ASPECTS OF DISPERSAL AND POPULATION STRUCTURE OF *Blattella germanica* (L.) IN FIELD HABITATS AND ATTITUDES CONCERNING AESTHETIC INJURY LEVELS

by

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INTRODUCTION

Cockroaches, as a group, are frequently used as research tools for obtaining physiological data that can be generalized to other insect species. The resulting literature provides information important to many disciplines of biology such as biochemistry, physiology, and medicine, but little of this growing body of knowledge is pertinent to understanding the cockroach as a unique animal.

Many aspects of the biology, behavior, and control of the German cockroach, Blattella germanica (L.), have been investigated. Cornwell (1968), Guthrie and Tindall (1968), Ross (1929), and Roth and Willis (1957, 1960) provided much of the basic knowledge on this well-known pest species. Some researchers have considered the German cockroach as a potential disease vector and allergen (Alcamo and Frishman 1980, Bernton and Brown 1964, 1970, Frishman and Alcamo 1977, Kang 1976, Roth and Willis 1957). Other researchers have contributed information toward a better understanding of German cockroach population biology and ecology in laboratory and field studies. The works of Izutsu et al. (1970), Burgstahler et al. (1975), Breed et al. (1975), Bell et al. (1978), and others have furnished information on aggregation and agonistic behavior, and behavioral response to pheromones. Ono and Tsuji (1972), and Mueller (1978) have reported the effects of food and water availibility on population structure. Tsuji and Mizuno (1972, 1973), and Ogata (1976) examined the effects of temperature on German cockroach development, reproduction, and survival. Ross and Wright (1977), Keil (1981), and Sherron et al. (1982) discuss population structure in the field. Akers and Robinson (1981), and Ross et al. (1982) provide data on dispersal behavior of laboratory strains of the German cockroach in established field situations.

Interest in clarifying German cockroach biology and habits is frequently directed toward achieving control of this pest in buildings occupied by man and animals. Chemical control has always been the predominant strategy for reducing infestations. Cornwell (1976) prepared an exhaustive review on chemical control of the German cockroach up to 1972. Since 1972, chemical formulations and application techniques for German cockroach control have undergone major changes (Story 1977, Reierson et al. 1979, Breeden et al. 1981, Wright and Dupree 1982, Zungoli and Robinson 1982). Changes in control procedures have occurred, in part, due to German cockroach resistance and cross-resistance to commomly used insecticides (Collins

1973, Grayson and Robinson 1976, Grayson 1980). German cockroach populations in various parts of the United States have been tested for chemical resistance (Grayson 1965, Rust and Reierson 1978, Wood 1980). The varying levels of resistance to carbamate and organophosphate insecticides reported in these studies are an indication that chemical resistance may be increasing.

Alternatives to chemical control strategies for the German cockroach are few, and are largely at the investigative stage (Ross and Cochran 1973, Burgstahler et al. 1975, Keil and Ross 1977, Bell et al. 1978, Ross et al. 1981). Researchers have also investigated better ways of using the chemicals available, in conjunction with mechanical procedures designed to make the cockroach habitat less ideal. Building cockroach control into new construction (Ebeling and Wagner 1964, Ebeling et al. 1969) or into equipment (Moore 1973) is not a new concept, although very little research has been conducted to confirm its effectiveness. Sanitation has been proposed as a strategy for suppressing German cockroach populations. Wright (1979) reported a correlation between large cockroach populations and poor sanitation. Sherron et al. (1982) reported that sanitation had a significant effect on population density in kitchens, and that apartments with a sanitation rating of poor had larger cockroach populations. Gupta (1973, 1975) had previously reported similar results, and also showed reduced insecticide effectiveness due to poor sanitation. However, Owens (1980), was unable to significantly reduce German cockroach numbers by improving sanitation alone. Farmer (1982) investigated the feasibility of isolating and limiting cockroach harborage areas by crack and crevice caulking.

Research investigating use of several control strategies in combination has yielded conflicting and confusing results. However, a research base is needed to develop innovative and effective control programs. The integration of more than one control strategy is a pest management approach, whereby pest populations are reduced to tolerable levels by implementing a combination of several coordinated techniques. The concept of tolerable pest levels is the premise upon which pest management programs are based.

Although some basic information on German cockraoch habits is still lacking, German cockroach pest management programs are being designed and implemented (Darley 1976, Slater et al. 1979, Wood 1980, Robinson and Zungoli, in preparation). Little is known about dispersal behavior and spatial patterns of distribution of the German cockroach in field situations, although recent investigations have provided some significant data (Ross and Wright 1977, Akers and Robinson 1980, Owens 1980, 1982, Sherron et al. 1982). Information is also needed concerning the appropriateness of managing, rather than eradicating a pest that is found in such close association with man -- a pest that has been implicated as a serious potential threat to public health (Roth and Willis 1957, Frishman and Alcamo 1977). A survey of urban housing residents (Wood et al. 1981) showed that German cockroaches were perceived to be a serious problem. Results indicated that cockroaches are not acceptable to residents even at low levels.

The purpose of the research presented here is to investigate aspects of German ccckroach dispersal and spatial patterns of distribution in apartment buildings. The data presented provides information that is applicable to designing programs for control of the German cockroach. Further, data is offered on the feasibility of establishing aesthetic injury levels (tolerable population levels) for the German cockroach as an important fundamental aspect of designing control programs.

PART I - MARK-RECAPTURE STUDIES

INTRODUCTION

Data generated from field research is an important key to designing successful management programs for the German cockroach. While laboratory study yields valuable information collected under controlled environmental conditions, understanding the biology, behavior and distribution patterns of wild populations of *Blattella germanica* (L.) in field situations is essential. Researchers must use apartments, homes, and other urban structures as their laboratories to collect data that accurately describes German cockroach behavior in the field.

Dispersal

Information on the dispersal behavior of cockroaches in the field is limited, and information specifically on *B. germanica* is only now being collected (Akers and Robinson 1981, Owens 1980, 1982, Ross et al. 1981).

Two mark-recapture studies were conducted to examine the movement of the American cockroach, *Periplaneta americana* (L.) between sewerage systems and adjacent homes. In both studies, the isotope, P^{32} was used to mark the cockroaches. Schoof and Siverly (1953) conducted a study in Phoenix, Arizona and concluded that there was virtually no _P_. _americana_ movement out of the trap-release location. Eads et al. (1953) conducted a similar study using the Tyler, Texas sewerage system and reported widespread dispersal from manhole release sites into adjacent homes. The major difference between these two studies was the way in which the researchers manipulated the natural populations of _P_. _americana_. Schoof and Siverly (1953) trapped, marked, and released American cockroaches from a single location. Insects were out of their natural habitat for a minimum period of time. Eads et al. (1953) trapped cockroaches outside the study area, marked them, and released them into new study sites in numbers four times that of the wild population. Jackson and Maier (1955) conducted another study using the Phoenix, Arizona sewerage system. They compared the methods used in the previous two studies, and concluded that undisturbed populations of _P_. _americana_ tend not to disperse, except for "sporadic emigrations of a few individuals." However, when extreme pressure is placed on a population, possibly increasing the number of individuals to a point beyond the carrying capacity of the habitat, _P_. _americana_ will emigrate to new locations, including homes adjacent to the sewerage system.

Bulow and Huggins (1968) used a mark-recapture technique to study P. americana, and the brown-banded cockroach, Supella longipalpa (Serville) in a building at Iowa State University. The objective of the study was to calculate an estimate of the resident cockroach population, but they also gathered data on sex ratio, movement, and activity patterns. They reported no movement by P. americana, and a minimum amount of movement by S. longipalpa.

Field research investigating dispersal of B. germanica has largely been conducted using genetically marked strains of this species. Akers and Robinson (1981) reported a study in which 200 male genetically marked black body mutant strain of German cockroaches were released into the basements of three, six unit apartment buildings. The introduction of 200 individuals was considered minor compared to the size of the existing German cockroach population. While the rates of movement in the three buildings varied, the marked insects did disperse through each building, and did not concentrate in any one area.

A shipboard study reported by Ross et al. (1981) investigated the feasibility of using sterile males as a biological control agent for the German cockroach control.

The "sterile" males were double translocation heterozygotes. Sterility is conferred due to partial embryonic lethality within an ootheca which results in complete entrapment of the remaining viable embryos. Results from this study indicated that sterile males did join and compete well with natural groups of B. germanica near release sites. However, neither sterile males nor the females with which they mated moved far from these sites. Movement from established groups was reported to be primarily represented by nymphs.

Owens (1980) trapped, marked, and released field collected populations of adult B. germanica to study adult movement in urban apartments. He reported rates of movement over a nine day period to range from 0 to 30.7%, with adult male movement greater than adult female movement. Owens also reported increased rates of movement when pyrethrins insecticides are used for cockroach control.

Spatial Patterns of Distribution and Habitat Preference

There have been several laboratory and field studies conducted to examine the population structure, dynamics, and ecology of the German cockroach. Ross and Wright (1977) examined the age structure of field-collected German cockroaches, and found the distribution for age classes generally to be uniform. There was no tendency for a decrease in numbers with age. This is in contrast to laboratory results obtained by Mele (1972) and Ross (1976). Ross and Wright (1977) found the kitchen to be the primary site of infestation with the living room, utility room, and bedrooms being secondary sites. Cockroaches were never captured in bathrooms from any of the houses included in the study.

Sherron (1979) trapped a sizeable number of cockroaches in bathrooms of the apartments used as his study sites; the greatest number of the early age groups occurred there. He reported more adults than nymphs in living room and bathroom sites. Further, he found that while sanitation did affect density, it did not affect age class structure

Akers (1979) examined spatial patterns of distribution for B. germanica and discussed data for buildings as well as for individual apartments. Each building was examined, and found to have at least one apartment with a high population in which food, water, and harborage were at an optimum. These "focus apartments", as they were called, were apparently responsible for cockroach problems in adjacent apartments in which sanitation was good, and food, water, and harborage were at a minimum. Trapping locations in this study included kitchen, bathroom, and pantry sites. Trap catches varied between buildings, but bathroom traps uniformly yielded approximately 40% of the total collection.

The location of a German cockroach population within a structure is related to temperature, humidity, and the availability of food, water, and harborage. Traditionally, sites of infestation have been considered to be kitchens and bathrooms (Gould and Deay 1937), although Shuyler (1956) speculated on a change in the habits of both German and oriental cockroaches.

Ambient temperature and relative humidity are important factors for German cockroach survival. Ogata et al. (1979) studied survival rates of B. germanica and two other domiciliary cockroaches in conditions simulating unheated buildings over a twelve month period. German cockroaches suffered 100% mortality during exposure to temperatures approximating winter months. Tsuji and Mizuno (1972, 1973) reported that in any stage of development B. germanica could not survive low temperature (5.5^{o}C) exposure over a 40 day period even when given a preliminary exposure of 100 days to a moderately cold temperature (15^{o}C). Nor could oothecae survive more than 20 days of low temperature exposure (5.5^{o}C). Ogata (1975) found an abundance of B. germanica in urban buildings such as offices, apartments, restaurants, and stores, especially those constructed in the last five years, while P. fuliginosa was the dominant species in farm houses. Ogata (1976) concluded that differences in species abundance in various types of buildings was due to the presence or absence of central heating. In a laboratory investigation, Gunn (1935) reported that B. germanica had a higher temperature preference (30°C) than P. americana and Blatta orientalis (L.). He states that because of the risk of dessication due to high temperature, B. germanica is not found in places where it cannot easily obtain water to drink at least once a day.

Ono and Tsuji (1972) found that a population of B. germanica at equilibrium is in direct proportion to the amount of food supplied. Mueller (1978) reported that temporary deprivation of food and water reduces the survival rate of B. germanica by 23% compared to a control group. The greatest impact of temporary deprivation on population development occurred at the level of oothecae formation. Seventy-one percent fewer oothecae were produced by females deprived access to food, and water, and those oothecae which were produced had one-third fewer egg compartments per capsule. Mueller (1978) also reports that water deprivation has a greater effect than food deprivation. Kunkel (1966) reports an expansion of the interval between molts in B. germanica under conditions of deprivation. This is not unexpected since nymphal weight approximately doubles with each molt (Woodruff 1938). Kunkel (1966) also reports that B. germanica females use approximately 90% of the food accumulated during the preovipositional period on a single ootheca, and additional oviposition is not stimulated until feeding has occurred in a new preovipositional period.

Since cockroaches are both gregarious and negatively phototaxic, the importance of available harborage to B. germanica development should not be minimized. Berthold and Wilson (1967) discussed German cockroach resting behavior and characterized harborage preference by height of space available. Klunker (1977) reported on the size of cracks through which various developmental stages of German cockroach could pass, thus allowing for speculation on potential harborage sites.

Harborage provides a location for communication between individuals in a German cockroach population. This is particularly important in reproduction. Contact chemoreception of the male antennae with the female has been identified as a primary factor in illiciting mating behavior in males (Bell et al. 1978, Nishida et al. 1975).

An aggregation pheromone present in the feces of the German cockroach stimulates gregarious behavior (Ishii and Kuwahara 1967, 1968). Pettit (1940) reported increased developmental time for nymphs reared in isolation. Sommer (1975) reported that aggregation pheromone deposited with the feces in the harborage induces nymphs to return to the protection of the harborage after seeking food and water, and thus maintaining contact with other individuals of the species.

Sites of infestation of B. germanica in an apartment, house, office, or other urban environment are related to several key factors: temperature, humidity, food and water availabilty, and harborage. The interaction between these variables determines the spatial patterns of distribution and habitat preferences of B. germanica.

MATERIALS AND METHODS

Two mark-recapture studies were conducted to investigate German cockroach movement in apartment buildings. The first study was designed to examine a wild population in the field. Population statistics on both adults and nymphs were collected, but because nymphs do not retain a topical mark from molt to molt, only adult movement data was generated from the first study. A second experiment was conducted using genetically marked cockroaches to provide data on movement of German cockroach nymphs.

All apartments used in the study are maintained by the Roanoke Redevelopment and Housing Authority in Roanoke, VA. The apartment buildings used were selected on the basis of two criteria: presence of a measureable German cockroach infestation, and cooperation of all building residents. Infestation levels were determined by placing 3 Mason jar traps in each apartment for a 24 hour period. Traps were placed in sites previously noted by Akers and Robinson (1981) as preferred harborages -- under the kitchen sink, in the pantry, and in the linen closet adjacent to the bathroom. All routine pest control practices were suspended during the study period and residents were asked to not use any insecticides in their apartments.

A. Adult Movement Study

This first mark-recapture study was conducted in Lincoln Terrace. The seven-week study period was from May, 1980, to July, 1980. Each apartment building used in the experiment had at least one apartment with a large German cockroach infestation, as noted by a 24-hr trap catc of 75 or more individuals.

Study Sites. The two apartment buildings used in this study consisted of four adjacent apartments. There was a basement under one end apartment and a crawl space under the remainder of the building. All apartments were occupied during the study period.

Building 1 consisted of two, two bedroom and two, three-bedroom apartments. Plumbing was shared by the end and adjacent apartment in each case. All apartments in Building 2 were two-story.

Building 2 consisted of two, four bedroom, two-story apartments with a single story, one bedroom apartment on either end. The plumbing in this building was shared by the two center apartments, while the end apartments had plumbing separate from the neighbors.

Traps. Traps consisted of 1-qt Mason jars baited with a 4-dram vial of water with a sponge wick, and a 1-oz cup of boiled raisins. The inner lip of each jar was lightly coated with petroleum jelly. A paper towel was secured around the outside of the jar with a rubber band.

Nine to fifteen traps were placed in each apartment, depending on the number of bedrooms present. Two traps were placed in each bedroom and living room. Two traps were also placed in the kitchen: one under the kitchen sink and one next to the refrigerator, and an additional (third) trap was placed in the pantry or in a closet in the kitchen. Single traps were placed in the bathroom behind the toilet, and on the floor of the linen closet.

Marker. Liquid Paper® (Liquid Paper Inc., Dallas, TX), a correcting fluid for typographical errors, was used to mark the cockroaches. A preliminary laboratory study showed that adult cockroaches retained the Liquid PaperR mark when applied to the thorax and wings, in small quantities, for at least an eight week period with no mortality. Walker and Wineriter (1981) tested four materials for direct marking of insects, and Liquid PaperR was the most durable material tested on insects considered difficult to mark including *Periplaneta americana*. Ten colors of the marking fluid were used. A number, 0 through 9, was assigned to each color, so that each cockroach had a unique number. This allowed for identification of individual adults.

Capture-mark-release procedure. Traps were placed in each apartment for three, 24-hour periods each week. During the first four weeks of the study, German cockroaches were trapped, marked, recorded, and returned to the original trap location. Only adult cockroaches were marked, although data was also collected on nymphs. Insects were immobilized in a Mason jar placed in an ice bath for approximately 20 minutes to allow for marking and data collection. There was no adult mortality due to this procedure, but some small nymphs were occaisionally killed due to drowning in the condensation formed on the inside of the glass jar. Cockroaches were released back into their original trap location within 4-6 hours after removal. In the final three weeks of the study, trapped cockroaches were removed from the study site for counting and data collection, and were not returned (Table 1).

B. Nymphal Movement Study

The eight-week nymphal movement study was conducted in Lansdowne Park from November, 1981 through January, 1982. Pairs of adjacent apartments were chosen based on the presence of a moderate cockroach infestation in at least one of the apartments in the pair. A moderate infestation was indicated by collecting 25 to 50 German cockroaches in a 24-hr pre-trap period of each apartment. Trapping procedures were as previously described for the Adult Movement Study.

Study sites. Four pairs of adjacent apartments were included in the study. Apartments within each pair were separated by a fire wall, but shared common plumbing. One pair of apartments consisted of two, three-bedroom units. The other three pairs of apartments consisted of two-bedroom units. All eight apartments were two story units.

<u>Traps</u>. Two types of traps were used in the study - Mason jar traps an Roatel® traps (Fumakilla Limited, Tokyo, Japan). Ross (1981) reported an increase in capture of small German cockroach nymphs with Roatel® traps in comparison to 1-quart Mason jar traps. All other life stages were trapped in approximately equal numbers by both types of trap in the Ross study (1981).

Mason jar traps consisted of jars baited with one-quarter of a slice of white bread soaked in beer. The inner lip of each jar was lightly coated with petroleum jelly. A paper towel was secured around the outside of the jar with a rubber band. Eleven to thirteen traps were placed in each apartment.

Roatel® traps were also baited with one-quarter of a slice of white bread soaked in beer. Eleven to thirteen Roatel® traps were also placed in each apartment. Roatel® traps were placed directly next to the Mason jar traps in a side-by-side fashion.

Two of each type of trap was placed in each bedroom and living room. Two traps were also placed in the kitchen: one under the kitchen sink and one next to the refrigerator, and an additional (third) trap was placed in the pantry of each kitchen. Single traps were placed in the bathroom behind the toilet, and on the floor of the linen closet.

Marker. Five strains of mutant German cockroaches were used for the study. The strains used were orange body, black body, rose eye, pallid eye, and black body-rose eye. All mutants were reared from colonies maintained at the Genetic Stock Center at Virginia Polytechnic Institute and State University in Blacksburg, VA under the direction of Dr. Mary H. Ross. Reproductive capacity and longevity of the mutant strains are comparable to field strains of *B. germanica* (Mary H. Ross, personal communication).

Gravid German cockroach females of two mutant strains were released in two locations in each apartment. Oothecae for each female were developmentally synchronized for release in each pair of apartments. Forty gravid females were released under the kitchen sink (downstairs), and 40 gravid females were released in the linen closet of each apartment (upstairs). Four different mutant strains were released in each pair of apartments. Thus, any movement beween apartments or between the first and second floors within an apartment could be detected. Black body-rose eye, rose eye, and pallid eye cockroaches were released in the downstairs release sites, while orange and black body cockroaches were released in the upstairs release sites.

At the time that gravid females were released in each pair of apartments oothecae were 10 to 14 days from hatch. Releases were made at that stage in oothecal development to allow the females to establish themselves in harborage sites prior to ootheca deposition, and to avoid premature ejection of the egg case. Trapping began one week following each set of releases and continued for seven additional weeks. Each trapping period for the eight weeks following release of the gravid females was for 24 hours.

RESULTS AND DISCUSSION

A. Adult Movement Study

1. Spatial Patterns of Distribution and Habitat Preference.

The data examined concerning spatial patterns of distribution and habitat preference were taken from trap catches collected during the first four weeks of the mark-recapture study. The latter three weeks of data were excluded, because trap catches collected after the initial four weeks were not returned to apartment trap sites, and consequently population structure was altered. Inclusion of the data from the latter three weeks of the study could convey an inaccurate evaluation of field population structure.

The German cockroach population trapped during the first four weeks of the study had a female to male sex ratio of 1:1.2 which is close to the expected 1:1 ratio, and an adult to nymph ratio of 1:1.4 (Figure 1). Ross and Wright (1977) also report a 1:1 sex ratio in a study of field-collected populations of the German cockroach. Their collections were made in such a way as to remove totally the populations from the study sites. They report adult female to nymph ratios that were in the range of 1:1 to 1:13. The latter ratio is not in line with other data collected in the study and is thought to be due to unusual conditions at that particular collection location. If this ratio is excluded, the data on adult to nymph ratios collected in the Ross and Wright (1977) study are in agreement with the data presented here. The age class of nymphs was nearly uniform with early instar nymphs occurring with a slightly greater frequency than middle or late instar nymphs (Figure 1).

It was anticipated that the German cockroach population in an apartment would not be evenly distributed over all trap locations. German cockroaches are known to focus in kitchen and bathroom areas where direct access to water is probable (Gould and Deay 1937). Table 2 supports this hypothesis. The sampled population of all trapped cockroaches is distributed as expected over trap locations, with 65% occurring in either a kitchen or a bathroom/linen closet trap. The downstairs bedroom in all apartments having one, opened directly into the kitchen. This arrangement, apparently increased the number of cockroaches in that room compared to upstairs bedrooms. The percentage for upstairs bedrooms represents all upstairs bedrooms combined. If the percentage trap collection for the downstairs bedroom, which opens to the kitchen, is combined with the kitchen and bathroom/linen closet collections, 76% of the total trapped population is accounted for in areas considered to be traditional sites of German cockroach infestation. The remaining 24% is spread across all other locations. The distribution pattern when viewed in this way is not unexpected.

When the distribution of cockroaches in a non-focus apartment is compared to a focus apartment, there is a distinct shift in the pattern (Figure 2). Akers and Robinson (1981) defined a focus apartment as one in which food, water, and harborage are at an optimum, and a large infestation of cockroaches is present, and a non-focus apartment is characterized by generally good sanitation and a low cockroach infestation. In the non-focus apartment the population is centered in the kitchen and bathroom, with the kitchen being the predominant site of infestation. Bedroom and living room traps in a non-focus apartment only represented 10% of the total trapped population. In the focus apartment there is no single site in which the bulk of the population is centered (Figure 2). The trapped population is distributed almost uniformly between traditional and non-traditional sites of infestation.

These data have obvious implications for designing effective control strategies in focus and non-focus apartments, especially with respect to placement of insecticides. When the availability of resources necessary for survival is no longer limited to the traditional locations, neither will German cockroach populations be limited to those traditional locations. Presumed shifts in habitat preference are perhaps not attributable to real changes in German cockroach behavior as Shuyler (1956) proposed, but rather to real changes in the actual habitat.

Adult distribution by trap location (Figure 3) shows little variation in sex ratio, although more males were collected in the downstairs bedroom trap. Sex ratio ranged from 1:1.0 to 1:1.7 (female:male) (Table 3).

When apartments are examined individually (Figure 4), apartments 1C (N = 1172), 1D (N = 1624), and 2B (N = 1427) can be identified as focus apartments. All three apartments had excessive food, water, and clutter (harborage), and had large populations of the German cockroach. Sex ratios are similar in apartments 1C and 1D. These two focus apartments are adjacent to each other. Mark-recapture data discussed in detail in a later section of this paper demonstrates an equal exchange of individuals between these two apartments. Sex ratios may be similar because these two apartments have similar conditions -- excessive food and water and in general, very poor sanitation. If the two populations are responding to similar limiting factors, it would logically follow that their growth and development will also follow a similar pattern. Apartment 2B, also a focus apartment, had a preponderance of males in the population. No clear explanation for variations in sex ratio between focus apartments can be offered.

The distribution of nymphal stages across trap locations shows slightly more late stage nymphs in non-traditional sites of infestation -- living rooms and bedrooms -- and slightly more early instar nymphs in the traditional sites of infestation -- kitchens, bathrooms --

and in the case of these apartments, downstairs bedrooms (Figure 5). The downstairs bedroom is combined with the latter group due to its proximity to the kitchen. There is apparently some survival value in placing an egg case in a location where food, water, and harborage are abundant. Considering the general feeding habits of cockroaches, even the bathroom/linen closet location could provide substantial food and water. Ross et al. (1981) identify late stage nymphs as the primary dispersers from established groups. If this is the case, then they are also the primary explorers, and this may explain why more late stage nymphs are found in non-traditional sites of infestation.

The adult to nymph ratio in focus apartments, 1C, 1D, and 2B, was uniform (Figure 6). All three focus apartments had an adult to nymph ratio of 1:1.4. The adult to nymph ratio in all non-focus apartments was variable.

The data reported here may aid in understanding the variablity in population data reported by other researchers (Mele 1972, Ross 1976, and Ross and Wright 1977). Ono and Tsuji (1972) reported a laboratory study in which they established that nymphs comprise 80% of a population of _B_. _germanica_ at equilibrium. That proportion of nymphs is 21% higher than that found in the field study reported here. While field collected data must be tempered by the biases associated with trapping procedures, a higher proportion of nymphs is not unexpected in a controlled laboratory experiment in which behavior patterns are altered, and food, water, and harborage are readily available.

Infestations in focus apartments likely represent stable populations which are at the carrying capacity for that particular type of habitat. An equilibrium may be established in focus apartments, and the stability of the 1:1.4 adult to nymph ratio in trap collections is likely to be density dependent, with respect to carrying capacity. The density and structure of any population of animals will be defined by the availability of resources required for reproduction and survival. Food and water may not be limiting factors in resource abundance in focus apartments, but sufficient harborage may be scarce. Limited harborage may have an adverse impact on population. Populations occurring in non-focus apartments are challenged variably by their environment. German cockroach density in non-focus apartments may also be constrained by limited resources. Harborage will not be the limiting resource, but the availability of food or water in non-focus apartments could potentially keep a population or a certain age class within a population suppressed. Carrying capacity is determined by a different set of criteria in focus and non-focus apartments, but a carrying capacity exists for both situations. Since resources in non-focus apartments are variable, the expected population structure will also be variable.

2. Dispersal Between and Within Apartments.

Between Apartment Movement. During the initial four week period of the mark-recapture study, 3299 adult German cockroaches were marked, and 6304 nymphs were trapped. Since adults were marked in such a way as to allow for recognition of individuals, it is possible to trace specific patterns of movement over time and space for each marked cockroach.

In Building 1, 2128 adult German cockroaches were marked. There were 641 recaptures in the first four weeks and an additional 243 recaptures in the last 3 weeks of the study. Over 10,000 cockroaches were trapped in 7 weeks in Building 1, and 56% were nymphs. Two adjacent apartments were the predominant contributors of cockroaches in Building 1 - Apartments 1C and 1D. Both apartments had large populations. Total trap collections for the two apartments represent approximately 80% of all catches for the entire building. Apartment 1A had a minor infestation, and 1B had virtually no infestation, as evidenced by only 7 cockroaches trapped during the study period.

Thirty-one instances of movement were detected between Apartments 1C and 1D. Sixteen individuals moved from Apartment 1C to Apartment 1D, and 15 individuals moved from Apartment 1D to Apartment 1C. The individuals that moved represented 19 males, 11 females, and 1 female bearing an ootheca. The 1:1.6 (female:male) sex ratio of these individuals was higher than the 1:1.2 sex ratio calculated for all trap catches. Owens (1980) reports adult male German cockroaches are more mobile than adult females due to superiority of females over males in agonistic interactions, and mate seeking by males. While these may be contributing factors, results may merely be attributable to the specific environmental conditions in the study sites, or the reproductive state of the female. Only one case of movement by an egg-case bearing female was detected. Data reported by Kunkel (1965) concerning the lack of feeding behavior of ovipositional females could explain this result. Cochran (unpublished data) further supports this premise with similar data showing that the egg-case bearing female has no reason to leave an undisturbed harborage since she does not seek large quantities of food or water.

In approximately two-thirds (68%) of detected instances of dispersal, movement occurred between the upper floors of the apartments. This may be an artifact of routes of access between the two units, or it may be that upper floors of apartments and homes provide conditions that are less than ideal. Consequently, fewer niches are available to provide food, water, or harborage, and movement away from these locations may be more common.

In Apartment 1C, 1.7% of the marked cockroaches dispersed out of the apartment, and in Apartment 1D, 1.3% dispersed out of the apartment. There was nearly an equal exchange of population numbers between these two apartments. It is possible that due to the high populations which may have induced movement because of a limited resource, the populations occurring in Apartments 1C and 1D are not reproductively isolated, and are, potentially one and the same population.

In Building 2, 1171 adults were marked. Two hundred sixty-four were recaptured in the first four weeks of the study, and 148 in the latter three weeks. Sixty percent of the nearly 5200 cockroaches trapped, were nymphs.

Sixty-five percent of adult cockroaches that were marked were trapped from a single apartment - Apartment 2B. Only two occurences of dispersal were detected in Building 2 - one male and one female. Movement occurred out of Apartment 2B to the adjacent apartment, 2C. One case occurred between the upper floors and one case occurred between the lower floors.

All observed instances of German cockroach movement between apartments in both Buildings 1 and 2 occurred out of apartments with large infestations, and movement only occurred between adjacent apartments sharing common plumbing (Figures 7 and 8).

Detectable movement appears to be dependent upon density and available routes of access. This is in agreement with the findings of Owens (1980, 1982). In Building 1 movement only occurred between apartments 1C and 1D (Figures 10 and 11). No movement was detected between 1C and 1B probably due to limited access between apartments, even though 1C had a large German cockroach infestation. The same phenomena can be observed in Building 2 (Figures 12 and 13). Apartment 2B maintained a large German cockroach population, yet movement out of 2B was only observed into the adjacent apartment sharing common plumbing (2C), and never to the other adjacent apartment (2A), which did not have plumbing in common. Dividing each apartment from the one adjacent to it in both Building 1 and 2 is a fire wall. No breaks occur in the fire wall with the exception of plumbing when it is shared by two apartments. Consequently, in Building 1 only Apartments 1C and 1D, and in Building 2 only Apartments 2B and 2C had any obvious routes of access by which cockroaches could travel. The availability of a pathway between apartments is probably the single-most important factor contributing to movement between apartments within a building, no matter what the population density.

Density, in relation to carrying capacity, can also be identified as a very important factor evoking dispersal behavior in the German cockroach. In apartments able to sustain large populations of the German cockroach, food and water are not usually limited. It would seem that at some point all accessible harborage in an apartment becomes saturated. Preferred harborage or traditional sites of infestation are probably occupied first, followed by less desireable harborage sites. This is directly related to data previously discussed concerning spatial patterns of distribution in focus and non-focus apartments. Emigration would occur at that point in time when all preferred and non-preferred sites of infestation become saturated. In apartments unable to sustain large infestations the same phenomenon is at work. There may still be a limiting factor, perhaps not harborage, but rather food or water. Movement may also be occurring out of these environments, but due to the small number of individuals the probablity of detection may be imperceptible. Prior to reaching carrying capacity, in either type of environment, the risk involved in movement to an unknown site, out of an area of ample food, water, and harborage would be prohibitive. Consequently, dispersal out of low density habitats i.e., habitats below carrying capacity, is not probable. It is not until the risk of staying is greater than the risk of leaving that dispersal will likely be observed.

These results are comparable to the work of Eads et al. (1953) and Jackson and Maier (1955) in which movement by P. americana from a sewer to the adjacent community was induced by placing extreme density pressure on a population. The habitat abruptly became inadequate for the number of occupying individuals. It would be difficult to suppose that a sewer as a habitat for P. americana would be limited in its offering of food or water, but limited harborage is not improbable. In the cases of _P_. _americana_ in the sewerage system studies (Eads et al. 1953, Schoof and Siverly 1953, Jackson and Maier 1955), and of _B_. _germanica_ in the study presented here harborage availability is an important mechanism regulating population density and dispersal from a given habitat.

Within Apartment Movement. Movement of adult German cockroaches within apartments was more pronounced than movement between apartments, but a large amount of movement was still not observed within the apartment study sites. Within apartment movement is delineated in Figure 9. Of 885 individuals that were recaptured at least once during weeks 1 through 4 of the study 67%, were recaptured in the same room in which they were originally trapped. This represents 52% recaptured at their original trap location, and 15% recaptured in a different trap, but in the same room as the original trap location.

The remaining 33% of the recaptured adult population had a variety of dispersal patterns. Fifteen percent of the marked cockroaches traveled either between the bathroom and linen closet or between the kitchen and pantry. The bathroom and linen closet, and the kitchen and pantry can be interperted as a single room due to their proximity (Figures 10, 11, 12, 13). They provide a balanced habitat for the German cockroach, i.e. offering the food, water, and harborage necessary for survival.

Eleven percent of the marked adults traveled from either a bedroom or living room trap to either a kitchen or bathroom/linen closet trap. Bedrooms and living rooms are not likely to be optimal habitats, even in focus apartments. Individuals trapped in one of those locations may be transient residents seeking a habitat where food, water, and harborage are more abundant, or they may be moving in response to cleaning activities in the apartments. Either situation is likely, and movement into a kitchen or bathroom/linen closet is not unexpected.

Only 4% of the cockroaches moved between kitchen trap locations and bathroom/linen closet trap locations. It was anticipated that this would be a low number since either of these locations would provide all the components necessary for German cockroaches to succeed. Consequently, there would be no impetus to move to a new location.

The minimal amount of movement observed in *B. germanica* should not be unexpected. Similiar behavior has been observed in studies of other cockroach species (Bulow and Huggins 1968, Schoof and Siverly 1953, Jackson and Maier 1955).

B. Nymphal Movement Study.

Recapture of genetically marked cockroaches was inadequate to make any definitive statements concerning nymphal movement in field situations. Each release of 40 egg case-bearing females into a field location represented a potential of approximately 1200 to 1920 cockroaches upon successful collective hatch of all oothecae, based on a reproductive potential of 30-48 eggs per ootheca (Truman et al. 1976). Each apartment received the release of two strains of 40 genetically marked gravid females, yet only 53 genetically marked cockroaches of various stages were recaptured following the releases (Table 4). This was out of a hatch potential of 9600-15,360. Three of the mutant strains -- black rose, rose eye, and pallid eye -- were never captured at all.

Ninety-two percent of the captures of genetically marked cockroaches, both nymphs and adults, occurred within the first four weeks after releases were made. Movement away from the original release site was detected in the majority (96%) of captures. Eight individuals were detected to move between floors within an apartment with two of these being nymphs.

Interapartment movement was detected. Both egg-case bearing females (3 cases) and non-egg case bearing females

(2 cases) were detected to have traveled between adjacent apartments. Similarly, one small nymph was collected in an apartment adjacent to the parent release site. It is unlikely that a nymph in an early instar (1st or 2nd instar) moved that far a distance, and it is assumed to have hatched from an egg case deposited in the apartment by a parent female who moved, rather than having moved to that location itself.

Only 25% of the total captures of genetic strains were nymphs. There was apparently some deterrent to either successful hatch of oothecae, or to nymphal survivorship. It is unknown what may have been the factor(s) responsible for low overall survivorship.

The mutant strains that were successfully recaptured, black body and orange body strains, had been originally released in the upstairs release sites in all apartments. Consequently, all but eight of the recaptures occurred at the second floor of the apartments. Five of these went from the upstairs release site to one of the three kitchen traps, and three went to a living room trap. Eighty-two percent of all of the recaptured genetically marked cockroaches were of the black body strain.

The majority (26) of the captures of genetically marked cockroaches occurred in a bedroom trap (Table 4).

This may indicate that the release site did not provide suitable conditions for egg case-bearing females. The linen closet may have already been at or near carrying capacity for the resources available. This is somewhat surprising since the linen closet has previously been identified as a preferred harborage in other studies (Akers and Robinson 1981, Zungoli unpublished data). If release sites were already at carrying capacity, it could account for some of the lack of survivorship of genetically marked nymphs. Only fourteen of the captures were nymphs -- thirteen small, one medium -- with only three of these captures occurring in either a kitchen or bathroom trap.

All three of the German cockroach strains that were never recaptured had eye color as a mutation - black rose, rose eye, and pallid eye. It is presumed that these strains had decreased fitness related to their eye pigment mutation.

Cockroaches have superposition eyes, as do most nocturnal species of insect. This type of eye permits the passage of light through the ommatidial wall (Snodgrass 1938). The light absorbing pigment is dispersed during the daytime, but in darkness the pigment becomes concentrated increasing the light sensitivity of the eye

(Langer 1975). The actual position of the pigment is controlled by the level of ambient light (Day 1941). Dreisig (1981) reported the dynamics of pigment migration in insect superposition eyes and suggests that a circadian pattern to migration may occur. Black rose, rose eye, and pallid eye strains of the German cockroach have varying degrees of pigment deficiency. The pallid eye strain lacks eye pigment entirely. It is possible that pigment deficiencies cause decreased fitness of these strains due to an inability to function properly in low light environments. Eye pigment may also be linked to other genetic factors and overall fitness may not be equal to wild strain German cockroaches due to other associated mechanisms (Brower 1981).

While the genetically marked cockroach release experiment did not yield the desired information on German cockroach movement behavior, it was possible to use the data from the trap collections of marked and wild type cockroaches to compare two methods of trapping - 1-quart Mason jar and Roatel® traps.

Seven-weeks of trapping data representing 448 pairs of Mason jar and Roatel® traps were included in the comparison. Nymph age class was recorded as small (SM), medium (MED), or large (LG). Small nymphs included first and second instar cockroaches. Medium nymphs included third and fourth instars, and all instars above the fourth were designated as large (LG). Insects were placed in categories by visual sorting. Females were separated into two categories, egg case bearing (EC), and non-egg case bearing (♀). The trap locations included in the comparison were kitchen-sink (KS), kitchen-refrigerator (KR), pantry (P), living room (LV), 2 bedroom traps (BD1, BD3), linen closet (LC), and bathroom (B). In these locations Roatel® and Mason jar traps were placed side-by-side.

Table 5 is a compilation of trap collections for seven weeks of data. As can be seen, trap counts were low, but there are obvious trends in the data.

Roatel® traps were found to trap 1.5 times as many German cockroaches compared to Mason jar traps when placed side-by-side for a 24-hour trapping period. Roatel® traps caught approximately equal numbers of small and large nymphs, but were found to collect almost twice as many males than the jar traps, and only half the number of medium nymphs. Females were also differentially captured by these two trapping methods. Greater than three times as many non-egg case bearing females, and greater than twice as many egg case bearing females were captured in Roatel®

traps than in Mason jar traps. These data are summarized in Tables 5 and 6.

Trap location had a bearing on trap numbers (Table 7). Trap collections were approximately equal for both trapping methods in trap locations KR, LV, BD1, and BD3. Variations occurred at trap locations KS, P, LC, and B,with a range from 1.7 to 2.9 times more cockroaches trapped in Roatel® traps.

These results are different from the results of Ross (1981) who reported similar collections for all age classes except small nymphs in a comparison of Roatel® and Mason jar traps. The disparity in the result between these two sets of data may be attributed to several factors such as differences in sample size, variations in trap locations, structure of resident populations, longevity of the experiment, and differences in the baits used as an attractant.

Table 1. Procedure followed in adult mark-recapture study.

Week	Regime
1-4	- Trap (3, 24-hr periods/wk) - Mark and record adults - Record nymphs (S, M, L) - Return adults and nymphs to original trap location - Replace traps
5-7	- Trap (3, 24-hr periods/wk) - Record adults - Record nymphs - No replacement of adults and nymphs - Replace traps

Table 2. German cockroach population distribution by trap location (weeks 1-4)

Trap location	Percentage of total collection		
	Adults	Nymphs	Adults and Nymphs
Kitchen	15	16	31
Bedroom (down)	4	7	11
Living room	1	6	7
Bathroom/ linen closet	12	22	34
Bedroom (up)	6	11	17

Table 3. Adult sex ratio based on trap location.

Trap location	Female:Male
Kitchen	1:1.3
Living room	1:1.3
Bedrooms (down)	1:1.7
Bathrooms/linen closet	1:1.0
Bedroom (up)	1:1.1

Table 4. Capture date for genetically marked German cockroaches showing differential trap catches for black body (Bl), and orange body (Or) strains with data separated for both Roatel® (R) and Mason jar (J) traps.

	Capture Sites											
	B		LC		BD		K		LV		TOTAL	
STRAIN	R	J	R	J	R	J	R	J	R	J	R	J
Bl	2	1	0	0	3	5	0	2	0	0	5	8
Or	0	0	0	0	1	1	0	0	0	0	1	1
Bl	4	3	2	2	4	3	1	0	0	1	11	9
Or	0	0	0	0	3	1	0	0	0	0	3	1
Bl	0	1	0	0	3	1	1	1	0	0	4	3
Or	3	0	0	1	1	0	0	0	0	1	4	2
Bl	0	0	0	0	0	0	0	0	1	0	1	0
Or	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL												
Bl	6	5	2	2	10	9	2	3	1	1	21	20
Or	3	0	0	1	5	2	0	0	0	1	8	4

Table 5. Collections of German cockroaches for a 7-week period. Collections represent the pooled results of 448 pairs of Roatel' and Mason traps.

TRAP	1-QT. MASON JAR TRAP							Roatel Trap						
Location	SM	MED	LG	♀	EC	♂	TOTAL	SM	MED	LG	♀	EC	♂	TOTAL
KR	25	12	8	8	4	13	70	5	5	6	27	12	26	81
KS	5	3	0	2	0	4	14	3	4	3	11	6	10	37
P	5	8	1	5	2	4	25	9	5	1	30	7	21	73
LV	13	23	10	11	4	26	87	15	8	9	21	11	25	89
BD1	30	11	3	12	3	8	67	17	5	6	16	10	16	70
BD3	2	6	5	3	6	11	33	6	3	2	13	6	12	42
LC	8	2	1	3	3	2	19	5	1	1	15	3	8	33
B	16	2	3	8	5	11	45	31	6	6	32	10	20	105
TOTAL	104	67	31	52	27	79	360	91	37	34	165	65	138	530

Table 6. Comparison of Mason jar and Roatel® traps based on life stage, sex, and reproductive state of females.

Stage	Jar	Roatel®	R/J
SM	104	91	0.9
MED	67	37	0.5
LG	31	34	1.1
♀	52	165	3.2
EC	27	65	2.4
♂	79	138	1.8
TOTAL	360	530	1.5

Table 7. Comparison of Mason jar and Roatel® traps based on trap location.

Trap Location	Jar	Roatel®	R/J
KR	70	81	1.2
KS	14	37	2.6
P	25	73	2.9
LV	87	89	1.0
BD1	67	70	1.0
BD3	33	42	1.3
LC	19	33	1.7
B	45	105	2.3
TOTAL	360	530	1.5

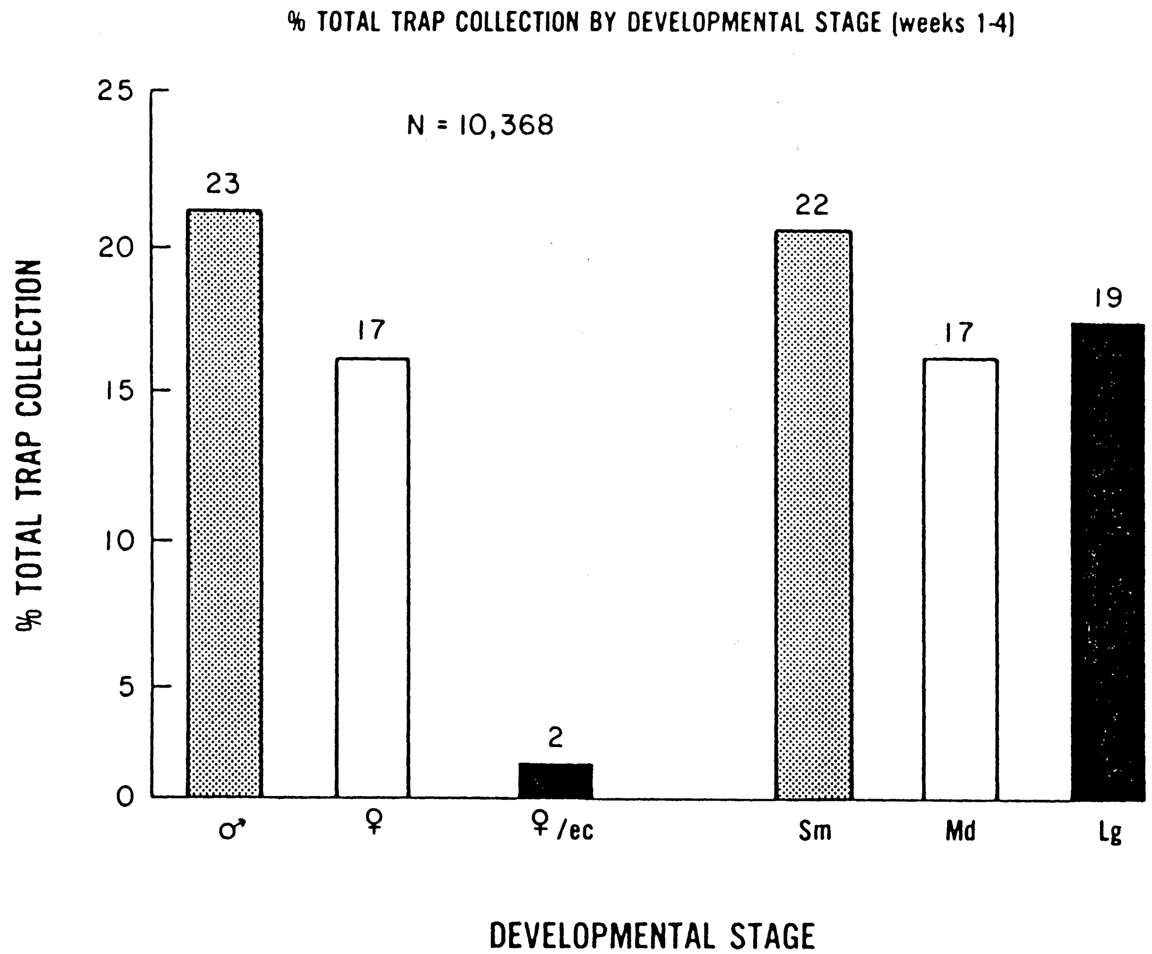

Figure 1. Percentage total trap collection by developmental stage (4 weeks).

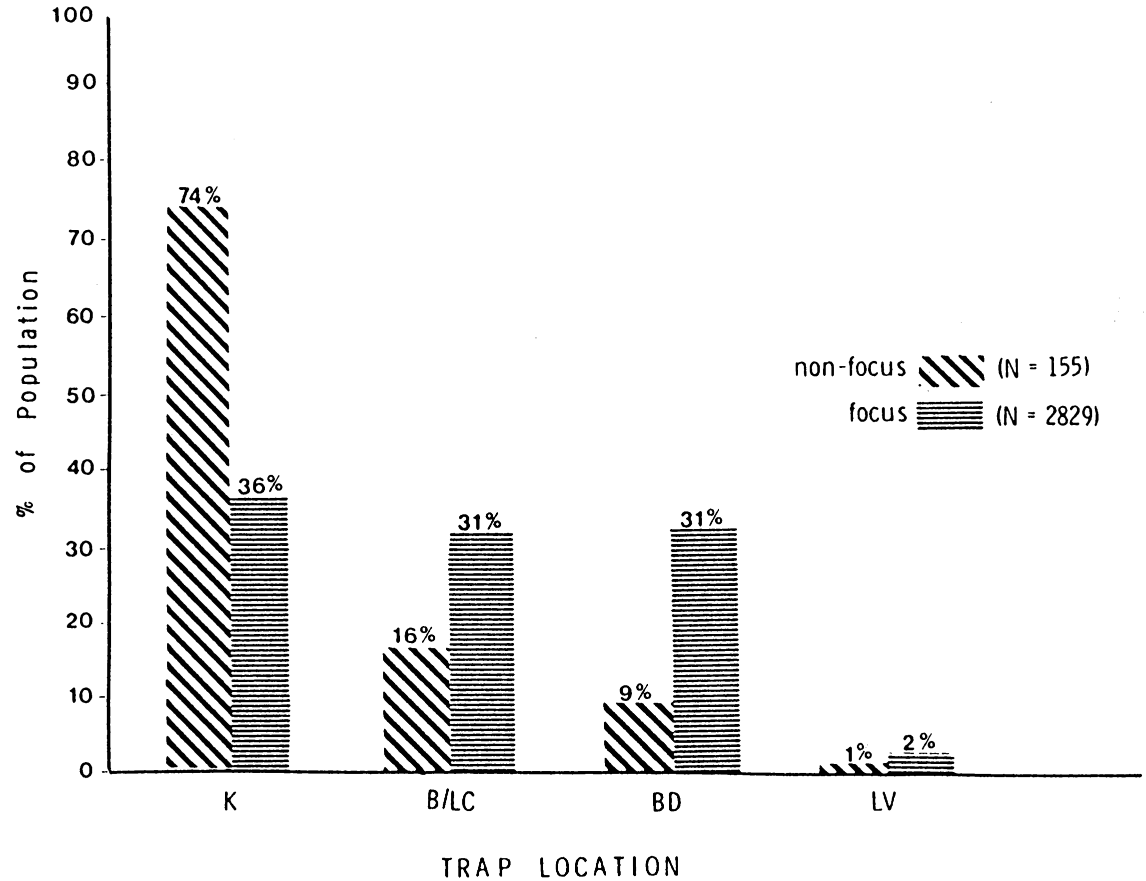

Figure 2. Population distribution by trap location in focus and non-focus apartments (4 weeks).

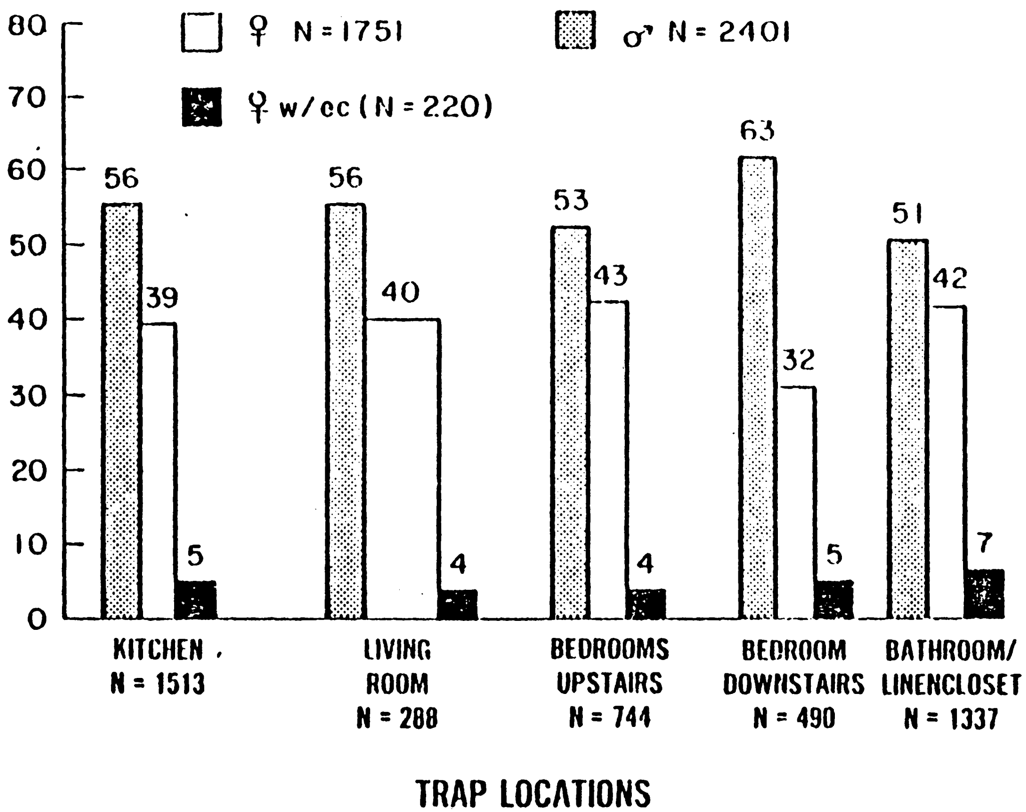

Figure 3. Percentage adult cockroaches trapped per location by sex (4 weeks).

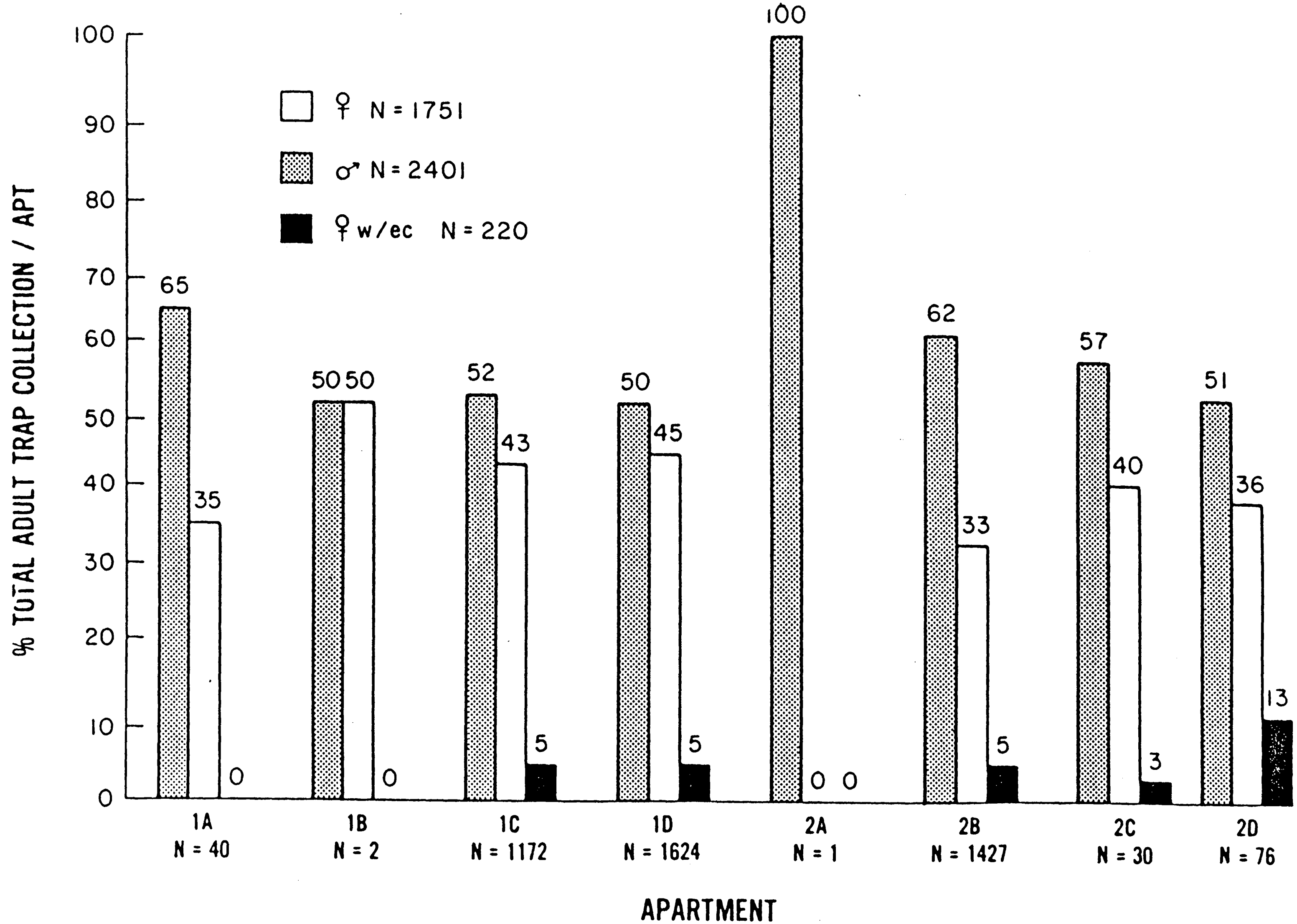

Figure 4. Percentage adult cockroaches trapped per apartment by sex (4 weeks).

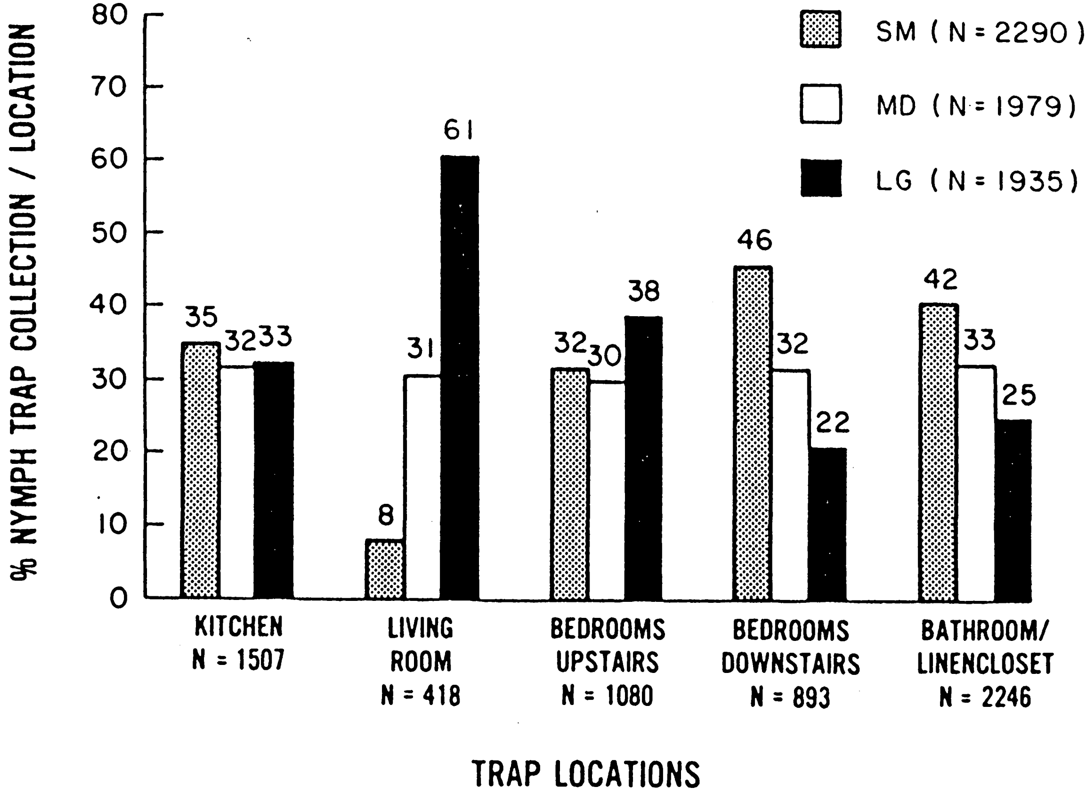

Figure 5. Percentage cockroaches trapped per location by nymphal stage (4 weeks).

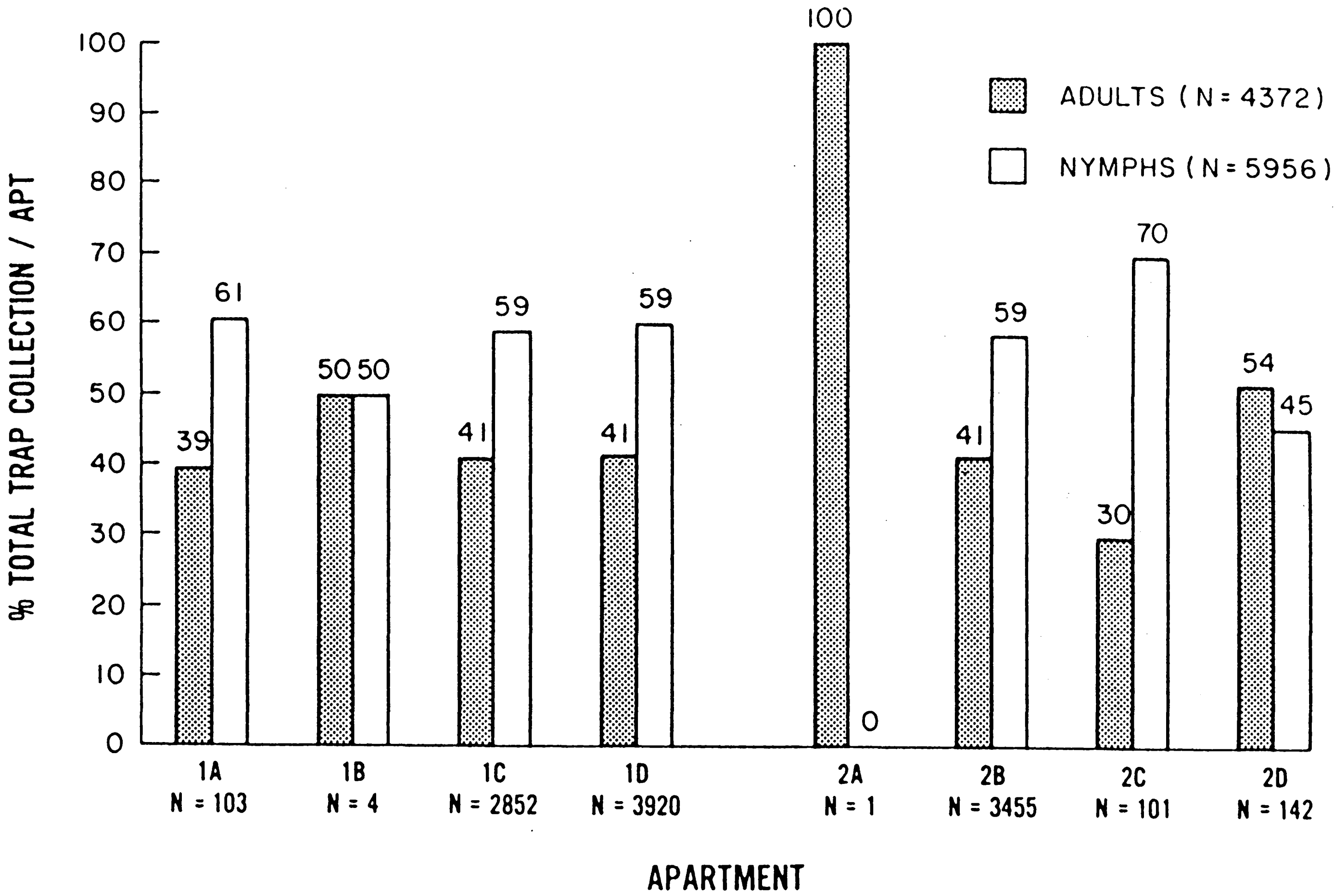

Figure 6. Percentage cockroaches trapped per apartment by developmental stage (4 weeks).

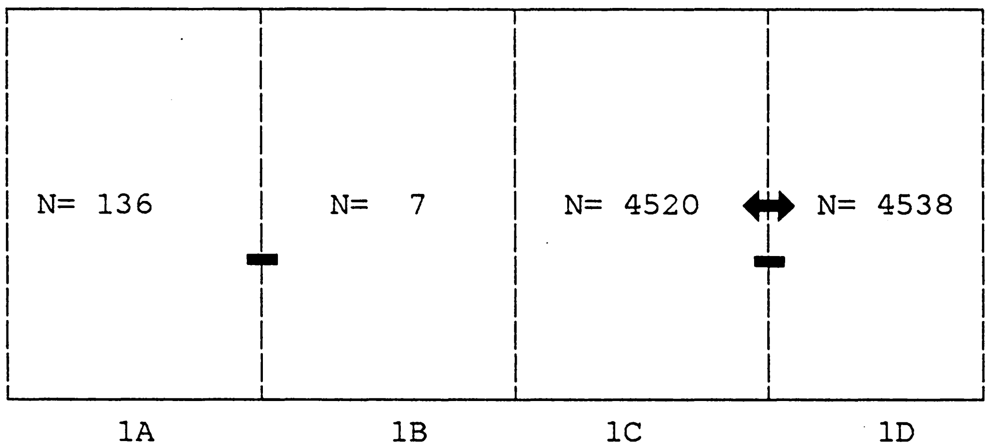

Figure 7. Diagram of Building 1 showing location of plumbing in apartments, plumbing connections between apartments, and direction of adult movement.

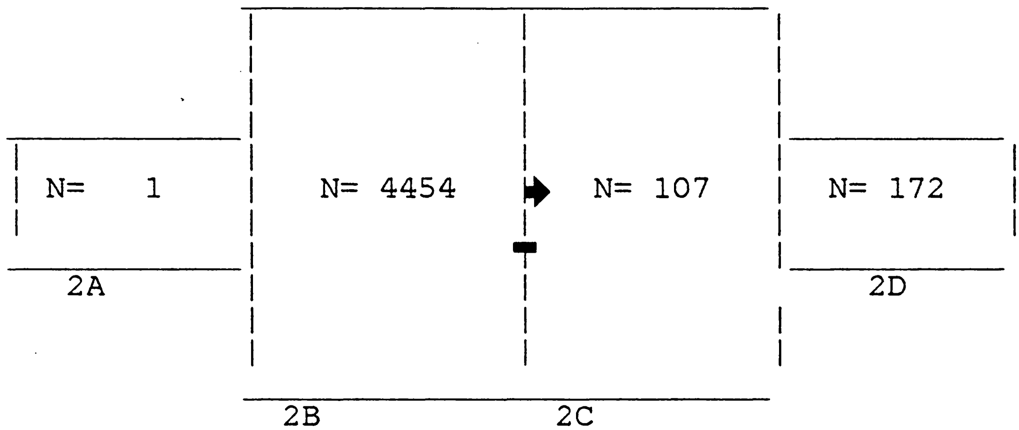

Figure 8. Diagram of Building 1 showing location of plumbing in each apartment, plumbing connnections between apartments, and direction of adult movement

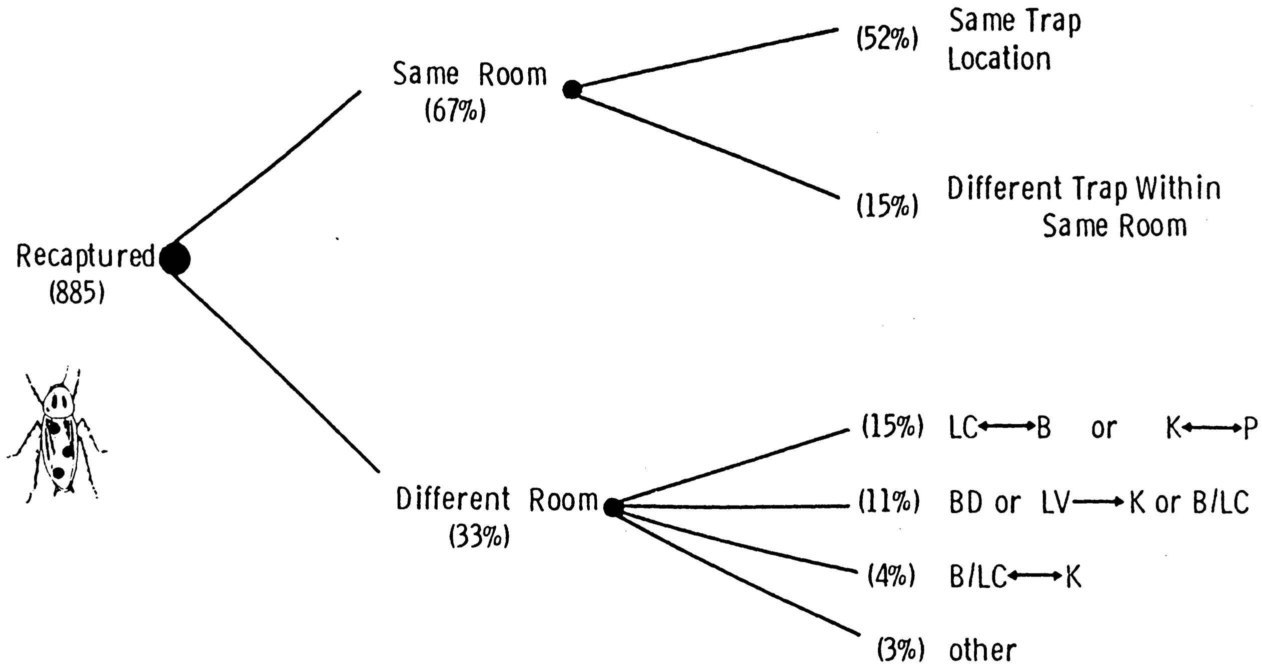

Figure 9. Within apartment adult German cockroach movement.

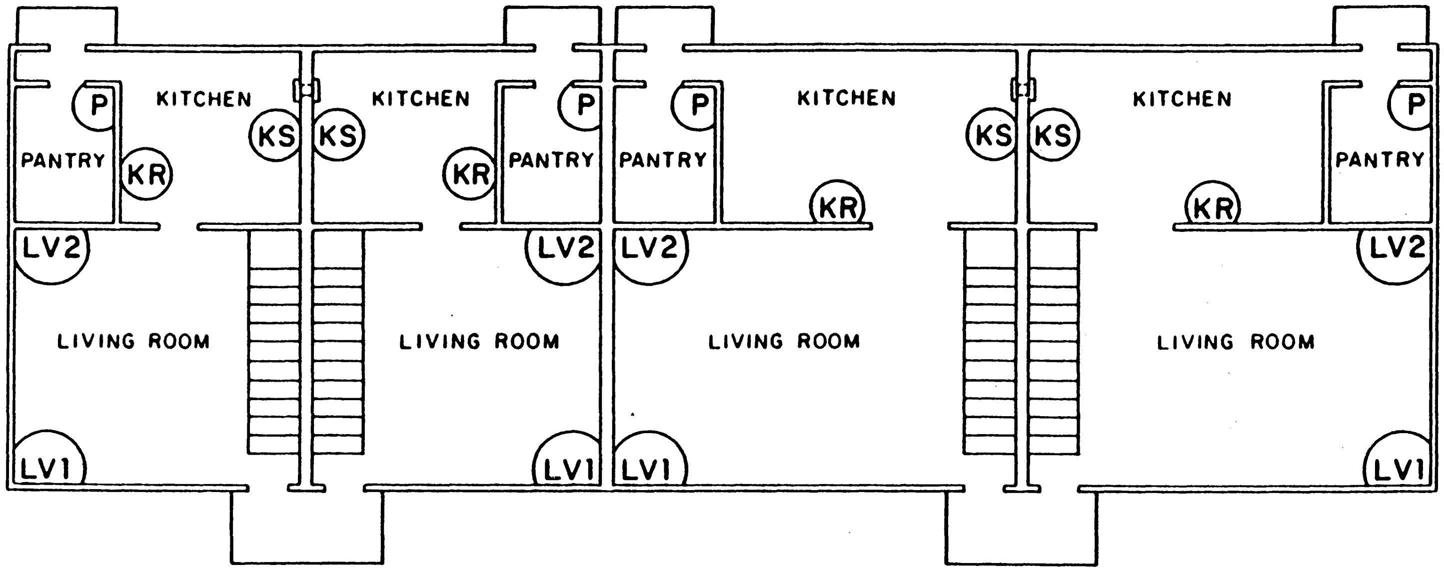

Figure 10. Diagram of the first floor of Building One showing trap locations and plumbing between apartments.

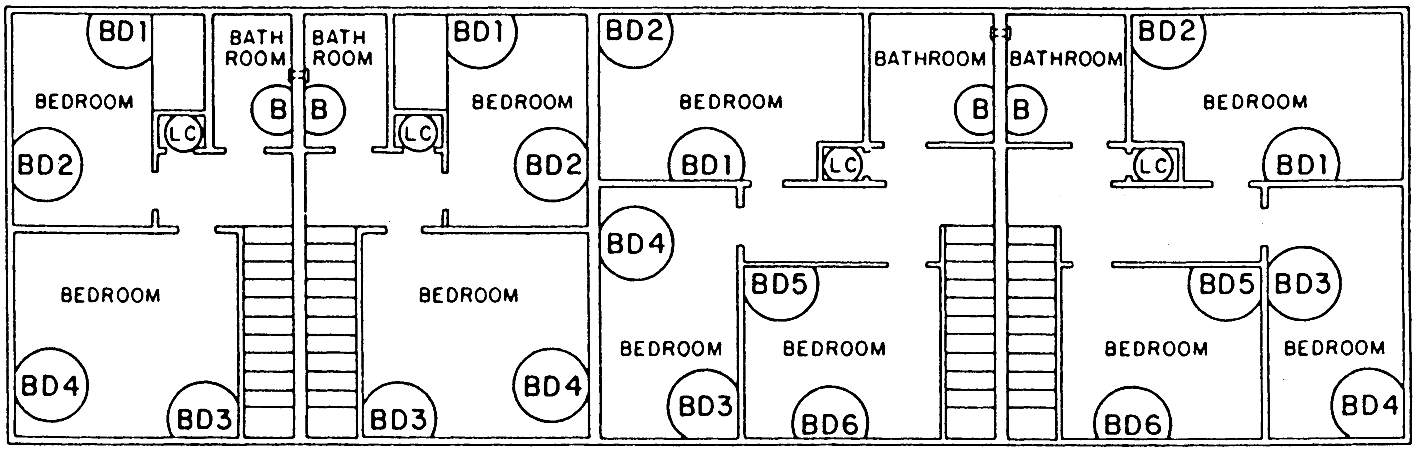

Figure 11. Diagram of the second floor of Building One showing trap locations and plumbing between apartments.

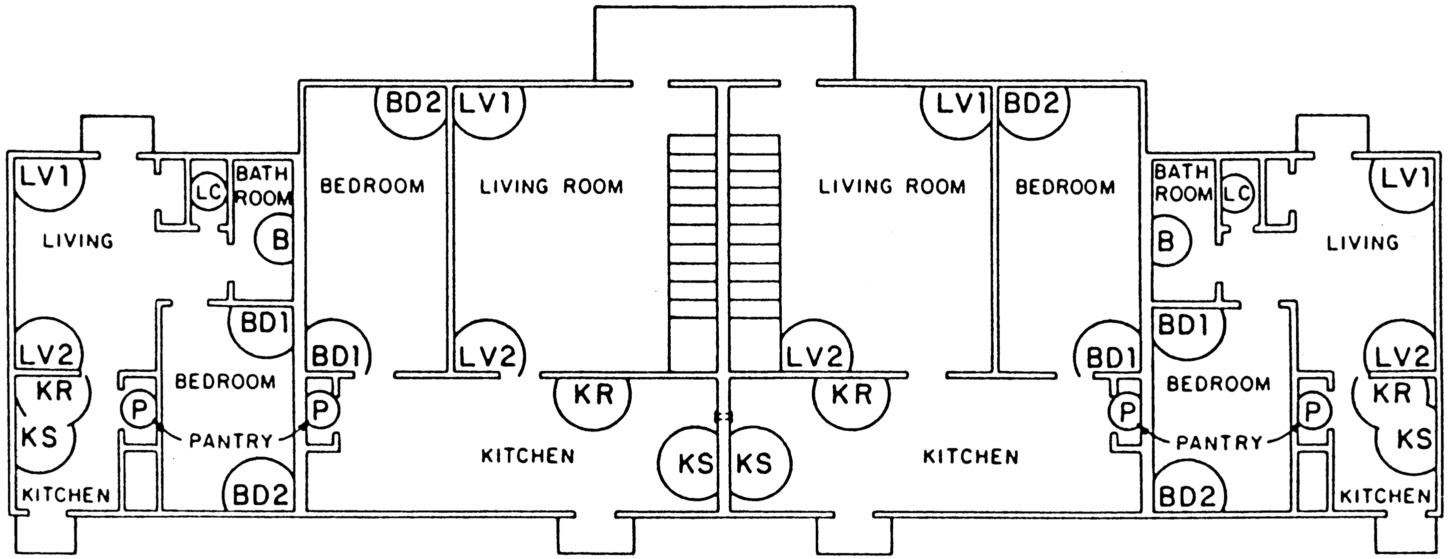

Figure 12. Diagram of the first floor of Building Two showing trap locations and plumbing between apartments.

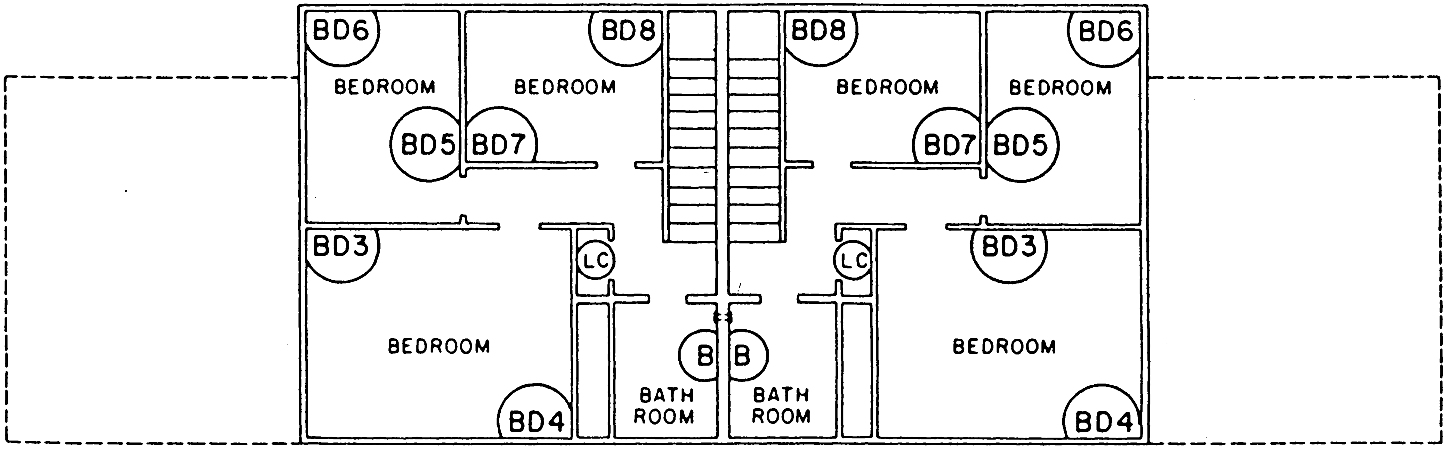

Figure 13. Diagram of the second floor of Building Two showing trap locations and plumbing between apartments.

PART II - AESTHETIC INJURY LEVEL

INTRODUCTION

The basic principles of integrated pest management (IPM) can be applied to almost any ecosystem, but applications are most common in agriculture. Since it was first proposed, the concept of "integrated control" (Stern al. et al. 1959), has evolved from theory to accepted practice in many cropping systems (Metcalf and Luckmann 1975, Smith and Pimentel 1978). It is in the agro-ecosystem that the principles of IPM were first tested and proven effective (Stern 1966), and it is here that IPM is being practiced today.

As the concept of IPM expands to encompass pest control situations outside the realm of agriculture, new aspects, not found in the agro-ecosystem must be included. Urban IPM programs must be designed for pests in close association with man: pests that threaten food, fiber, and both mental and physical health. Consequently, urban IPM programs must consider more directly the sociological and psychological needs of the public sector, including the aspects of social acceptance of various control methods, and the level of control desired or necessary.

There is little evidence that the special needs of urban IPM are being researched for the purpose of program implementation (National Research Council 1980). Workers in urban IPM have adopted a posture of borrowing agricultural IPM concepts for developing an urban IPM philosophy. The appropriateness and effectiveness of transferring agro-technology to urban problems must be thoroughly examined prior to implementation.

Two of the most important aspects of agricultural pest management are 1) management, not total elimination of a pest population, and 2) the establishment of an economic injury level for pest populations (Stern et al. 1959, Smith 1969). The economic injury level is considered to be the lowest pest population that causes economic damage. It is one of the most difficult aspects of pest management due to the complex nature and dynamic interaction of crop, pest, cropping practices, micro- and macro-environment, economic conditions and many other considerations. Establishment of an economic injury level allows for pest population management rather than pest population control. The difference between management and control is perhaps semantic. However urban pest problems demand consideration of these concepts as separate goals. For the purposes of this paper, the term management indicates suppression of a pest population, and control is meant to indicate total elimination of the pest population.

In designing an urban pest management program for street trees in Berkeley, CA, Olkowski (1974) proposed the use of aesthetic injury level (AIL) to replace the agricultural concept of economic injury level. He reasoned that street trees, like other ornamental plants are maintained for reasons difficult to measure entirely in economic parameters. He stated that there is a need for some standard of intolerable aesthetic injury in order to prevent unnecessary treatments. The application of an AIL to ornamental plantings is a logical transfer of the economic injury level concept from agriculture. An issue that can be addressed in establishing an AIL for ornamentals is economics. While plantings of this type are maintained for aesthetic purposes, they are also quite costly. Thus it can be concluded that injury levels for outdoor urban pest problems are both aesthetic and economic (Reichelderfer and Davidson, personal communication).

In designing management/control programs for pests inside the urban environment (office buildings, homes, restaurants, grocery stores), rather than the exterior, researchers must realize the necessity of emphasizing aesthetic as well as economic factors. In so doing, researchers must ask questions related to tolerable pest levels, such as how many fleas are acceptable?, or how many rats, or flies, or flour beetles, or cockroaches can/will the general public tolerate?

A basic starting point for developing urban pest management programs is an understanding of the attitudes and knowledge of residents toward the target pest. A survey conducted in HUD-subsidized public housing projects in Baltimore, MD, Norfolk, VA, and Roanoke, VA, (Wood et al. 1981) provided preliminary information on the feasibility of establishing an aesthetic injury level (AIL) for cockroach pest management programs. The results of that survey indicate that the willingness of public housing residents to accept even a low number of cockroaches is minimal. In an effort to examine further the application of the AIL concept in designing cockroach pest management programs, a survey was conducted in those same eastern cities emphasizing tolerance levels for German cockroaches (Appendix A). One hundred surveys were randomly conducted in public housing projects in each of the cities. It is concluded from the analyses of the survey results that AIL for the German cockroach is such a dynamic (fluctuating) number that it is not feasible to incorporate the concept into pest management programs aimed toward pests in close association with man.

MATERIALS AND METHODS

One hundred surveys were taken in each of three eastern cities - Roanoke (R), VA, Norfolk (N), VA, and Baltimore (B), MD. All non-elderly public housing projects in Roanoke and Norfolk were included in the sample, and 17 non-elderly projects were sampled in Baltimore (Table 8). A discussion of demographic data and an economic profile of public housing residents for each of the cities can be found in Wood et al. (1981).

The number of surveys taken in a given project was based on the percentage of the total number of units in the entire sample that was represented by that particular project. Households were randomly chosen for interviews. Replacement households were sampled when an interview could not be obtained after two attempts at contact were made on two different days. The survey was conducted by one person as a door-to-door interview. Three people served as interviewers. Housing designed specifically for the elderly (age 55 or older) was not included in this survey because previously collected data indicated an apparent difference between residents in elderly housing and in non-elderly public housing projects in attitudes, and in the levels of cockroach infestation (Wood et al. unpublished data).

Survey Question

The survey consisted of eleven questions (Appendix A). It took approximately 5 minutes to conduct each survey interview. All of the questions that required the respondant to estimate a number were open-ended, and were later categorized for easier discussion. The survey was pre-tested in Roanoke, and slight adjustments were made in the phrasing of questions to enhance clarity.

Data Analysis

Most of the statistical treatment of the data is of a descriptive nature and required no further statistical analysis. Chi-square analysis was applied to determine the relationship between some of the questions. Where chi-square analysis yielded significant results contingency coefficients were calculated in some instances to determine the strength of some the relationships (Gibbons 1977). Maximum values for contingency coefficients (CC) were calculated as :

CC = t-1/t

where t = minimum number of rows
or columns whichever
is the lower of the two values

Analysis of variance (ANOVA) at $p<0.01$ was applied to data to determine differences in responses between cities Duncan's Multiple Range test at $p<0.01$ was used to determine where differences occured when ANOVA was significant. All data was analyzed by computer using an SPSS program (Nie et al. 1975).

RESULTS AND DISCUSSION

Profile of Residents

age

	R(yrs)	N(yrs)	B(yrs)	X(yrs)
mean43	45	42	43	
median	38	44	38	40
range	18-92	18-88	15-82	15-92

sex

	R(%)	N(%)	B(%)	X(%)
female	89	76	85	83
male11	24	15	17	

The residents questioned for this survey were 18 years or older, except in situations where the head of the household was under 18 years of age. As seen by the reported range and median for age, public housing residents are a diversely aged group. In the majority of (83%) households included in the survey, the respondents were women. It is not uncommon for women to be the head of household in a public housing community (Office of Organization and Management Information 1979).

Seriousness of Cockroach Problem

Q. Do you think that roaches are a serious problem
A.

	R(%)	N(%)	B(%)	X(%)
yes	73	81	95	83
no	26	15	5	15
don't know	1	4	0	2

Q. How many roaches do you see in a 24 hour period? (or per week or per month?)

A.

	R(%)	N(%)	B(%)	X(%)
<1	37	14	9	20
1-5	28	20	23	23
6-10	19	11	13	15
11-25	8	27	19	18
26-50	7	12	16	12
51-100	1	13	16	10
>100	0	3	5	2
mean	8	29	36	24
median	3	12	15	8
range	0-55	0-300	0-350	0-350

Most resident (83%) perceived cockroaches to be a serious problem. The percentage of yes responses to this question was highest in Baltimore (95%), and lowest in Roanoke. The number of cockroaches seen in a 24 hour period was significantly higher in Norfolk and Baltimore than in Roanoke (ANOVA at $p<0.01$, Duncan's Multiple Range Test at $p<0.0000$). During the period that the survey was being conducted, Baltimore Housing and Community Development had recently suspended the scheduled cockroach treatment program in the housing projects. However, many residents seemed unaware that cockroach control efforts had ceased. This is probably because when the pest control program was in effect, apartment units were treated 3-4 times a year, and many residents were not yet due for treatment. Roanoke and Norfolk both had on-going cockroach control programs at the time of the survey. In Roanoke, apartments are sprayed for cockroaches 4 to 6 times per year. In Norfolk treatment occurs 1 to 2 times per year. Whether or not a resident perceives cockroaches to be a serious problem may be influenced by the effort and presence of a treatment program in their project. There is a significant relationship between how many cockroaches were seen in a 24 hour period and whether or not cockroaches were thought to be a serious problem

(X^2=40.56 at p <0.0000 with 6 df), although the strength of the association is low (contingency coefficient = 0.3456). The low contingency coefficient may indicate that while people have high cockroach populations perceive the situation to be a serious problem, people with low populations also feel that having cockroaches is a serious problem. Residents who have not had previous experience with German cockroaches, would likely have a low tolerance to their presence.

Willingness to Pay for Pest Control

Q. If the Housing Authority did not provide pest (roach) control, would you hire a pest control company to spray for roaches in your apartment?

A.

	R(%)	N(%)	B(%)	X(%)
yes	21	56	51	43
no	79	44	49	57

Q. If you would hire a pest control operator, how much would you be willing to pay each month?

A.

$	R(%)	N(%)	B(%)	X(%)
1-10	11	19	23	18
11-20	7	27	25	20
21-30	2	8	3	4
>30	1	1	0	1
n/a	79	44	49	56

Many residents (43%) said they would hire a commercial pest control operator if the housing authority did not provide a free service. In fact, 12% of the respondents in Norfolk, and 8% in Baltimore said they already hire a commercial pest control operator to treat for cockroach problems.

Eighteen percent of those questioned said they would be willing to pay from $1 - $10 per month for pest control, and an additional 20% of the residents said they would be willing to pay $11 - $20 per month. The willingness of people to pay for pest control was significantly higher in Baltimore and Norfolk than in Roanoke (ANOVA at $p<0.0000$, Duncan's Multiple Range at $p<0.01$), and residents in Baltimore and Norfolk were willing to pay significanlty more for treatment than in Roanoke (ANOVA at $p<0.0000$, Duncan's Multiple Range Test at $p<0.01$). This result is compatible with the higher infestation levels found in Baltimore and Norfolk. Since public housing residents in those two cities have more serious infestations they are more likely to be willing to spend money to alleviate the problem.

Of the 57% that said they would not hire a commercial pest control operator even if the housing authority did not provide a treatment program, 44% either said they would want to, but wouldn't be able to afford it, or they would purchase insecticides on their own to spray for cockroaches themselves. When the annual average income of public housing residents is considered (Wood et al. 1981), it becomes even more apparent that residents perceive cockroaches to be a serious problem.

These data can aid in the evaluation of urban pest problems in economic parameters. There is a significant difference between Norfolk and Baltimore compared to Roanoke in the number of cockroaches seen in a 24 hour period, in whether or not a resident would hire a pest control operator in the absence of free public housing pest control, and in the amount of money a resident would spend for cockroach control (ANOVA at $p<0.0000$, Duncan's Multiple Range Test at $p<0.01$). There also is a significant relationship between how many cockroaches are seen in a 24 hour period, and both willingness to hire a pest control operator ($X^2=16.36$ at $p<0.001$ with 3 df), and the amount of money a resident is willing to spend for control ($X^2=31.63$ at $p<0.006$ with 9 df). In other words, the more cockroaches seen in a 24 hour period, the more willing a resident is to hire pest control services, and the more money the resident is likely to spend when a commercial pest control operator is engaged.

Infested Foods

Q. Have you ever thrown food away because of roaches?

A.

	R%)	N(%)	B(%)	X(%)
yes	33	49	56	46
no	67	51	44	54

Q. Do you ever see pests other than roaches in your kitchen?

A.

	R(%)	N(%)	B(%)	X(%)
yes	54	40	29	41
no	46	60	71	59

Q. Have you ever thrown food away because of pests other than roaches (moths, weevils)?

A.

	(R%)	N(%)	B(%)	X(%)
yes	6	11	6	8
no	94	89	94	92

Q. If you saw weevils in your flour would you remove them or would you throw all the flour away?

A.

	R(%)	N(%)	B(%)	X(%)
discard	91	93	86	90
remove	9	7	14	10

Q. How many weevils would you be willing to remove from your flour before you would just throw it all away?

A.

no. removed	R(%)	N(%)	B(%)	X(%)
1-5	4	6	10	7
6-10	4	1	4	3
n/a	92	93	86	90

Other insect pests were a problem to the residents on an occasional or seasonal basis (Table 9), although many people commented that nothing was as bothersome as cockroaches.

Forty-six percent of the respondents had discarded food because of contamination by cockroaches, while only 8% had discarded food because of insects other than cockroaches. There is a significant relationship between a resident's perception of cockroaches as a serious problem and whether or not food had been discarded because of cockroaches (X^2=35.67 at p<0.0000 with 2 df). Even people who are not bothered by insects in general, will likely be troubled by insects in or around their food. Besides making food undesireable and possibly unhealthy, foods infested by insects can represent an economic loss.

The type of food discarded varied (Table 10). When pests other than cockroaches were the problem in foods, dry goods or foods left out in the open (uncovered) were typically the foods that had to be discarded. Only 10% of those people who indicated a problem with other pests in their foods, said that they would be willing to to remove them and use the food , and only 3% would remove more than 5 insects without discarding all of the infested food. When cockroaches were the pest problem in foods, there were several food types that were infested. Because cockroaches were sometimes found in the refrigerator, there was often little the resident could do to prevent contamination. Many residents who reported problems with cockroaches expressed a feeling of hopelessness concerning their ability to eliminate them. Apparently, there is no tolerable level of infestation when pests are associated with food. Whether the pest is a cockroach or a flour weevil people are unlikely to view their presence as acceptable.

Eliminating Cockroaches

Q. Do you think its possible to completely eliminate 100% of all the roaches in your apartment?

A.

	R(%)	N(%)	B(%)	X(%)
yes	56	46	48	50
no	25	48	44	39
don't know	6	3	5	5
don't have roaches	13	3	3	6

Q. If you don't think it's possible to eliminate 100% of the roaches, why don't you think so?

A.

	R(%)	N(%)	B(%)	X(%)
all units not sprayed	2	11	5	6
neighbors/movement	16	33	37	28
don't know	6	3	2	4
N/A	75	52	55	61

Thirty-nine percent of the respondents didn't think it was possible to eliminate all of the cockroaches. Seventy-two percent of those that said it wasn't possible to eliminate cockroaches completely, thought that it wasn't possible due to factors beyond their control, such as neighbors, cockroach movement, no cooperation, etc., i.e. in other words, through no fault of their own. It is likely that when the presence of cockroaches is attributed to someone else, then the responsibility for control is also passed to someone else. This is one reason why resident education should be a core component part of all programs. Giving residents a basic understanding for the causes of cockroach infestations, the difficulties associated with control, and their neccessary responsibility to a successful program is vital to meeting the goals of a German cockroach control program.

Tolerance of Cockroaches

Q. How many roaches can you put up with seeing in a 24 hour period before you do something to control them?

A.

	R(%)	N(%)	B(%)	X(%)
0	12	5	9	9
1	51	17	34	34
2	10	16	10	12
3	8	3	5	5
4	2	4	8	5
5	3	8	7	6
6-10	5	18	16	13
11-20	5	17	9	10
21-30	2	6	1	3
>30	2	6	1	3

The final question to be discussed, is perhaps the most important: Is there a tolerance level for the German cockroach?

Nine percent of the residents implement some measure of control regularly, whether they see cockroaches or not. Another 34% take action upon seeing only one cockroach. Over half (55%) of the people would tolerate only zero to two cockroaches before initiating control. This indicates that if populations could be suppressed to a low enough level to ensure no more than one sighting in a 24 hour period, then on the average 57% of the residents would be satisfied, but if individual cities are considered this does not hold true. In Norfolk that same level of control would satisfy 88% of the people, while in Roanoke it would satisfy only 27% of the people. There is a significant difference between the three cities in the tolerance of residents to the presence of cockroaches (ANOVA at $p<0.0001$, Duncan's Multiple Range Test at $p<0.01$). From these data it is apparent that tolerance levels are variable, and if they can be established at all, it is necessary to set that number based on the attitude of the target audience.

There is a significant relationship between how many cockroaches are seen in a 24 hour period and the number of cockroaches that a person will tolerate before implementing a control measure ($X^2 = 56.98$ at $p<0.0000$ with 6 df). This indicates that the AIL might vary with the level of infestation, i.e., as the level of cockroach infestation was reduced, the tolerance level would also likely decline. Thus, the feasibility of using the injury level concept in urban cockroach control programs is questionable, unless it is set at a very low level, 1 or <1 per day.

It is likely that resident acceptance of an AIl can be enhanced with the initiation of educational programs designed to give a basic understanding of cockroach biology, and the difficulties of cockroach control. It is also likely that cockroach control will be enhanced by these same educational programs by creating an environment of cooperation and resident acceptance of some responsibility for a successful control program.

Borrowing concepts, philosophies, and strategies of control from agriculture for implementation of urban programs, dictates a need to understand thoroughly all of the implications associated with adhering too stringently to ideas that are valid in an agroeconomic setting. Even the most basic tenets of pest management may not be appropriate when put into practice inside the living quarter. The two concepts examined in this paper, economic injury level, and population suppression rather than elimination, have been evaluated as having limited use for pests populations that are in close association with man i.e., pests of food, fiber, and health.

Table 8. Housing projects sampled for aesthetic injury level survey and number of surveys taken in each project.

Roanoke		Norfolk		Baltimore	
Project	Sample no.	Project	Sample no.	Project	Sample no.
Bluestone	7	Bowling	7	Broadway	5
Hunt Manor	7	Calvert	6	Brooklyn Homes	5
Hurt Park	9	Diggs	9	Cherry Hill	16
Indian Village	7	Granby	8	Claremont	3
Jamestown	14	Liberty	15	Douglass	4
Lansdowne	28	Merrimack	10	Fairfield	3
Lincoln Terrace	28	Moton	3	Gilmore	6
		Oakleaf	5	Hollander Ridge	10
		Roberts	5	Latrobe	7
		Roberts East	4	Lexington Park	7
		Tidewater	9	McCulloh	7
		Tidewater So.	4	Mount Winans	2
		Young	15	O'Donnell	9
				Perkins	7
				Poe	3
				Rosemont	1
				Somerset Ext.	1
				Westport	4

Table 9. Pest problems other than German cockroaches encountered by public housing residents.

Pest	Number of cases*
ants	19
bats	1
cockroaches (*Blatta*, *Periplaneta*)	41
crickets	7
flies	7
mice	14
rats	5
silverfish	2
spiders	38
termites	4
weevils	4

* Represents combined total for all three cities.

Table 10. Food discarded due to infestation by either cockroaches or, other insect pests.

Type of food	Number of instances of infestation*	
	Cockroaches	Other
dry goods	51	10
food left out	71	7
bread	52	0
sweets	11	0
food in refrigerator	11	0
other	10	4

*Represents combined total for all three cities.

APPENDIX A

Aesthetic Injury Level Survey

1. Project__________________ R B N

2. Do you think roaches are a serious problem?

(0) yes _____
(1) no _____

3. Do you think it's possible to completely eliminate 100% of the roaches in your apartment?

(0) yes _____
(1) no _____
(2) don't know _____
(3) don't have roaches _____

If no, why?

4. Have you ever thrown food away because of roaches?

(0) yes _____
(1) no _____

If yes, what have you thrown away?

5. How many roaches do you see in a 24 hour period? (or per week, or per month?)________

6. If the housing authority did not provide pest (roach) control would you hire a pest control company to spray for roaches in your apartment?
(0) yes _____
(1) no _____

If yes, how much would you be willing to pay each month? _____

7. How many roaches can you put up with seeing in a 24 hour period before you do something to control them? _____

8. Do you ever see pests, other than roaches in your apartment?

(0) yes _____
(1) no _____
If yes, what other pests do you see?

9. Have you ever thrown food away because of pests other than roaches (moths, weevils)?

(0) yes _____
(1) no _____

If yes, what have you seen?

10. If you saw weevils in your flour would you remove them, or would you throw all the flour away?

(0) throw away _____
(1) remove _____

If you would remove the insects, how many would you be willing to remove before you felt you had to throw all of the flour away? _____

11. Age _____

12. (0) Male _____ (1) Female _____

SUMMARY

The research presented in this paper provides information that can be directly incorporated into German cockroach pest management/control programs. It was designed to contribute basic research data that could have a direct impact on applied German cockroach programs.

The results indicate that German cockroaches do not move between apartments as much as was once thought. Movement occurs out of high density situations into areas that are easily accessible. Accessible areas can include an adjacent apartment that shares common plumbing with another apartment, as well as the next room in the same apartment. The point being that when density approaches carrying capacity, there is ample reason for resident German cockroaches to move away from the saturated environment.

The limiting factor in the German cockroach environment could be one of three resources -- food, water, or harborage. It is assumed that the resource which becomes scarce first is harborage, and that when harborage sites become saturated the impetus to move from a habitat rich in food and water increases. This is based on the observation that movement occurred out of habitats with sufficient food and water.

Movement within apartments was greater than movement between apartments, but was still not as great as anticipated prior to conducting this research. Most German cockroach adults (67%) remained in the same habitat over time. This is also probably related to resource availability. There is no reason to risk moving to a second unknown habitat if resources are sufficient in the first known habitat.

The lack of movement combined with data on habitat preference in focus apartments compared to non-focus apartments has obvious implications for control recommendations. Treatment for the control of German cockroaches must be thorough. Standard treatment practices are frequently limited to kitchen and bathroom areas of residences. In focus apartments that type of treatment procedure potentially would only eliminate approximately two-thirds of the German cockroach population. The remaining one-third of the population would be protected by virtue of their lack of movement out of untreated areas.

Data on the feasibility of incorporating the aesthetic injury level concept into control programs for the German cockroach in urban buildings further establishes the need for thorough treatment programs. The data indicate that as populations decline so do German cockroach tolerance levels. Consequently as control increases so do the expectations of the target audience, and fewer cockroaches will be tolerated. Education could probably increase tolerance, but control rather than management must realistically be the goal of German cockroach treatment programs.

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ASPECTS OF DISPERSAL AND POPULATION STRUCTURE OF

BLATTELLA GERMANICA

and

ATTITUDES CONCERNING AESTHETIC INJURY LEVEL

by

Patricia A. Zungoli

(ABSTRACT)

Movement behavior of *Blattella germanica* (L.) was investigated using two mark-recapture techniques -- 1) marking field collected populations of adult German cockroaches with a unique number, and 2) releasing strains of genetically marked German cockroaches to observe nymphal movement.

Movement by adult cockroaches was studied by marking 3299 field collected German cockroaches in eight apartments. Adults were marked with Liquid Paper'. This allowed for recognition of specific individuals in the population. After marking, cockroaches were released at their original site of capture. Biological data was recorded on both nymphs and adults. Results indicate that movement of adult German cockroaches between apartments is

minimal. Movement within apartments is greater, but not substantial. Movement appears to be linked to carrying capacity of the habitat (=apartment). When a vital resource -- food, water, or harborage -- becomes limited, adult movement can be detected when populations are large. Trapped populations in focus and non-focus apartments are spatially distributed in different ways. German cockroaches in non-focus apartments are trapped predominately in traditional sites of infestation -- kitchen and bathroom areas, with 90% of the collections occurring in these sites. In focus apartments trap collections indicate that one-third of the population is found in areas traditionally identified as non-preferred sites of infestation.

Movement of German cockroach nymphs was investigated using releases of genetically marked strains f cockroaches. Collections of marked individuals were limited, suggesting that the strains used, especially eye-color mutants, were not competitive in field environments. Results of this study were inconclusive.

The feasibility of applying the aesthetic injury level concept to control programs within the urban environment rather than to pests occurring on the exterior was investigated. A random survey was conducted in non-elderly public housing projects in Roanoke, VA, Norfolk, VA, and Baltimore, MD. One hundred surveys were taken in each of the cities. The results of the survey indicate that the aesthetic injury level concept can not be successfully applied to control programs for insect pests occurring inside the home. Tolerances are variable, and are dependent upon the extent of the infestation experienced by each resident. It is speculated that as infestation levels decline, tolerance of the pest would also decline.