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Source: The American Midland Naturalist, 146(2):321-328. 2001.
Published By: University of Notre Dame
DOI:
URL: http://www.bioone.org/doi/full/10.1674/0003-0031%282001%29146%5B0321%3AEOWOIO%5D2.0.CO%3B2

Am. Midl. Nat. 146:321–328

Effect of Weather on Infestation of Buildings by the Invasive Argentine Ant, Linepithema humile (Hymenoptera: Formicidae)

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ABSTRACT.—Weekly reports of the abundance of the Argentine ant, *Linepithema humile,* in 69 households for 18 mo (1/98–7/99) in the San Francisco Bay Area in northern California were compared with weather data. Ant abundance inside homes was highest in cold rainy weather, and there was a second smaller peak of ant abundance in hot dry weather. Pesticide use in the home decreased ant abundance, from one week to the next, only when ant abundance was extremely high.

INTRODUCTION

The Argentine ant, *Linepithema humile,* was introduced in California about 100 y ago (Woodworth, 1908) and has since spread throughout much of the state. This invasive species has important effects on native ecosystems worldwide. Wherever the Argentine ant becomes established, native ant species disappear and the distributions of other arthropods change dramatically (Erickson, 1971; Cole *et al.*, 1992; Holway, 1995; Human and Gordon, 1997). Argentine ants are the target of substantial pesticide use. The ant is an agricultural pest because it tends homopterans and thus interferes with biological control of scales and aphids (Flanders, 1945; DeBach, 1951). In urban areas Argentine ants invade buildings, and such infestations are often treated with pesticides.

Argentine ants form aggregations of loosely connected nests with no apparent boundaries between distinct colonies. Nests reproduce by budding. Nests contain multiple queens and males. One or more queens, and possibly males, along with workers, will leave one nest to begin a new one elsewhere. This differs from the usual dispersal mode in ants, in which winged reproductives fly to a mating aggregation and then newly mated queens, without any workers, found new colonies. Workers apparently can join any nest in the vicinity of their own (Markin, 1970a); this also differs from most ant species, which are aggressive to non-nestmates.

Argentine ant invasions of buildings seem to be associated somehow with the weather, but there are no previous studies of this. This association would occur if ants tend to relocate or bud off new nests when conditions in nests outside are unfavorable. For example, in hot

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dry weather ants may seek to emigrate to more humid places; in cold or wet weather ants may seek to emigrate to warm or dry places. There is some evidence that, even outside of buildings, Argentine ants emigrate in search of more favorable abiotic conditions. Budding of new nests may be more common in some seasons on the French Riviera (Passera and Keller, 1992) and in California (Markin, 1970b; Erickson, 1971). Argentine ants may also be more likely to forage inside buildings when weather conditions are unfavorable.

The unusual biology of Argentine ants may make them especially refractory to pesticides. The most common method for delivering pesticides to ants is in the form of bait. Poisoned bait is intended to be carried by workers back to a central nest, where the poison is fed to, and kills, the reproducing queens. However, when workers can take bait back to a number of nests, each with many queens, and the nests themselves bud off frequently, such pesticides are diffused among many nests and even large amounts of pesticide may have little effect.

Here we examine the patterns of Argentine ant infestation of buildings in northern California. We conducted a survey in which 69 households in the San Francisco Bay Area reported weekly for 18 mo on the estimated numbers of ants inside their homes.

We ask: (1) Is there a temporal pattern in the intensity of infestation? (2) Is there an association between current weather and intensity of infestation? (3) Does pesticide use affect the intensity of infestation?

METHODS

The survey was initiated because we received many letters in response to a newspaper article about our research on Argentine ants. Survey participants were selected by sending a letter to everyone who wrote asking if they would be willing to participate in the survey. There were 63 participants, of which 6 were people who moved during the course of the study, for a total of 69 separate buildings all on the west side of the Peninsula in the San Francisco Bay Area between Redwood City and Gilroy. Within this area Argentine ants are extremely well established (Human and Gordon, 1997) and it is very unusual for ants of other species to come inside buildings. None of the other possible species are of the same size and color as Argentine ants. Using as criteria location of the building, behavior and location inside the building of the ants, body size and color, initial correspondence with every household strongly indicated that the ants were Argentine ants.

The survey was conducted for 78 wk from January 1998 through July 1999. Each week we asked the following questions by e-mail or telephone: (1) Estimate the largest number of ants you saw at one time inside your home during the past week: None, no ants seen; Few, fewer than 10 ants; Some, 10 to 150 ants; Many, more than 150 ants. (2) Did you use any pesticides in your home this week? What kind?

At the end of the survey, in August 1999, we asked each current participant to supply the following information about his or her home: age of building, whether participant's home was on the ground floor and frequency of watering of lawn or garden around the building. We received 41 responses from the 69 households to questions about characteristics of the building.

The response data on ant abundance consist of 69 records (one per household), where each record comprises 78 weekly reports, each being 0, 1, 2, or 3, for "none," "few," "some" or "many" ants, respectively. Thus, the data are an array of 69 rows (households) and 78 columns (wk), with about one-third of the cells missing, in a haphazard pattern. We treated the responses (0,1, 2, 3) as if they were equally spaced on an interval scale.

Weather data were obtained from six weather stations (San Jose (20 buildings), Gilroy (4), Palo Alto (24), Watsonville Waterworks (1), Los Gatos (14), Redwood City (6)). Weather data for each household were from the closest weather station. Weekly rainfall and temperature were recorded, and coded as rainfall in inches and maximum and minimum weekly temperatures in degrees Fahrenheit.

RESULTS

Effect of weather on ant infestation.—We expected that households would vary in their reports of ant abundance in the same week because of both physical factors and response bias in the use of the terms "few," "some" and "many." Similarly, we expected week-to-week variation. If the abundance data had been complete, the weekly averages would have shown the weekly variation. But because of missing data, different households enter into the average in different weeks. We used a 2-way ANOVA (with household and week as main effects) to obtain an adjusted weekly average Y_t for week t, t = 1. . . 78. Y_t represents the difference between the weekly average and the overall average.

We considered the effect of the following weather variables: (1) Rainfall (R), average total rainfall for the week, (2) Average temperature (T), calculated as $1/2\ (T_{max} + T_{min}) - 62$. The temperature in the week when reported ant abundance was at a minimum was 62, so this method of calculating average temperature gives a parabolic plot of average weekly response vs. average temperature, with a minimum at 62, and (3) Average temperature squared, T^2. We averaged over all six weather stations. We also analyzed the data using different weights for the six stations, taking into account the number of households in the area serviced by each station, but the results were virtually identical. We also investigated the square of rainfall and all other second-order terms but these added no information.

To fit weekly values of ant abundance, Y_t, against values of R_t and T_t and T_t^2 by ordinary least squares is a dubious proposition because of the correlation between one week's weather and the next. We performed multiple regression allowing for auto-correlated error (Chatterjee and Price, 1977) because the value of the Durbin-Watson statistic following ordinary least squares was 0.97, indicating a correlation of about 0.52 between the error terms of successive weeks. We used the iterative method of Cochrane and Orcutt (Chatterjee and Price, 1977) to correct for the autocorrelation. The Durbin-Watson statistic after applying the autocorrelation correction was 2.092, corresponding to a correlation of about −0.05 between the errors in successive weeks. The autoregressive fit yielded a 6-variable fit which used R_t, T_t, and T_t^2 together with the same variables for the preceding week, R_{t-1}, T_{t-1}, and T_{t-1}^2. For the multiple regression taking autocorrelation into account (model df 6, SS 1.03, F 9.56, $P < 0.0001$), the adjusted R^2 was 0.41.

The similarity between Figure 1A, which shows the observed ant abundance, and Figure 1B, which shows the fitted values calculated by the model, is impressive. The main difference lies in the greater vertical range (from −0.4 to 0.7) of the values of Y_t in Figure 1A compared to the range (−0.2 to 0.4) in the fitted values of Y_t in Figure 1B. This is to be expected because Figure 1A displays the variation in Y, which is the sum of the variation in the fitted values of Y (shown in Figure 1B) plus the error associated with both weeks and households.

Ant abundance was highest in winter months with a smaller peak in abundance in late summer (Figs. 1A, B). When abundance of ants is plotted against both rainfall and temperature (Fig. 2), it is clear that abundance is highest in winter when the weather is cold and wet, and there is a second smaller peak in the hotter, drier part of the summer.

Effect of pesticide on infestation.—To assess possible effects of pesticide use on ant abundance we used the abundance data described in the previous section. We calculated average reported 1 wk abundance changes where pesticide was used, and average reported 1 wk abundance changes where pesticide was not used. If average abundance dropped more where pesticide was used, that would indicate that pesticide was effective. To perform this analysis we proceeded as follows.

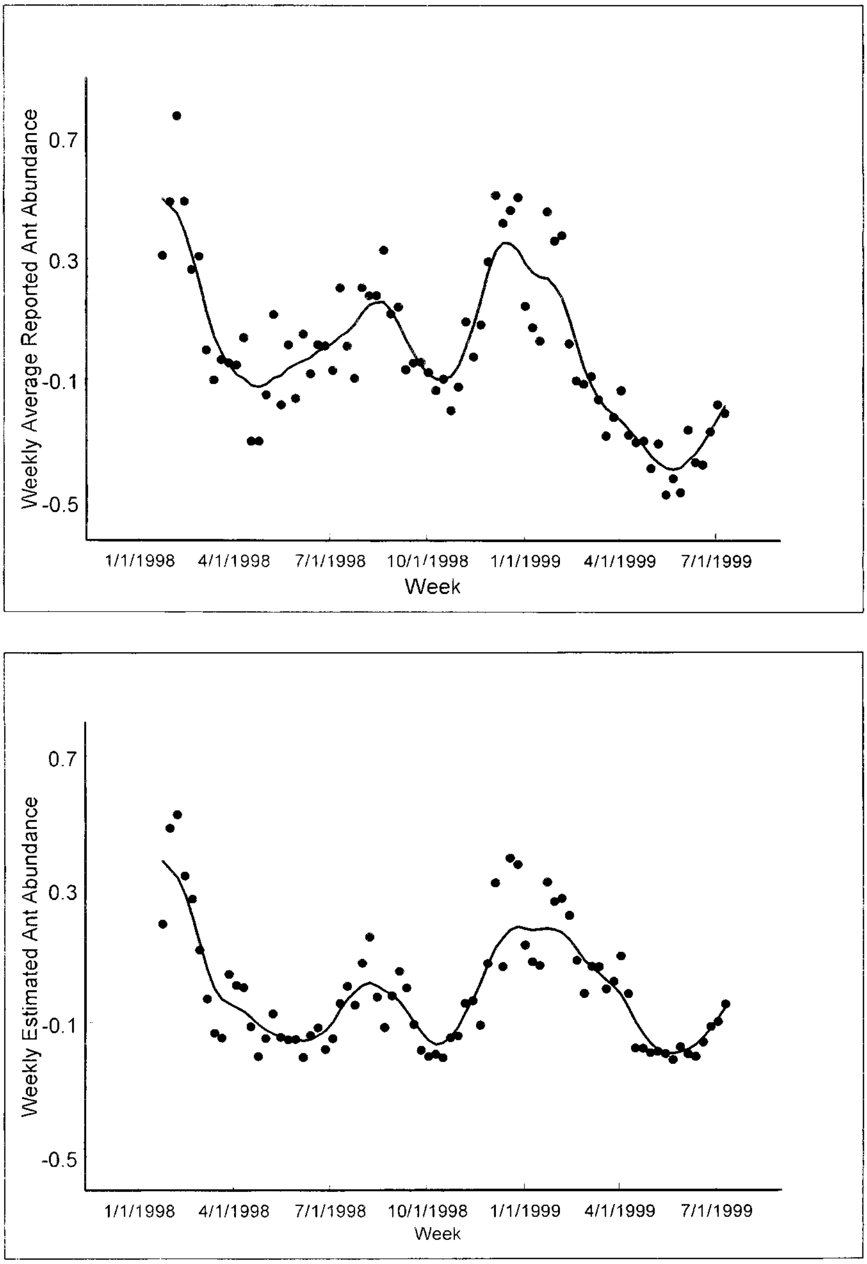

FIG. 1A.—(upper)—Weekly reported ant abundance during the 78 wk of the study. The figure shows the values of Y_t plotted against time from January 98 to July 99. Y_t is the deviation of the weekly average abundance from the overall average. Abundance was scaled as 0, 1, 2, 3 for None, Few, Some and Many. The smooth curves in Figs. 1 and 2 were produced by applying Friedman's Super Smoother from S-plus (Venables and Ripley, 1998). B. (lower) Weekly estimated ant abundance. The figure shows

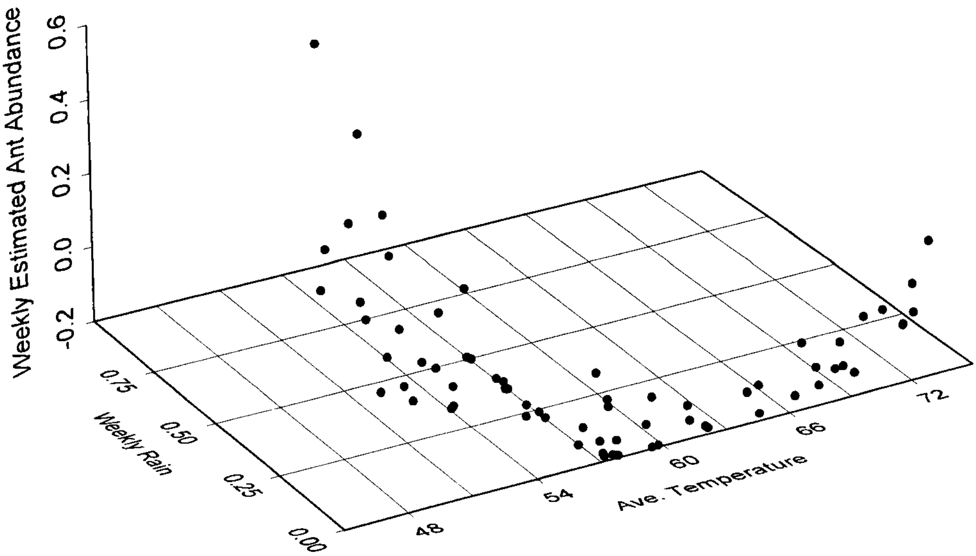

FIG. 2.—Ant abundance related to temperature and rainfall. The figure shows the fitted values calculated by the model, plotted against rainfall and temperature. The z-axis represents weekly estimated ant abundance, calculated using the model described in the text. The y-axis shows average weekly rainrall, and the x-axis shows average weekly temperature

For each household we identified each pair of successive weeks or ''dyads'' (with a maximum possible of 77 dyads per household) for which abundance was reported in both the earlier and later week, and where the use or non use of pesticide for the earlier week was also reported. There were 1187 of these informative dyads. We then sorted those informative dyads into four batches, according to whether the initial abundance was 0, 1, 2 or 3. We analyzed those batches separately. To assess statistical significance of the differences between abundance changes when pesticide was used and when it was not used we applied the bootstrap (Venables and Ripley, 1998). The results showed that an effect of pesticide use emerged when the intial abundance was 3 (the highest value, ''many''), but not otherwise. Abundance dropped more when pesticide was used than if it was not, only when the initial abundance was 3.

We then performed three further analyses for the subset of 178 informative dyads with initial abundance 3. First we found, for each week in which at least one of these 178 dyads occurred ($n = 96$ wk), the proportion of pesticide users for which ant abundance decreased from an initial value of 3 to a later score less than 3, and the proportion when pesticide was not used. When pesticide was used the mean proportion was 0.545, SE 0.056, $n = 53$ wk; when pesticide was not used, the mean proportion was 0.217, SE 0.051, $n = 43$ wk. Thus a higher proportion of the dyads decreased in ant abundance when pesticides were used

←

the fitted values of Y_t, calculated from R_t, R_{t-1}, T_t, T_{t-1}, T^2 and $T_{t-1}{}^2$, plotted for $t = 1, \ldots 78$. Each dot shows the estimated deviation of the weekly average abundance from the overall average. Estimates are made from weather data, based on the model described in the text than when pesticides were not used. The difference between proportions that decreased when pesticides were used and not used was more than 2 standard deviations from 0, indicating statistical significance at $P < 0.05$ (Sokal and Rohlf, 1995).

Second, we considered only those weeks in which we had informative dyads from both pesticide users and nonusers in the same week (n = 34 wk), and found the difference in each week between the proportions of pesticide users and non-users for which ant abundance decreased. The mean of these differences between proportions was 0.394, SE 0.08, again indicating that the difference is signicantly greater than 0 at $P < 0.05$. Ant abundance was more likely to decrease when pesticides were used.

Finally, to determine if results were affected by variation among households in the number of reports, we performed a bootstrap analysis for 1000 cycles. In each cycle we randomly chose 1 dyad per household and then performed the same calculation as in the second analysis described in the previous paragraph. The bootstrap mean difference between proportions of pesticide users and nonusers for which ant abundance decreased was 0.335, SE 0.126, indicating that the difference is significantly greater than 0 at $P < 0.01$.

The analysis described above was performed without distinguishing among categories of pesticide. We then classified pesticides as follows: (1) Bomb/fumigant; (2) Cleansers (Windex, bleach, ammonia, soap, 409, detergent, bathroom foam cleaner); (3) Herbal or natural (hot pepper, sesame oil, chili oil, rosemary and orange, lemon, vinegar and water, mint extract, diatomaceous earth); (4) Sprays (Raid, Hot Shot, Black Flag, Peperonyl butoxide, unidentified pesticides sprayed by professional exterminators); (5) Baits/Other Traps, including Combat, Raid with Metatstop, Ant motels; Baits: Raid Ant Bait Plus, Grant's Bait, Grant's Stakes, Long's Bait, Maxatrax Bait; Boric Acid, Borax, Diazone, Ortho Ant Kill, Termite poison).

We compared the numbers of dyads within each pesticide category in which ant abundance decreased from ''many'' in week 2, with the numbers in which ant abundance remained at ''many.'' The same household used different pesticides; sometimes the same household used more than one pesticide in a given week, so in this comparison, reports from a given household may appear in more than one category. As the previous analysis indicated, when a household reported many ants, using some pesticide was more effective than none (Fig. 3): the second pair of columns shows that ant abundance remained high (filled bars) more often than it declined. This overall effect is apparently due to the effects of all pesticides except perhaps herbal or natural ones; the frequency of a decline in abundance seemed to be about the same for the Cleanser, Sprays or Baits/Other categories. Sample sizes are small and differ greatly among categories, and there is no clear difference among pesticide categories. No further analysis was performed.

Effect of building characterstics on infestation.—Responses from up to 41 households on characteristics of the home building were categorized as follows, with numbers of each type in parentheses: (1) Age of building: built before 1950 (7); built 1950–1969 (22); built after 1970 (11); missing (29); (2) Ground floor or not: ground floor (33); above ground floor (6); missing (30); (3) Frequency of watering: < 2 times per week (7); 2–4 times per week (22); almost daily (11); missing (32). We plotted the average reported ant abundance for each household, over all 78 wk, according to these categories. The plots indicate no effect of any of these characteristics on ant abundance, so no further statistical analysis was performed.

DISCUSSION

There is clearly an association between the weather and the level of infestation by Argentine ants. Ants are most likely to enter homes in cold wet conditions, typically in the

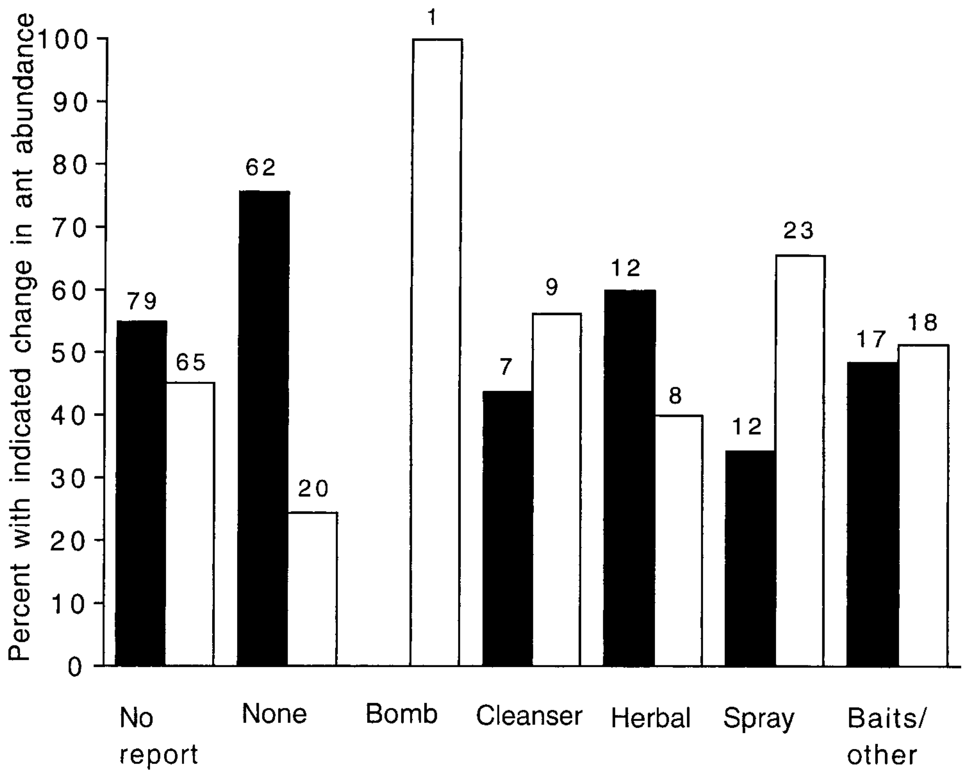

FIG. 3.—Effect of pesticide type on ant abundance. Data were reports from two successive weeks, in which ant abundance was high (3 or "many") in week 1. Filled bars indicate ant abundance remained high (3 or "many") in week 2; open bars indicate ant abundance decreased in week 2. Numbers above bars are numbers of reports in the indicated category. See text for definitions of pesticide types

winter in northern California. There is a second smaller peak in the level of infestation in hot dry conditions, typically in August and September. The result that ants enter homes in particular weather conditions, and are absent from homes in other conditions, suggest that in certain conditions the ants prefer to be outside.

Argentine ants seen inside a building may be foragers travelling to and from a nest outside, or they may have moved to a nest inside the building. Ants may look for food inside buildings on some occasions and for nest sites on others. We do not know whether the ants in budding or emigrating nests tend to choose new nest sites in places where they have already found food, or choose a nest site and then begin to forage from the new site once they have moved. The link between food retrieval and choice of nest site may itself vary with season. More work is needed to learn when Argentine ant nests bud off and move from one site to another. The opportunity to use buildings in unfavorable weather conditions may allow populations of Argentine ants to increase. Previous work in a biological reserve suggested that proximity to buildings best predicts the occurrence of Argentine ants (Human *et al.*, 1998).

Our study suggests that pesticides decrease ant abundance only when infestation is high. We found no indication that certain pesticides are more effective than others. For example, household cleansers apparently diminish ant abundance about as much as baits or traps. The results of this study suggest that it is not helpful to use pesticides to control Argentine ant infestation when weather conditions make infestation unlikely. Efforts to control infestation will be most useful during extended periods of hot or rainy weather, and the most reliable cause of a decline in infestation may be a change in the weather.

Acknowledgments.—We thank Jennifer Marshall and Miler Lee for their help with data collection, Jerry Halpern for help with statistical analysis and Heather Murapa for help with GIS analysis of household locations. Nathan Sanders provided helpful comments on the manuscript. This study was supported by the Structural Pest Board of the Consumer Affairs Agency of the state of California.

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SUBMITTED 13 DECEMBER 2000 ACCEPTED 1 MAY 2001