

# Sampling Efficacy for the Red Imported Fire Ant *Solenopsis invicta* (Hymenoptera: Formicidae)

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**ABSTRACT** Cost-effective detection of invasive ant colonies before establishment in new ranges is imperative for the protection of national borders and reducing their global impact. We examined the sampling efficiency of food-baits and pitfall traps (baited and nonbaited) in detecting isolated red imported fire ant (*Solenopsis invicta* Buren) nests in multiple environments in Gainesville, FL. Fire ants demonstrated a significantly higher preference for a mixed protein food type (hotdog or ground meat combined with sweet peanut butter) than for the sugar or water baits offered. Foraging distance success was a function of colony size, detection trap used, and surveillance duration. Colony gyne number did not influence detection success. Workers from small nests (0- to 15-cm mound diameter) traveled no >3 m to a food source, whereas large colonies (>30-cm mound diameter) traveled up to 17 m. Baited pitfall traps performed best at detecting incipient ant colonies followed by nonbaited pitfall traps then food baits, whereas food baits performed well when trying to detect large colonies. These results were used to create an interactive model in Microsoft Excel, whereby surveillance managers can alter trap type, density, and duration parameters to estimate the probability of detecting specified or unknown *S. invicta* colony sizes. This model will support decision makers who need to balance the sampling cost and risk of failure to detect fire ant colonies.

**KEY WORDS** surveillance, food preference, foraging distance, detection, model

The ability to locate incipient populations of invasive species increases the likelihood of successful eradication attempts (Simberloff 2003). Subsequent control and eradication costs are reduced if propagules are detected before becoming established. However, associated costs in detecting small populations are expected to be high because of their inherently cryptic nature and low population densities (Mehta et al. 2007). If eradications of new invasive species are to succeed, regulatory authorities need to have highly efficient, yet cost-effective surveillance methods.

The red imported fire ant, *Solenopsis invicta* Buren, is an invasive tramp ant species whose spread is often associated with and facilitated by human activities (Forys et al. 2002, King and Tschinkel 2008). It is a member of the *Solenopsis saevissima* species-group, native to South America (Shoemaker et al. 2006), that was accidentally introduced to the southern United States in the early 1930s (Tschinkel 2006). *Solenopsis invicta* has been discovered in many other parts of the

world, e.g., Mexico (Sánchez-Peña et al. 2005), the West Indies (Davis et al. 2001), Puerto Rico (Callcott and Collins 1996), Taiwan (Chen et al. 2006), and Australia (Natrass and Vanderwoude 2001). However, there are still many more suitable habitats around the globe that are at risk from invasion (Morrison et al. 2004).

In New Zealand, nests of *S. invicta* have been detected and eradicated on three separate occasions (Corin et al. 2008). The first incursion was detected by a grounds keeper at Auckland International Airport in 2001 (Pascoe 2002). This occurrence led to the establishment of an annual National Invasive Ant Surveillance (NIAS) program which was implemented to detect new incursions of invasive ants (Peacock 2011). The NIAS program detected the next *S. invicta* incursion in 2004 at the Port of Napier (Sarty 2007) but not an unrelated incursion ≈10 km away (outside of the annual surveillance area) in 2006 (Gunawardana and Sarty 2006). Nests were destroyed and intensive surveillance of surrounding areas over a number of years did not detect any *S. invicta*.

The food preferences of *S. invicta* have been investigated by several authors (Howard and Tschinkel 1980, Glunn et al. 1981, Hooper-Büi et al. 2002). Foods tested generally include sugars in the form of sucrose, and protein or fat-based products commonly presented as a ground meat product with the oily, protein based products performing the best in starved colo-

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nies. However, in the field sampling of fire ants have included foods such as potato chips in Taiwan (Yang et al. 2009), tuna baits (Tschinkel et al. 1995), moistened dried cat food (Martin et al. 2008), and hotdogs (Kafle et al. 2008), or by trapping in pitfall traps (Stuble et al. 2009). The New Zealand eradication programs have historically used pitfall traps partially filled with ethanol and a protein and sugar food bait (Gunawardana and Sarty 2006): 1) a combination of a sweet peanut butter in soybean oil with ground meat (beef:pork, 60:40); and 2) 30% sugar water on cotton wool. Foods have been offered in 55-mm by 40-mm-diameter vials for 2 hr before collection and identification. It is appropriate that the efficacy of such detection methods be examined.

The ability of a surveillance program to detect *S. invicta* will be influenced by a variety of interacting factors such as the size of the *S. invicta* colony and the density of bait distribution. Large colonies have larger foraging areas (Tschinkel et al. 1995) and may show different foraging behavior relative to small colonies (Kafle et al. 2008), which may be related to behavioral plasticity change with relation to colony size (Sagata and Lester 2009).

As no *S. invicta* have been detected after the initial nests have been discovered and subsequently destroyed, our goal in this study was to assess and refine the current detection methodology used for *S. invicta* in New Zealand to be able to place some confidence around results indicating that no ants are present.

## Materials and Methods

*Solenopsis invicta* have been predicted to be able to survive in northern New Zealand (Ward 2009). We chose a study site and sampling time that was climatically similar to Auckland (36° 53' 47.80" S, 174° 48' 09.77" E) in northern New Zealand. Our study sites were situated in the Gainesville area, FL (29° 38' 52.74" N, 82° 19' 46.80" W). The weather in Gainesville is characterized by warm wet tropical summers, with cooler dry winters. The experiments were conducted in Florida from October to December 2008 (autumn) and March–May 2009 (spring), when weather conditions were most similar to those in Auckland during summer.

**Food Preference.** The likelihood of detecting *S. invicta* with food-baited traps depends on several factors, including the type of food source used to attract or recruit workers. Food preference experiments were conducted on naturally occurring *S. invicta* colonies found in the field at the USDA–ARS in Gainesville. Different food sources were put into 55-mm-long and 40-mm-wide circular vials. Vials were placed in random order on their sides, 10 cm from the edge and equidistant around the target colonies (large >30 cm, and small-sized 0- to 15-cm mound width) with the open ends facing the colony, similar to the cafeteria experiments of Sanders and Gordon (2003). The food sources were: 1) water on cotton wool; 2) 30% sugar water on cotton wool; 3) beef hot dog sliced into ≈1-cm-long pieces (Oscar Mayer, Madison, WS); 4)

≈1-cm<sup>3</sup> (1.54 g ± 0.08) ground meat (a beef and pork blend, 60:40); 5) 3-cm by 1-cm smear of sweet peanut butter mixed with soybean oil (20:1); and 6) 3-cm by 1-cm sweet peanut butter mixed with soybean oil and ≈1-cm<sup>3</sup> ground meat offered together.

The cafeteria experiment was conducted in both autumn ( $n = 10$  large colonies sampled twice) and in spring (with both large  $n = 9$  and small  $n = 9$  sized colonies sampled twice) to determine the best food source. The food sources were checked for bait occupancy and counts of ants were made after 60 min. Comparisons were made between the 60-min occupancy rates at food sources. Bait occupation rates were analyzed using an analysis of deviance with binomial errors by using GenStat V9 (Payne et al. 2006).

**Foraging Distance.** Food baiting and pitfall trapping were conducted at increasing distances from isolated *S. invicta* colonies of different sizes to investigate the role of nest size on foraging distance. Naturally occurring and transplanted monogyne (one functional queen per nest) and polygyne (multiple functional queens per nest) colonies of varying size were used for the trials. The social form of the colonies, either monogyne or polygyne, were assumed from previous studies in the area and confirmed at the conclusion of the study by Gp-9 analysis (Ross 1999). Mound size was measured with a measuring tape across the widest point. Three different mound sizes were tested: 24 small (0–15 cm), nine medium (15–30 cm), and 11 large (>30 cm). Mound size was used as a proxy for colony size (Vinson 1997). Different maximum foraging distances were tested for the different colonies, as the small colonies were unlikely to forage far from the nest. Three field sites were used during the trial to increase the number of foraging distance assays that could be performed. There was an uneven distribution of nest sizes between the different sites as not all sites could have nests transplanted into them. The field sites differed slightly from each other: 1) urban unkempt-low vegetation with little solid canopy cover not well irrigated; 2) urban maintained- buildings with accompanying grassed areas, likely to be well irrigated; and 3) industrial, a previous industrial site that had a cracked cement pad visible in the center of the site. There was cement, stone chips, and sand surrounding the central pad and this was covered with predominantly tall grass and cacti, into which nests or pitfall traps were dug. The grass and cacti were mown to ≈ 5-cm height before experimentation.

Ant mounds were isolated from one another by either broadcasting granular baits (Advion- indoxacarb) at the label rate (1.75 kg per ha) or mound drenches (Garden insect killer, pyrethrins and piperyonyl butoxide). Granular broadcast baits were used to eliminate or drastically reduce fire ant densities areas that historically had the polygyne social form present. Only mound drenches were applied to non-target nests in sites that historically had the monogyne social form. The last broadcast granular bait was applied a minimum of 2 wk before nests being transplanted into the area. Any subsequent nests discovered at any site were treated with the mound drench.

This contact insecticide is fast acting and quick to break down in soil (Antonious et al. 1997).

Because of the difficulty of finding small naturally-occurring nests, 20 surrogate nests of each social form were prepared from larger field-collected nests in spring. Small colonies contained either one queen (monogyne) or three functional queens (polygyne) and  $\approx 500$  workers and 1,300 brood of mixed age. These nests were placed into the field. Of the 40 nests that were transplanted, 24 (two monogyne and 22 polygyne) survived and settled on site. The large number of polygyne nests indicated by GP-9 analysis showed that assumed monogyne nests at the commencement of the trial, from which the surrogate nests were created, were actually polygyne. Large nest sizes were transplanted in autumn into the areas cleared of ants 2 wk after the last application of Advion granular bait (Dupont, Wilmington, DE) applied at the label rate. Large nests were checked for queen presence and were then transplanted whole with soil into a hole dug to correspond in size to the soil volume of the colony to be transplanted. The soil in the hole was watered with 10 liters of water 2 min before transplantation. Of the 18 nests transplanted, seven were not used as they did not settle and continued to move out of the treatment area. Three other nests failed during experimentation and were removed from analysis. The eight remaining nests moved  $<5$  m and settled. After which time these nests and three naturally occurring large nests at another site were left alone for 1 wk before experiments were conducted.

Four transects radiated from the central nest. In each trial, two of these transects were randomly allocated to one distance treatment, and the other two transects to a second distance treatment as measured from the center of the nest. For small nest mounds ( $n = 24$ ), we used distances of 0.25-, 0.5-, 1-, 1.5-, 2-, 3-, 4-, and 5-m intervals between vials. For large nests ( $n = 11$ ), we used intervals of 0.25-, 0.5-, 1-, 1.5-, 2-, 3-, 4-, 5-, 7-, 8-, 9-, 11-, 12-, 13- and 17-m intervals between vials. Medium nests ( $n = 9$ ) had the same intervals between vials as large nests, except that 0.25- or 0.5-m distances were not used. Food baits (peanut butter plus ground meat) were offered in 55-mm-long and 40-mm-diameter specimen vials. These vials were left horizontally on the soil surface for up to 2 hr at 18–25°C, or only 1 hr when the air temperature was above 25°C, after which they were collected, as is the protocol for ant surveillance in New Zealand (Stringer et al. 2010). The ant species and the number present were recorded. Food-baited vials were placed at the predetermined distances along each transect between 8:30 and 10:00 a.m. and 3:00 to 5:00 p.m., with a minimum of 5 hr between trials.

To confirm the origin of ants recruiting to food vials, ant trails were followed back to the nest where possible. In the case of ants using underground foraging tunnels, a bioassay was conducted where foraging ants in the vial were transported to the target mound and allowed to interact with the ants from the nest. Observations were made for 2 min. If any aggression was observed, from touch and run to biting, pulling and

stinging, the foragers were deemed to have come from a different colony (Suarez et al. 2002). Subsequently, that nest was located and destroyed with the mound drench; this occurred on 16 occasions. This aggression assay could only be used in areas where the monogyne social form was present, as aggressive intraspecific interactions were unlikely to occur between individuals from separate polygyne nests (Morel et al. 1990). When baits were occupied by fire ants from nontarget nests, that distance replicate was not resampled because of time constraints and the likelihood of ant boundary effects arising from the recently destroyed colony (Adams 1998).

After bait vial testing was complete, two additional transects were allocated to eight nests to test pitfall trap success in detecting *S. invicta*. Both baited:  $\approx 0.5\text{-cm}^3$  sweet peanut butter mixed with soybean oil and  $\approx 1\text{-cm}^3$  ground meat offered together unmixed in 5 ml, 70% ethanol in Teflon-coated glass test tubes (Siltech, Auckland, New Zealand) (17 mm internal diameter), and nonbaited pitfall traps (5 ml, 70% ethanol), were put out as distance pairs (i.e., if a baited pitfall trap was placed at a distance along one transect, the corresponding nonbaited trap of the pair was placed at the same distance along the other transect). Pitfall traps were left in the field for 14 d. Spring pitfall data had a bimodal distribution of fire ant detection probability, with large ant counts close to and far from the target nest. This distribution probably was made because new colonies moved into the test area after toxic baiting. As the small nest size pitfall data were collected in the spring, compared with the large and medium nest pitfall data that were collected in autumn, the detection probabilities were estimated from short-scale distances only by comparing the relative difference between small to medium and large nests at close distances and extrapolating this to larger distances. It was assumed that the close distances were unlikely to be affected by trap catch from colonies further away.

Foraging distance data from the food bait and pitfall trap studies were analyzed using a generalized linear model for the counts of ants in each trap and were fitted using a Poisson distribution with over-dispersion by using GenStat V 9. The overdispersed model allows for nonindependence on the individual ants probability of being trapped. Coarse weather data were used in the model: sunny, partly cloudy, and overcast.

**Simulation Model.** The data were modeled using a generalized linear model with binomial (presence and absence) errors. The predicted detection probabilities derived from the GLM analysis were imported into a Microsoft Excel-based interactive worksheet where four parameters could be changed to give an estimate of detection probability, assuming the detection traps used were placed out in a grid array, bound by an 80% confidence limit. To estimate the probability of detection over time and events, independence was assumed between trapping on different days by using fresh baits each time for the baited vials. The predicted probability of detection and the complement of the calculated probability of not detecting any ants over

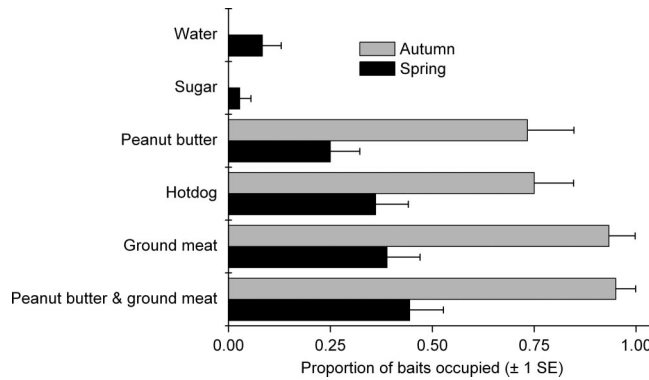


Fig. 1. Proportion of each food type occupied by large (>30-cm-diameter) *Solenopsis invicta* nests after 60 min in a cafeteria experiment in October 2008 (autumn) and the following April 2009 (spring).

the duration of the trial were combined to provide estimates of ant detection over time. The variable parameters in the model were: 1) trap type (food-bait, baited pitfall trap, or nonbaited pitfall trap); 2) nest size (small 0- to 15-cm mound diameter, medium 15–30 cm, > large 30 cm mounds, and mounds of unknown size- a mix of the three sizes); 3) duration of sampling (1–30 d per events); and 4) distance between traps (1–200 m). This model allows users to modify aspects of a surveillance regime before implementation to a specified level of detection sensitivity by altering the different parameters to estimate the detection probability for single isolated nests of different size.

**Results**

**Food Preference.** There was a large colony size difference in food occupation between the small and large-sized colonies, with the small size only occupying two of the 108 vials offered (total number of four foragers in the peanut butter-baited vials) compared with 54 of 108 vials (1,389 individuals) for the large-sized colonies in spring. As only the large colony size was assessed between autumn and spring, results are given for the large-sized colonies only. There was a significant effect of food type on ant vial occupation (deviance ratio = 93.17,  $P < 0.001$ ) and no seasonal effect on occupation rates (deviance ratio = 0.23,  $P = 0.631$ ), although there was an interaction of food type  $\times$  season (deviance ratio = 5.52,  $P < 0.001$ ). The rank occupancy rates for the different foods remained constant between the two seasons (autumn and spring), with the sweet peanut butter plus ground meat mix vials always ranked first for occupancy for both time periods (Fig. 1). The water and sugar water treatment only trapped ants in the spring (three to water and one to sugar water).

**Foraging Distance.** In total, 1,400 peanut butter plus ground meat mixed with soybean oil-baited vials were placed out over the two field seasons, with six vials lost to wildlife. Of the remaining 1,394 vials, 131 (9%) traps caught fire ants from the target nest, 18 vials trapped nontarget *S. invicta* originating from 16 nests, and 293

(21%) of vials caught other ant species. The other ant species collected in the vials were *Dorymyrmex* sp., *Pheidole* spp., *Crematogaster* spp., and *Brachymyrmex* sp. Two vials trapped both fire ants from the target nest and an additional species (*Dorymyrmex* sp.).

There were significant main effects of nest size, distance, site, and season on the occupancy rates of the baited vials (Table 1). We observed a significant interaction between distance and nest size, indicating different foraging distances for the different nest sizes with workers from small and large nests foraging up to a maximum distance of 3 and 13 m, respectively. There were foraging distance  $\times$  site and nest size  $\times$  site interactions, suggesting that foraging success differences between sites may be because of nest sizes not being evenly distributed between the different sites. There was no social form, ‘gyny’, effect on bait occupancy rates. We observed a significant ( $P < 0.001$ ) transect  $\times$  nest interaction effect indicating foraging bias along particular transects for different nests. There was a weather effect on foraging success for the small nests (Table 2), with greatest likelihood of bait occupation during overcast weather, which was hid-

Table 1. Analyses of deviance of occupancy rates for *Solenopsis invicta* at food-baited vials at different distances from the nest

Factor	Deviance			
	d.f.	Deviance	Ratio	Chi pr.
Site	2	10.23	5.12	0.006
Distance	3	85.11	28.37	<0.001
Nest size	2	79.72	39.86	<0.001
Season	1	12.00	12	<0.001
Gyny	2	4.61	2.3	0.1
Date	29	39.90	1.38	0.086
Transect	3	0.42	0.14	0.935
Weather	2	3.58	1.79	0.167
Distance $\times$ site	2	6.16	3.08	0.046
Distance $\times$ nest size	2	15.47	7.74	<0.001
Distance $\times$ season	1	0.95	0.95	0.33
Distance $\times$ gyny	2	2.68	1.34	0.262
Distance $\times$ weather	5	9.06	1.81	0.107
Transect $\times$ nest	159	277.66	1.75	<0.001
Residual	1,396	609.514		
Total	1,611	1,157.058		



**Table 2.** Analyses of deviance of occupancy rates for small sized colonies of *Solenopsis invicta* at food-baited vials

Factor	Deviance			
	d.f.	Deviance	Ratio	Chi pr.
Site	1	0.703	0.7	0.402
Distance	3	50.359	16.79	<0.001
Gyny	1	0.153	0.15	0.696
Date	15	24.063	1.6	0.064
Weather	2	6.714	3.36	0.035
Distance × site	1	6.205	6.21	0.013
Distance × gyny	1	0.002	0	0.964
Distance × weather	3	14.888	4.96	0.002
Residual	740	175.370		
Total	767	278.457		

den in the main analysis that included all nest sizes (Table 1).

During both seasons, 128 pitfall traps were placed at the same distance as in the food foraging distance trials. Spring data showed a bimodal distance catch relationship with ants trapped close to and far from the nest. It was assumed that nests or foraging workers were moving into the areas previously cleared of mounds (free territory). Converse to the food-bait data, the pitfall data did not indicate nest size as a significant factor in trapping, probably influenced by this bimodal distribution in trap catch. There was an uneven distribution of nest sizes between the different sites and this was indicated in the analysis with a significant effect of field site on trapping success ( $P < 0.001$ ) and site × distance interactions ( $P < 0.001$ ). There was a greater likelihood of trapping ants in baited pitfall traps over nonbaited pitfall traps ( $P = 0.026$ ) (Table 3), suggesting food odors attracted the ants to the pitfall traps. As for the food-bait data, orientation of the transect from the central nest influenced trapping success in the pitfall traps ( $P = 0.041$ ) (Table 3). In late autumn, a single ant was trapped in a baited pitfall trap 17 m from a large target nest. We could not verify that this ant originated from the target nest, but it is possible, as the surrounding area had been cleared of ants and it was unlikely that ant colonies would have been expanding into the treatment area at this time of the year.

**Table 3.** Accumulated analyses of deviance of trap catch of *Solenopsis invicta* trapped in pitfall traps in autumn 2008 and spring 2009

Factor	Deviance			
	d.f.	Deviance	Ratio	F pr.
Site	1	287.55	14.5	<0.001
Distance	2	263.14	6.64	0.002
Nest Size	1	34.73	1.75	0.187
Baited	1	99.6	5.02	0.026
Transect	3	166.48	2.8	0.041
Distance × site	2	713.34	17.99	<0.001
Distance × nest size	2	51.72	1.3	0.273
Distance × baited	2	29.1	0.73	0.481
Distance × transect	6	90.71	0.76	0.6
Residual	227	4,500.56		
Total	247	6,236.93		

**Simulation Model.** The simulation model demonstrated the influence of trap density and surveillance duration on the detection probability for different nest sizes. Using different traps at a density of one per meter laid out in a grid pattern to detect small nests, the probability of detection is the greatest for baited pitfall traps (0.72) followed by nonbaited pitfall traps (0.54) then food-baits (0.42) when sampled once, whereas all the other nest sizes have a probability  $>0.85$  (Fig. 2). To increase the probability of detection up to  $>0.99$  for small-sized nests when the detection traps are only spaced 1 m apart, baited pitfall traps need to be left in operation for 4 d, nonbaited traps for 6 d, and 9 d for food-baits (Fig. 3). When decreasing the trap density to one every 2 m, the detection probability for the small-sized nests is halved (Fig. 2). Once traps are placed 5 m apart, the probability of detecting a small *S. invicta* nest is quite low ( $<0.1$ ) (Fig. 4). The best trap ranking for small nest detection remained the same for different densities and duration: baited pitfall traps, nonbaited pitfall traps followed by food-baits (Figs. 2 and 3).

For all of the larger nests, the food-baits appear to be better at detecting ants at greater distances than the pitfall traps, which performed best closer to the nests (Fig. 2). There was a high probability of detecting large nests by using the different traps at 1-m spacing on one occasion (24 h for pitfall traps, 2 h for the food vials), ranked baited pitfall, nonbaited pitfall then food-bait (Fig. 2). When traps were placed 5 m apart, the ranking changed and food-baits out-performed both of the pitfall traps. See Ministry of Agriculture and Forestry, Biosecurity New Zealand (2011) for the interactive model <http://www.biosecurity.govt.nz/pests/red-imported-fire-ant>.

## Discussion

We found that food preferences were similar for the two time periods, with current food attractant baits used in New Zealand, a mix of sweet peanut butter in soybean oil and ground meat (beef and pork) being the top ranked occupied food item. Only in spring did water and sugar water baits attract ants, but not in similar numbers to those ants attracted to the protein-based foods. The mix of the sweet peanut butter in soybean oil and ground meat probably offered *S. invicta* colonies a good combination of carbohydrates, oils, and protein food resources required for colony growth and maintenance (Porter 1989). This combination of food types delivered in one vial may alleviate some of the problems associated with different seasonal or spatial preferences of the ants, as observed elsewhere (Glunn et al. 1981). It should be taken into account that small ant colonies may not be good competitors for food sources (Sagata and Lester 2007), probably because of a low forager number (McGlynn 2000). As such, low-quality resources that do not interest the strongest colony and are left free for a less competitive colony such as a small fire ant nest may still be of benefit for surveillance (Palmer 2003).

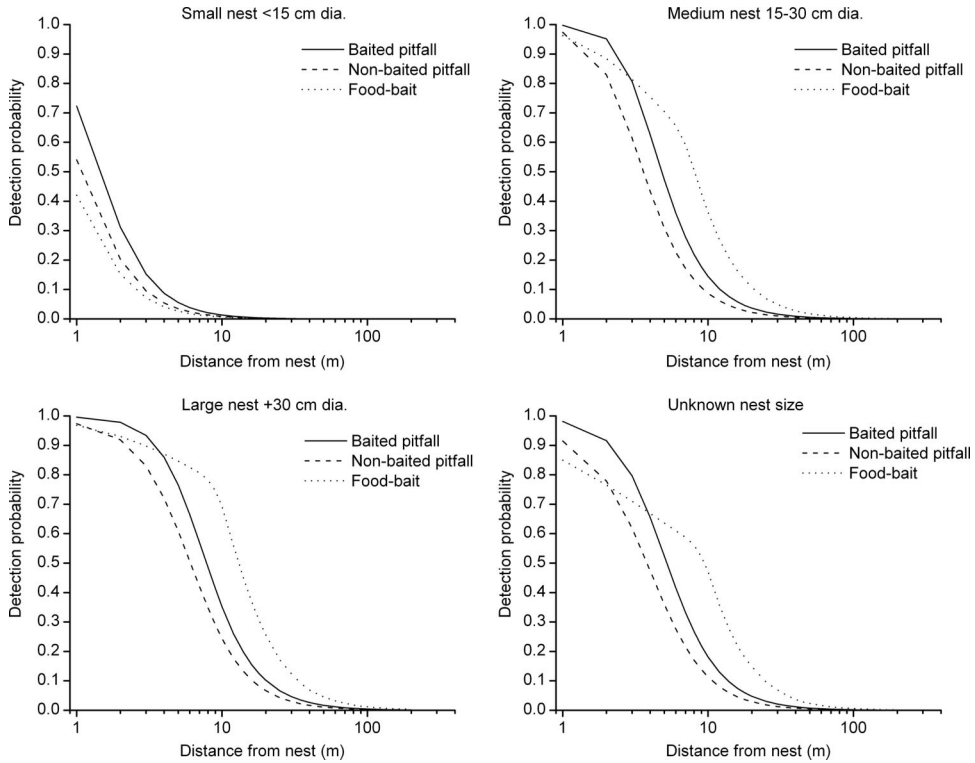


Fig. 2. The probability of detecting foragers from different sized *Solenopsis invicta* nests by placing different detection traps at different densities in a grid layout during a single surveillance event, 1–2 h for food-baits and 24 h for pitfall traps.

Small-sized colonies did not forage far from the nest, resulting in low-bait occupation even when the food source was only 10 cm away from the nest in the food preference trials. There appeared to be a weather effect on foraging success with the greatest likelihood of bait occupation occurring during over-cast weather. This pattern does make sense as small-

sized nests can least afford losing foragers to desiccation.

The small-sized colonies were transplanted into the experimental plots, similar to what could be expected from an incursion of a small nest arriving into a new area. Although care was taken to allow time (minimum of 1 wk) for nests to establish into one spot followed by up to 5 wk of trials, there still may have been limited foraging because of their recent transplantation, resulting in their maximum foraging distance of 3 m. Although, small nests may obtain sufficient food resources for colony maintenance and growth from underground foraging (Tennant and Porter 1991). Furthermore, ants may behave differently when small in size to their expected foraging behavior when the nest is mature (Sagata and Lester 2000). Our results are not encouraging for quarantine authorities who ideally would want to find small nests soon after their arrival in a new range before expansion.

Ants from larger colonies foraged to baited vials up to 13 m away in 2 hr. This occurred on a single occasion. The 2-hr time frame may have been insufficient for ants to discover the food, even though they may have the potential to forage further (Martin and Vinson 2008). The pitfall trap data suggest that ants from large nests may forage up to 17 m away. Only one individual was trapped at this distance in a baited pitfall trap and it could not be determined that the ant

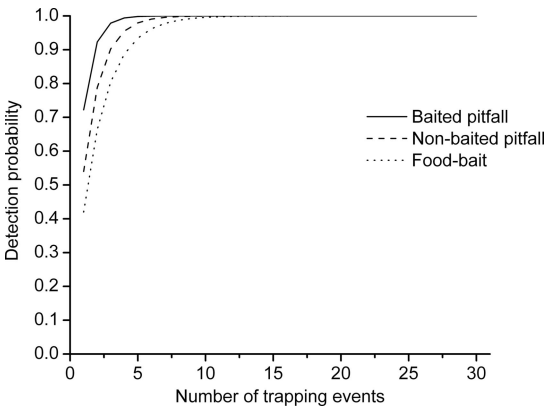


Fig. 3. The probability of detecting small *Solenopsis invicta* colonies by increasing the number of trapping events when the detection trap is only 1 m apart placed in a grid. One event consists of 1–2 h for food-baits and 24 h for pitfall traps.

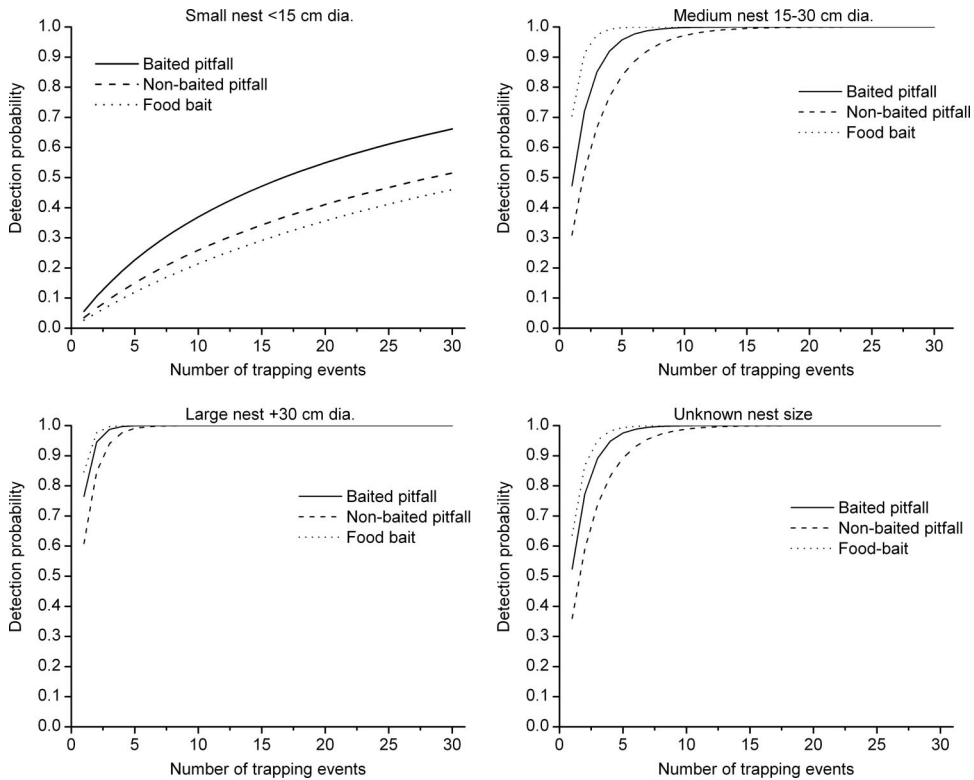


Fig. 4. The probability of detecting foragers when the detection traps are placed 5 m apart in a grid layout for different *Solenopsis invicta* nests by using different trapping techniques for multiple trapping events (increasing duration); one event consists of 1–2 h for food-baits and 24 h for pitfall traps.

originated from the target nest. Assuming the individual ant originated from a large transplanted nest that would have been in place for 26 d by the end of the trial, the maximum foraging distance potential of ants from large nests may not have been determined. Based on laboratory work of Martin and Vinson (2008), the maximum foraging distance of workers from a large isolated *S. invicta* nest is likely to be between 16 and 32 m. There may be foraging direction preferences from the nest as indicated by the nest  $\times$  transect interaction, indicative of foraging biases toward particular transects. This preference could be a result of asymmetrical underground tunnels that radiate out from the central nest, creating uneven forager distributions (Tschinkel 2006). As there was an uneven distribution of nest sizes, site effects were largely biased by the nest size data, thus we cannot determine the effect that site had on the foraging success of different sized nests.

We found that the likelihood of detecting isolated nests of *S. invicta* was related to the size of the colony, trap type, the density of traps, and the duration of the trapping. We were able to produce estimates of isolated ant colony detection dependent on the above variables by using an interactive Microsoft Excel-based model that is easy to manipulate. This tool will allow surveillance and incursion managers to estimate the likely cost and benefit in detecting *S. invicta* at

different growth stages by using different detection techniques at varying densities for any number of days. Each tool's success depends on the length of time it is operated and the density of traps per unit area (James 2004). We found that the likelihood of detection increases with an increased number of trapping events, and that as the density of the traps per unit area increased (shorter distance between traps), the likelihood of detecting fire ants increased.

It appears that pitfall traps are the best method for detecting small fire ant nests. Pitfall traps remove the need for ants to be competitive at food baits used for surveillance; they allow capture through random walking or attraction in the case of baited pitfall traps (Stanley et al. 2008). Apart from visual surveys for large fire ant mounds, food baits appear to be the best of the traps tested for detecting fire ants. Although depending on the distance between traps, a different method may be more efficient where repeated sampling is required.

Detecting incipient *S. invicta* colonies is feasible with food-baits and pitfall traps, although it is likely to be expensive because of the density of traps required. A similar number of traps could be used over a larger area, with the aim of detecting large colonies by increasing the area of surveillance, followed by a more intensive eradication program when detected. With our model, surveillance managers can estimate the cost and probability of fire ant detection using three

surveillance methods: food-baits and baited and non-baited pitfall traps. Furthermore, eradication managers can assess the progress and success of an eradication attempt with the number of ant detections through time. As the foraging distance values are further refined, model estimates may vary.

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