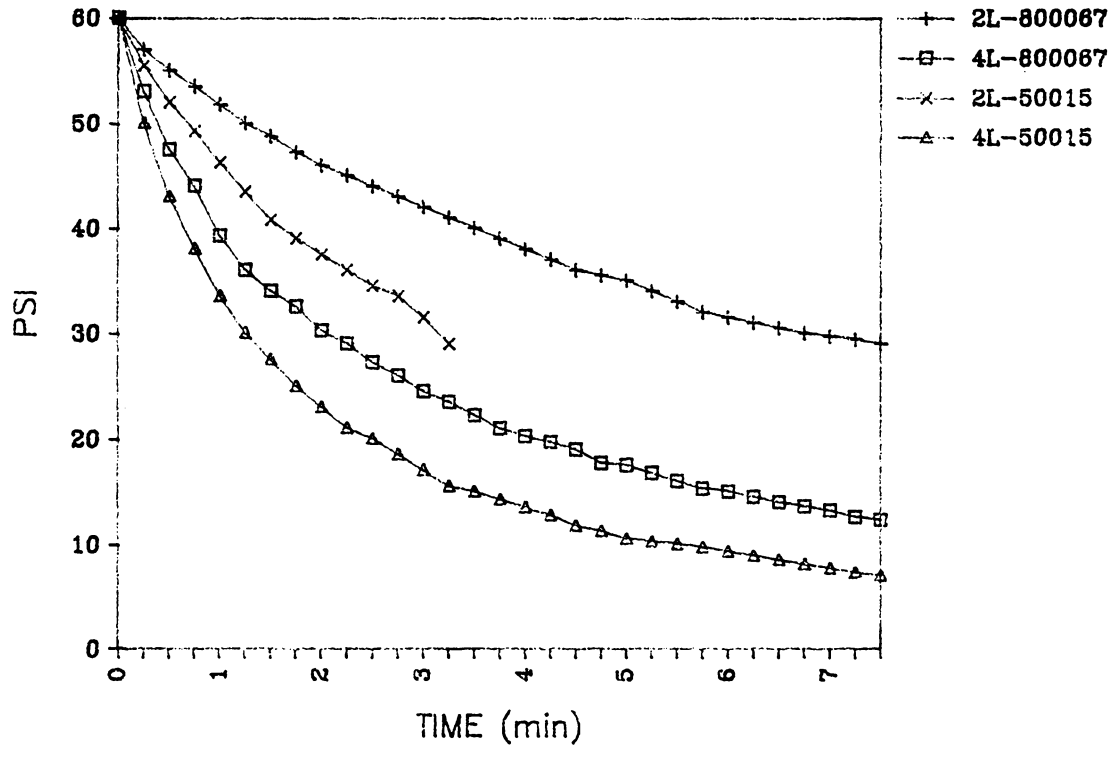


Figure 4.6: Mean pressure loss over time of a 1-gallon compressed-air sprayer while using 800067 and the 50015 nozzle orifices with two different initial fluid volumes of two and four liters.

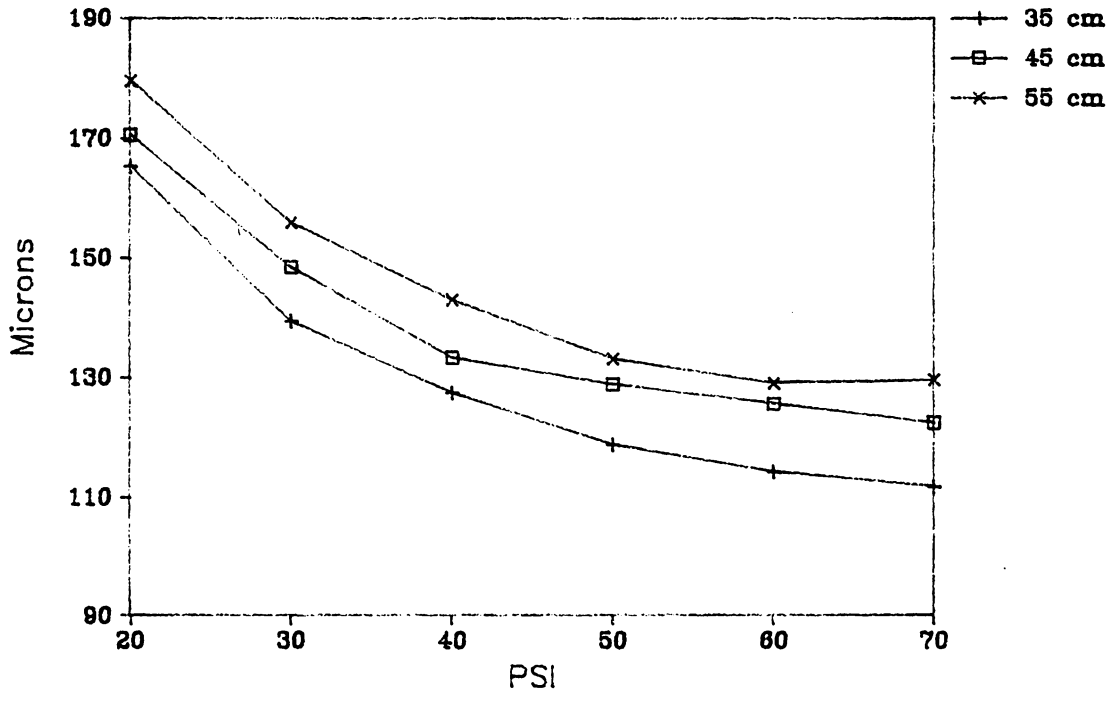


Figure 4.7: Mean values for mass median diameter of droplet spectra of the 800067 nozzle tip acquired from a Malvern 2600HSD LASER particle sizer taken over six pressures at three spray heights.

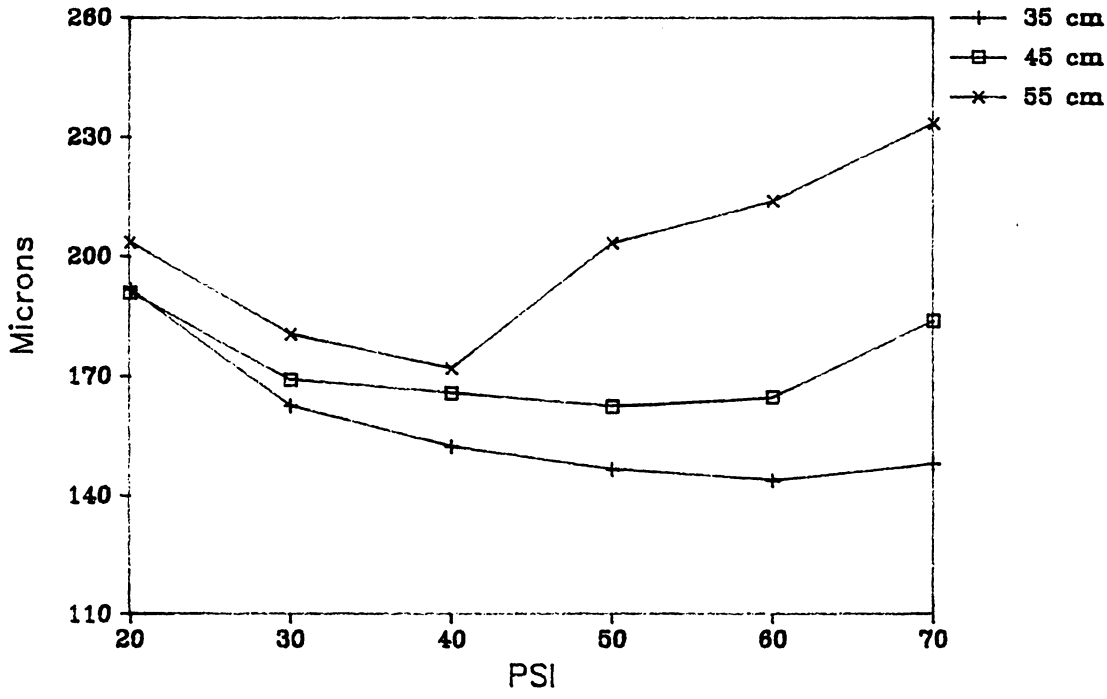
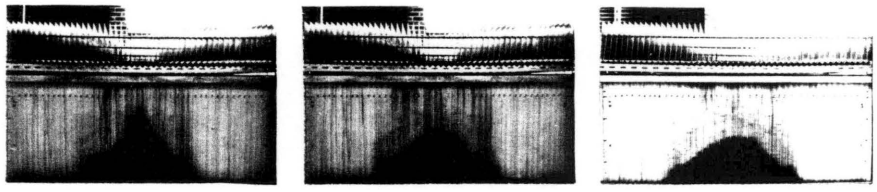
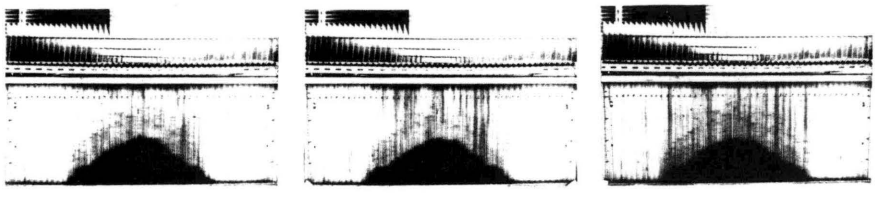


Figure 4.8: Mean values for mass median diameter of droplet spectra of the 80015 nozzle tip acquired from a Malvern 2600HSD LASER particle sizer taken over six pressures at three spray heights.



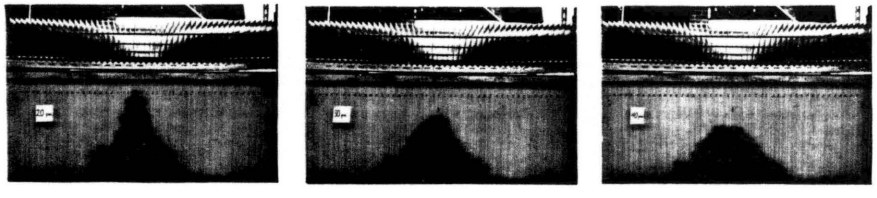
9a. 20 psi 9b. 30 psi 9c. 40 psi

80015



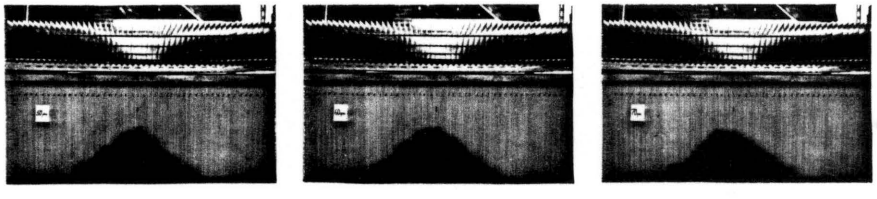
9d. 50 psi 9e. 60 psi 9f. 70 psi

80015



9g. 20 psi 9h. 30 psi 9i. 40 psi

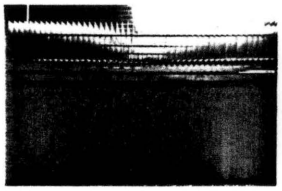
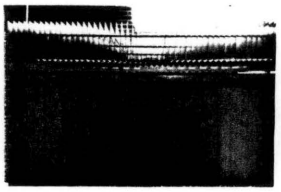
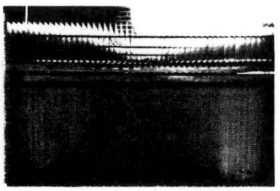
800067



9j. 50 psi 9k. 60 psi 9l. 70 psi

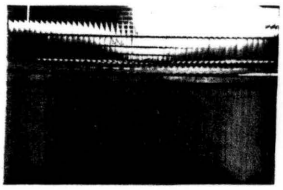
800067

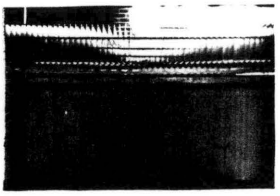
Figure 4.9: Patternations of 80015 and 800067 nozzle tips at 20, 30, 40, 50, 60, and 70 psi all acquired at a spray height of 35 cm on a 50 tube spray table.

10a. 20 psi 10b. 30 psi 10c. 40 psi

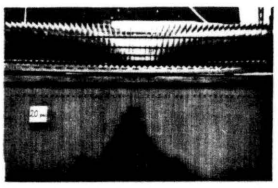
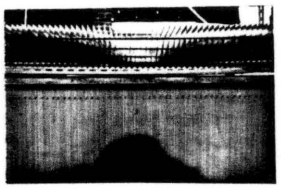
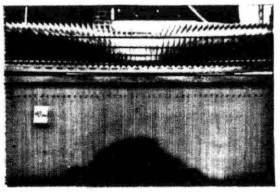
80015





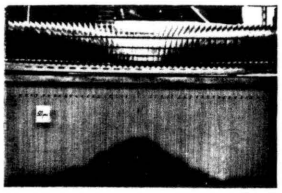
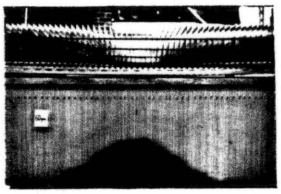
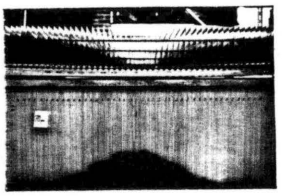
10d. 50 psi 10e. 60 psi 10f. 70 psi

80015

10g. 20 psi 10h. 30 psi 10i. 40 psi

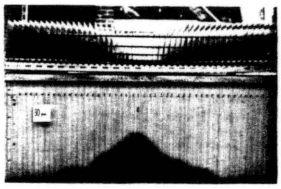
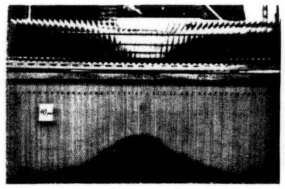
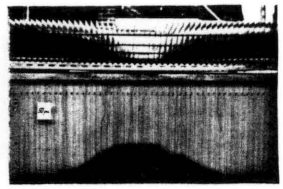
800067

10j. 50 psi 10k. 60 psi 10l. 70 psi

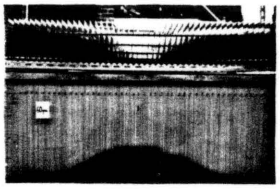
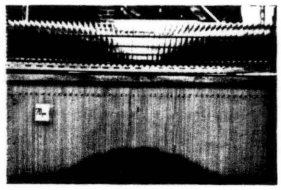
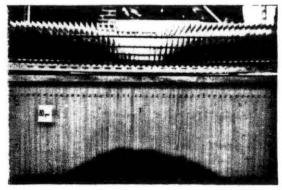
800067

Figure 4.10: Patternations of 80015 and 800067 nozzle tips at 20, 30, 40, 50, 60, and 70 psi all acquired at a spray height of 45 cm on a 50 tube spray table.

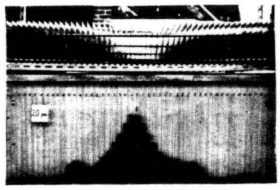
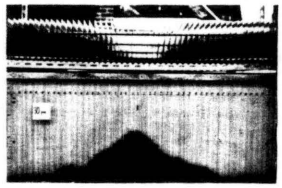
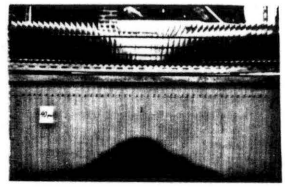
11a. 20 psi 11b. 30 psi 11c. 40 psi

80015

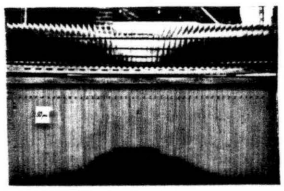
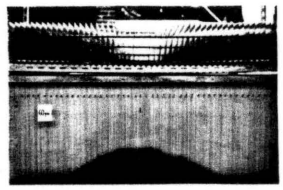
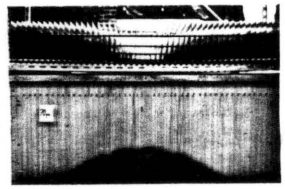
11d. 50 psi 11e. 60 psi 11f. 70 psi

80015

11g. 20 psi 11h. 30 psi 11i. 40 psi

800067

11j. 50 psi 11k. 60 psi 11l. 70 psi

800067

Figure 4.11: Patternations of 80015 and 800067 nozzle tips at 20, 30, 40, 50, 60, and 70 psi all acquired at a spray height of 55 cm on a 50 tube spray table.

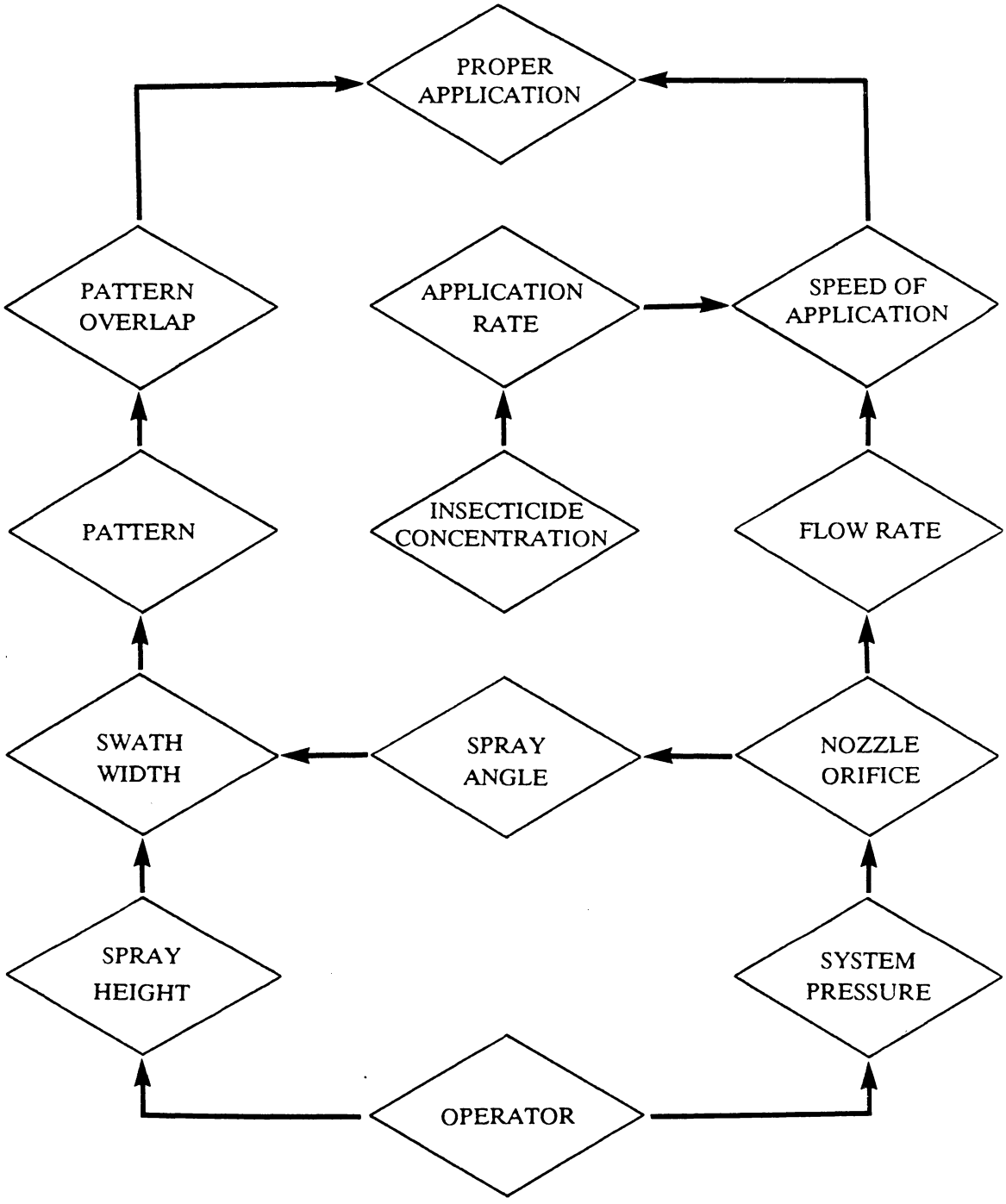


Figure 4.12: Conceptual flow of logic for the critical components involved in insecticide application.

CHAPTER V

METHOD FOR DETERMINING SPRAY PENETRATION INTO CARPET

5.1 INTRODUCTION

In the United States 45% of all households have at least one dog and/or cat. These 99 million canine and feline pets serve as excellent hosts for the cat flea, Ctenocephalides felis (Bouché) (Anonymous 1986). The cost of control and resultant damage from flea infestations was estimated to be $230 million in 9 Southeastern states in 1983 (Hamer 1985).

Adult male and female cat fleas feed and mate on the host. Females lay eggs on the host which later dislodge from the pelage and fall to the substrate below. After hatching, larvae feed on adult flea excrement and other organic debris in household carpet. Full-grown larvae pupate in the carpet; after emergence from the cocoon, adults return to a warm-blooded host. The flea life-cycle includes two different harborages. Eggs, larvae, and pupae develop in the protected environment of carpet, and adult fleas exist on the pet host. Chemical control of an indoor flea population involves treatment of the host, and application of residual insecticides to carpet to control immature stages. Treating the host has limited effectiveness, and the results of carpet spraying for control of larvae are suboptimal (Koehler et al. 1986).

Flea larvae spend a majority (83%) of time on the base of carpet, beneath the pile fibers (Byron and Robinson 1986a). Flea eggs and pupae are not affected by conventional insecticides because of the protection provided by the egg chorion and the silken pupal case.

The goal of any pesticide application is the safe control of a pest population. To achieve chemical control, the pesticide must be delivered to the environment of the pest. The objective of the research presented here was to quantify insecticide penetration into carpet using a coarse-fan (80015) nozzle while varying application pressure and spray height.

5.2 MATERIALS AND METHODS

5.2.1 Materials and Equipment

Materials used in this investigation included; saxony pile (18 mm) carpet (Ege, Fantasy); fluorescein sodium (C.I. 45350), a water soluble fluorescent dye (Strecher et al. 1968); Agral (ICI Plant Protection Division), a non-ionic wetting agent; CIPAC D (WHO standard water) (Raw 1970); and a KH_2PO_4 / NaOH pH 7.4 buffer (Weast 1972). Equipment used included; an 80015 fan nozzle (Spraying Systems Inc.); a fifty collection tube patternator; a Mardrive biological, walk-in, constant-velocity, closed-system spray cabinet designed and constructed by the Chesterford Park engineering workshops in conjunction with Marine Engineering Co. Ltd. (Stockport, Cheshire, England); a Malvern 2600HSD LASER droplet particle sizer; and a Perkin-Elmer 650-10S fluorescence spectrophotometer.

A specially designed tool to horizontally segment the carpet samples was also built by the Chesterford Park engineering workshops. It consisted of a hard plastic piston 5.1 cm in diameter by 7.0 cm with a 3.0 x 7.0 cm handle. The piston had 3 mm holes bored in 3 mm increments vertically down a portion of its length. A glass sleeve 5.11 cm (inside diameter) with a pair of opposing holes drilled to match those of the piston was locked in place at a specified level with a 2.9 mm diameter brass rod. The carpet was affixed to the upper surface of the plastic piston using double-sided tape (Figure 5.1).

5.2.2 Sample Application

A coarse fan (80015) nozzle was patternated, and particle size distributions were separately acquired at 6 pressures (137.9, 206.9, 275.8, 344.8, 413.7, 482.7 kPa {20, 30, 40, 50, 60, 70 psi}) at 3 heights (35, 45, 55 cm) for a total of 18 patternations and 18 droplet spectra. Patternations were done to acquire swath widths for each pressure/height treatment. During each patternation, the time to discharge one liter was recorded to acquire a liter/minute flow rate at each pressure.

Using the formula:

$$V = \frac{600 \times \text{flow rate (l/min)}}{\text{Swath Width (m)} \times 400 \text{ (l/ha)}}$$

one could solve for V (the application velocity), to apply equal volumes of spray solution to all carpet samples with respect to the treatments involving variations in pressure and spray height. A walk-in, constant-velocity, application chamber was used to apply the solution to carpet samples. Set velocites were electronically controlled. The application rate of the spray solution duplicated the rate recommended by FBC Ltd. for their product, Ficam 80 WP, which calls for 5 l/125 m^2.

Prior to application the upper surface of the carpet samples, which measured 9 x 9 cm, were gently brushed with a gloved hand to erect the fibers to allow for maximal penetration of the spray solution. The samples were then placed on a stand within the application chamber. The stand was located directly beneath the nozzle located within the chamber. Prior to the application, a 5.08 cm (inside diameter) x 1.0 cm glass petri dish was placed adjacent to and directly in front of the carpet sample in

line with the direction of the spray. A solution of 0.24% fluorescein sodium, 0.1% wetting agent in CIPAC D water was added to the solution reservoir mounted above the nozzle housing in the application chamber. The nozzle housing and reservoir were mounted on a track system controlled by belts which accelerated to a velocity specified through the equipment's electronics. Following acceleration, the constant velocity was held for a distance of one meter while it passed over the carpet samples and glass petri dish; the apparatus then decelerated. The solution was applied to individual carpet samples at the velocities specified in Table 5.1 so that equal volumes of solution were applied over all the pressure/height treatments. Following each application, approximately 30-40 seconds elapsed to allow the air space within the application chamber to be evacuated (a safety feature of the apparatus). After this time, the petri collection dish was removed and weighed. The weight of the dish was subtracted from the total weight after spray application and the weight of the spray applied (specific gravity = 1.0) to the dish was recorded. This measurement was made to determine the actual amount of spray applied to the 5.08 cm diameter carpet sample which was taken later from the center of the carpet for analysis. Removal and use of only the central area of the treated carpet, reduced possible edge effects from application of the spray to exposed sides of the carpet pile.

Application of each treatment (pressure/height combination) was replicated 3 times using a different piece of carpet for each replication. Following an application, the sample was carefully grasped by the edges and placed in a storage tray, the bottom of which was lined with absorbent material. Upon completion of all 54 applications the storage trays were placed in darkness at $5^{o}C$ for 48 hours to allow for complete drying.

Prior to horizontal segmentation each carpet sample had a circle (5.08 cm diameter) removed from the center of the 9 x 9 cm square with a wad punch. The punch was carefully worked down into the nap of the sample to avoid dislodging of the dye or contamination of lower layers from those above. Between each sample the punch was rinsed with acetone and wiped clean.

Segmentation of each circular sample was done using the tool described in the equipment section above. The sample was affixed to the top surface of the plastic piston and the glass sleeve was set, sliding upwards from the lower end of the apparatus, to expose the top 3 mm of carpet pile. Then the brass rod was inserted through the glass sleeve and the plastic piston to lock the apparatus in place. The entire apparatus was then inverted to prevent contamination of lower levels from those above. The upper 3 mm layer of carpet was then removed using scissors; collected over a 30 x 30 cm sheet of glycine paper, weighed, and stored. The brass rod was then removed from the sectioning apparatus and the glass sleeve lowered 3 mm. Then the brass rod was reinserted to again lock the apparatus in place. The scissors were wiped with acetone between the removal of each layer. Inverting the apparatus, the next 3 mm of pile were removed and collected below on a new piece of glycine paper. This procedure was continued until the the final 3 mm attached to the 3 mm thick jute backing of the carpet was reached. This final layer was then weighed and stored. All layer samples were stored in darkness at $5^{o}C$ until analysis.

5.2.3 Dye Extraction

For each treatment, 100 mg of each of the 4 upper layers and 100 mg of carpet fiber cut from the 5^{th} layer (fiber attached to the jute backing) was removed. These subsamples were placed in 30 ml glass reaction vessels to which 5 ml of the KH_2PO_4 / NaOH buffer was added. The vessels where submerged in a $35^{o}C$ constant

temperature water bath and shaken at 140 linear agitations per minute for 15 minutes. The solutions were decanted into 12 ml centrifuge tubes, and then centrifuged at 1000 rpm for 10 minutes. The supernatants were decanted into 14 ml storage vials and stored at 5^{o}C until analysis. The efficiency of the dye extraction technique was determined by spiking 100 mg rug fiber samples with known quantities of dye (at the high and low end of the range of quantities seen in actual treatment carpet samples). The samples were dried, and then extracted following the extraction procedure used for the treatment unknowns.

5.2.4 Sample Analysis

The analysis of samples was performed using a fluorescence spectrophotometer with the excitation wavelength set at 460 nm and the emission wavelength at 517 nm. The lower sensitivity threshold for the instrument was 6 ng/ml (6 ppb). A series of standard concentrations (range: 6 ng/ml - 15 µg/ml) plotted against the corresponding fluorimetric output yielded a linear regression line with a correlation coefficient of 0.999.

5.2.5 Data Analysis

Data (fluorimetric units) were converted to values of percent deposition and transformed using a square-root arcsin transformation then analyzed using an analysis of variance and Duncan's New Multiple Range procedures (Sokal and Rohlf 1981). Analyses were performed using Statistical Analysis System (SAS 1982).

5.3 RESULTS AND DISCUSSION

The data indicate that within the pressure and height ranges studied no significant differences in penetration existed (Figure 5.2). Regardless of the

pressure/height combination tested, more than 93% of the spray applied was deposited in the upper third, i.e. first 2 layers, of the 18 mm carpet pile (Table 5.2).

The average recovery ($\pm$ SEM) of the fluorescein sodium from the spiking experiment was 47.6 $\pm$ 2.23 percent. The average recovery from unknown (treatment) extracted carpet samples, corrected by using the extraction efficiency, was 41.2 $\pm$ 0.98 percent.

The low percentage recovery of dye in the carpet sample extractions may be attributable to physical binding of the dye to the nylon fibers of the carpet pile. The adsorptive characteristics of polyamid fibers could have accounted for a significant retention of the dye (Monsanto Chem. Co. personal comm.). A second factor which could be partly responsible for the low percentage recovery of the experimental samples may have been that as application pressures were increased, there was a decrease in the amount of spray solution which reached the carpet sample. An example of this phenomenon is depicted in Figure 5.3 which depicts the penetration from a height of 35 cm with varying application pressures. The lines do not cross between layers one and two nor between layers two and three for 30, 40, 50, and 70 psi. The Y-axis units are given in units of fluorescence.

The results of the collection dish placement adjacent to the carpet sample at application support the observation of a decreased volume of spray reaching the target at increased application pressures. Figure 5.4 represents mean spray volumes collected at each height/pressure treatment. In addition to the loss in spray volume reaching the sample from decreased droplet size, bounce-out from the firm surface of the glass could also have been a possible reason for the decreased volume collected. This appears especially evident at the 35 cm spray height, where the velocity of droplets could have been sufficient to cause a bounce-out effect. At 45 and 55 cm the velocities of the majority of droplets may have decreased to a point

where bounce-out might not have been as significant. This bounce-out factor would probably not have occurred on the surface of the carpet samples applied at these higher pressures, regardless of the height due to the surface texture of the substrate.

An alternate explanation for the decrease in spray solution reaching the carpet samples at the higher pressures tested could be that increasing pressure results in a decreased mass median diameter (mmd) of the droplet size distribution. The application chamber exhaust fans evacuated approximately 25 m^3 of air volume before the door latch was released, allowing the sample to be removed from the chamber. This process took on the average, 40 secs. The volume of the walk-in chamber was approximately 8 m^3, resulting in a 3-fold evacuation of the interior air space. At higher spray pressures, an increasing proportion of the droplets were aerosol ($<50\,\mu$) sized droplets (Table 5.3). These droplets may never have reached the target (carpet sample) before they were evacuated from the air space by the exhaust fan, resulting in an overall decrease in the amount of spray solution reaching the carpet sample. Evaporation of the collected spray contained in the glass petri dish might also have occurred during the evacuation of the air space within the spray chamber.

5.4 CONCLUSIONS

The results from this investigation indicate that prescribed chemical applications for flea control in terms of specified pressure and spray height are not critical. Specific attention should be given to accurate overlapping of spray patterns to ensure thorough coverage of the substrate. The Spraying Systems Inc. 80015 coarse-fan nozzle was designed to be used at 275.8 kPa (40 psi) and the best results will be achieved at this pressure in terms of even coverage of the substrate and optimal droplet size distribution. The higher pressures that can be attained using a hand-

held, compressed-air sprayer could lead to misapplication of pesticides with respect to the increasing number of aerosol-sized droplets. Preventing contamination of non-target substrates and organisms in any pesticide application should always be a primary concern.

Considering the intent of insecticide application onto carpet for control of indoor flea populations, i.e. insecticide placement in the lower reaches of the carpet, none of the pressures attainable through the use of hand-pressurized spray equipment ($\leq$ 70 psi) can reach this goal and the height (between 35 and 55 cm) at which the nozzle is above the substrate has very little effect on penetration potential.

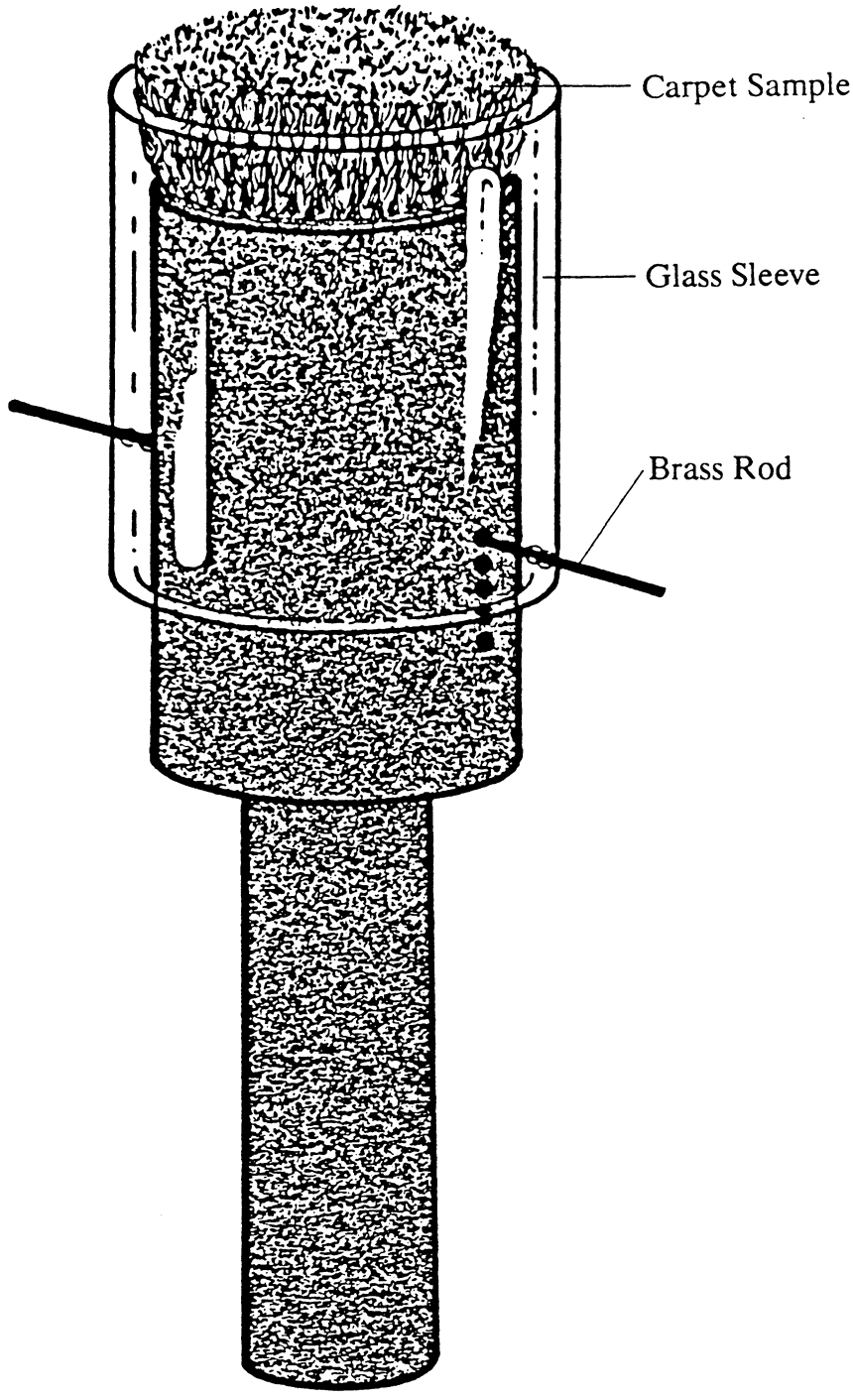


Figure 5.1: Specially designed tool used with scissors to horizontally segment carpet samples following spray application for observation of spray penetration.

Table 5.1: Velocities in seconds/meter used to apply the spray solution to carpet samples at various pressure/height treatments to ensure equal volume of application to each.

	Height in cm		
PSI	35	45	55
20	3.61	4.54	5.78
30	3.01	3.89	4.65
40	2.91	3.45	3.98
50	2.59	3.26	3.83
60	2.36	3.06	3.50
70	2.17	2.81	3.30

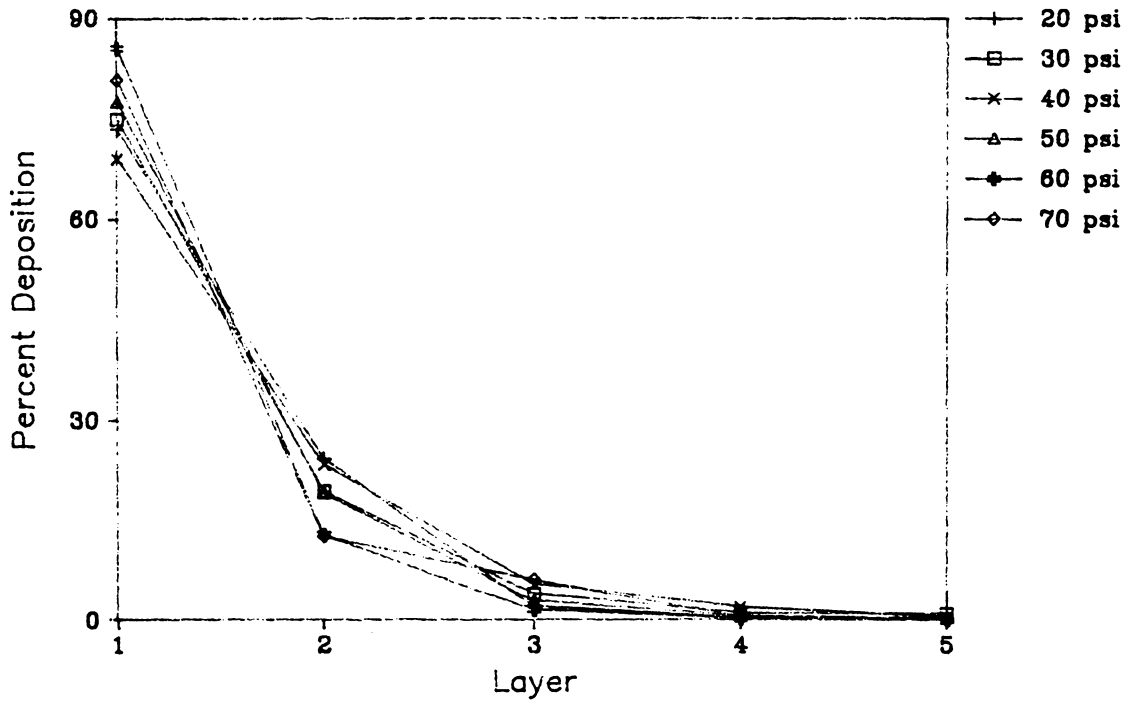


Figure 5.2: Mean percent depostion versus carpet layer for fluorescein sodium, depicting no significant difference in penetration while varying pressure at a spray height of 35 cm using the 80015.

Table 5.2: Experimental data reported as percent deposition within each layer over all pressure/height treatments.

			Height = 35 cm		
PSI	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
20	73.4	24.2	2.0	0.2	0.2
30	74.8	19.3	4.0	1.0	0.9
40	68.9	23.3	5.5	1.9	0.4
50	77.4	19.0	2.9	0.5	0.2
60	85.5	12.8	1.5	0.2	0.0
70	80.7	12.6	6.1	0.4	0.2

			Height = 45 cm		
PSI	Layer 1	Layer 2	Layer 3	Layer 4	Layer5
20	79.6	17.0	2.9	0.4	0.1
30	73.2	22.9	3.2	0.5	0.2
40	77.0	19.0	2.9	0.9	0.2
50	75.3	20.2	3.6	0.6	0.3
60	75.6	19.9	3.4	0.9	0.2
70	67.8	21.8	8.0	1.5	0.9

			Height = 55 cm		
PSI	Layer 1	Layer 2	Layer 3	Layer 4	Layer5
20	79.2	17.9	2.5	0.3	0.1
30	77.0	20.3	2.2	0.4	0.1
40	73.8	22.5	3.1	0.5	0.1
50	70.4	22.8	5.3	1.3	0.2
60	75.8	22.1	1.8	0.3	0.0
70	69.1	26.0	4.2	0.5	0.2

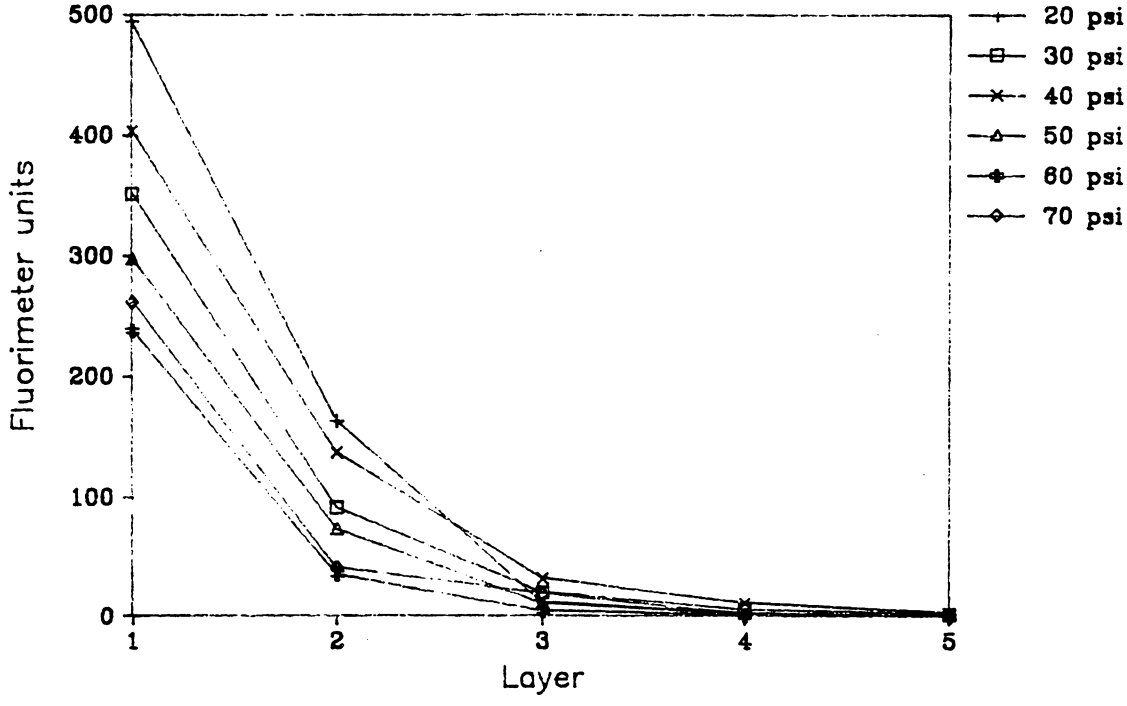


Figure 5.3: Mean fluorimeter units versus carpet layer, depicting penetration at 35 cm while varying the application pressure using the 80015.

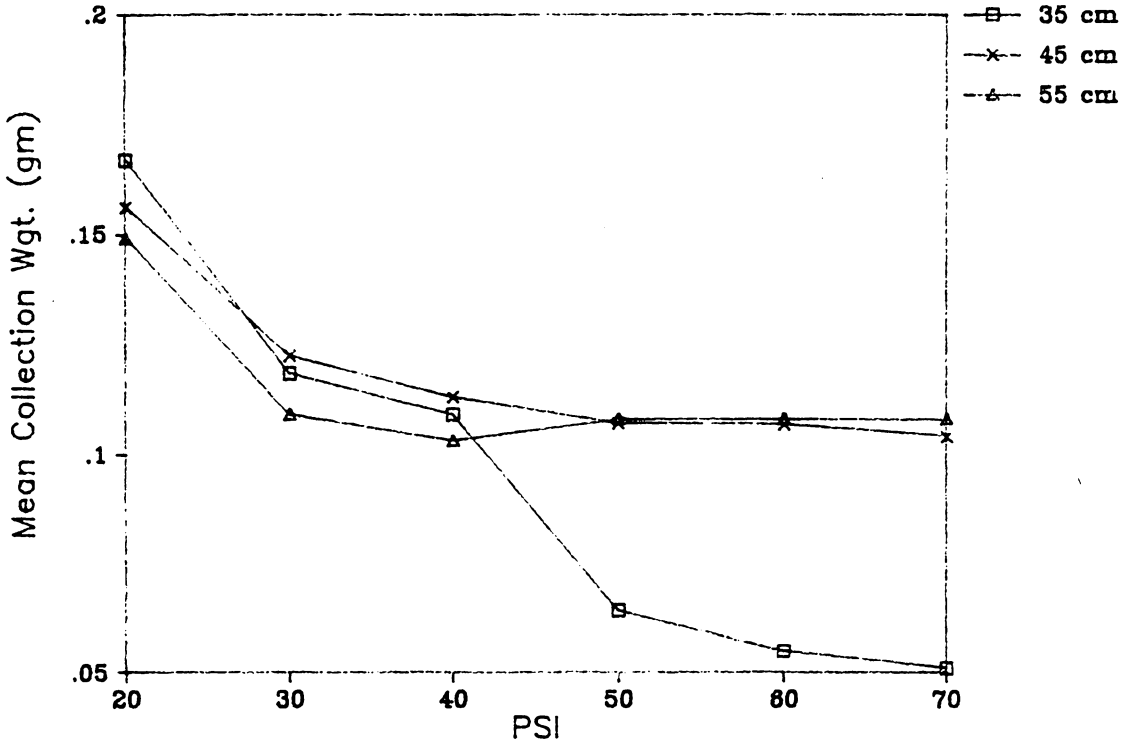


Figure 5.4. Plot of mean spray volumes collected in petri dish versus application pressure by height, depicting loss of spray volume with increasing pressure and decreasing spray height.

Table 5.3. Mean cummulative percentage of droplets below 40 μ in diameter of the total spray passing through the LASER beam of a Malvern 2600HSD Particle Sizer.

		Mean Cummulative Percentage Below 40μ ± SD		
PSI	n	35	45	55
20	3	0.90 ± 0.10	0.83 ± 0.06	1.13 ± 0.06
30	3	1.83 ± 0.06	1.70 ± 0.26	2.00 ± 0.10
40	3	2.87 ± 0.06	3.30 ± 0.10	3.13 ± 0.35
50	3	3.83 ± 0.23	4.13 ± 0.40	5.57 ± 1.03
60	3	4.80 ± 0.36	5.50 ± 0.61	7.17 ± 0.25
70	3	6.10 ± 0.46	6.93 ± 0.83	8.50 ± 0.53

CHAPTER VI

SURVEY OF PET OWNERS TOWARD HOUSEHOLD INFESTATIONS OF THE CAT FLEA

6.1 INTRODUCTION

The word pest denotes an organism causing some damage. Damage can be realized as economic, physical, psychological, or aesthetic impacts on objects or individuals. The individual(s) upon which the organism exerts an effect defines whether the actions of the organism are damaging, giving the organism some status as a pest. Byrne et al. (1984) reported that certain demographic variables such as sex, level of education, and place of residence can affect an individual's attitude toward urban arthropods.

The purpose of audience evaluations of urban arthropods is to define tolerance levels of the target audience toward the target pest population. Surveys can also yield valuable information about the audience's knowledge of particular urban arthropod pests. Surveys of the public and of specific target audience's in regards to knowledge and attitudes toward a variety of urban arthropods have been conducted (Robinson 1980, Wood et al. 1981, Levenson and Frankie 1983, Robinson and Atkins 1983, Zungoli and Robinson 1984, Byrne et al. 1984, Ravlin and Robinson 1985, Thoms and Robinson 1986). The collection of data on tolerance levels, and knowledge and attitudes of the target audience toward a specific pest can aid in the design and implementation of pest management programs (Robinson and Atkins 1983, Robinson and Zungoli 1985, Thoms and Robinson 1986).

There is considerable information on the biology and habits of the cat flea. Laboratory and field research on this pest have been conducted in the western U.S.(Silverman et al. 1981, Silverman and Rust 1983, Osbrink and Rust 1984) and the eastern U.S. (Byron and Robinson 1986a, b). However, there is little or no information on the perceptions of the target audience, pet owners, toward cat flea infestations.

The objectives of this investigation were to determine the perceptions and knowledge of pet owners toward flea infestations, and to evaluate their tolerances of fleas in their homes and on their pets. Other objectives were to quantify the respondent's willingness to pay for a "flea-free' environment and on the actual expenditures for flea control and prevention.

6.2 MATERIALS AND METHODS

The survey was conducted as face-to-face interviews. Subjects were contacted by one person while visiting a local veterinarian for 4-6 days during each sampling month. The survey consisted of 14 open-ended questions, and three questions in which response choices were provided by the interviewer. Information on five categories of demographic data was collected. Flashcards were handed to the respondents for three of the demographic questions after which they were asked to select a letter which corresponded to an answer on the card (Appendix D). This method was used for information that might have been considered confidential by the respondent. Each interview took between 7 and 10 minutes to complete.

Twenty-one pretest surveys were conducted to provide input for the development of the final question wording, order, and overall format for a questionnaire (Appendix C). One-hundred and fourteen (114) surveys were conducted during three separate periods: July, September, and November of 1986.

These months were chosen based on information and experience indicating that they coincided with increasing (July), peak (Sept.), and declining (Nov.) flea populations in this area.

6.2.1 Data Analysis

All data were coded and analyses were performed using Statistical Analysis System programs (SAS 1985). All data in the form of percentages were transformed using an arcsin square-root plus one transformation prior to statistical analysis. Parametric statistical procedures that were used to analyze the data included, Pearson X^2 tests to observe the strength of association between variables, linear regression procedures to observe for significance of relationships between continuous variables, analysis of variance procedures to test for significant differences among variable means, and Student Neuman Kewell's procedures were used to separate the means (Sokal and Rohlf 1981). Spearman's rank correlation test was used for nonparametric analysis (Sokal and Rohlf 1981). For all analyses, an alpha level for significance was set at 0.05.

6.3 RESULTS AND DISCUSSION

The majority (76%) of the respondents were female. The average age of the respondents was 41 (SEM = 1.14) and the average salary of the respondents was nearly $20,000 (mean $\pm$ SEM = 19,887 $\pm$ 804), and nearly all (84%) lived in a house, versus a mobile home or apartment. On the average, the respondents owned 3 pets (SEM = .244) (dogs or cats). The mean percentage ($\pm$ SEM) of the day that the animal(s) spent within the domicile was 55% ($\pm$ 3.2%), and was not associated with the number of animals that the respondent owned (ANOVA: F = 0.923; P = 0.3387).

6.3.1 Perceptions of Flea Infestations

Respondents were asked how they rated the flea problems on their pet(s) in the past two months on a scale from zero to ten, ten being the worst. In a separate question they were asked to rate the flea problems in their home on the same scale. Due to the subjectivity of the rating scale for both questions, analyses were conducted on three classes of the perceptions of flea infestations on the pet and in the home; 0 = none, 1 - 5 = moderate, and 6 - 10 = severe.

There was an association between the month when the survey was conducted and the pet owner's perception of the flea infestation on their pet (X^2 = 14.67; df = 4; $P < 0.005$). Significantly more (71%) of the September respondents rated pet infestations as being severe than those of the July (29%) or November survey period (X^2 = 83.77; df = 2; $P < 0.005$). There was also an association between the month when the survey was conducted and the pet owner's perception of the flea infestation in their home (X^2 = 11.83; df = 4; P = 0.019). Significantly more (75%) of the respondents surveyed during September rated household infestations as being severe compared to the July (12%) or the November (13%) respondents (X^2 = 106.79; df = 2; $P < 0.005$).

Ratings for for an individual's perception of the household flea infestation was closely associated to the rating for their perception of the infestation on the pet for all survey periods (Spearman Rank Correlation Coefficient = 0.768; $P < 0.0001$). This indicates that pet infestations and household infestations go hand-in-hand in the minds of pet owners. The rating given to the infestation on a pet was almost always greater than (49%) or equal to (45%) their rating of the household. Their association of the severity of the problem on the pet was significantly greater than or equal to that in the home (X^2 = 34.21; df = 2; $P < 0.005$). This suggests that the pest status of this insect is partly psychological. The observance of the family pet in

physical discomfort apparently evokes a stronger response and resultant perception of the severity of the problem than the occasional presence of adult fleas in the domicile.

Pet owners were asked whether flea problems had become better, worse, or stayed the same in the past three years. About half (47%) of those surveyed reported that the problems had stayed the same, while the remaining 52.6% were split between considering the problem worse (27%) and better (26%).

6.3.2 Knowledge of Flea Biology and Habits

Pet owners were asked where they thought fleas were "breeding" in their home. Half of the respondents (50%) said that carpet was the breeding site, 30% identified outside areas, and the remaining 20% identified the pet, or furniture, or did not know. Educating homeowners/pet owners about basic biology and habits of a target pest is an important part in the design and implementation of effective pest management strategies (Robinson and Zungoli 1985, Wood et al 1981). The results of this survey indicate that the average homeowner should be informed that the animal is the adult flea breeding site and that flea eggs fall from the host to develop as larvae in furniture, pet bedding, and carpet. This could improve the effectiveness of homeowner control tactics such as vacuuming and other methods of mechanical control.

6.3.3 Tolerance to Flea Infestations

Urban entomologists have reported on the tolerance thresholds of a variety of target audiences for cockroaches of different species (Thoms and Robinson 1986, Zungoli and Robinson 1984; Wood et al. 1981), mosquitoes (Robinson and Atkins 1983), and other insects (Byrne et al. 1984). In this survey, respondents were asked

how many flea bites, and in a separate question, how many sightings of fleas they or members of their family would tolerate before reacting to control them. The respondents indicated that they tolerated more flea bites (1.28) (ANOVA: $F = 8.54$; $P < 0.0004$) and sightings (2.22) of fleas (ANOVA: $F = 5.92$; $P < 0.0037$) in November, the time when the flea populations would be declining, than they did during the July (bites = 0.76; sightings = 1.39) or September (bites = 0.99; sightings = 1.66) sampling periods.

The apparent tolerance level variability for fleas is strikingly different from that reported for German cockroaches by Zungoli and Robinson (1984). They reported that tolerance thresholds were variable given the condition of a cockroach population. When cockroach populations were high, the audience's tolerance threshold was correspondingly high, yet when the population declined there was a decline in the tolerance threshold. In the present survey, results opposite that of Zungoli and Robinson (1984) were observed. Homeowners seeing fewer fleas and receiving fewer bites during the decline of a household flea population had an increased tolerance.

6.3.4 Willingness to Pay

The average amount that the respondents indicated they were willing to pay per month, during the flea season for a "flea-free" environment, was $25.15 (SEM = 1.72). The time when the survey was conducted (July, September, or November) influenced the amount that the individuals were willing to pay per month to completely eliminate flea problems from their home and/or pet(s) (ANOVA: $F = 7.65$; $P < 0.0009$). Pet owners stated that they were willing to pay significantly more (mean = $32.78) for a flea-free environment in July, than they were willing to pay in September (mean = $24.81) or in November (mean = $17.60) which were not

significantly different. Their willingness to pay more in July may indicate that they make initial purchases of insecticide products and services when flea populations are first noticeable. Some of the flea-control products may last throughout the remainder of the flea season.

The willingness to pay for flea control was dependent on the number of pets owned by the respondent (ANOVA: $F = 5.23$; $P < 0.025$). Through the estimate of the slope from the regression line ($Y = 1.46X + 21.04$), for each additional pet the respondents were willing to pay $1.46 more for flea control.

The respondents were willing to pay more for control of the problem as their perception that the intensity of the problem increased. The pet owner's willingness to pay for flea control was dependent on their perception of the infestation on the pet (ANOVA: $F = 13.72$; $P < 0.0004$) and in the home (ANOVA: $F = 13.15$; $P < 0.0005$). The significance of the response to flea infestations is enhanced considering that the salary of the household was not related to the homeowner's willingness to pay to eliminate fleas from the pet or house ($F = 3.40$; $P < 0.069$). Regardless of the socio-economic class of the family that owns a pet, there is no certain percentage of the annual income that homeowners would devote to flea control. Unlike some other urban pests, such as cockroaches, fleas pose a problem of physical irritation, unlike cockroaches which are primarily an aesthetic pest.

6.3.5 Actual Expenditures for Flea Control

The average amount of money that the respondents had spent on flea control in the two months prior to the survey period, combined over all of the survey periods, was $15.21 (SEM = 1.40). The actual expenditure for flea control products and services was not related to the time when the survey was conducted (ANOVA: $F = 0.88$; $P < 0.418$). The costs incurred by the pet owner also were not related to the

annual income of the household (ANOVA: $F = 0.11$; $P < 0.739$). Apparently, money is spent to reduce problems from flea infestations, regardless of the family income.

The actual amount of money spent by homeowners for flea control did not approximate what the respondent was willing to pay ($F = 1.274$; $P < 0.264$) ($Y = 0.19X + 25.72$). The question on willingness-to-pay was for a one-month period during the flea season, while the actual amount spent was for the two-month period prior to the survey. In many (19%) cases the respondents had already spent more money in two months than they had stated they were willing to pay in one. Responding to a question on how much they would be willing to pay involves speculation or imagination on the part of the respondent. The intangible amount that someone projects as to what they are willing to spend does not always equate to what is actually spent. The average homeowner may not realize how much they have actually spent on flea control products and services until asked to add up total expenditures.

6.3.6 Comparative Pest Status of Fleas

Individuals were given a choice between fleas or an alternate household pest. Each was then asked which was considered to be a more serious problem if both were harboring in their home. Fleas (94%) were thought to be more important than house flies (6%) ($X^2 = 38.72$; $df = 1$; $P < 0.005$), spiders (20%; fleas - 80%) ($X^2 = 18.00$; $df = 1$; $P < 0.005$), and ants (24%; fleas - 76%) ($X^2 = 13.52$; $df = 1$; $P < 0.005$). The responses to the choices between fleas (59%) or mice (41%) and fleas (51%) or cockroaches (49%) were not found to be significantly different.

There were apparent physical, psychological, and aesthetic factors involved in the choices. Mice may be a psychological nuisance; they do not pose a serious physical (health) threat nor do they usually cause serious structural damage. House flies and ants probably elicit responses similar to those of mice, but ants can be very persistent and frustrate homemakers. Spiders elicit fear in many people and hence a fairly high percentage of people thought they were worse than having fleas. Cockroaches are considered to be disease carrying, noxious, and unaesthetic to homeowners (Wood et al. 1981). The close comparison to fleas in terms of intolerability from the survey indicate that homeowners will no more tolerate the meandering habits of cockroaches than the jumping and biting habits of fleas.

6.4 CONCLUSIONS

The economic importance and the pest status of flea infestations appears to be based on physical, psychological, and economic impacts on homemakers. Individuals surveyed during September rated flea infestations in the home and on the pet as being more severe than July or November respondents. The respondent's perceptions of infestations on the pet were associated with that in the house over all of the survey periods. The tolerance threshold for flea infestations was found to be variable. Respondents tolerated more flea bites and sightings when populations were declining, during the November survey period, than during July or September. The respondents were willing to pay significantly more money for flea control in July (i.e. at the onset of the flea season) than they were at the peak or the decline of flea infestations. They were also willing to pay more as their perception of the intensity of the problem on the pet or in the home increased. The household income did not affect the respondent's actual expenditures or their willingness to pay for flea control on their pet or in their home.

Pet ownership in the urban/suburban sector has risen over the past decade and will probably continue to do so. Flea populations have a secure niche in this environment and pose unique challenges to pest control practitioners. To effectively control or manage flea infestations, the needs and expectations of the receivers of pest control products and services should guide pest management actions and evaluate their degree of success. Pest management practices should be designed and implemented with these needs and expectations in mind.

CHAPTER VII

SUMMARY:

THE PAST, PRESENT, AND FUTURE OF INTEGRATED PEST MANAGEMENT OF CAT FLEA INFESTATIONS IN THE HOME ENVIRONMENT

7.1 INTRODUCTION

The research discussed in Chapter I has provided some basic information on the biology, behavior, and control of various life stages of the cat flea. This information provides a foundation for future research based on biological principles.

In many cases, this earlier research on the cat flea has been of a basic scientific nature. Future research of a more applied nature on cat fleas and cat flea populations is needed, given the household habitat and pest status of this insect. The research reported here was designed and carried-out with this in mind. The information obtained in these studies could then be incorporated into a pest management strategy. The results of this research do not answer all of the remaining questions about cat flea biology, behavior, or control. In fact, it proposes more questions than it answers.

7.2 PRESENT RESEARCH

A series of research projects which have attempted to afford a composite approach to a cat flea integrated pest management program are presented.

Initially, larval behavior was investigated. Although the larval stage is not normally the stage causing problems, it is the primary target stage when insecticides are applied indoors. The behavior of this stage within the carpet environment directly affects the success of chemical control. If the target stage and the insecticide are not in the same place at the same time, control efforts will be less than optimal. The positive geotactic and negative phototactic behavior of the larva result in its harboring at the base of carpet pile for a large portion of time. These behaviors require that insecticides penetrate to the base of carpet pile if they are to be maximally effective.

The studies on the penetration of insecticides applied with a compressed-air sprayer carpet pile showed that the solution penetrated approximately 6 mm into the pile. In many households in the U.S. the thickness of the pile in carpets is far greater than 6 mm thus the insecticide is not being placed in the location of the target pest.

Cat flea larvae were also found to exhibit a coiling behavior when disturbed. In the carpet environment this coiling results in the larvae acquiring a secure hold on its substrate, preventing its removal. A vacuum extraction study was conducted to quantify the percentage recovery of cat flea larvae and eggs from carpet over a range of 4 qualities defined by pile height and fiber density. The morphological characteristics (segmental setae), and the behavioral response of coiling resulted in the removal of less than 30% of the larvae, given any of the carpet qualities tested.

The studies on egg and larval dispersion demonstrated that the habits of the pet are primarily responsible for the dispersion and location of immature stages in the indoor environment. Eggs were deposited onto those carpeted areas frequented by the pet. First instar larvae were shown not to move from the location of eclosion. Second instar larvae also did not appear to move far from the location of egg

deposition. These results are important in that they can be used to predict where larval populations will be located, enabling pesticide applicators to place insecticides in a more efficacious manner.

The accurate prediction as to where concentrations of immature stages will be located, requires communication with the homeowner. Customer observations of pet habits during the flea season can be used to direct the pest control technician to areas where the pet frequents.

A survey of pet owners was also conducted to acquire information on the pet owner's knowledge of cat flea biology and habits, and their perceptions of infestations. The results of this survey demonstrated that customers of flea control services need to educated about cat flea biology and habits, and about control tactics that should be conducted by the homeowner such as vacuuming, and sanitation of the pet bedding areas. A cooperative environment between the pest control technician and the customer will benefit both, and will result in better control of a flea infestation. The target audience should be continuously surveyed, and consulted to ensure that the pest control research is discovering and delivering what is needed. This close association also permits the evaluation of pest management programs in terms of their success or short-comings.

The insecticide application equipment most commonly used for indoor flea control was examined with regards to efficiency. Nozzles were evaluated as to their pattern formation at the attainable and usable pressures generated from the spray system. The conclusions drawn from these studies indicated that the 800067 and the 50015 nozzles are not optimally compatible with the pressurizing system. Theses nozzles were designed to be used at 40 psi, yet the pressurizing system can not maintain this pressure for more than one minute. Many pest control companies will not allow a technician to set the sprayer down within the home of a customer. This

prevents re-pressurizing the tank and results in the technician using pressures below those recommended for the nozzle. Accurate patterns and flow rates cannot be achieved at these lower pressures. This suggests that insecticides are being applied ineffectively and inefficiently into the home environment.

7.3 FUTURE RESEARCH

Research which has been conducted in the past, and that which is presently reported has afforded a much clearer view of the indoor situation with respect to cat flea infestations. Information is still needed on the habits of the adult cat flea both on and off the pet. The adult fleas that are found on the pet influence nearly all parameters of an indoor infestation, yet little is known about the movement of adult fleas from outdoors to indoors. Another broad area of research that has been largely ignored is that concerning the biology, behavior, and control of outdoor flea populations. The information currently available on indoor infestations of the immature stages of the cat flea represents a small portion of that necessary for the design of effective pest management programs.

The existing basic control strategy for cat flea infestations involving treatment of the pet, and treatment of the indoor environment is sound, but there are other tactics which have yet to be investigated. In terms of non-chemical control tactics, steam-cleaning carpet could be effective against those stages located within this environment. However, to date no studies have been made of this as a possible control tactic. Alteration of the indoor environment with regards to temperature and relative humidity, may also have some practical, non-chemical applications. This sort of environmental manipulation has never been experimentally examined as a method for controlling indoor flea infestations.

Insecticide application systems could be improved. Different nozzles could be used with the same pressurizing system to achieve more effective and efficient usage of insecticides in the home environment. Also, new approaches for the application of insecticides to carpets for flea control should be developed, this would enable the applicator to deliver insecticides to the locations where the immature stages of the cat flea harbor.

7.4 CONCLUSION

Optimal pest management strategies should incorporate a variety of sources. Information on the target pest and target audience should be associated with acceptable yet effective methods of control. Methods of evaluation which utilize the perceptions and objectives of the target audience should be incorporated into the pest management program.

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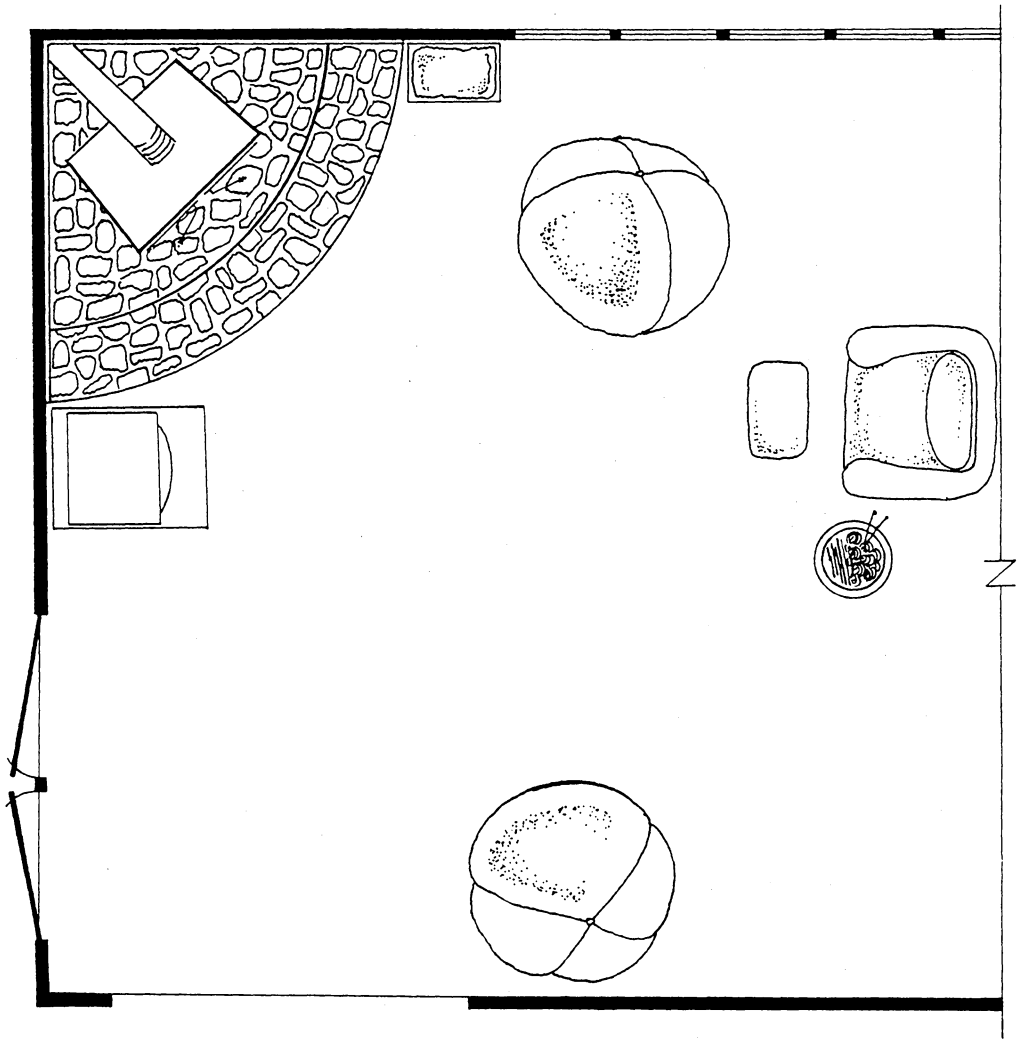
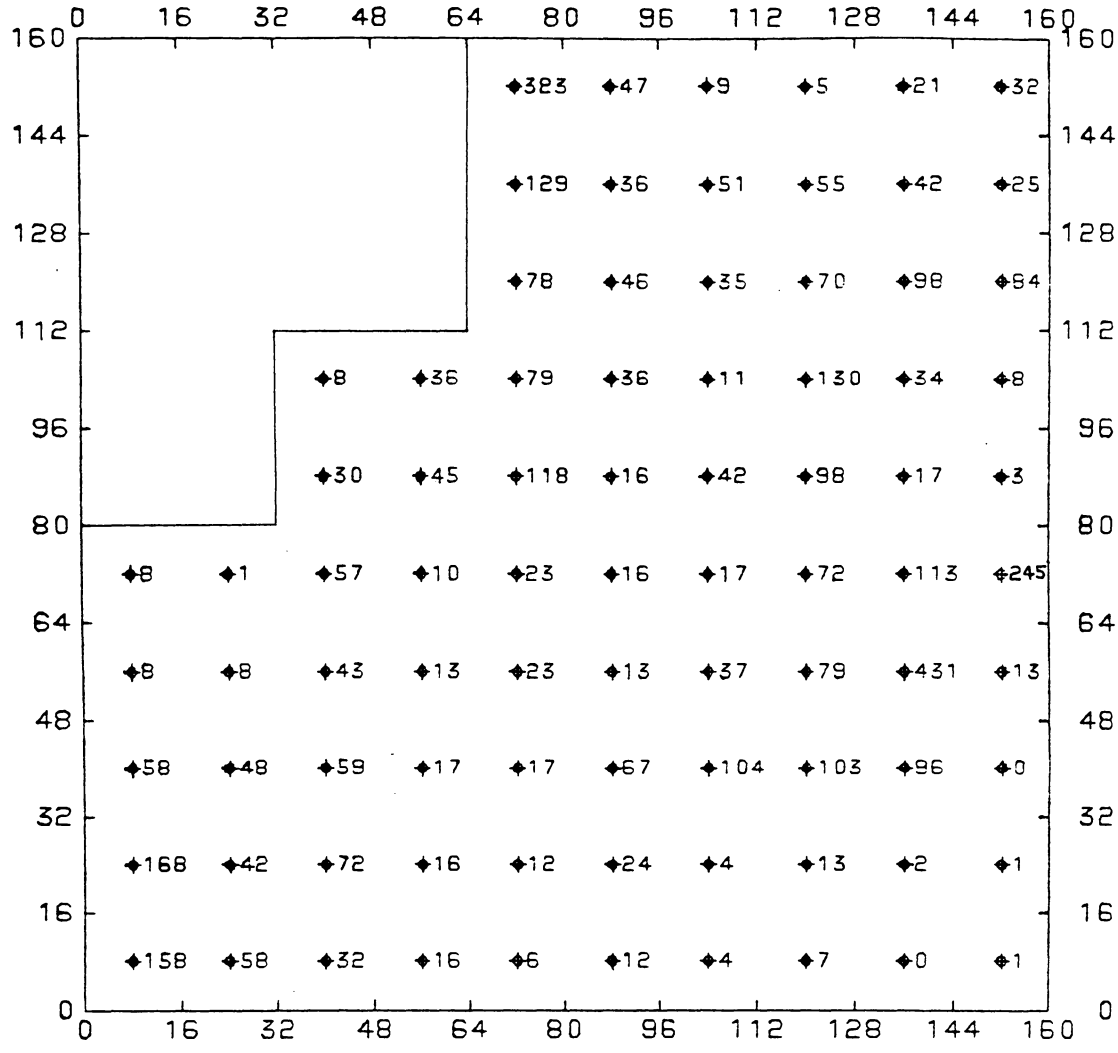


Appendix A-1: Posting of tally data for hatched eggs from family-room (scale: 1 cm = 1 ft).



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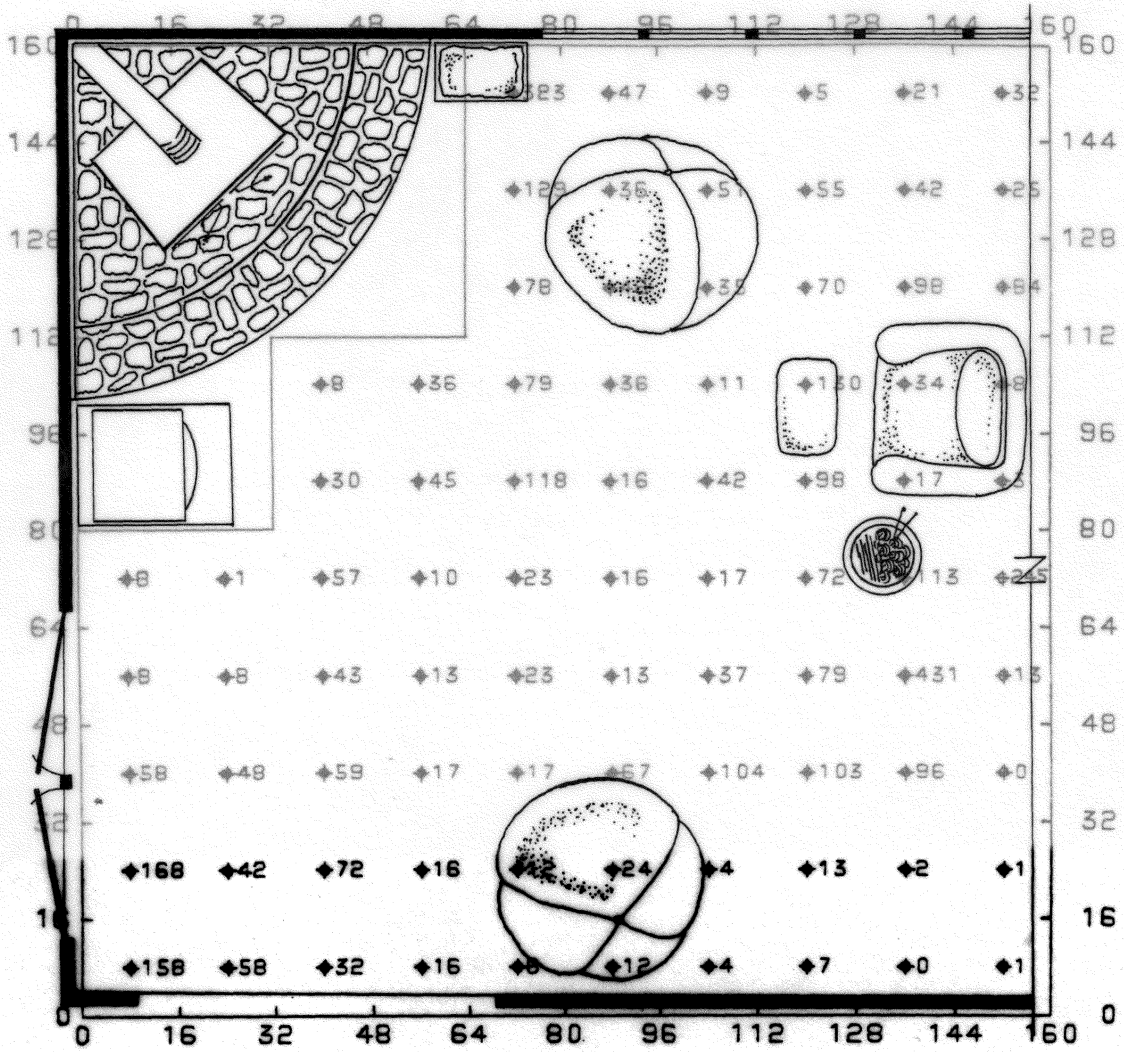

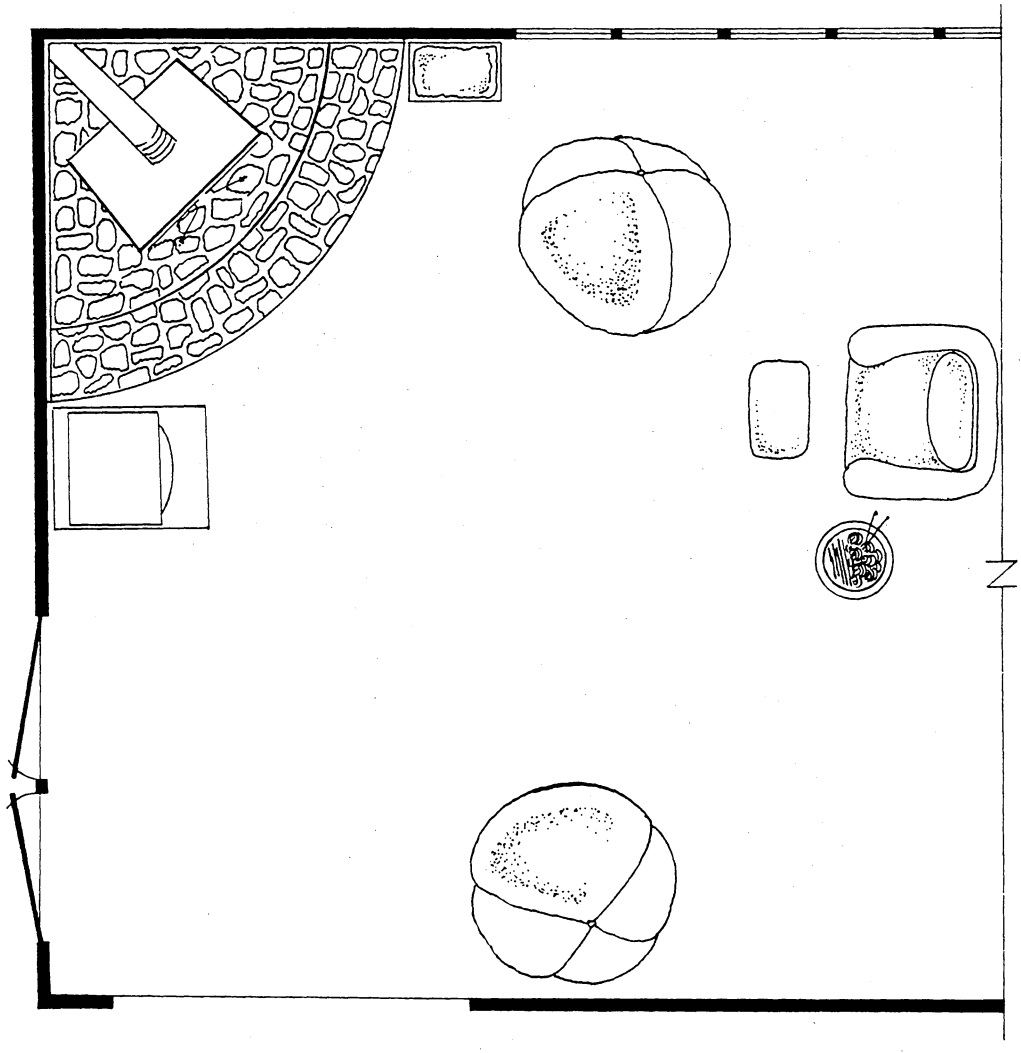

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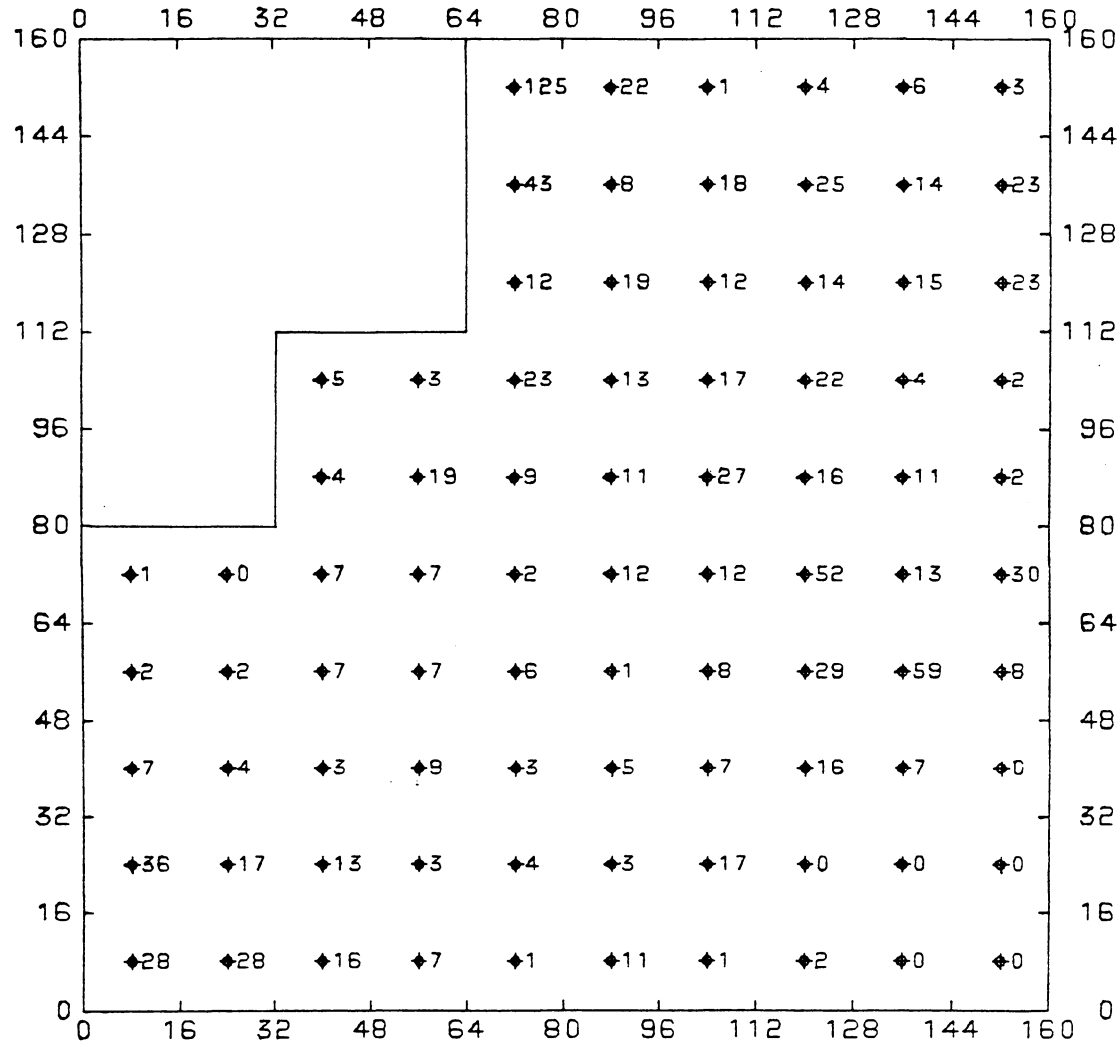
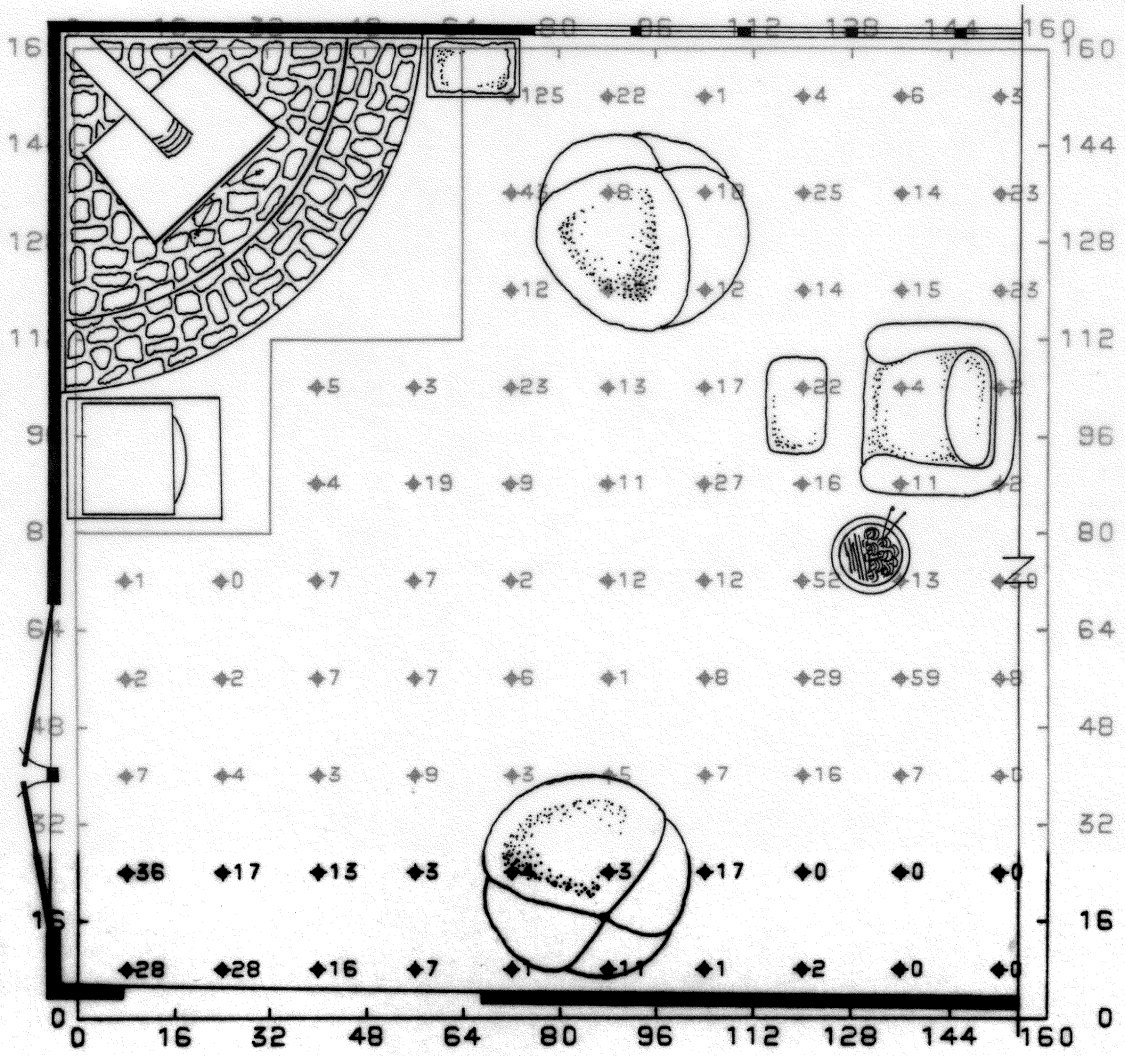
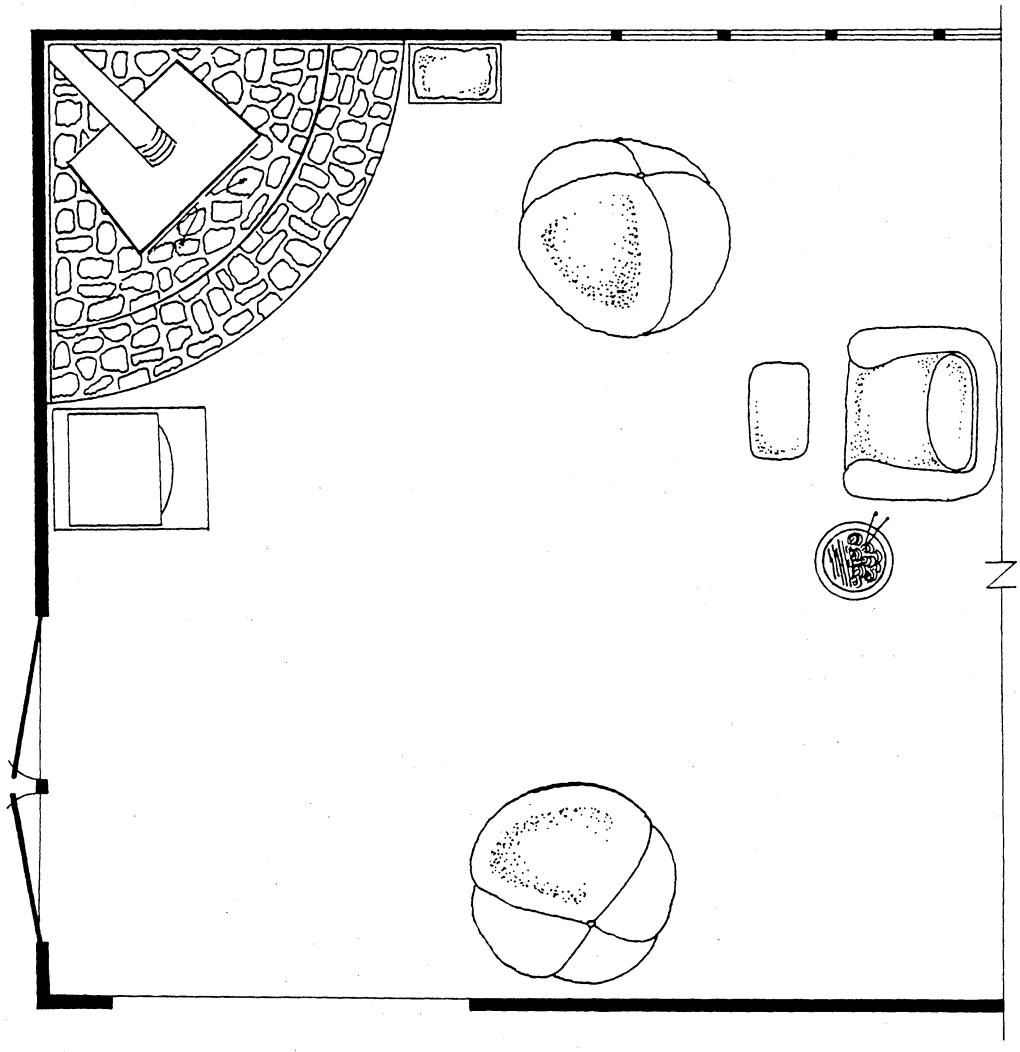
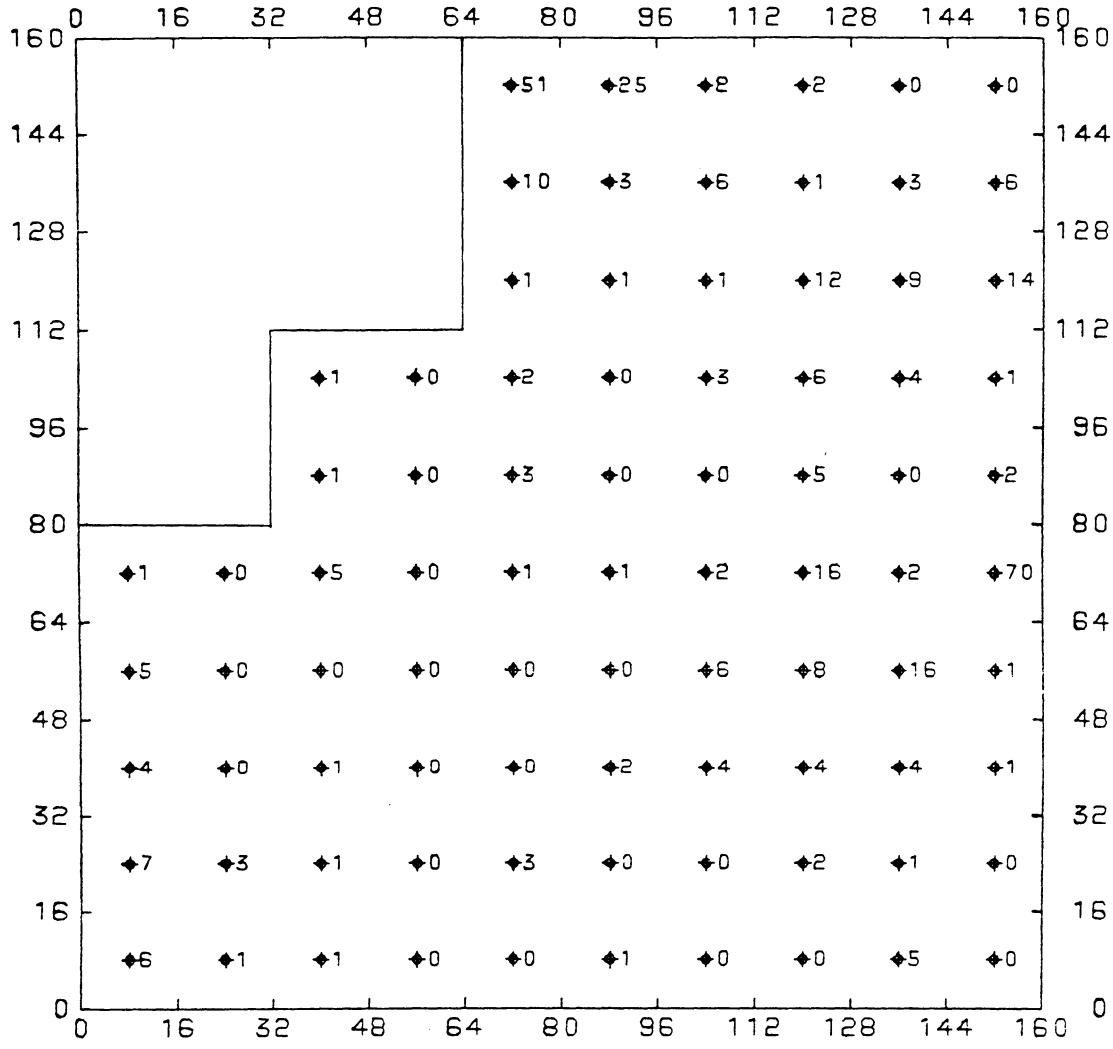


Appendix A-2: Posting of tally data for unhatched eggs from family-room (scale: 1 cm = 1 ft).

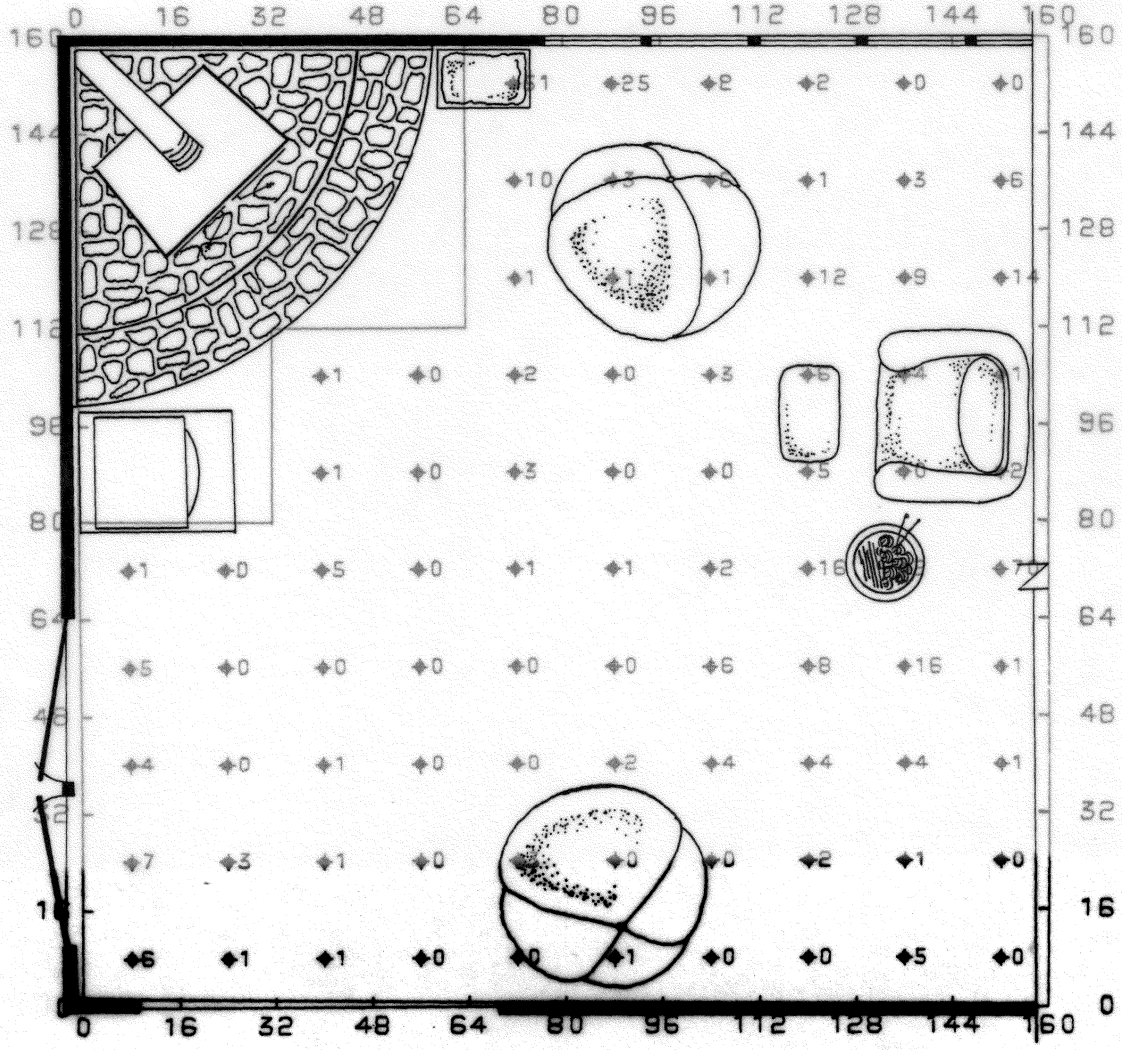


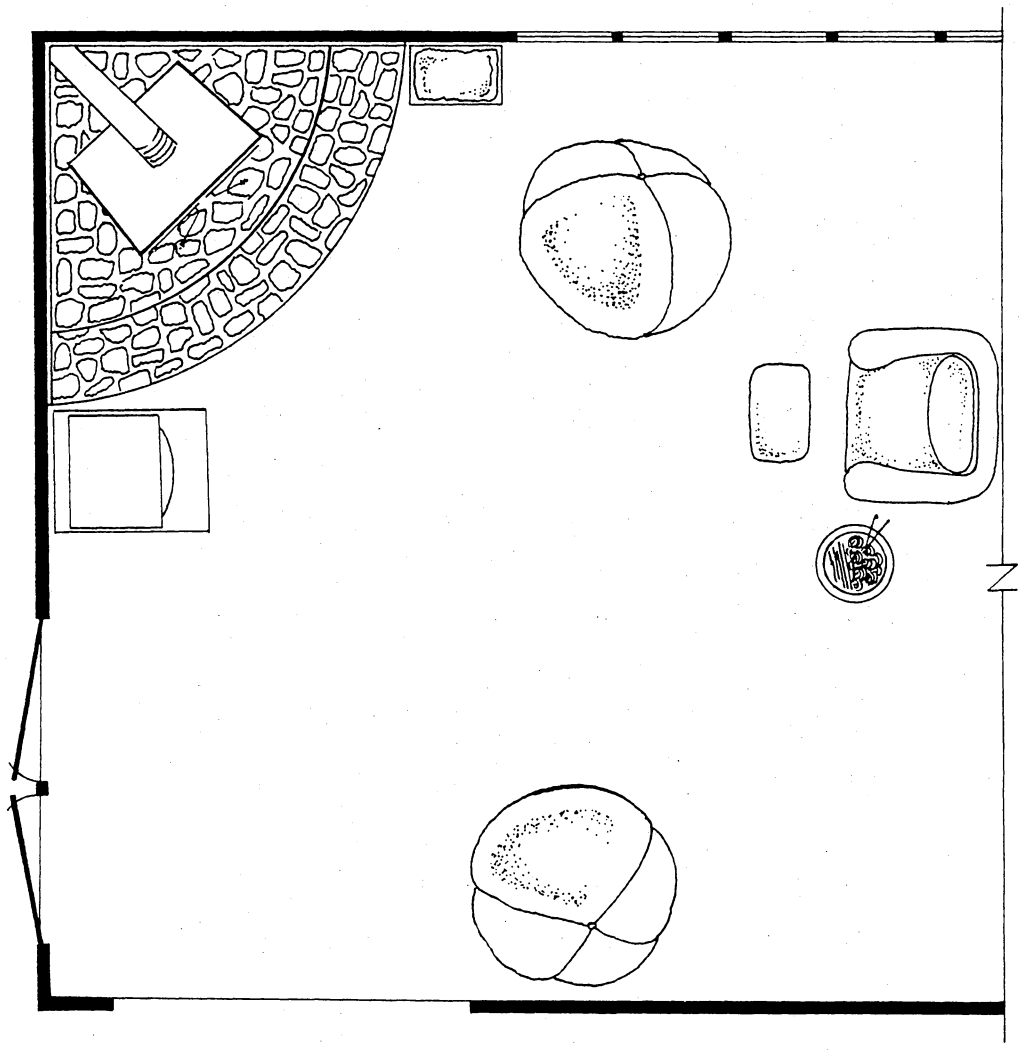


Appendix A-3: Posting of tally data for larval exuviae from family-room (scale: 1 cm = 1 ft).

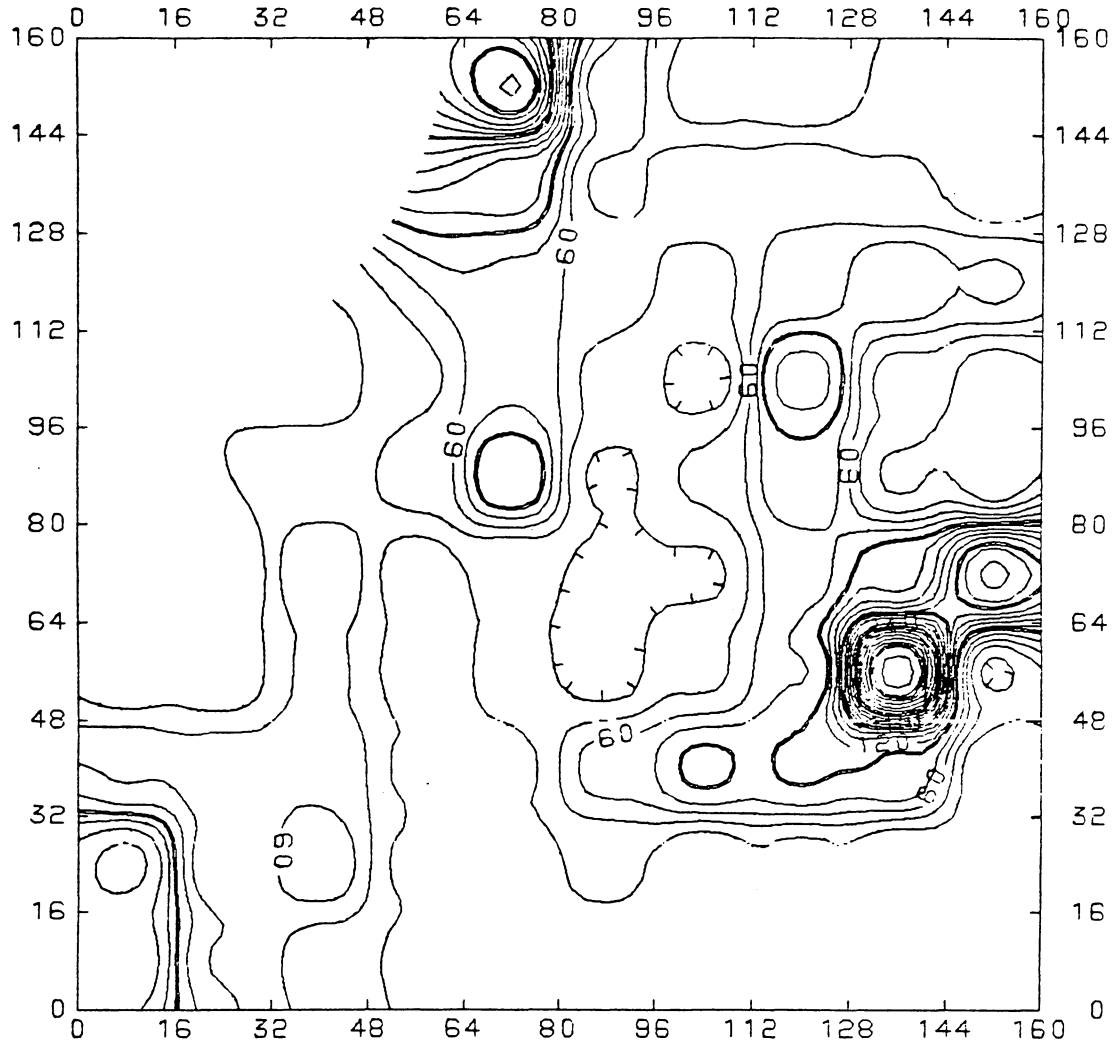


Appendix A-3: Posting of tally data for larval exuviae from family-room (scale: 1 cm = 1 ft).

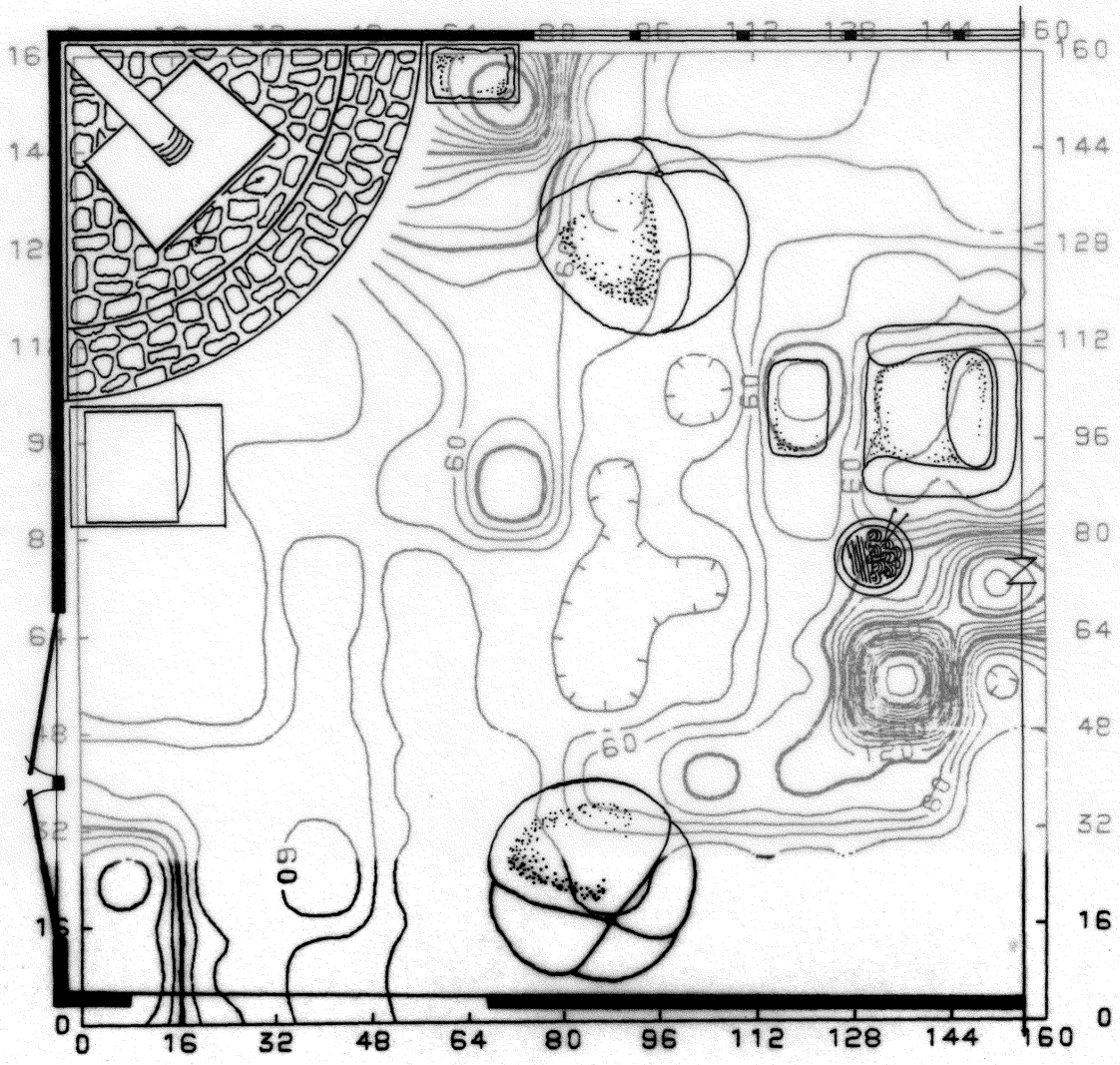


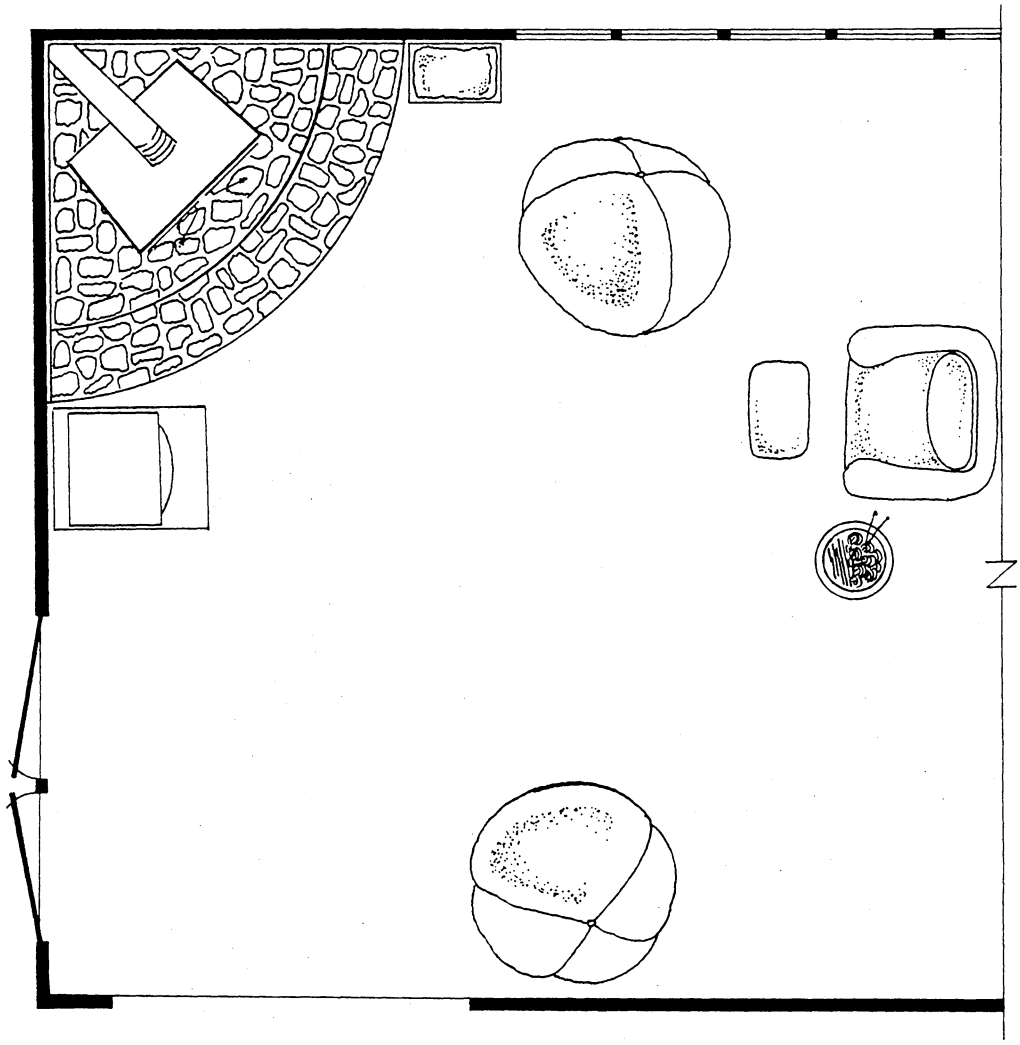


Appendix A-4: Contour map of hatched eggs from family-room (scale: 1 cm = 1 ft; contour interval = 20).

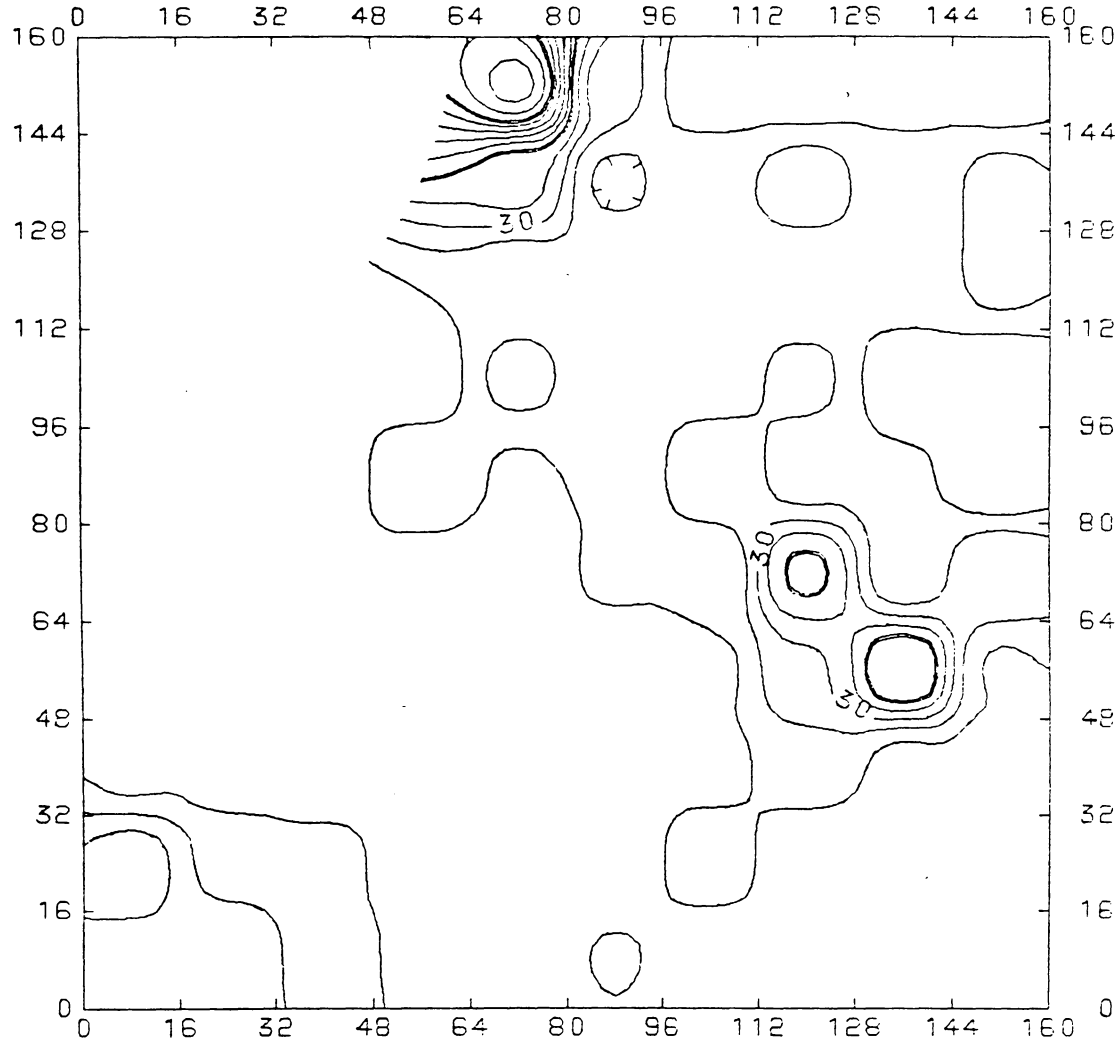


Appendix A-4: Contour map of hatched eggs from family-room (scale: 1 cm = 1 ft; contour interval = 20).

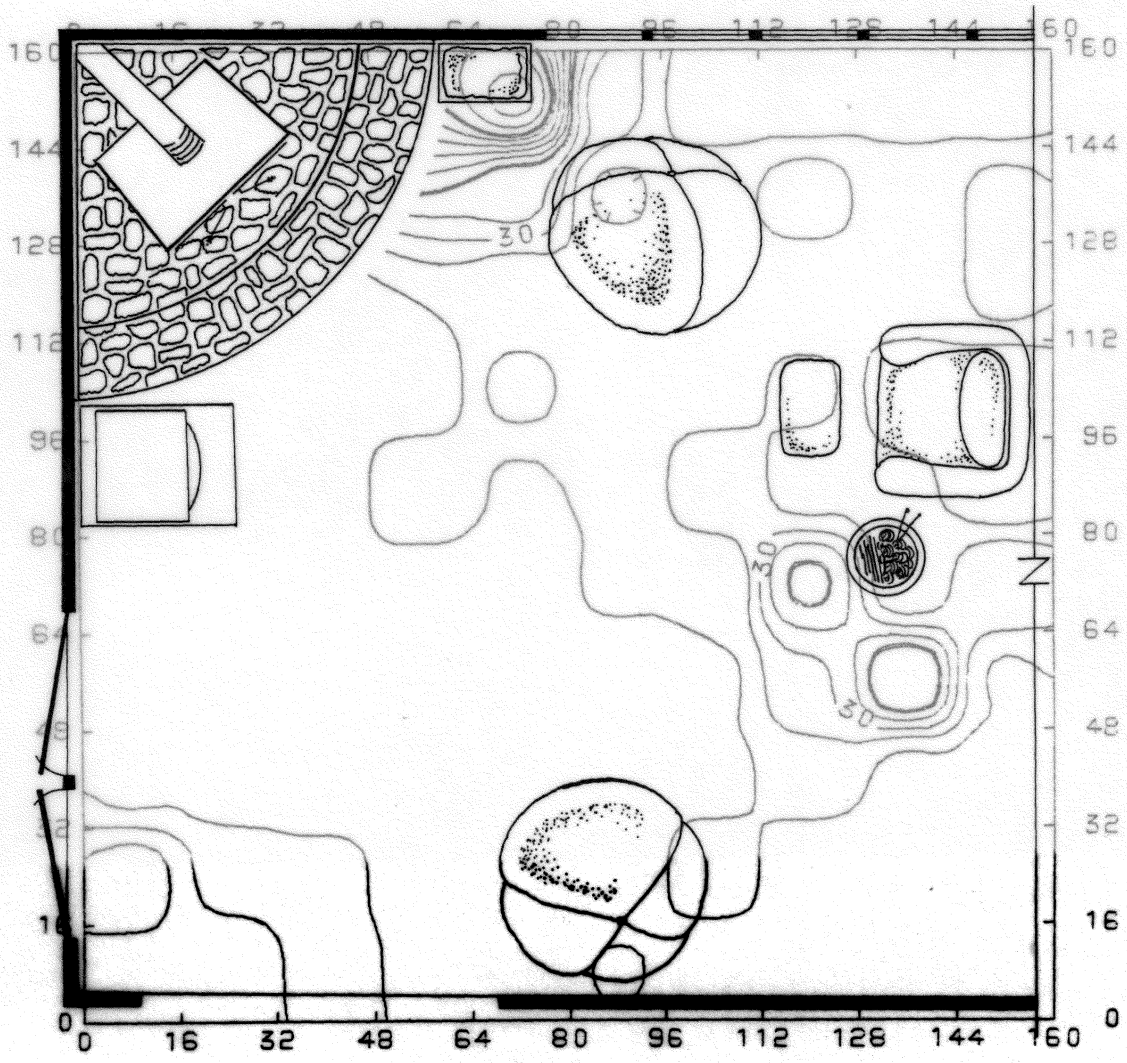


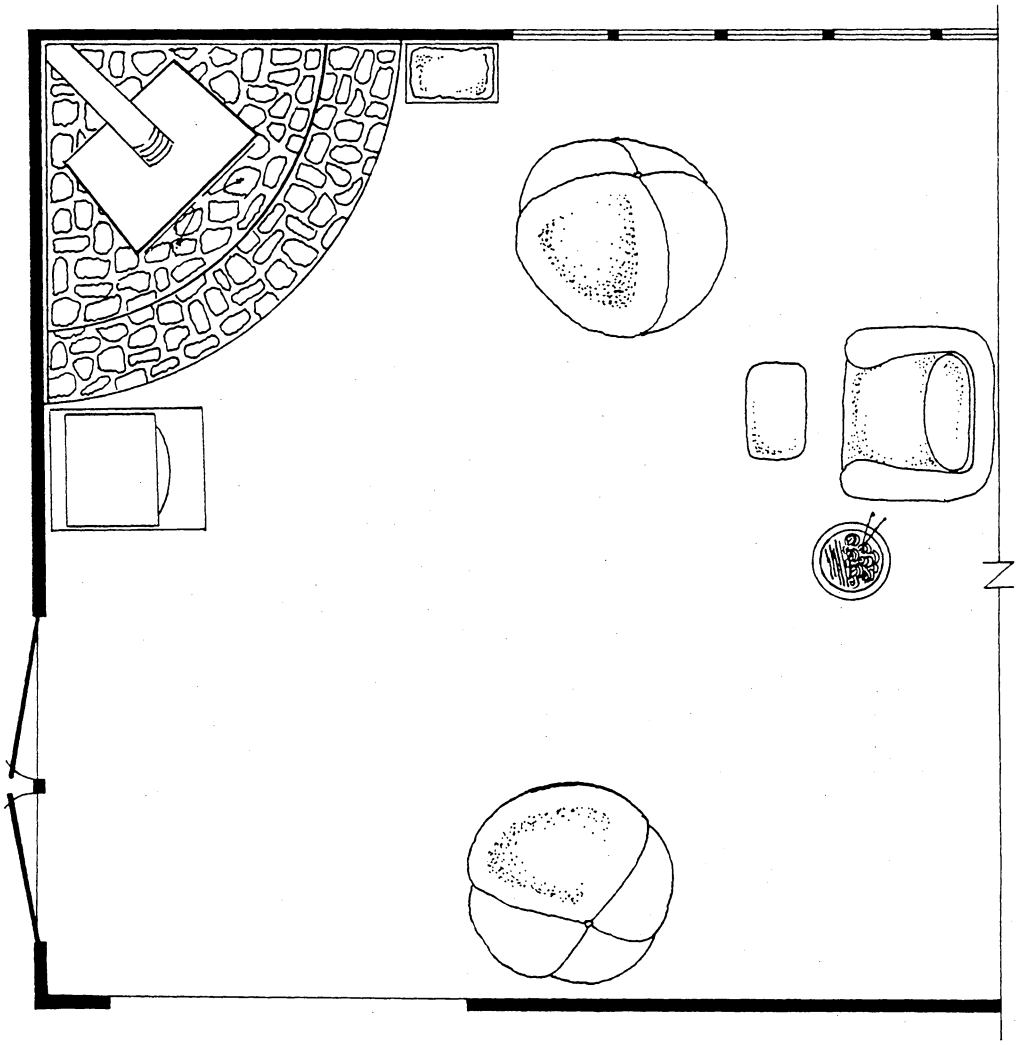


Appendix A-5: Contour map of unhatched eggs from family-room (scale: 1 cm = 1 ft; contour interval = 10).

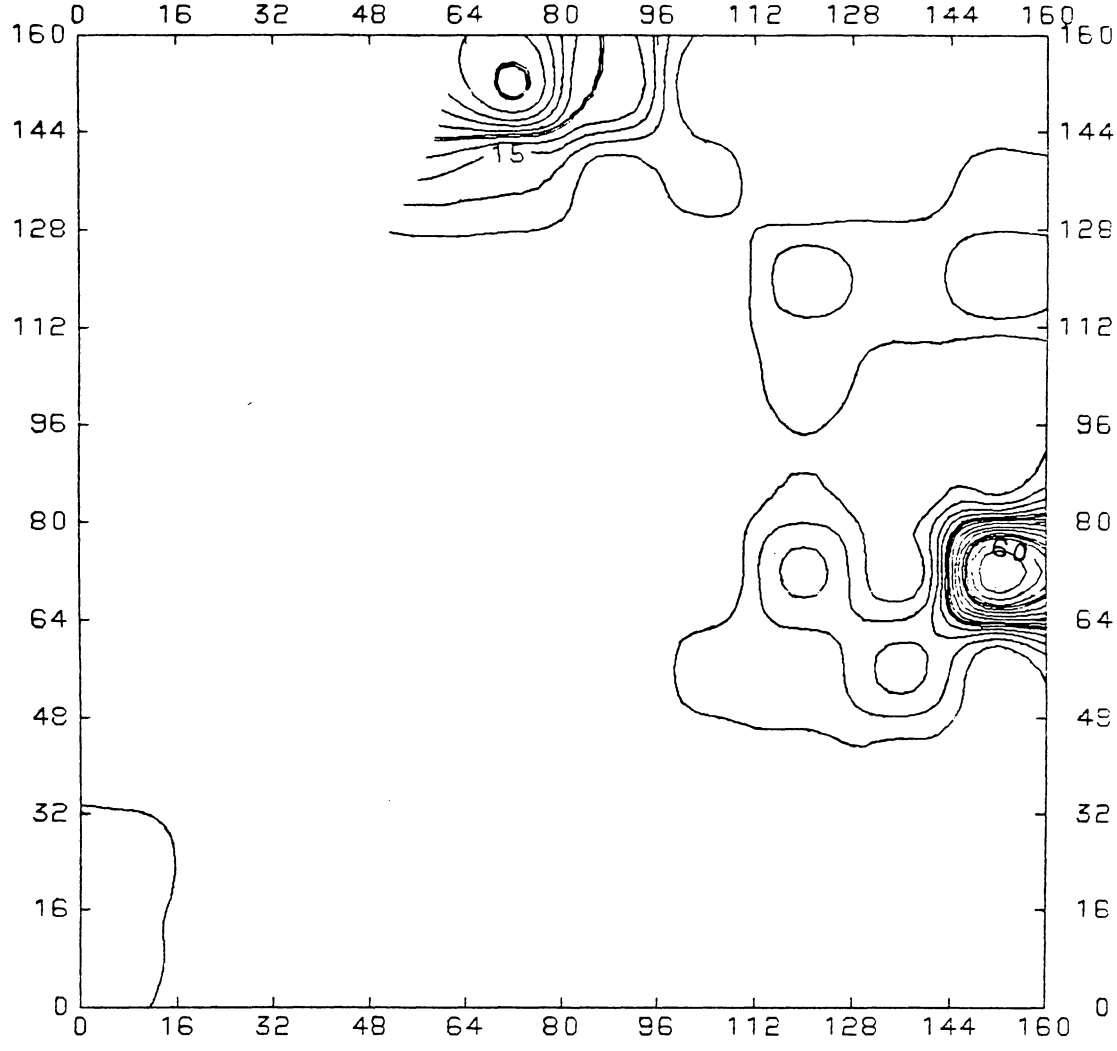


Appendix A-5: Contour map of unhatched eggs from family-room (scale: 1 cm = 1 ft; contour interval = 10).

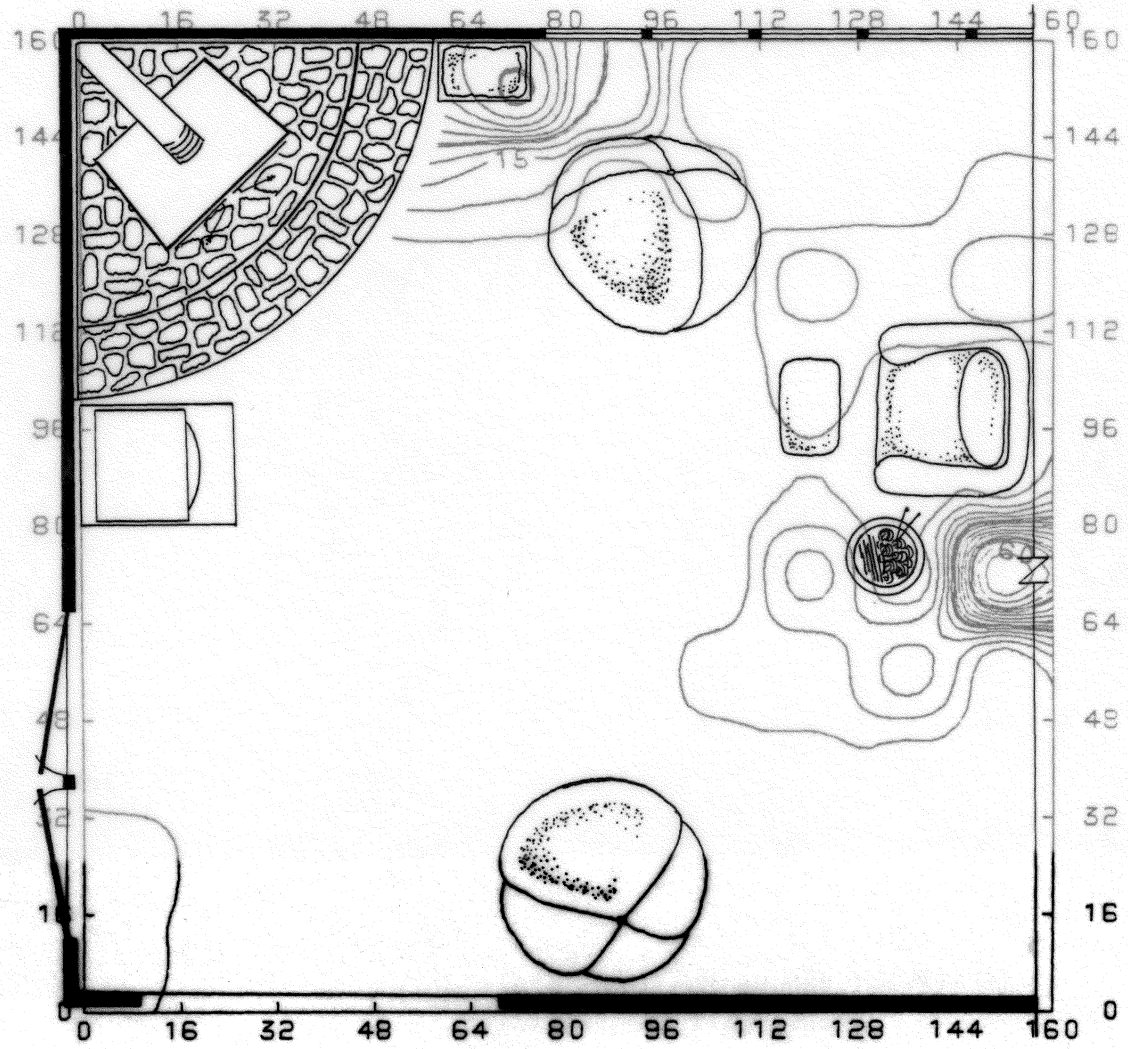


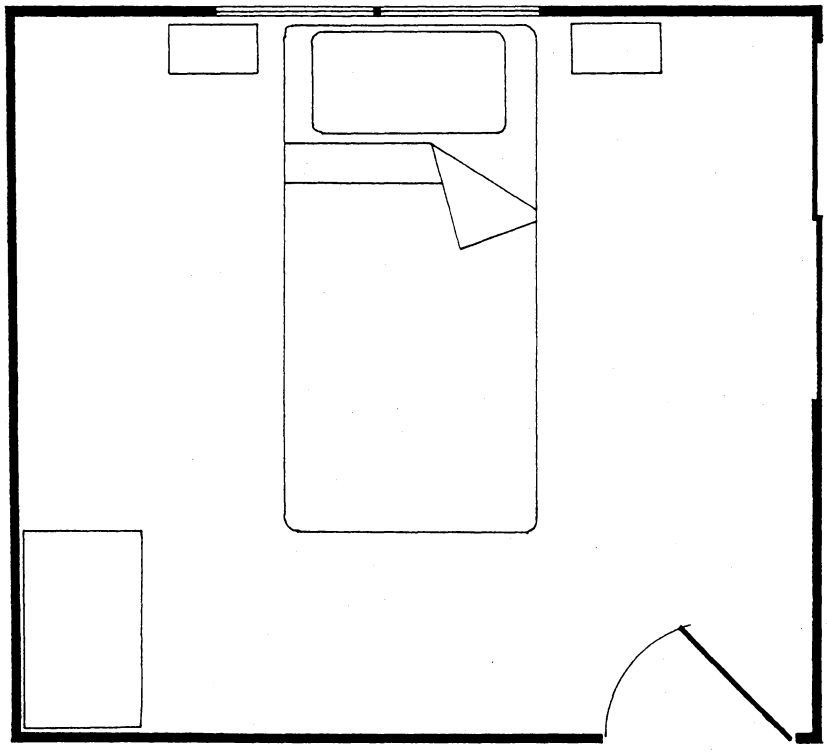


Appendix A-6: Contour map of larval exuviae from family-room (scale: 1 cm = 1 ft; contour interval = 5).

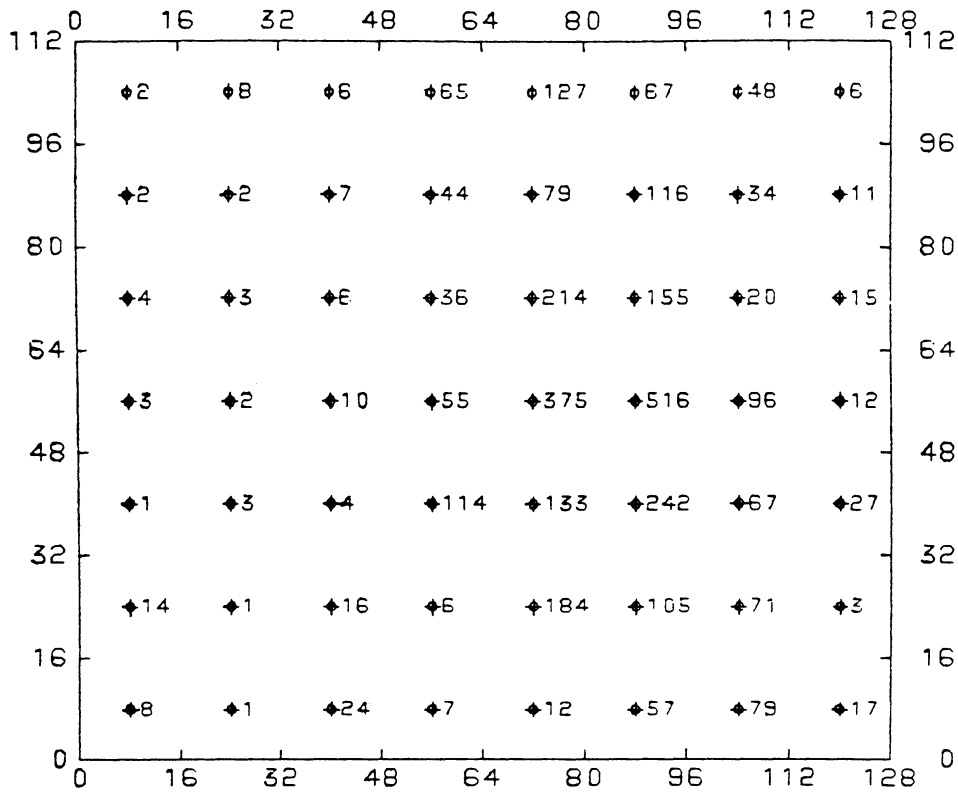


Appendix A-6: Contour map of larval exuviae from family-room (scale: 1 cm = 1 ft; contour interval = 5).

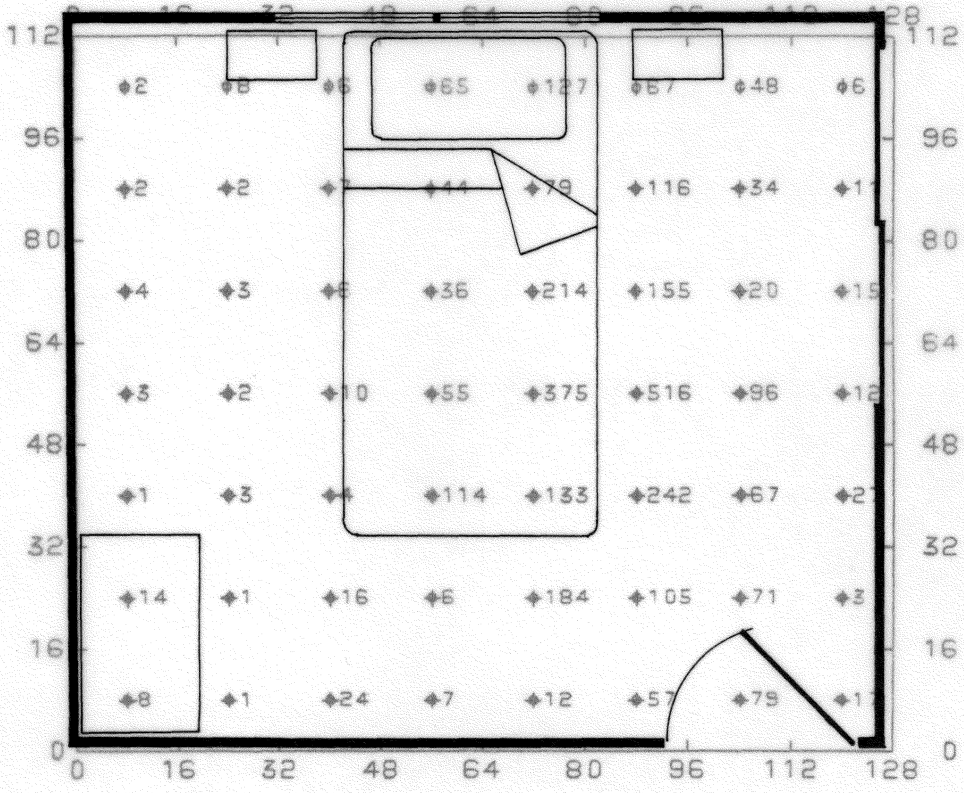


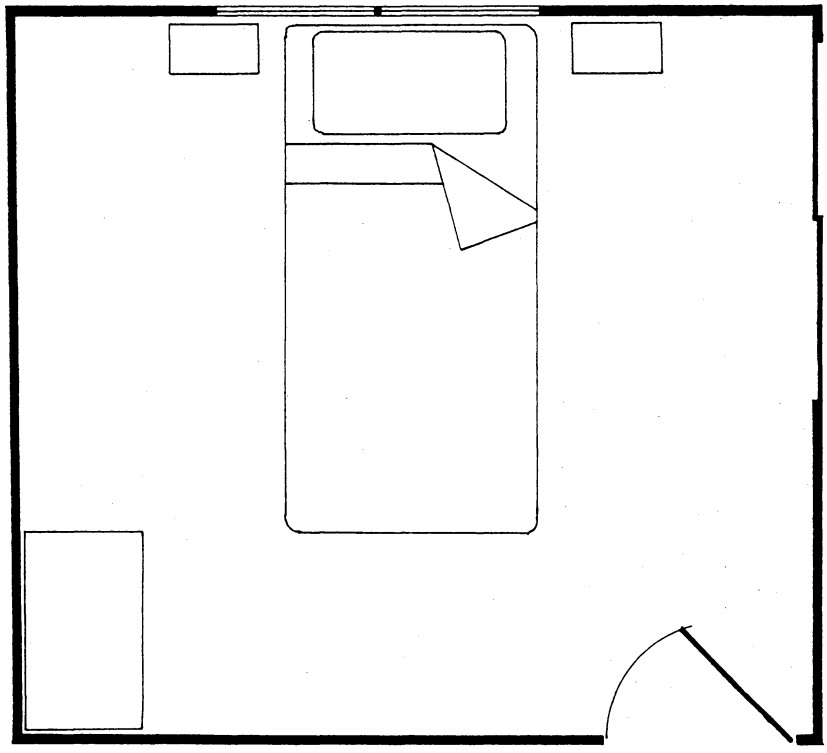


Appendix B-1: Posting of tally data for hatched eggs from bedroom (scale: 1 cm = 1 ft).

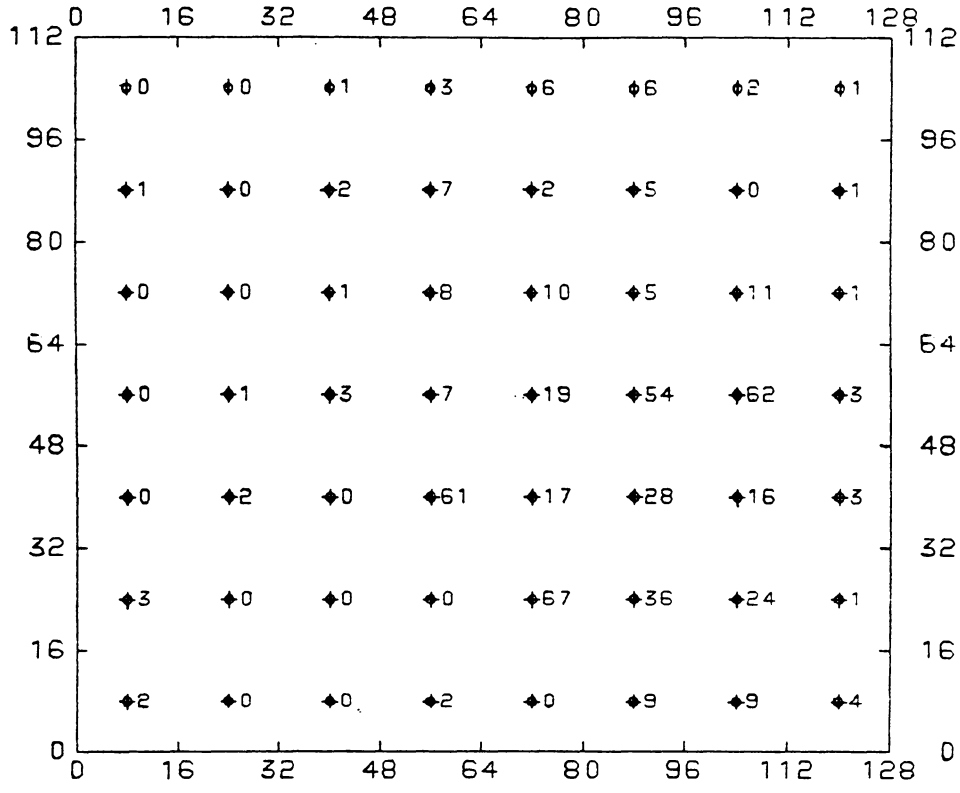


Appendix B-1: Posting of tally data for hatched eggs from bedroom (scale: 1 cm = 1 ft).

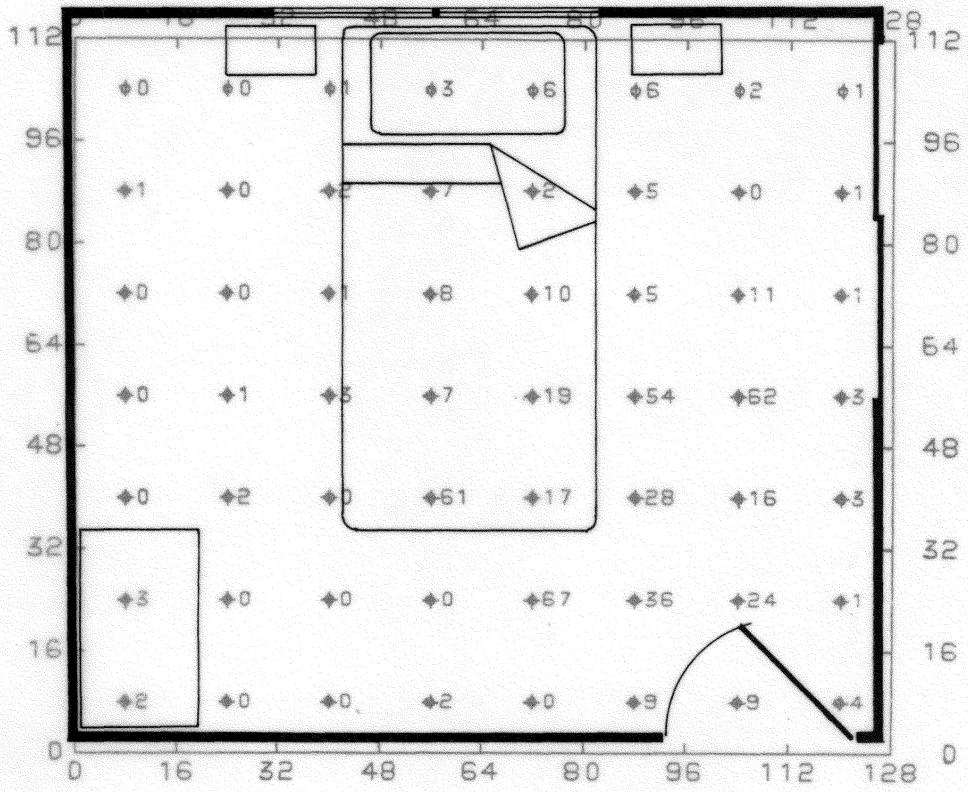


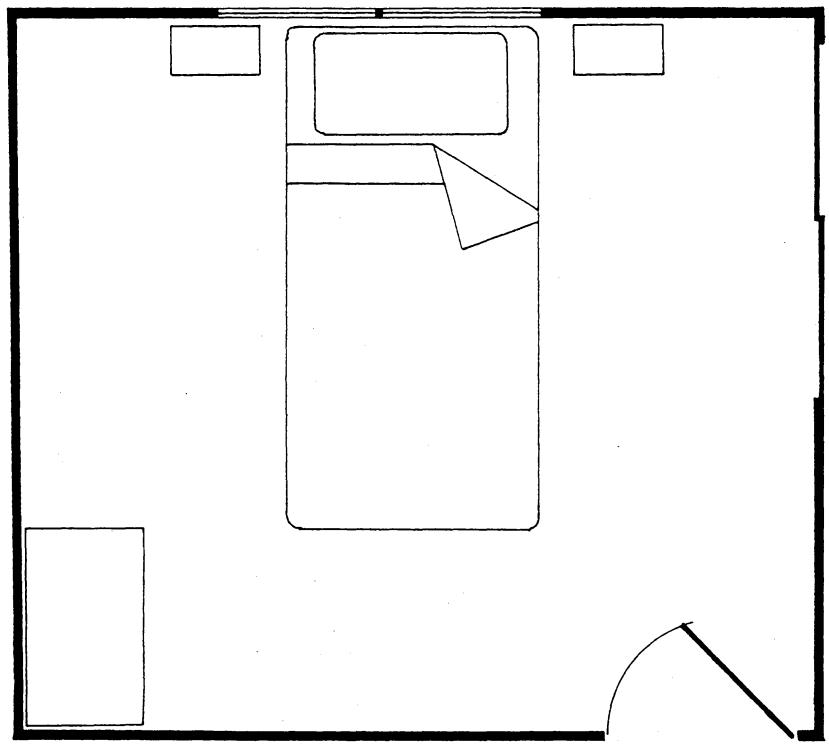


Appendix B-2: Posting of tally data for unhatched eggs from bedroom (scale: 1 cm = 1 ft).

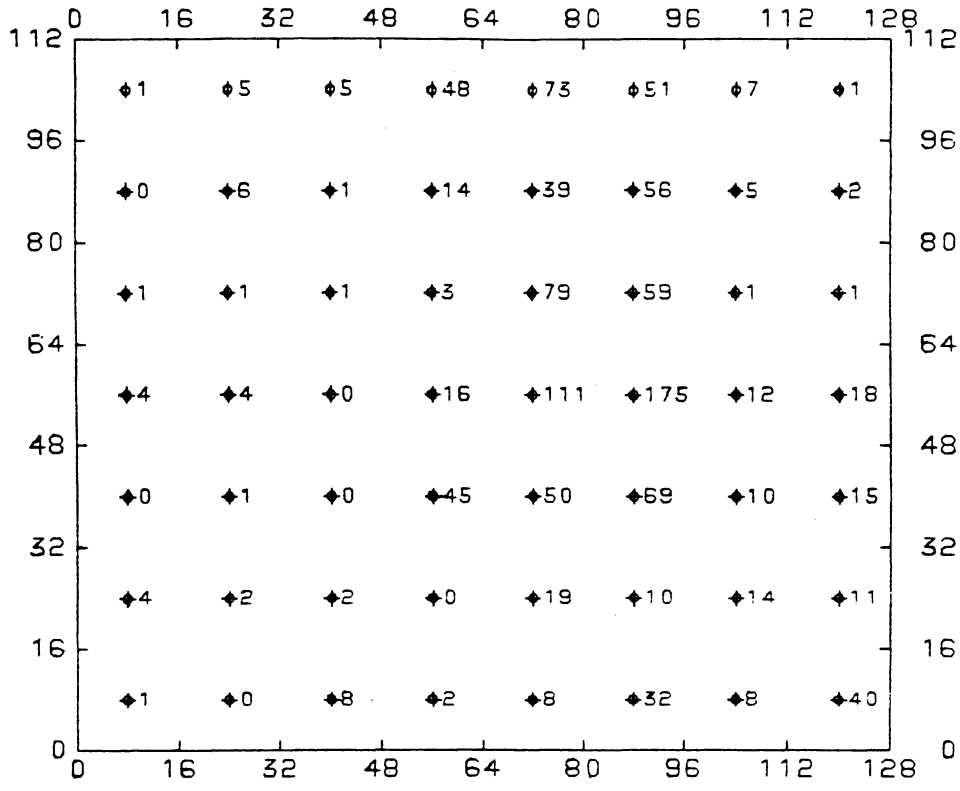


Appendix B-2: Posting of tally data for unhatched eggs from bedroom (scale: 1 cm = 1 ft).

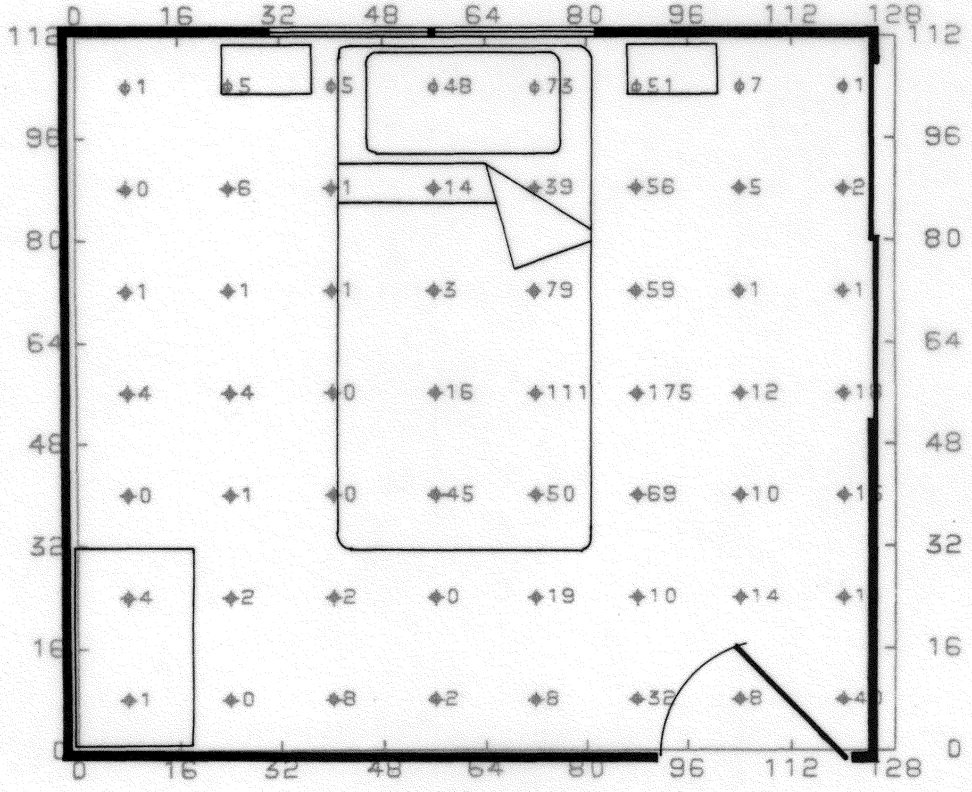


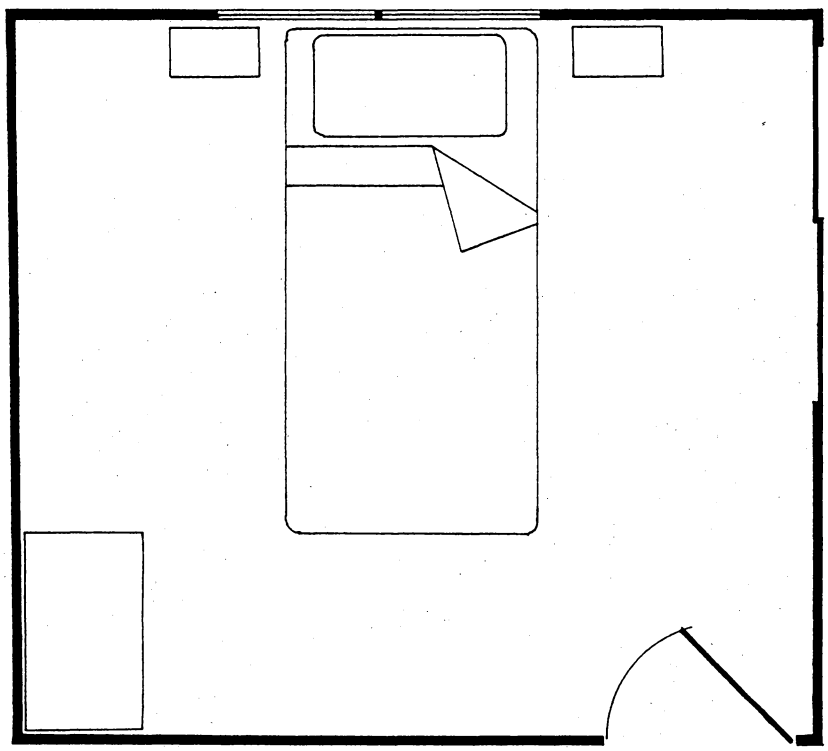


Appendix B-3: Posting of tally data for combined first- and second-instar larval exuviae from bedroom (scale: 1 cm = 1 ft).

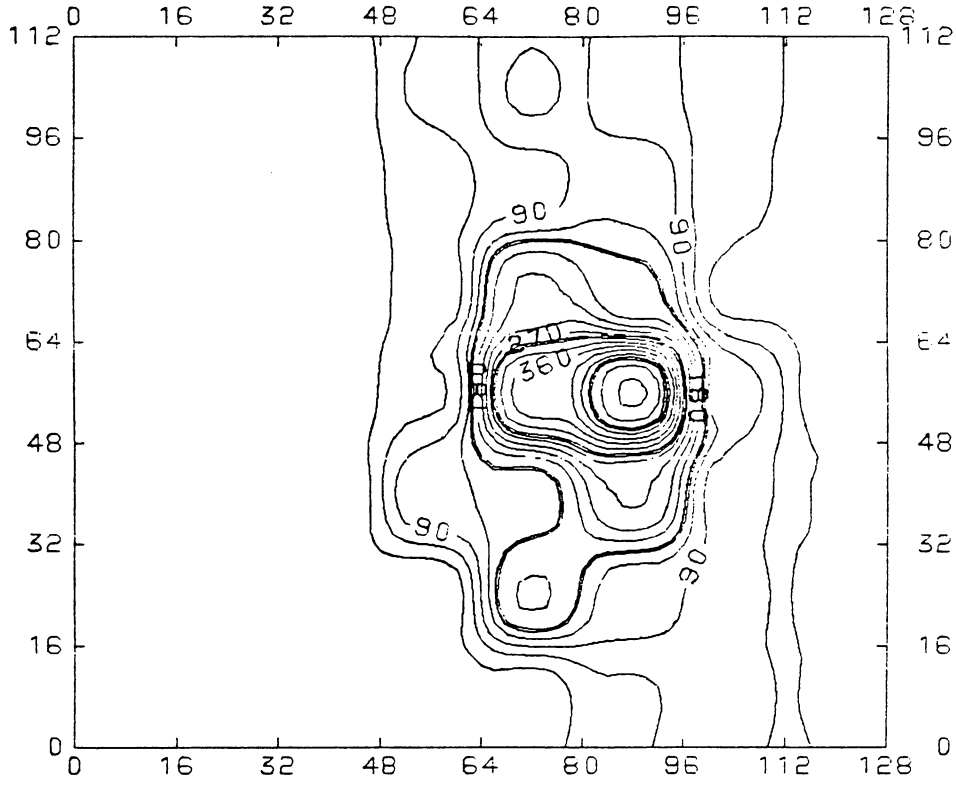


Appendix B-3: Posting of tally data for combined first- and second-instar larval exuviae from bedroom (scale: 1 cm = 1 ft).

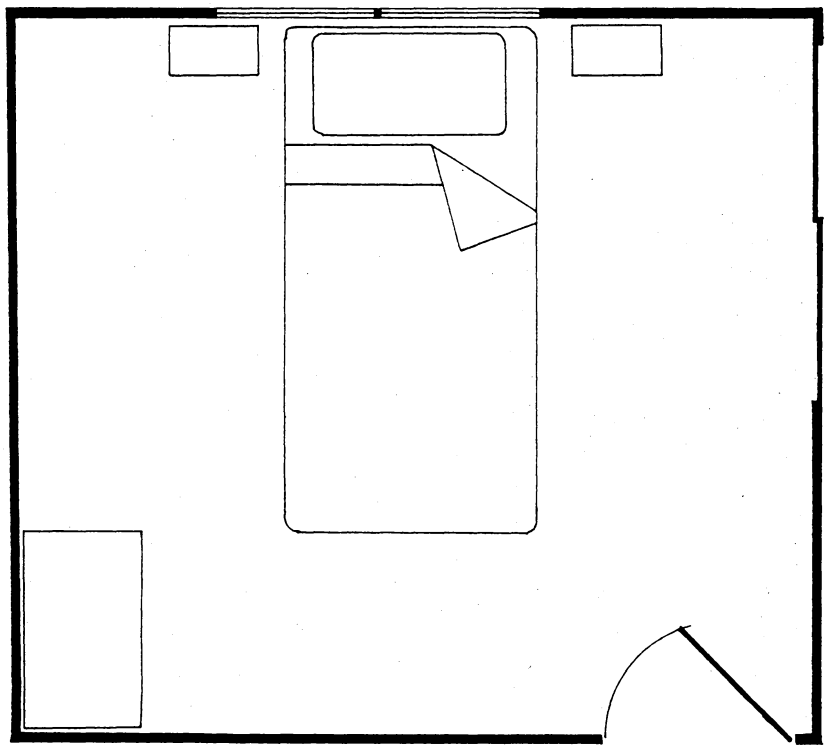




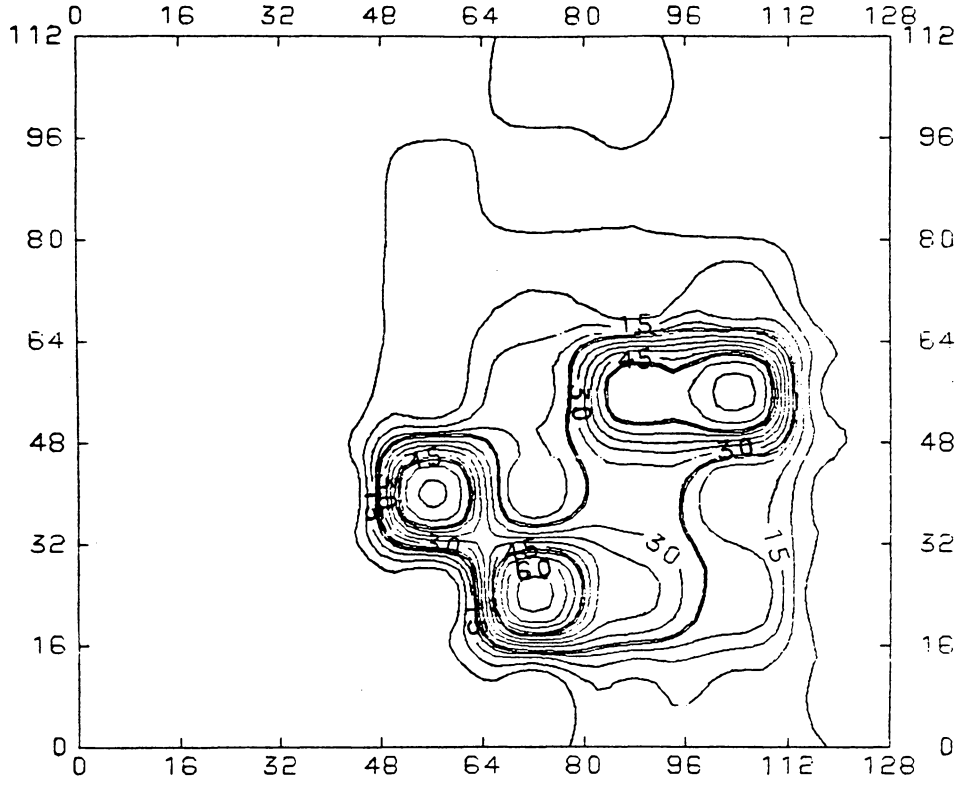
Appendix B-4: Contour map of hatched eggs from bedroom (scale: 1 cm = 1 ft; contour interval = 30).



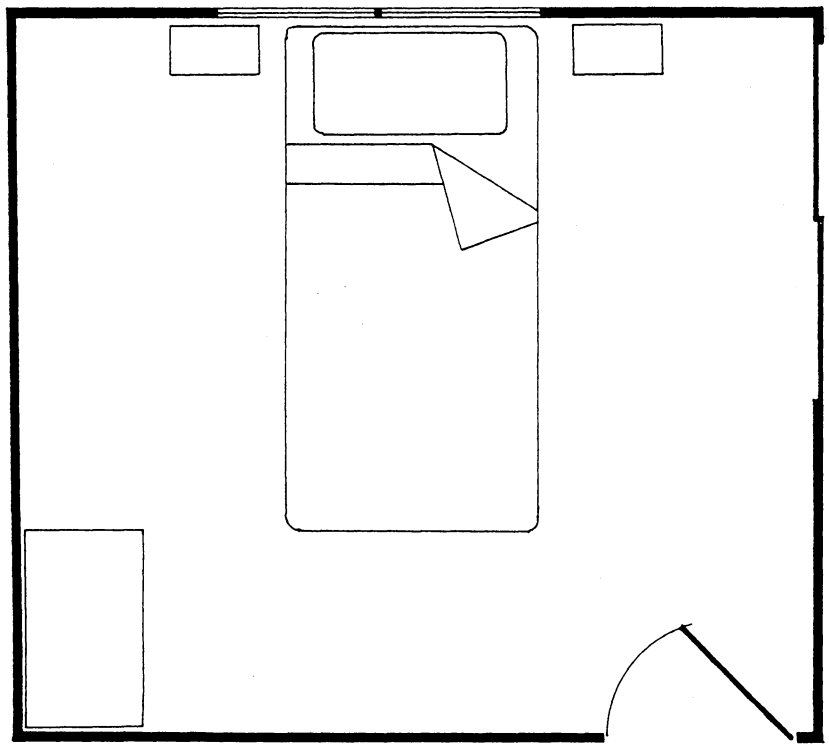
Appendix B-4: Contour map of hatched eggs from bedroom (scale: 1 cm = 1 ft; contour interval = 30).



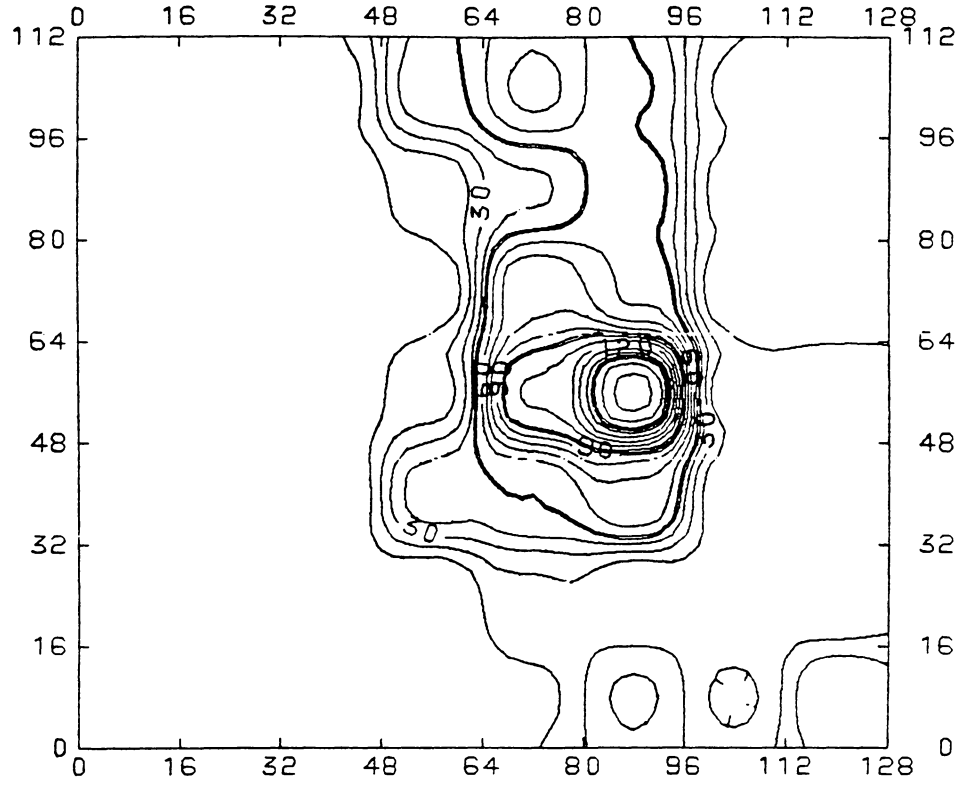
Appendix B-5: Contour map of unhatched eggs from bedroom (scale: 1 cm = 1 ft; contour interval = 5).



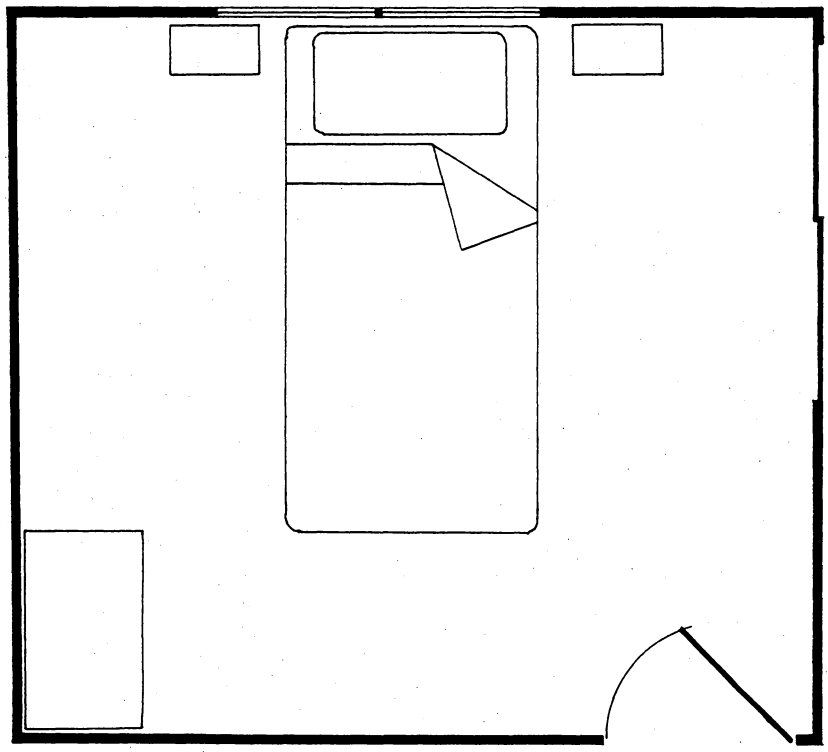
Appendix B-5: Contour map of unhatched eggs from bedroom (scale: 1 cm = 1 ft; contour interval = 5).



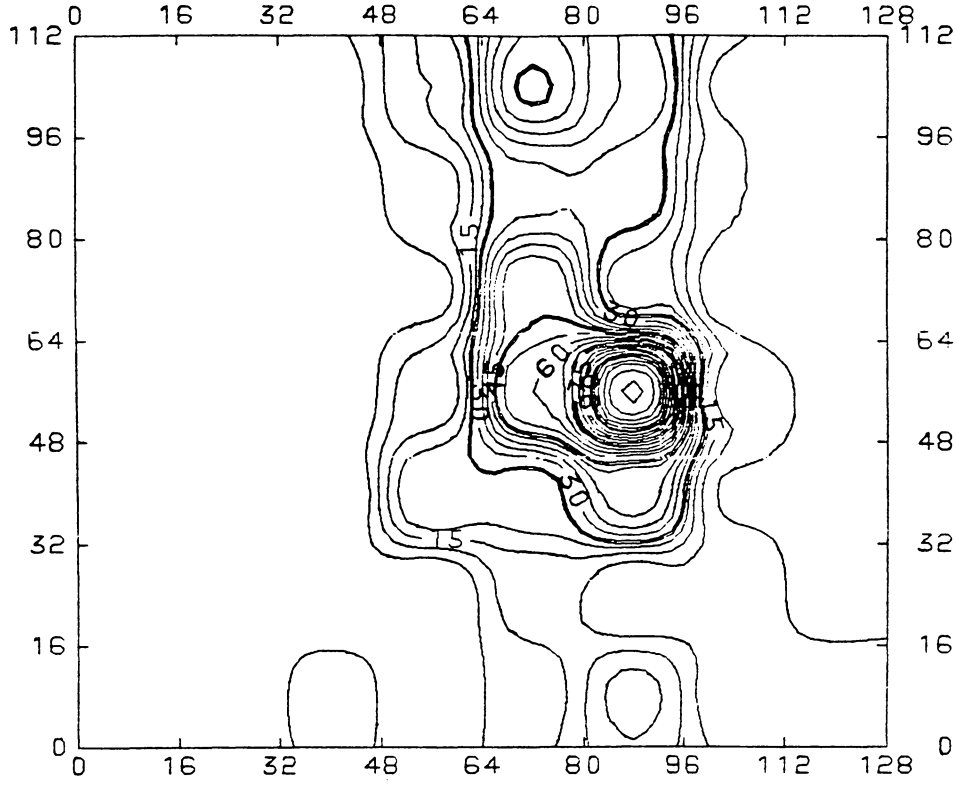
Appendix B-6: Contour map of combined first- and second-instar larval exuviae from bedroom (scale: 1 cm = 1 ft; contour interval = 10).



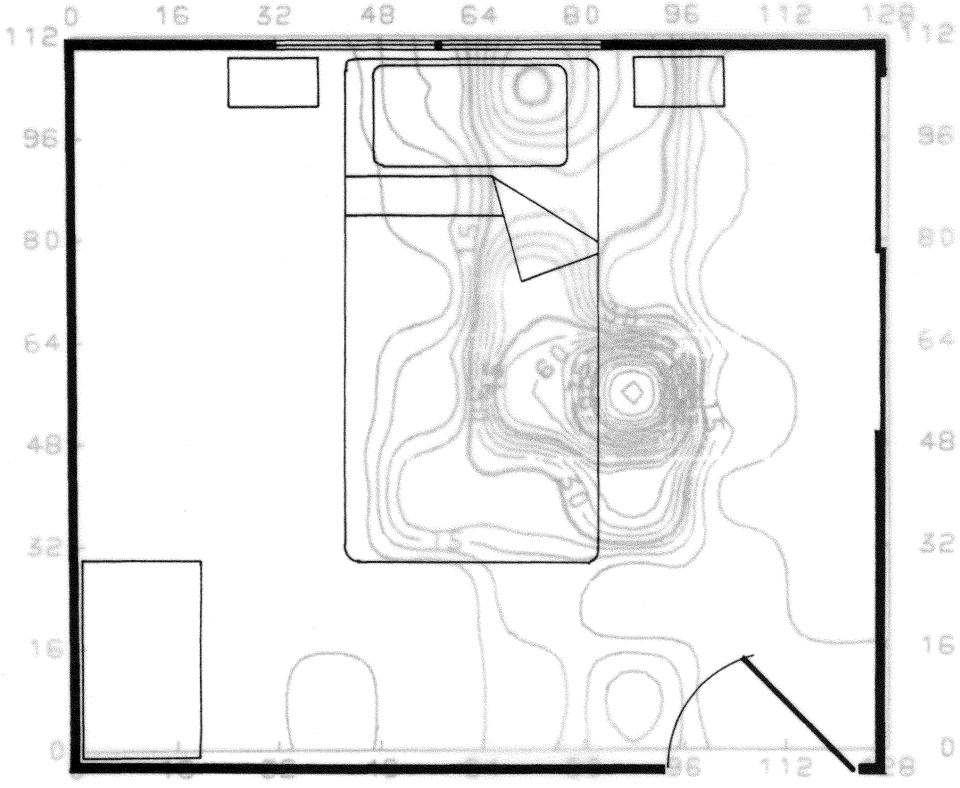
Appendix B-6: Contour map of combined first- and second-instar larval exuviae from bedroom (scale: 1 cm = 1 ft; contour interval = 10).

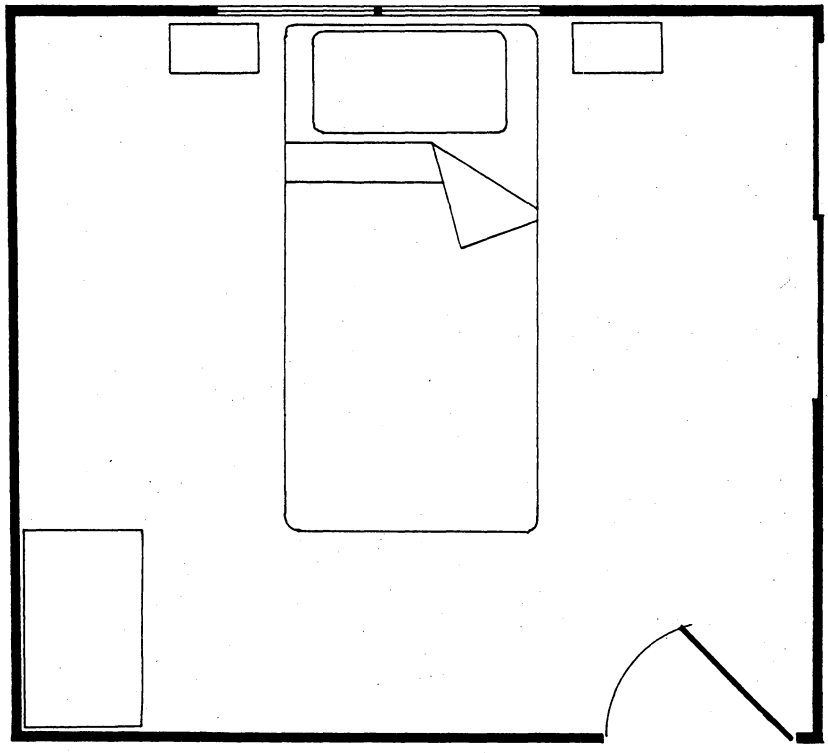


Appendix B-7: Contour map of first-instar larval exuviae from bedroom (scale: 1 cm = 1 ft; contour interval = 5).

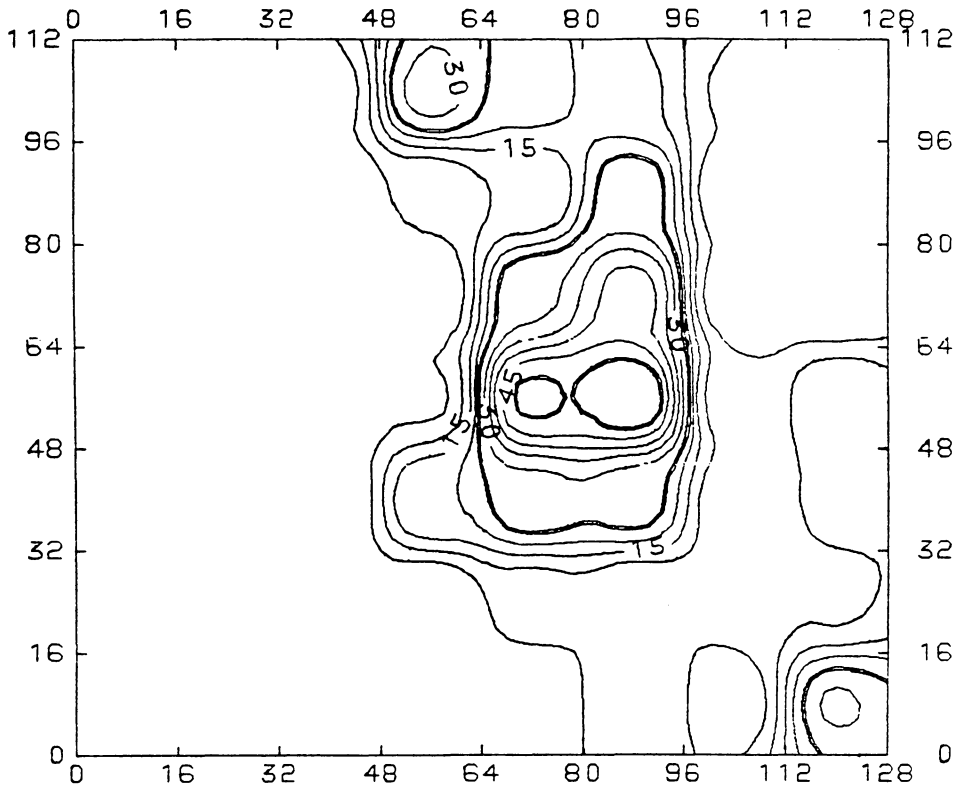


Appendix B-7: Contour map of first-instar larval exuviae from bedroom (scale: 1 cm = 1 ft; contour interval = 5).





Appendix B-8: Contour map of second-instar larval exuviae from bedroom (scale: 1 cm = 1 ft; contour interval = 5).



Appendix B-8: Contour map of second-instar larval exuviae from bedroom (scale: 1 cm = 1 ft; contour interval = 5).

Appendix C: Questionnaire used to survey pet owner attitudes and knowledge toward cat flea infestations.

___survey # __month __day visit _f _nf

1. How many dog(s) and/or cat(s) do you have? __d __c

2. What % of the day do you think the pet(s) spend inside? __%

3. In which room(s) does your pet spend most of its time? _bedroom _livingroom _den _basement _kitchen _bathroom _other

4. On a scale from 1 to 10 (10 being the worst), how do you perceive flea problems on your pet in the past 2 months? __

5. (same) how do you perceive flea problems in your home past two months? __

6. In what rooms in your home are the flea problems the worst? _bedroom _livingroom _den _basement _kitchen _bathroom _other

7. Where do you think fleas "breed" in your home? _pet _carpet _other

8. Have flea problems gotten _better _worse _or stayed the same in your home in past 3 years?

9. Are people in your household ever bitten by fleas? _yes _no _don't know

10. If yes, one person more than others? _no _don't know _yes __age _m _f

11. How many flea sightings do you or your family members tolerate before you react by doing something to control them? __

12. How many flea bites do you or your family members tolerate before you react by doing something to control them? __

13. What do you think is the best way to control fleas in your home? _dog dip _you or _vet
_spray _indoor _outdoor _both-- _you or _pco
_vacuum
_other

14. How much money would you be willing to pay per month during the flea season to completely eliminate flea problems from your home? $___

15. Have you purchased insecticides or services in the past 2 months to control fleas in your home? _no _yes
$___ca how much have you spent __#cans __# bombs __dips professional services __# times $___ca how much/visit

16. Lets play devils advocate. Which do you think is the worse of the two? all of these will be thought of as in your home!
fleas _ or mice _
fleas _ or house flies _
fleas _ or spiders _
fleas _ or cockroaches _
fleas _ or ants _

17. Residence _ & how long have you been in that home __years?

18. Sex _m _f

19. Estimated age _10-20 _20-30 _30-40 _40-50 _50-60 _60-70 _70-80

20. Income _

21. Education_

Appendix D: Information contained on flashcards which were given to respondents to acquire confidential demographic data.

Question 17. Would you please tell me which letter on the card best describes the structure in which your family resides.

A. A one-family house detached from any other house.
B. A one-family house attached to one or more houses.
C. A mobile home or trailer.
D. A building for two families (duplex).
E. A building for three or four families.
F. A building for more than four families.
F. Other.

Question 20. Would you please tell me the letter on the card which best represents your total family income in 1985 (before taxes).

A. Under $10,000
B. $10,001 to $15,000.
C. $15,001 to $20,000.
D. $20,001 to $25,000.
E. $25,001 to $30,000.
F. $30,001 to $40,000.
G. More than $40,000.

Question 21. Would you please tell me which letter on the card most closely describes the degree or degrees that you have received.

A. Less than high school.
B. High school diploma (or equivalency).
C. Bachelor's degree.
D. Master's degree.
E. Doctorate degree.
F. Professional degree (MD, DDS, etc.).
G. Other.

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