ADDITIONAL STUDIES OF DISPERSION PATTERNS OF AMERICAN COCKROACHES FROM SEWER MANHOLES IN PHOENIX, ARIZONA

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Cockroaches in abundance are often associated with human activities and, thus, are convenient animals for ecological experiments. As a matter of general concern, cockroaches often live in association with filth and are known to carry a large number of microorganisms, some of which are pathogenic to man (Roth and Willis, 1957). That cockroaches might serve as elevator mechanisms, bring enteric disease organisms from underground sewer systems up to areas of human contact, prompted a series of experiments to determine the various factors affecting movement patterns in American cockroach (*Periplaneta americana* [L]) populations.

An initial study in Phoenix, Arizona, determined that during the summer American cockroaches had limited movements from sewer manholes under undisturbed conditions but extensive emigration when the manhole population balance was disrupted by the super-imposition of a large number of extraneous roaches (Jackson and Maier, 1955). Movements into yards, an adjacent apartment, and 350 ft downstream in the sewers were recorded.

The following dispersal tests were a continuation of these studies to determine movement patterns in other seasons. The possible inhibitory effects of cooler weather on roach movements were investigated during January 1954; and, since some miscellaneous observations had indicated increased numbers of cockroaches above ground during the late spring, dispersion patterns were investigated also during June 1954.

METHODS AND PROCEDURES

A paired manhole experimental design, similar to that of the previous experiment (Jackson and Maier, 1955), was used. The cockroach population in one manhole was removed, marked, and immediately returned to its source. At the same time, in a comparable manhole on a different sewer lateral, a thousand or more marked cockroaches, collected from other sections of the city, were superimposed on the resident cockroach population. The dispersion patterns of these two populations were compared by recoveries of marked individuals in traps set in yards, apartments, and manholes up and down stream from the release site. This approach was designed to determine behavior patterns occurring under the usual, undisturbed conditions as well as those resulting from concentrations of large numbers of roaches, such as might occur during sewer stoppages or flooding.

In addition, a release with superimposition of marked roaches was carried out in the manhole in a Latin-American housing project from which extensive dispersion had been demonstrated during the previous summer's tests. This was done to compare the dispersion patterns in two somewhat different environments. Population samples prior to each new release indicated that no marked individuals remained from the previous experiment.

American cockroaches, the only cockroach species inhabiting sewer manholes in Phoenix, were collected with traps consisting of one-quart wide-mouthed mason jars having an inward-directed, plastic screen cone held in place by a standard

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cover ring. Ripe bananas served as bait. A vacuum cleaner with a padded receiving attachment was used when all the cockroaches were to be removed from a manhole. The use of carbon dioxide gas facilitated handling the cockroaches. The same traps, slipped into half-gallon ice cream cartons to reduce light intensity, were placed in yards in tall grass, under bushes, near garbage cans, or adjacent to building foundations. Traps used in apartments were usually placed on the floor in kitchens or occasionally in bathrooms and were without cartons.

The cockroaches were marked in the laboratory with radioactive phosphorus (P^{32}) by spraying groups up to 1000, held in a garbage can, with about 75 ml of a 5 percent aqueous casein solution containing 10 μc of P^{32}/ml. This resulted in an average individual tag intensity of several thousand counts per minute. A beta-gama radioactivity monitor (Model 1615, Radiation Sentinel, Nuclear-Chicago) was used to measure the intensity of the beta radiation. The cockroaches were placed about 0.5 cm from the window of the Geiger tube.

In addition to the American cockroach, the German cockroach (*Blatella germanica* [L]) and the brown-banded cockroach (*Supella supellectilium* Serv.) were caught both indoors and outdoors, and the field roach (*Blatella vaga* Hebard) was caught only outdoors. These additional species are not considered in this discussion.

Winter dispersion. A well sanitated, Anglo-American housing project was used for the winter experiments. The manhole in which the resident population was marked exposed drainage from several rows of apartments having a total of 20 units. Upstream manholes were 273 and 421 ft distant; downstream manholes were 273, 431, and 629 ft away, the latter being the juncture with a trunk sewer line.

The cockroach population of 300 was removed, marked, and returned to the manhole on January 19. Trapping was done in surrounding yards, homes, and manholes for the succeeding 9 days.

An extraneous group of 1500 cockroaches was superimposed on a manhole population of 125 roaches in another part of the same project on January 14. This manhole exposed drainage from a quadrangle of 36 apartments. A single manhole existed 180 ft upstream, and manholes downstream were at distances of 173, 333, 490, 670, and 833 ft. Intensive trapping continued for 11 days.

The comparison release test in the Latin-American housing project occurred on January 29 when 1300 cockroaches were superimposed on a native population of 275. This manhole exposed drainage from a quadrangle of 24 apartments. A single upstream manhole was 165 ft distant, and downstream manholes were 185, 350, 535, and 700 ft away. Intensive trapping was done for 10 days.

The resident roach populations in the latter two releases were not marked. To have used radioactive phosphorus tags on those would have made them indistinguishable from the superimposed individuals, and other techniques were not employed. Movements of such resident roaches cannot be determined from these experiments.

Spring dispersion. The late spring experiments were carried out in a fairly well sanitated, Negro housing project. The manhole in which the resident population was marked exposed drainage from an apartment quadrangle of 24 units. A single manhole was 165 ft upstream, and manholes were downstream at distances of 160, 325, 410, and 495 ft, the next to the last being a trunk sewer line juncture. In this test the cockroach population of 700 was tagged on June 3, and intensive trapping was carried on for 2 weeks.

An extraneous group of 2000 marked cockroaches was superimposed on an unmarked resident manhole population of 400 on June 4. This manhole exposed drainage from a series of apartment rows, a total of 22 units. Two upstream manholes were at distances of 160 and 525 ft; the first two manholes downstream, 145 and 620 ft distant, were on a trunk line. Intensive trapping was carried on for two weeks.

A comparison release in the Latin-American project was made on June 8, when 1300 tagged cockroaches were superimposed on the unmarked resident population of 600. Intensive trapping was continued for two weeks.

RESULTS

Winter dispersion.—No radioactive cockroaches were recovered from the winter releases outside of the manhole with the marked resident population, and only one individual was recovered from the release with superimposed roaches (table 1). This individual, caught without the use of a trap 10 ft from the manhole several minutes after garbage cans nearby had been emptied, presumably had emerged through a hole in the manhole cover and taken refuge in or among the cans.

TABLE 1

Summary of trapping results in two American cockroach dispersion experiments

January experiment	No. roaches marked	Apt. traps	Yard traps	Manhole traps
Resident population	300			
Number of traps		24	29	5
Number of trap nights*		206	257	39
Total number of roaches caught		2	0	117
No. marked roaches recaptured		0	0	0
Superimposed population	1500			
Number of traps		31	40	5
Number of trap nights*		356	415	65
Total number of roaches caught		1	0	443
No. marked roaches recaptured		0	1**	0
Reference superimposed population	1300			
Number of traps		20	31	4
Number of trap nights*		181	305	40
Total number of roaches caught		631	5	337
No. marked roaches recaptured		0	2	0
June experiment				
Resident population	700			
Number of traps		27	33	5
Number of trap nights*		366	411	60
Total number roaches caught		46	4	1425
No. marked roaches recaptured		0	0	8
Superimposed population	2000			
Number of traps		19	24	4
Number of trap nights*		241	316	53
Total number roaches caught		38	40	495
No. marked roaches recaptured		7	29	2
Reference superimposed population	1300			
Numer of traps		—	29	5
Number of trap nights*		—	374	70
Total number of roaches caught		—	48	2901
No. marked roaches recaptured		—	17	56

*A trap night is one trap operating for one night.
**Recovered in alley without use of trap.

Only two radioactive individuals were recovered in the comparison release test in the Latin-American housing project. Both were caught in yard traps, one 10 ft and the other 60 ft from the release site manhole. No marked roaches were recovered from adjacent manholes. Similarly, no marked cockroaches were found in manholes adjacent to release sites when these manholes were cleared of roaches with the vacuum cleaner at the termination of the trapping period. A repetition of this procedure 2 to 3 weeks later was likewise negative. Population samples taken from the release sites at the close of the experiment showed 69 of the 70 cockroaches from the resident manhole and 48 of the 58 individuals from the manhole with superimposed roaches to be radioactive.

Spring dispersion.—During the spring dispersion tests eight marked cockroaches were recovered from the manhole with only the resident population tagged. One was found in the manhole 160 ft downstream and seven were recovered from the manhole 325 ft downstream. After two weeks of trapping, vacuum cleaner collections from adjacent manholes produced no additional radioactive individuals.

Thirty-eight marked cockroaches were recovered outside the superimposition manhole (fig. 1). Of the seven caught in apartment traps, single catches occurred in two traps, each 90 ft from the manhole, and the remaining five came from an apartment 28 ft away.

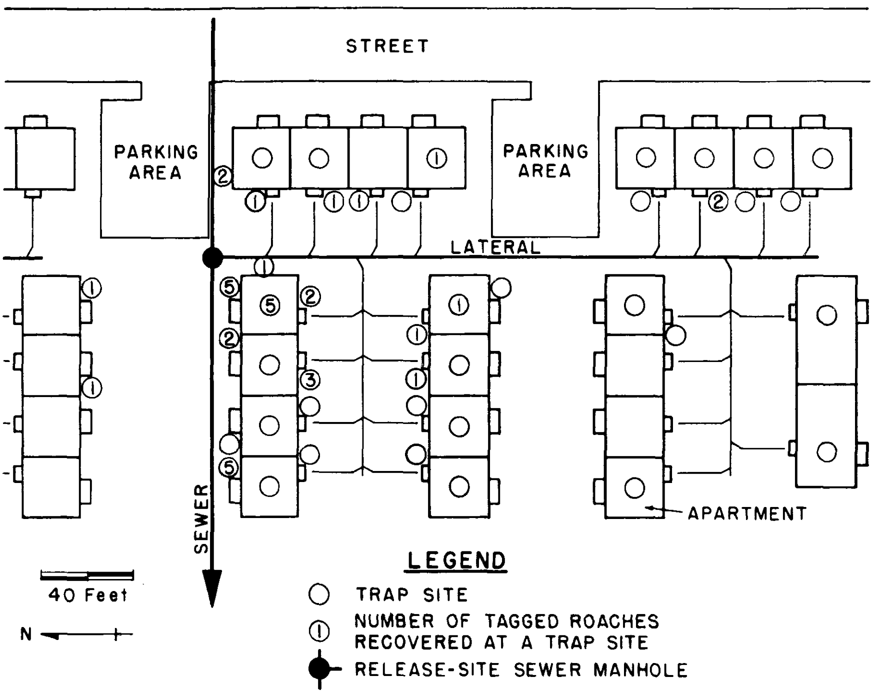

FIGURE 1. Apartment area in Phoenix, Arizona, showing the release and recovery sites of tagged American cockroaches for the June experiment where extraneous roaches were superimposed on an existing population.

Fifteen yard traps caught 29 tagged individuals, and about half were caught within 50 ft of the release site. Following is an enumeration of trap distances in feet with the number of marked cockroaches caught shown in parentheses: 15 (5), 23 (1), 28 (2), 38 (2), 38 (1), 50 (2), 50 (1), 55 (1), 65 (5), 70 (3), 70 (1), 73 (1), 90 (1), 95 (1), and 200 (2). Two radioactive cockroaches were trapped in the manhole 475 ft downstream and a single tagged individual was recovered 145 ft downstream (with the vacuum cleaner) after the trapping period.

From the reference release with superimposed roaches in the Latin-American project, 73 tagged cockroaches were recovered by trapping. No apartment traps were placed during this period. Seventeen roaches entered nine yard traps.

Trap distances in feet are listed with the number of marked roaches shown in parentheses: 30 (4), 33 (1), 38 (1), 40 (1), 48 (2), 50 (1), 60 (3), 75 (2), and 95 (2).

Manhole traps caught 56 released individuals. The upstream manhole (165 ft) had 13, and the first downstream manhole (185 ft) had 43. Removing roaches from the manholes by vacuum cleaner after the trapping period produced an additional 3 from the former and 27 from the latter. No radioactive cockroaches were found in the manholes further downstream.

DISCUSSION

Dispersal has been described as "the innate tendency . . . which seems to be present to a greater or smaller degree in all animals [and] may [be] accentuated by crowding, hunger, warmth, wind, and so on" (Andrewartha and Birch, 1954). Experiments with various natural insect populations have shown largely random movement from a point of concentration (the release site of several thousand or more marked individuals) for fruit flies (Dobzhansky and Wright, 1943), several species of domestic flies (Bishopp and Laake, 1921; Lindquist et al., 1951; Schoof et al., 1952), and codling moths (Steiner, 1940). These movements were often considerably influenced by topography, winds and other climatic factors, and the nature and locations of attractants and traps.

To ascribe innateness to a behavior pattern may mask the full explanation, since the environment, both physical and biotic, plays such an overwhelming role in the development and function of the innate. The present experiments attempt to relate certain patterns of movement of cockroaches with associated environmental conditions. Under stress conditions, dispersal movements usually occurred; but under undisturbed conditions virtually no movement could be detected with the techniques used.

The movement pattern of cockroaches resulting from the creation of a population greater than the carrying capacity of the environment has been shown under summer conditions in Phoenix, Arizona (Jackson and Maier, 1954). In a superimposition type of experiment, 5.9 percent of the 1200 cockroaches released were recaptured at distances up to 350 ft from the release-site manhole. In contrast, only 0.8 percent of the 500 individuals marked in an undisturbed population were recaptured at distances up to 170 ft.

This pattern of marked movement away from a site of positive population pressure could not be replicated in a cooler, winter period. Measurable dispersion of the marked cockroaches from manholes was either very small or nonexistent, regardless of whether or not extraneous individuals were superimposed on the resident population.

Some movement into appurtenant laterals evidently took place during January, since manhole populations did not remain at high levels after extraneous roaches were introduced, but was of too short a distance to be detected by the trapping procedure used. No dispersion of roaches through the keyhole in the manhole cover occurred during the 80 min immediately following the release of superimposed roaches at the Latin-American Housing Project, and there were no clusters of cockroaches around the keyhole on the underside of the lid during this time.

Roaches in the manhole were observed to move much more slowly than during the summer; and the numbers of cockroaches entering traps, both in manholes and in apartments, were considerably reduced despite large populations observed in the manholes and reported by householders. Temperature probably played the major role in this changed activity pattern. The mean temperature reported by the U. S. Weather Bureau in Phoenix for January was 52° F with an average maximum of 66° F and minimum of 38° F. Manhole temperatures, recorded by hygrothermographs suspended in the manhole near the floor, averaged about 66° F, with maximum and minimum temperatures of 72° F and 55° F, respectively. In contrast, summer maximums in Phoenix average above 100° F with a mean of about 90° F, and mean manhole temperatures average above 95° F, with individual manholes having a daily termal range of about 5 Fahrenheit degrees.

The dispersion pattern in the late spring (June) was similar to that observed during the previous summer. Where only the resident population was tagged, observed movement was limited to downstream manholes. However, when the manhole population balance was drastically disrupted by the superimposition of roaches, extensive emigration into adjacent manholes, yards, and apartments occurred.

The fact that large-scale movement of roaches into adjacent manholes from the one with superimposed individuals did not occur in the June test, as it did in the comparison tests in the Latin-American project, is not adequately explained. These adjacent manholes had satisfactory microclimates as judged by the results of other studies made in Phoenix; but still they had few or no cockroaches, even prior to the experiment.

Twenty-four cockroaches were counted between 2000 and 2100 hours emerging from this superimposition site manhole through holes in the cover the night after the release. Individual roaches were observed to run a short distance over the cover, then go back into a hole and, in some cases, emerge again later. Others ran directly away from the manhole into the grass. Roaches that were followed moved slowly through the grass, and some eventually came to rest on the walls of nearby apartments. Clusters of cockroaches were observed around the inner edge of each cover hole.

Similar observations at the Latin-American project manhole the night after the release revealed seven cockroaches leaving in 40 min between 1950 and 2030 hours. Subsequent observations indicated that this pattern continued in both sites during the course of the experiments. These dispersal movements were not observed to occur from manholes where only resident roaches were studied.

The entry portal of the cockroaches into apartments was of particular interest in these studies because some marked roaches were recovered from apartments. Cockroaches were observed to be strong swimmers whenever they fell into the sewage stream; and they will readily traverse plumbing water traps, at least in the laboratory, as has been demonstrated in our laboratory and elsewhere (Anon., 1953). Thus most plumbing connections offer the cockroaches a readily available portal of entry into homes from sewer systems.

In the present experiments, cracks under the doors seemed to be an added important means of entry. Housewives complained of many cockroaches and other insects crawling under the doors at night. One resident killed a cockroach just after it had entered a home from under a door, and subsequent examination showed it to be a marked individual released in the sewer manhole. However, the determination of the mode of entry into homes of recaptured roaches was not attempted in these studies.

Adult females predominated in the recoveries of tagged cockroaches, regardless of place or season of year. A summary of all the recovery records shows that of the 216 radioactive individuals recaptured, 150 (69%) were adult females, 8 (4%) were adult males, and 58 (27%) were nymphs; and of the nymphs 73 percent were caught in manholes. Of the 44 cockroaches seen as they emerged from holes in manhole covers, no nymph was recorded, and 34 were listed as adults. Dim illumination prevented accurate classification of the remainder.

At least 40 percent of the individuals marked in each experiment were nymphs, and about 75 percent of the adults were females. On this basis, greater proportions of nymphs and males would have been expected among the recaptures than were actually found. That differential trapping success is not the explanation is indicated by generally similar proportions of nymphs to adults and sexes in both trap and vacuum cleaner collections. This would then seem to indicate that adults, and particularly females, are primarily involved in population pressure adjustments. The possibility of differential mortality cannot be excluded, but no field data are available to evaluate this hypothesis. In the laboratory, Gould and Deay (1940) found that males tended to have a shorter life span than females.

Observations on sewer manhole cockroach populations in other studies in Phoenix have indicated that minimum population levels occur in late winter and that a population increase occurs in late spring. This increase may be associated with a movement of individuals from appurtenant laterals into manholes with the advent of warmer weather. An increase in the proportion of adults also occurs.

These factors appear to establish a suitable basis for the increased outdoor occurrences of cockroaches in the late spring and summer. With both the increase in total numbers of individuals and in the proportion of adults, the carrying capacity of the environment may be exceeded, and equilibrium is reestablished by means of emigration. Evening observations indicated that emigration through holes in manhole covers was occurring from some of the manholes not involved in the experiments but with histories of large populations in the Latin-American housing project.

These studies have indicated that the sporadic movement of American cockroaches from sewer manholes may be somewhat increased during the late spring by population readjustments and that major disruptions of population balances, such as from sewer flooding may well result in extensive emigration. While an occasional cockroach moving out from a contaminated area is of little importance epidemiologically, extensive emigrations could convert cockroaches into important elevators of enteric pathogens.

SUMMARY

Additional studies of the movements of American cockroaches (*Periplaneta americana* [L.]) from sewer manholes in Phoenix, Arizona, were made using a radiophosphorus marking technique. Little or no movement was recorded during a winter experiment, even when 1500 extraneous cockroaches were superimposed on a resident manhole population of 125. In late spring experiments, limited movement was recorded from an undisturbed manhole population, but extensive emigration resulted from the superimposition of 2000 extraneous cockroaches on a manhole population of 400. Recoveries of tagged individuals were made in nearby yards, apartments, and manholes. About 50 percent of the yard recoveries were made within 50 ft of the release site manhole, but some recaptures were made up to 200 ft away and from a manhole 475 ft downstream. These results indicate that a sudden population increase may result in widespread cockroach emigration and that some emigration may normally occur in the spring and summer from populations readjusting to the carrying capacity of their environment.

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