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Author(s): Eleanor Spicer Rice, Jonathan Z. Shik and Jules Silverman

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Effect of Scattered and Discrete Hydramethylnon Bait Placement on the Asian Needle Ant

ELEANOR SPICER RICE, JONATHAN Z. SHIK, AND JULES SILVERMAN¹

North Carolina State University, Department of Entomology, Campus Box 7613, Raleigh, NC 27695-7613

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ABSTRACT The Asian needle ant (*Pachycondyla chinensis* Emery) is invading natural and disturbed habitats across the eastern United States. While recent studies document the impact of *P. chinensis* on native ecosystems and human health, effective control measures remain unknown. Thus, we evaluated the field performance of a hydramethylnon granular bait, Maxforce Complete Granular Insect Bait, dispersed in clumps or scattered against *P. chinensis*. We also measured the effect of this bait on *P. chinensis* outside of the treatment zone. Surprisingly, unlike reports for other ant species, we achieved nearly complete *P. chinensis* population reductions 1 d after treatments were applied. Significant ant reductions were achieved until the end of our study at 28 d. No difference was recorded between clumped and scattered application methods. We found no overall difference in ant reductions from the edge out to 5 m beyond the treatment zone. Other local ant species appeared to be unaffected by the bait and foraging activity increased slightly after *P. chinensis* removal from treated areas. We suggest that Maxforce Complete Granular Insect Bait can be effective in an Asian needle ant treatment program.

KEY WORDS Asian needle ant, *Pachycondyla chinensis*, hydramethylnon, granular bait, control

The Asian needle ant, *Pachycondyla chinensis* (Emery), is spreading in both urban and natural habitats across the Eastern United States. Introduced to the United States from Japan, this pest negatively impacts native ant species across its invaded range (Guenard and Dunn 2010, Yashiro et al. 2010). *P. chinensis* also infests homes, zoos, nursing homes, and schools, and they can cause allergic reactions in humans with its venomous sting (Leath et al. 2006). Despite an emerging need for an adequate management program, little is known about effective treatment strategies for this species. One possible solution is toxic baits, which are widely used for ant control in and around urban structures (Klotz et al. 1997, Silverman and Brightwell 2008, Gusmao et al. 2011).

When selecting an optimal bait to control a given ant species, the foraging strategy of the ant must be considered. Ant bait distribution method can affect product performance. Ants use solitary (individual acquisition of resources) or mass recruitment (individuals directing multiple nestmates to resources) foraging strategies (Hölldobler and Wilson 1990). *P. chinensis* workers are solitary foragers but exploit large immobile food resources using a unique behavior, tandem carrying, in which individual workers carry nestmates to food resources (Guenard and Silverman 2011). While the relative effectiveness of clumped versus scattered granular bait against mass-recruiting

species has been investigated (Krushelnycky and Reimer 1998, Klotz et al. 2000, Silverman and Roulston 2003), bait distribution procedures have not been explored against solitary foraging or tandem-carrying pest ants. Solitary foraging ant species may be less likely to retrieve discrete compared with scattered food (bait) sources. Thus, we measured the efficacy of clumped versus scattered bait placement against *P. chinensis*.

Baits used to control large ant colonies often rely upon delayed toxicity, because a latent period provides time for workers to distribute toxicant to nestmates (Rust et al. 2004). However, delayed toxicity is less optimal for controlling venomous ants (e.g., *Solenopsis invicta* Buren, *Wasmannia auropunctata* (Roger), *P. chinensis*), as this delay can increase health risks, especially in nursing homes where residents are relatively immobile (deShazo et al. 2004, Rupp and deShazo 2006). Laboratory tests indicate that baits with the active ingredient (AI) hydramethylnon caused 70–100% *P. chinensis* mortality by day 10 compared with 9–50% *P. chinensis* mortality for other AIs, including abamectin, sodium tetraborate decahydrate, fipronil, thiamethoxam, and indoxacarb (Spicer Rice and Silverman in press). However, mortality of other urban ant species exposed to hydramethylnon baits is often delayed for longer periods compared with toxicants such as indoxacarb and spinosad (Oi and Oi 2006). A significant delay in worker mortality could reduce the utility of hydramethylnon baits in a *P.*

¹ Corresponding author, e-mail: jules_silverman@ncsu.edu.

chinensis treatment program. To test this, we used a field experiment to evaluate the short and long-term effects of a hydramethylnon bait (Maxforce Complete granular) on *P. chinensis*.

When evaluating bait efficacy, it is also important to quantify the spatial extent of control. As with other invasive ant species, *P. chinensis* can form large populations across their invaded area (Guenard and Dunn 2010), which may limit the effective range of baits to within the application zone and increase the risk of reinfestation from nearby untreated locations (Silverman and Brightwell 2008, Guenard and Dunn 2010). We considered that *P. chinensis* control with hydramethylnon bait might be restricted to the area treated and thus examined this by sampling ants both in and beyond the treatment zone.

A final criterion for evaluating bait performance is target specificity. When pest management professionals apply bait for *P. chinensis* control, they risk eliminating native ant taxa as well. However, many native ants active during periods when baits were applied were smaller than *P. chinensis* and may be unable to retrieve bait granules (Hooper-Bui et al. 2002). Therefore, we recorded the presence of other ant species in areas treated by Maxforce Complete.

Materials and Methods

Field Sites. We performed five replicate transects nested in plots for each of three treatments (scattered, clumped, and untreated control) at three locations: an office park in Morrisville, NC (35.8542° N, 78.824151° W) (RTP 1, RTP 2; $n = 2$ plots); an office park in Raleigh, NC (35.795599° N, 78.740873° W) (Judicial1, Judicial2; $n = 2$); and a recreational area in Raleigh, NC (5.778994° N, 78.662249° W) (pullpk; $n = 1$). Within sites, plots were separated by at least 15 m and bait was applied in areas ranging from 44.6 to 241.5 m². We randomly assigned treatments to plots and performed experiments between August and October, 2011, a period when *P. chinensis* are active.

Treatment and Application Method. We evaluated clumped and scattered applications of Maxforce Complete granular insect bait (AI = hydramethylnon, 1.0%) (Bayer CropScience, Monheim, Germany) against *P. chinensis*. For the clumped bait application, we constructed one transect bisecting each plot and placed a pile of granules at a rate of 28.35 g for every 3.81 m. Scattered bait treatments received product scattered evenly by hand at a rate of 28.35 g per 4.6 m². We also performed an untreated control.

We measured treatment efficacy by sampling plots for *P. chinensis* before bait application (day 0) and then after 1, 3, 7, 14, and 28 d. To sample ants, we constructed transects bisecting each plot and placed note cards (7.6 × 12.7 cm) baited with 0.5 g of tuna in oil at 3.81 m intervals across transects. We recorded the number of *P. chinensis* at each card after 30 min. Plot size, and thus transect length, was constrained by landscape features across sites, so the number of monitoring stations per transect ranged from 5 to 11. We also recorded the identity and number of non-*Pachy-*

Table 1. The non-*Pachycondyla* genera present at baits in hydramethylnon bait-treated plots at each site initially and on day 14

Site	Pretreat	Day 14
RTP	<i>Linepithema</i>	<i>Solenopsis</i> , <i>Lasius</i> , <i>Linepithema</i>
Judicial	<i>Camponotus</i>	<i>Tapinoma</i> , <i>Lasius</i>
Pullen	<i>Solenopsis</i> , <i>Pheidole</i>	<i>Solenopsis</i> , <i>Forelius</i> , <i>Crematogaster</i> , <i>Monomorium</i> , <i>Brachymyrmex</i>

condyla genera on bait cards before treatment and at day 14.

We used two way repeated measures analysis of variance (ANOVA), with site as a random factor to test the effects of Maxforce application type (clumped, scattered, or none) on *P. chinensis* number across time. The important term in the analysis was the time × treatment interaction. We used post hoc Tukey tests on least square means to explain significant treatment effects within sampling days. Following this analysis, we examined the *P. chinensis* recovery trajectory after Maxforce application using the profile statement in SAS version 9.2 (SAS Institute, Cary, NC) to test for differences among serial baiting events.

Effect of Bait Outside the Treatment Zone. After recording nearly complete population reductions in treated plots and population increases in nearby (as close as 15 m away) untreated plots, we next determined whether the bait treatment effect extended outside of application plots. We constructed 5 m transects extending outward from the edge of each treated plot. For plots receiving a clumped bait application the area outside the treatment zone began 1 m from each clump, while monitoring outside the scattered treatment zone began 1 m from the treatment perimeter. We placed note cards with tuna at 1 m intervals and sampled ants on day 28 after bait application as described above.

We used a mixed model to test the effects of site, treatment (clumped vs. scattered), transect (nested within treatment and site), and bait distance from plot origin (1–5 m) on *P. chinensis* abundance. Site was treated as a fixed factor, transect was random, and distance measured at bait stations within transects was treated as a repeated measure and modeled separately for each site. We applied the Kenward–Rogers correction for the calculation of the denominator degrees of freedom for F-test and LS means SE.

We modeled the covariance structure among distance levels as autoregressive of order one [AR(1)], which implies that the correlation between two distance points h units apart is given by ρ^h , where ρ is estimated AR(1) covariance parameter (as per Rowles and Silverman 2009). Type III F-tests were used for testing the null hypothesis of fixed effects and related contrasts.

Because the residual variation among sites varied from 0.23 to 105.23 and the AR(1) varied from 0.00 to 0.62 (Table 1), we followed with an analysis of the simple effects of treatment, distance, and their interactions within each site. The significance levels for

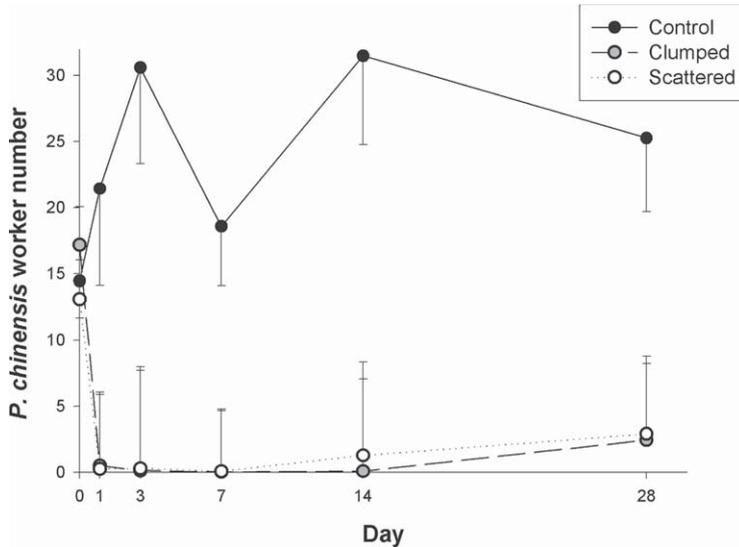


Fig. 1. The effects of Maxforce density on *P. chinensis* abundance before and after application beginning on day 1. Least square means beginning plotted SE for clumped and scattered plots and -SE for control plots.

these tests of simple effects were set at 0.001 to control for type I error.

Results

Treatment and Application Method. Both clumped and scattered bait treatments reduced *P. chinensis* abundance over time relative to the untreated control (Fig. 1). Worker abundance over time differed significantly across treatments (day \times TRT: $F_{10,420} = 21.06$; $P = 0.0001$). This was driven by a rapid decline in *P. chinensis* abundance from day 0 (no differences between plots; $F_{2,8} = 0.52$; $P = 0.62$) to day 1 ($F_{2,8} = 5.13$; $P = 0.04$), when both clumped plots (0.5 ± 0.6) and scattered plots (0.2 ± 0.27) had fewer ants than control plots (21.4 ± 22.0) (Pairwise Tukey tests for clumped vs. control: $P = 0.061$; scattered vs. control: $P = 0.060$).

Thereafter, significant overall treatment effects on days 3 ($F_{2,8} = 5.74$; $P = 0.03$), 7 ($F_{2,8} = 5.70$; $P = 0.03$), and 14 ($F_{2,8} = 6.94$; $P = 0.02$) were driven by lower *P. chinensis* abundance on control relative to both clumped and scattered plots (Fig. 1). This was indicated by significant Pairwise Tukey tests comparing clumped and scattered plots to control.

However, by day 28, *P. chinensis* exhibited signs of recovery on both clumped ($P = 0.051$) and scattered ($P = 0.057$) plots relative to control (Fig. 1). This slight increase in ant abundance from day 14–28 was limited to treated plots (Profile test, day 14 vs. 28: $F_{2,84} = 3.47$; $P = 0.04$) and was driven by slight increases during this interval from an average of 1–3 workers in clumped treatment plots, and 0–2 workers in scattered treatment plots (Fig. 1).

Effect of Bait Outside of Treatment Zone. On day 28, neither treatment nor distance from treated plot significantly affected overall *P. chinensis* abundance

(Table 2). However, because both overall site effect, and site \times treatment effects were significant (Table 2), we further partitioned the analysis by site. The site effects were driven by higher *P. chinensis* numbers surrounding scattered plots at RTP1 (site \times TRT; Fig. 2, Table S1 [online only]), slight *P. chinensis* increases 5 m away from both treatments at Judicial1 (site \times distance; Fig. 2, Table S1 [online only]), and significantly elevated *P. chinensis* numbers in scattered plots on bait cards >5 m from treatment site at Judicial1 (site \times TRT \times distance; Fig. 2, Table S1 [online only]).

The sites Judicial2 and RTP2 exhibited substantial spatial autocorrelation among baits within transects,

Table 2. Results from mixed model testing the effect of site, Maxforce treatment, and distance (from Maxforce treated plot; 1–5 m) on the abundance of workers of *P. chinensis* foraging at tuna baits on day 28 after Maxforce application

Source	F	Numerator df	Denominator df	P	Covar. estimate
Random effects					
Residual (Judicial1)	—	—	—	—	0.23
AR(1) (Judicial1)	—	—	—	—	0.00
Residual (Judicial2)	—	—	—	—	8.04
AR(1) (Judicial2)	—	—	—	—	0.41
Residual (RTP1)	—	—	—	—	29.00
AR(1) (RTP1)	—	—	—	—	0.00
Residual (RTP2)	—	—	—	—	105.23
AR(1) (RTP2)	—	—	—	—	0.62
Residual (pullpk)	—	—	—	—	0.45
AR(1) (pullpk)	—	—	—	—	0.21
Fixed effects					
Site	15.86	4	21.70	0.0001	—
Trt	0.00	1	12.70	0.95	—
Site*Trt	9.50	4	21.70	0.0001	—
Distance	0.21	4	72.70	0.93	—
Trt*Distance	0.55	4	72.70	0.70	—
Site*Distance	1.31	16	89.10	0.21	—
Site*Trt*Distance	0.90	16	89.10	0.57	—

Low AR(1) covariance estimates (e.g., <0.4) indicate a lack of spatial autocorrelation among monitoring stations within transects.

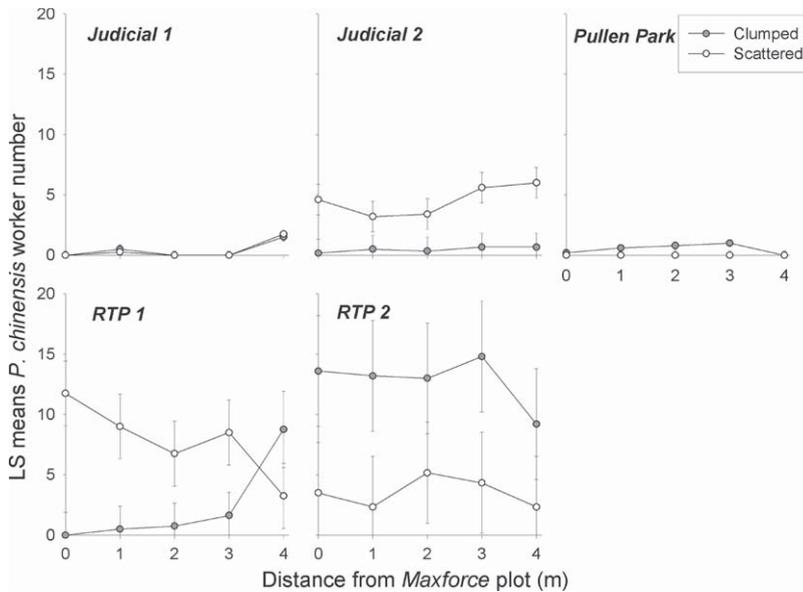


Fig. 2. Spatial extent of treatment effects. *P. chinensis* abundance on transects extending out from treatment plots on day 28. The first bait at 0 m was inside the plot. LS means were plotted, combining the effects of site, treatment, and distance.

with AR(1) covariance estimates of 0.41 and 0.62, respectively (Table 2; Fig. 2). This was because of a gradual increase in *P. chinensis* abundance leading away from treated plots at Judicial2 and a decline leading away from plots at RTP2 (Fig. 2). Because we expected that we would be most likely to detect ant reductions beyond the treatment zone at transects where no ants were sampled at the first bait inside the plot, we followed this test by a mixed model analysis of only these transects. Here, we treated site as a random factor. In this test, we detected a trend toward increasing *P. chinensis* activity away from plots ($P =$

0.12, (AR(1) covariance estimate = 0.29)) (Fig. 3; Table S2 [online only]).

Discussion

We demonstrated that a granular hydramethylnon bait (Maxforce Complete Granular Ant Bait) provided rapid control of *P. chinensis* in urban landscapes, while the effects of a single treatment last for at least 28 d. Moreover, in contrast to our initial solitary foraging hypothesis, clumped and scattered bait application yielded the same level of control. However, the effects

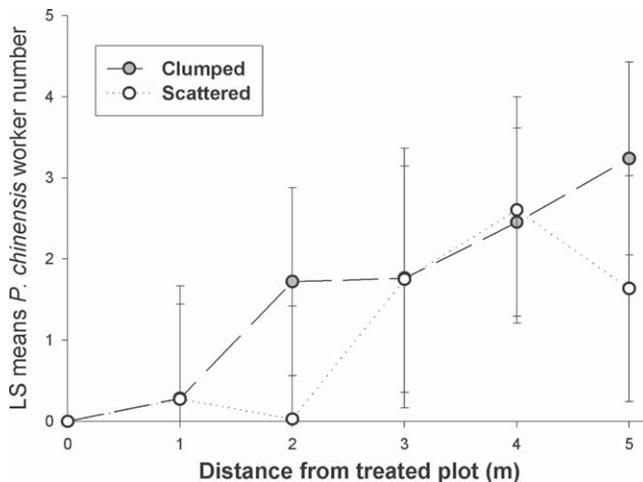


Fig. 3. The spatial extent of treatment effects in transects along which no *P. chinensis* were sampled at the first baits between plots. The first bait at 0 m was inside the plot. We treated site as a random factor and tested the effect of Maxforce treatment and distance (from Maxforce treated plot; 1–5m) on the abundance of workers of *P. chinensis* foraging at tuna baits on day 28 after Maxforce application.

of bait application outside of treated plots varied by site, and further studies will be needed to understand the efficacy at greater temporal and spatial scales.

Hydramethylnon is an inhibitor of electron transport with delayed effects (>2 d) against many pest ants including *Wasmannia auropunctata* (Hara et al. 2011), *Solenopsis invicta* (Thompson et al. 2009), *Tapiroma melanocephalum* F. (Ulloa-Chacon and Jaramillo 2003), and *Linepithema humile* (Mayr) (Hooper-Bui and Rust 2001). Delayed action insecticides provide an advantage over fast-acting insecticides when managing large populations of ants by allowing foragers to collect and share insecticide with nestmates before the onset of morbidity symptoms (Lopez et al. 2000, Rust et al. 2004). However, despite this apparent delayed action for other ant species, we observed control of *P. chinensis* that was both rapid and robust. In addition to rapid action, this hydramethylnon bait reduced *P. chinensis* in treated areas for at least 28 d. *P. chinensis* workers were nearly eliminated from the treated area with little migration from neighboring nontreated areas.

P. chinensis's food transport and storage mechanisms may be influencing the activity onset and duration of the hydramethylnon bait. For most ant taxa, proventricular restriction regulates trophallaxis with undigested nutrients stored in a sclerotized crop. More primitive species like *P. chinensis*; however, do not perform trophallaxis and do not store undigested communal food in their crops (Davidson et al. 2004, Hölldobler and Wilson 1990). Thus, we hypothesize that *P. chinensis* workers absorb hydramethylnon more quickly and consequently die faster than other ant species that consume hydramethylnon bait. This relatively fast-acting performance of hydramethylnon against *P. chinensis* would appear to be beneficial in that workers are eliminated from treated areas quickly hence reducing stinging risks to sensitive humans and their pets (deShazo et al. 2004, Rupp and DeShazo 2006).

Hydramethylnon is photolabile and degrades relatively quickly when applied outdoors (Mallipudi et al. 1986). However, in laboratory trials, *P. chinensis* workers tend to stockpile food, including insecticide bait granules, inside their dark nests (E. Spicer Rice, personal observation). Thus, light sensitivity may be offset if bait is rapidly harvested and stored after application. As reported for other pest ants (Krushelnycky and Reimer 1998, Klotz et al. 2000, Silverman and Roulston 2003), we saw no difference in bait performance whether granules were scattered or distributed in clumps. Accordingly, it appears that *P. chinensis* adjust foraging behavior to resource availability regardless of bait placement.

Because *P. chinensis* are polydomous (one colony can have multiple nest locations) (Gotoh and Ito 2008) in both native and introduced populations, we expected resources and toxicants to be translocated at larger spatial scales, with resource flow between nearby nests. Therefore, we predicted that hydramethylnon toxicity should extend beyond the treatment zone. However, our analysis across sites re-

vealed no overall effect 5 m outside treated plots (i.e., slight increases in *P. chinensis* abundance; Fig. 3, Table S2 [online only]), suggesting restricted movement of resources in this area. This contrasts with observations of greater spatial efficacy of treatment for other pest species moving resources between polydomous nests (Drees et al. 1992). Although other similar experiments for other pest species suggest that having a pool of unaffected ants may cause reinfestation (Oi et al. 2000, Silverman et al. 2006, Silverman and Brightwell 2008), further study will be needed to determine a timeline, beyond 28 d, for *P. chinensis* recolonization.

P. chinensis negatively impact native ant species (Guenard and Dunn 2010). By targeting an ant pest species over a broad area, the treatment can further impact local native ants (Zakharov and Thompson 1998). Though our sample size was small, we did not detect negative impacts on nontarget local ants, other than *P. chinensis*. In fact, eliminating *P. chinensis* from the habitat may have a slight positive effect on local ants.

Invasive ants often alter the structure of ant communities through competition (Sanders et al. 2003, Bos et al. 2008, Lessard et al. 2009, Rowles and O'Dowd 2009). They generally recruit to food resources more quickly and prevent native ants from accessing these resources (Human and Gordon 1996, Holway 1999, Holway et al. 2002). This behavioral dominance can also negatively impact invasive ants if they out-compete native ants at toxic baits (Buczowski and Bennett 2008). Food particle size acceptance by *P. chinensis* versus native ants could affect toxic bait selectivity, with larger granules retrieved by *P. chinensis*, but not other ants. Selectively removing invasive insects from a habitat can have a positive effect on native taxa (Hu and Frank 1996, Calixto et al. 2007). Our results may be applied to *P. chinensis* in natural environments, by selectively removing an invasive pest without affecting smaller native ants. While our results suggest that some native ants were unaffected by hydramethylnon bait, more extensive sampling is needed to understand bait selectivity.

We demonstrate how granular hydramethylnon bait can rapidly reduce *P. chinensis* in an urban landscape. Moreover, these effects persisted for at least 28 d. A clearer understanding of *P. chinensis* colony structure and foraging behavior is needed to optimize the delivery of bait granules in urban and natural habitats to prevent further spread of this invasive pest.

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