Population Ecology and Movement of the American Cockroach (Dictyoptera: Blattidae) in Sewers

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J. Med. Entomol. 48(4): 797–805 (2011); DOI: 10.1603/ME10255

ABSTRACT The population size, age-class structure, and movement of the American cockroach, *Periplaneta americana* (L.) (Dictyoptera: Blattidae), were studied in three sewers in Penang, Malaysia, from September 2008 to October 2009. Eighteen to 20 glass-jar traps (two per manhole) were deployed for a 24-h period during each sampling occasion at each sewer. Adults and nymphs were active throughout the study period, with an average monthly trap catch of 57–97 adults and 79–99 nymphs. The mean proportions of adults and nymphs at the three sewers ranged from 0.47 to 0.57. Of the 2,177 male and 2,717 female cockroaches marked and released over the three sewers, recapture rates were 29.4–45.8 and 30.8–47.0%, respectively. The proportion of marked males and females did not differ significantly from the proportion of recaptured marked males and females. However, the mean number of times a marked female was recaptured was significantly greater than that of males. Of the 783 males and 1,030 females that were marked and recaptured, 19.4 and 24.7%, respectively, had moved between manholes, and significantly more females than males moved between manholes. Of the 406 recaptured marked adults that moved between manholes, 90.4% moved a distance of 2–20 m from their initial release site; one male moved 192 m, the longest distance recorded. Trap catch on each sampling occasion was positively correlated with daily mean temperature. The number of cockroach movements between manholes also was correlated with the mean daily minimum temperature.

KEY WORDS *Periplaneta americana*, sewage system, population ecology, age-class structure, mark–recapture

The American cockroach, *Periplaneta americana* (L.) (Dictyoptera: Blattidae), is an insect pest of great medical and economic importance. Besides leaving stains and an unpleasant odor, *P. americana* is a potential mechanical vector of various pathogenic organisms, and it contains allergens that may responsible for allergies and asthma (Roth and Willis 1957, 1960; Gore and Schal 2007; Rust 2008; Lee and Ng 2009). In Southeast Asia, *P. americana* is a predominant domiciliary pest cockroach, and it also is able to thrive in large numbers in outdoor environments such as sewers and bin chutes, where conditions are favorable for its development (Lee and Lee 2000, Lee 2007, Lee and Ng 2009).

Concerns about the close association of *P. americana* with human wastes and the potential for this pest to be a carrier of enteric pathogens led to several mark–recapture studies of the dispersal of *P. americana* in and from sewers. In an experiment conducted in Arizona, Schoof and Siverly (1954) found no dispersal of *P. americana* within sewers, and only one radioactive-tagged cockroach was discovered in a trap placed outside a house 18 m away from the four manholes where 6,500 radioactive-tagged *P. americana* had been released. However, in another experiment conducted in Texas, Eads et al. (1954) reported that enamel-painted American cockroaches released in manholes were able to disperse within sewers and enter houses as far as a block away. Jackson and Maier (1955, 1961) demonstrated that seasonal and carrying capacity factors played a role in the dispersal of *P. americana* within sewers and from sewers into yards and houses in experiments conducted in Arizona. These early studies provided insight into the dispersal activity of *P. americana* in and from sewers, but they did not provide detailed information about population ecology of this species. Such information, including trap catch data, age-class structure, and movement rates, are crucial for a better understanding of this pest cockroach.

Studying the population ecology and behavior of pest cockroaches that are well adapted to the human environment is crucial to developing effective management strategies. For example, mark–recapture studies conducted on outdoor populations of smoky-brown cockroaches, *Periplaneta fuliginosa* (Serville),

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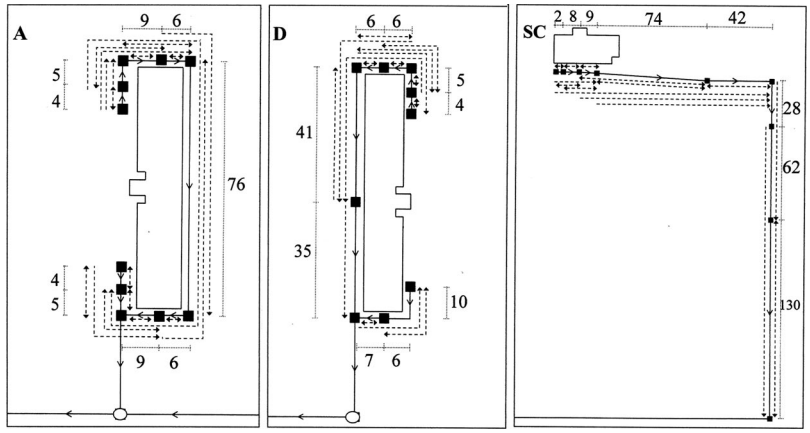

Fig. 1. Diagrams of the three sewers (sewers A, D, and SC) and the direction and distances moved between manholes by *P. americana* at Universiti Sains Malaysia, Penang. Numbers with dotted lines indicate distance (meters) between manholes; dashed lines indicate direction of cockroach movement; solid lines with arrows indicate sewer lines and direction of sewer flow; ■, manhole with traps; ○, manhole without trap; □, building).

identified their primary harborage sites, season of peak population size, and activity, and they also revealed that adult cockroaches were mobile, with an estimated home range of 108–300 m^2 (Fleet et al. 1978, Appel and Rust 1985, Brenner 1988). Brenner (1988) and Brenner and Pierce (1991) suggested that smokybrown cockroach invasion into houses is a function of population size and the distance between primary outdoor harborage sites and houses. Mark–recapture studies of German cockroach, *Blattella germanica* (L.), demonstrated that the presence of common plumbing connections resulted in significant intra- and interapartment movements by cockroaches, and the movements were independent of population size (Owens and Bennett 1982, Runstrom and Bennett 1984, 1990). Information obtained from population ecology studies on *P. fuliginosa* and *B. germanica* provided valuable information about coverage areas of cockroach management program, the role of an outdoor reservoir population to fuel indoor invasion, and the significance of landscape and structural features that are conducive to cockroach infestation (Fleet et al. 1978, Owens and Bennett 1982, Runstrom and Bennett 1984, Brenner and Pierce 1991, Smith et al. 1995). Such information is necessary for designing effective pest management strategies.

In the current study, we used the mark–recapture technique to study population size, age-class structure, and movement of *P. americana* in three sewers that service buildings on the Minden Campus of Universiti Sains Malaysia, Penang, Malaysia.

Materials and Methods

Study Sites. The study was conducted on the Minden Campus, Universiti Sains Malaysia, (5° 21′ N, 100° 18′ E), Penang, which is located on the northwestern coast of Peninsular Malaysia. Penang has a tropical climate with high temperatures and rainfall throughout the year. Mean daily temperatures during the day range from 30.4 to 32.2°C and from 23.2 to 24.2°C during the night. The average annual rainfall of 2,408 mm is distributed throughout the year; wet weather condition occurs more frequently during southwest monsoon from April to September (http://app2.nea.gov.sg/asiacities_malaysia.aspx). Based on a survey of the cockroach infestation levels in sewers on the Minden Campus, Universiti Sains Malaysia, three sewers with heavy infestation of *P. americana* were selected for this study (Koay 2002). One sewer services a sports complex (SC), and the other two service the Aman (A) and Damai (D) student dormitories (Fig. 1). Unlike the common tightly sealed manhole covers, the unsealed type manhole cover present in the selected sewers made it feasible for us to study the sewer population of *P. americana.* To access the sewer manholes, the square-shaped metal manhole covers were removed using the flattened end of a crowbar (45 cm in length) applied to the side of the cover. Sewer A consists of 10 manholes and sewers D and SC consists of nine manholes (1-m-diameter manhole shaft). The mean depth of the manholes in sewers A, D, and SC was 1.13, 1.07, and 1.62 m, respectively.

Sampling and Marking Technique. Traps consisted of 0.45-liter glass jars baited with one-fourth slice of beer-soaked bread. A layer of petroleum jelly/oil (3:1) mixture was smeared on the inner upper 3 cm of the glass jar to prevent escape of trapped cockroaches. Masking tape was used to cover the outer layer of the glass jar to increase trap efficacy because nymphs (first–fifth instars) are unable to climb a vertical glass surface (Willis et al. 1958, Granovsky 1983). A sheet of transparent polyvinyl chloride (15 by 10 cm) was folded over the opening of the glass jar and secured by inserting two protruding edges (3 by 2 cm) into the opening. This was used to exclude rain that flowed into the manhole. Two glass-jar traps were placed at the bottom half of each manhole shaft either on the floor or on the rungs of a ladder (U-shaped bars attached on the inner wall of manhole used as a ladder for access).

Therefore, 20 traps in total were deployed at sewer A, whereas there were 18 traps each in sewers SC and D during each sampling occasion. Traps were set up in the morning (between 0900 and 1200 hours) and examined after 24 h. The drains delivering the sewage flow were ≈30 cm in diameter. Each sewer was sampled three times per month (interval 7–14 d) from 16 September 2008 to 27 October 2009, for a total of 37 samples per sewer.

Trapped cockroaches were brought back to laboratory in polyethylene containers (1,000 ml) closed with a perforated cover; the inner side of the containers was smeared with a layer of petroleum jelly/oil (3:1) mixture to prevent escape of cockroaches. Each container was labeled with the location of capture. For the mark–recapture study, only adult cockroaches were marked because nymphs may lose the tag during molting process. Each adult cockroach was marked with a piece of masking tape (1 by 0.5 cm) that was individually coded with an alphanumeric code written in water-resistant pigmented ink (Ecco pigment fiber tip 0.2 mm, Faber-Castell, Nürnberg, Germany) (Fleet et al. 1978, Appel and Rust 1985). Alphabetical code was used to indicate the manhole from which the cockroaches were first captured, whereas the numerical code was used to record the number of cockroaches that were caught and marked in the respective manhole. Tissue paper saturated with acetone was used to clean the tegmen to remove epicuticular lipids and dirt before the masking tape tag was stuck to the tegmen (Appel and Rust 1985). Tegmen that was covered beneath another tegmen was chosen for tagging because it was protected and may increase tag adherence. An additional layer of transparent cello tape was used to cover the masking tape tag to provide a smooth surface to minimize the adherence of dirt on the rough surface of the masking tape. The marking process was facilitated by anesthetizing cockroaches with CO_2 (10-kPa pressure for 10–15 s). This brief anesthesia on *P. americana* was reported to have no significant effect on their survival and probability of being recaptured and has been used to handle this cockroach species in several studies (Coler et al. 1986, 1987; Smith and Appel 1996; Appel and Smith 1999). After being marked and recorded, all cockroaches were released back into the manhole from which they were captured in the evening.

During each sampling session, the numbers of trapped adult males, females, and nymphs (divided into three size-classes: small, ≤ 10 mm; medium, 11–25 mm; and large, >25 mm long) were recorded. Proportion of each life stage also was determined. The Jolly stochastic model was used to estimate adult cockroach population size for each time point at each sewer (Jolly 1965, Begon 1979). Estimated adult population size, trap catch, and proportion of each life stage were reported on a monthly basis by averaging data from each of the three sampling sessions per month at each sewer. The numbers of movements and longest distance moved by marked adult cockroaches between manholes were recorded. Data on the trap catch and movement of adult cockroaches from the three sewers were pooled to investigate the effect of meteorological factors on these data. Meteorological data were recorded at the Bayan Lepas weather station, located 8.5 km away from the study site, by the Malaysian Meteorological Department.

Data Analysis. The number of recaptures and the number of movements between males and females, and the proportions between adults and nymphs were compared using the nonparametric Mann–Whitney *U* test (Conover and Iman 1981). Proportions of nymphs among the three sewers were compared using nonparametric Kruskal–Wallis test, followed by posthoc comparisons between means using Mann–Whitney *U* test with a Bonferroni adjustment (significant level set at $P = 0.05/3 = 0.017$). Pearson's product-moment correlation was used to examine the relationship between meteorological factors (daily mean, maximum and minimum temperature, and rainfall) and trap catch on each sampling date. Daily maximum and minimum temperature were averaged over the days between sampling interval, and Pearson's product-moment correlation was performed to examine the correlation between these data and number of cockroach movements. Adult population estimates determined between sampling occasions were averaged, and Pearson's product-moment correlation was used to determine whether there was a correlation between these data and the number of cockroach movements. All analyses were performed using SPSS version 11.0 at $\alpha = 0.05$ (SPSS 2002).

Results

The mark–recapture study conducted between September 2008 and October 2009 revealed that *P. americana* was the dominant cockroach species trapped; only one *Pycnoscelus surinamensis* (L.) and one *Periplaneta australasiae* (F.) were trapped during the study. The mark–recapture study showed that the adult population peaked in December 2008 for sewers A and D and in January for sewer SC, with 295, 334, and 599 adult cockroaches, respectively. The lowest estimated adult populations of 100, 82, and 233 cockroaches were recorded in July, January, and May for sewers A, D, and SC, respectively (Fig. 2). Throughout the study period, the mean monthly adult trap catch at sewers A, D, and SC was 75, 57, and 97, and the mean monthly trap catch of nymphs was 99, 79, and 85, respectively (Fig. 2). The mean proportion of nymphs throughout the study at sewers A, D, and SC was 0.56 ± 0.02, 0.57 ± 0.02, and 0.47 ± 0.03, respectively (Fig. 3). The proportion of nymphs was significantly greater than the proportion of adults at sewers A and D (Mann–Whitney *U* test: A, $Z = -3.298$, $P = 0.001$; D, $Z = -3.294$, $P = 0.001$; $n = 12$ each), whereas there was no significant difference between these proportions at sewer SC (Mann–Whitney *U* test, $Z = -1.994$, $n = 12$, $P = 0.05$; Fig. 3). There were significant differences between the mean proportions of nymphs among the three sewers (Kruskal–Wallis test, $H = 7.826$, $df = 2$, $P = 0.02$). The mean proportion of nymphs at sewer A did not

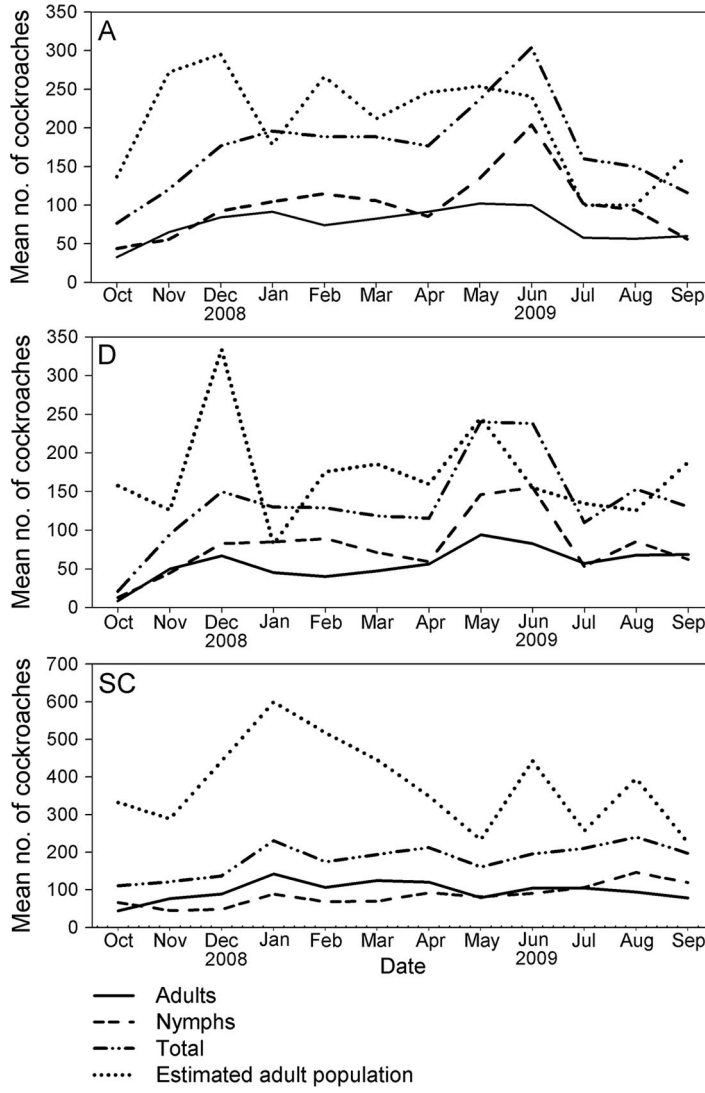

Fig. 2. Monthly estimated adult population and trap catch of *P. americana* found in three sewers (A, D, and SC) at Universiti Sains Malaysia, Penang from October 2008 to September 2009.

differ significantly from that of sewer D (Mann–Whitney *U* test, Z = −0.290, n = 12, P = 0.772), whereas both the mean proportions of sewer A and D were significantly greater than that of sewer SC (Mann–Whitney *U* test: A versus SC, Z = −2.400, P = 0.016; D versus SC, Z = −2.429, P = 0.015; n = 12 each). In general, the overall proportion of adults and nymphs was 0.47 (56% females) and 0.53 (16% small nymphs and 42% each for medium and large nymphs), respectively.

Of the 2,177 male and 2,717 female cockroaches marked and released over the three sewers, recapture rates were ranged from 29.4 to 45.8% and from 30.8 to 47.0%, respectively. Further analysis revealed that the proportions of marked males and females did not differ significantly from the proportions of recaptured marked males and females at each sewer (A, χ^2 = 1.324, P = 0.250; D, χ^2 = 0.093, P = 0.760; SC, χ^2 = 0.340, P = 0.560; df = 1 each; Table 1). However, the mean number of times a marked female was recaptured was significantly greater than that of males at each sewer (Mann–Whitney *U* test: A, Z = −2.846, P = 0.004; D, Z = −3.019, P = 0.003; SC, Z = −3.065, P = 0.002; Table 1).

Of the 1,813 recaptured marked adults, 406 adults (22.4%) moved between manholes, and 90.4% of the movements were restricted within the range of 2–20 m; one male moved a distance of 192 m, which was the longest distance recorded (Fig. 1 and Table 2). Based on the proportion of recaptured marked males and females, significantly more females moved compared with males (χ^2 = 5.511, df = 1, P = 0.019; Table 2). Mean number of movements per recaptured female was significantly greater than that of

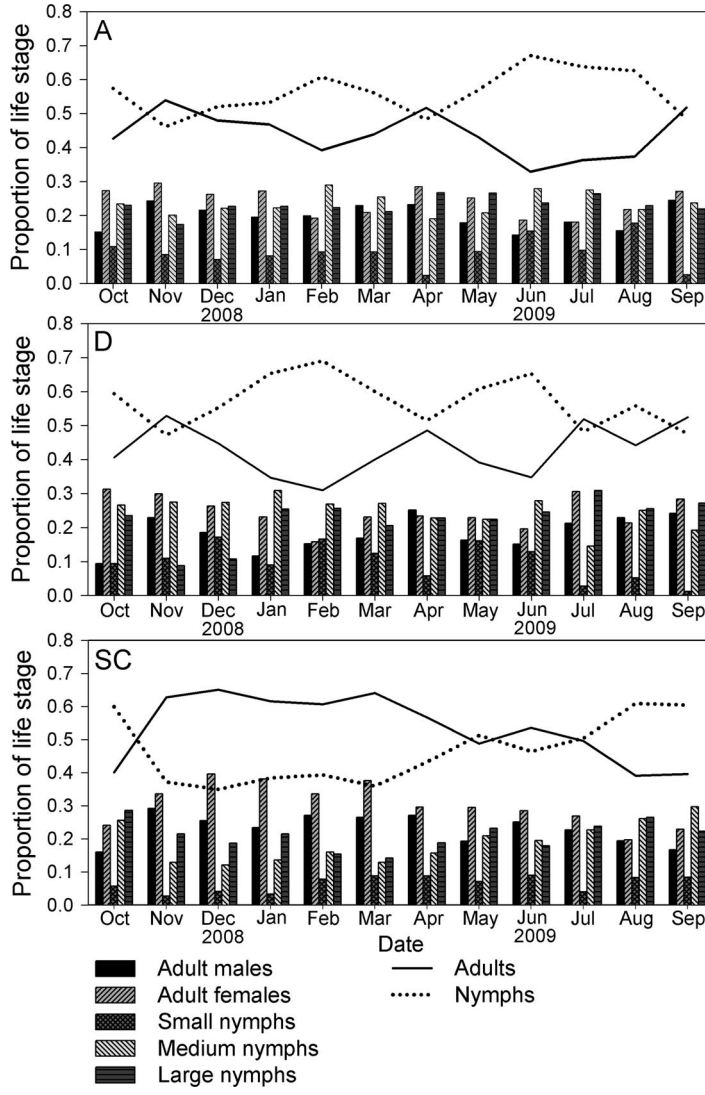

Fig. 3. Proportion of *P. americana* life stages in three sewers (A, D, and SC) at Universiti Sains Malaysia, Penang.

recaptured males (Mann–Whitney *U* test, Z = −2.849, *P* = 0.004; Table 3).

There was no correlation between population sizes and the number of cockroach movements at each sewer (Pearson's correlation coefficient: A, $r = 0.071$, $P = 0.690$; D, $r = 0.310$, $P = 0.075$; SC, $r = -0.004$, $P = 0.984$). Daily mean temperature (25.4–29.2°C) was positively correlated with the number of trap catch

Table 1. Summary of mark–recapture data for adult *P. americana* at three sewers

Sewer	Sex	No. marked cockroaches	No. recaptured marked cockroaches (n)	% recapture	No. times an individual marked adult was recaptured						No. recaptures	No. (mean ± SE) of recaptures/ recaptured adult
					1	2	3	4	5	6		
A	♂	730	277	37.9	203	64	9	1	0	0	362	1.31 ± 0.03
	♀	864	359	41.6	227	105	20	5	1	1	528	1.47 ± 0.03
D	♂	489	224	45.8	165	43	12	4	0	0	303	1.35 ± 0.04
	♀	619	291	47.0	179	75	23	12	2	0	456	1.57 ± 0.03
SC	♂	958	282	29.4	218	50	13	1	0	0	361	1.28 ± 0.03
	♀	1,234	380	30.8	253	95	25	5	2	0	548	1.44 ± 0.03
Overall	♂	2,177	783	36.0	586	157	34	6	0	0	1,026	1.31 ± 0.02
	♀	2,717	1,030	37.9	659	275	68	22	5	1	1,532	1.49 ± 0.02

Table 2. Percentage and number of adult *P. americana* that moved in the various ranges of distances between manholes

Sex	Distance travelled by individual cockroach from their initial release site (m)										No. recaptured marked cockroaches	No. recaptured marked cockroaches that moved	% recaptured marked cockroaches that moved
	2–5	6–10	11–15	16–20	21–24	35–47	58–74	82–90	116–135	192			
♂	58	71	5	8	1	2	1	2	3	1	783	152	19.4
♀	105	78	22	17	2	7	9	8	4	0	1,030	254	24.7
Total	163	149	27	25	3	9	10	10	7	1	1,813	406	22.4
% of cockroaches in each range of distance travelled	40.6	36.9	6.7	6.2	0.7	2.2	2.5	2.5	1.7	0.2			

(Pearson's correlation coefficient, $r = 0.400$, $P = 0.014$). The number of movements recorded for adult cockroaches was correlated with mean daily minimum temperature (23.5–24.5°C, Pearson's correlation coefficient, $r = 0.491$, $P = 0.002$).

Discussion

The study of pest cockroach populations is an important way to understanding their biology and behavior in the field. Trapping and mark–recapture techniques that allow assessment of the status of a population and its dynamics are widely used for this purpose. In the current study, the mean proportion of nymphs that ranged from 0.47 to 0.57 was lower than the 0.77 (based on the total number of cockroaches removed by trapping and a vacuum cleaner) reported for a green house population of *P. americana* by Coler et al. (1987). On the contrary, the value was higher than that documented from an outdoor population of *P. americana* (0.22) by Appel (1986). Differences in experimental design such as sampling technique and trap placement may partly explain variation in age-class structure. Placement of traps had been reported as a factor that affected the composition of trap catch. Traps placed near to harborage sites and areas with more concealment caught significantly more nymphs than other sites in the mark–recapture studies of *P. fuliginosa* (Fleet et al. 1978, Appel and Rust 1985). In our study, significantly lower nymphal proportion was recorded in the larger manhole shaft of sewer SC compared with the other two sewers; in this sewer, the traps might not have been reached so easily by most of the relatively less mobile nymphs that stay close to their harborage sites. Compared with sampling cockroaches in sewers, traps can be directed and placed at areas of cockroach activity (e.g., along the wall or near food sources) or near harborage sites in aboveground sampling. This may partly explain the relatively higher proportion of nymphs reported by Coler et al. (1987) for a green house population of *P. americana* where cockroaches were removed by glass-jar traps placed at corners and along the perimeter in addition to the aid of a vacuum cleaner that eventually captured a greater number of nymphs compared with our study. In addition, interspecific competition is also one of the factors that affect trap catch of cockroaches. *P. fuliginosa* nymphs were demonstrated to repel nymphal and male *P. americana* and their presence in glass-jar traps was found to affect the trapping of *P. americana* (Appel 1994). This interspecific competition may explain the relatively lower proportion of *P. americana* nymphs documented by Appel (1986) in an outdoor environment where *P. fuliginosa* occurred as a dominant species.

Several mark-recapture studies of *P. fuliginosa* and *P. americana* reported that marked females were more likely to be recaptured than marked males (Appel and Rust 1985, Appel 1986, Coler et al. 1986, Brenner 1988, Brenner and Pierce 1991). However, in our mark–recapture study, the proportion of marked and released males and females did not differ significantly from the proportion of recaptured marked males and females, indicating that the probability of recapture for marked males was not different to that of marked females. However, the number of times a female was recaptured was greater than that of males. Our finding is similar to the results of Fleet et al. (1978) who reported on *P. fuliginosa.* Coler et al. (1986) demonstrated that glass-jar traps were not biased toward trapping either sex of adult *P. americana* in their laboratory experiment. Nevertheless, trapping results from their field experiment showed that marked *P. americana* females were more likely to be caught than that of the marked males. Differences in behavior and physiology between males and females may explain differences in recapture rates and number of times a marked individual being recaptured. In outdoor activity studies of cockroaches, Appel and Rust (1986) and Appel (1986) reported differences in height-spe-

Table 3. Number of movements made between manholes by adult *P. americana*

Sex	No. recaptured marked cockroaches (n)	No. movements recorded for each individual cockroach				No. movements	No. movements/ recaptured adult
		0	1	2	3		
♂	783	631	145	7	0	159	0.20 ± 0.02
♀	1,030	776	219	29	6	295	0.28 ± 0.02
Total	1,813	1,407	364	36	6	454	0.25 ± 0.01

cific distribution between males and females in *P. fuliginosa* and *P. americana.* They found that males occupied significantly higher position (averaged 2.3–2.8 m) than females (averaged 0.4–0.8 m). Schal (1982) hypothesizes that height-specific distribution of males and females is a mate-finding strategy. A similar height-specific distribution of males and females was reported in his study in a few tropical cockroach species; males perched higher than females on vegetation during their active period. He suggested that micrometeorological gradients facilitated upward movement of volatile sex pheromones. Males positioned at higher level were able to detect sex pheromones released by females located at lower position. In the current study, the placement of traps close to or on the floor of the manhole shaft may have resulted in the higher frequency of recapture of females due to differences in spatial distribution between the sexes. In addition, Bell et al. (2007) found that male cockroaches had lower amounts of gut contents and narrower diets compared with females; they suggested that food intake by females may be related to the reproductive cycle and nutrient requirement for oogenesis or embryogenesis. Therefore, it is possible that a female may visit food-baited jar traps more frequently than males in those mark–recapture studies. Sampling period in Fleet et al. (1978) (16 mo) and our (12 mo) studies were longer compared with those mark–recapture studies (2–21 d). It is possible that longer sampling period may allow more marked individuals to be recaptured and contribute to the equal probability of recapture between males and females reported in Fleet et al. (1978) and our studies.

Contrary to several other studies that reported limited movements of *P. americana* in sewers, the 22.4% of recaptured marked cockroaches that moved between manholes in this study is high. Although the recapture rates were not adequately addressed, Schoof and Siverly (1954), Eads et al. (1954), and Jackson and Maier (1955, 1961) reported that 0, 0.2, and 0.6–4.3% of marked *P. americana* moved to adjacent manholes when 6500, 1,000, and 300–2,000 marked individuals, respectively, were introduced into the manholes. The experiment in the current study that included various distance ranges (2–192 m) may allow more cockroach movements being recorded. In Jackson and Maier's studies (1955, 1961), the distance of the nearest manhole adjacent to manhole in which the cockroaches were released was ≈50 m. The rate of dispersal in their studies (0.6–4.3%) is similar to the 6.9% of recaptured marked adults that moved within the distance range of 58–192 m in our study. The majority (90.4%) of the movements in our study occurred within the distance range of 2–20 m. Thus, the great distance between manholes in previous studies may have contributed to the relatively low movement rates reported in those dispersal studies. The result from this study provide information for managing *P. americana* in sewers because several studies of insecticide efficacy in controlling *P. americana* in sewers reported possible reinvasion of late nymphs and adults into the treated manholes from nearby sewers (Chadwick et al. 1977, Rust et al. 1991).

In the current study, daily mean temperature was correlated with the number of cockroaches caught in the traps. Fleet et al. (1978) and Brenner (1988) also found a positive correlation between daily maximum temperature and trap catch in outdoor populations of *P. fuliginosa* and *Eurycotis floridana* (Walker). In those studies, the increase in trap catch with increased temperature might have been due to the search for water, because the rate of water loss for *P. fuliginosa* is twice that of *P. americana* (Brenner 1988, Appel 1995, Smith et al. 1999). In sewers, lack of water is not a problem, so searching for water probably does not explain the positive correlation between trap catch and daily mean temperature (25.4–29.2°C). However, it may reflect the temperature preference of *P. americana.* In a temperature preference experiment where cockroaches were allowed to select their resting areas imposed with a thermal gradient, *P. americana* showed their preference for temperatures ranging from 23 to 33°C and were recorded to rest more in areas with 28–30°C (Gunn 1935).

Studies on the dispersal of *P. americana* in sewers showed that population pressure was one of the factors that may influence the movement of cockroaches in and from sewers (Jackson and Maier 1955, 1961). Jackson and Maier (1955) demonstrated that population stress induced by superimposing 1,200 radioactive-tagged cockroaches into a resident population of 300 *P. americana* resulted in 5.9% (71 cockroaches) of the tagged cockroaches caught in traps placed around and inside houses and in adjacent manholes, whereas only 0.8% (four cockroaches) was caught when a normal undisturbed population of 500 *P. americana* were marked and released. In our study, adult population fluctuations were not found to be related to the number of cockroach movements. It is possible that *P. americana* populations were thrived within the carrying capacity of the sewers in our study. Under such condition, population fluctuation may not have an influence on the movement of cockroaches.

In conclusion, the proportions of nymphs and adults among the populations of *P. americana* residing in the sewers studied herein were similar. *P. americana* was mobile in these sewers, and the majority of movements were within the range of 20 m. Temperature was found to be related to trap catch and movement of *P. americana* in sewers.

Acknowledgments

We thank Y.-F. How, K.-B. Neoh, and S.-J. Sam (Universiti Sains Malaysia) for technical assistance in the field. H.-S.T. was supported under an M. Sc. fellowship scheme by Universiti Sains Malaysia. This study was funded by Universiti Sains Malaysia-Research University Postgraduate Research Grant Scheme and DuPont Professional Products (Wilmington, DE).

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Received 29 November 2010; accepted 11 April 2011.