RESEARCH

Urbana House Ants 2.0: Revisiting M. R. Smith's 1926 Survey of House-Infesting Ants in Central Illinois After 87 Years

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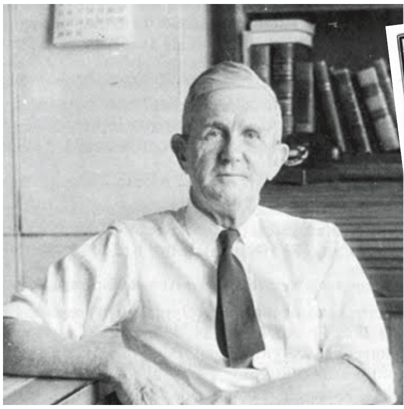
ABSTRACT: Quantifying the long-term ecological impacts of urbanization requires high-quality historical records and similar re-surveys over time. We replicated a survey conducted in 1924-1926 by Marion R. Smith of house-infesting ants in Urbana, Illinois, to examine how the house-infesting ant fauna and its control measures have changed over 87 years. We complemented residential sampling with pitfall, visual, and leaf litter surveys in the surrounding urban neighborhood and in three nearby forest fragments to characterize the ant fauna from which the house-infesting ants are drawn. In 1924-26, 12 ant species were collected in houses; the four most common were *Tapinoma sessile* (Say), *Lasius alienus* (Förster), *Camponotus pennsylvanicus* (DeGeer) and *Solenopsis molesta* (Say). In 2012-2013, we found eight species in houses, the four most common of which were *Tapinoma sessile*, *Tetramorium caespitum* (Linnaeus), *C. pennsylvanicus*, and *C. nearcticus* (Emery). Ant control measures have also changed dramatically, with the average amount spent per household in 2012-2013 nearly doubling (adjusted for inflation). We also found that the residential urban site had similar estimated species richness to one of the nearby forest remnants, demonstrating that the diversity of some arthropod groups can remain high in forested urban environments. Moreover, each site had a unique community of species, reinforcing the value of both small forest fragments and urban sites for supporting biodiversity. Our survey revealed changes in urban and house-infesting ant communities since the 1920s, but, in view of the global abundance of invasive ant species and the extensive changes in land use patterns in central Illinois, the relative similarity of the ant communities separated in time by 87 years was unexpected.

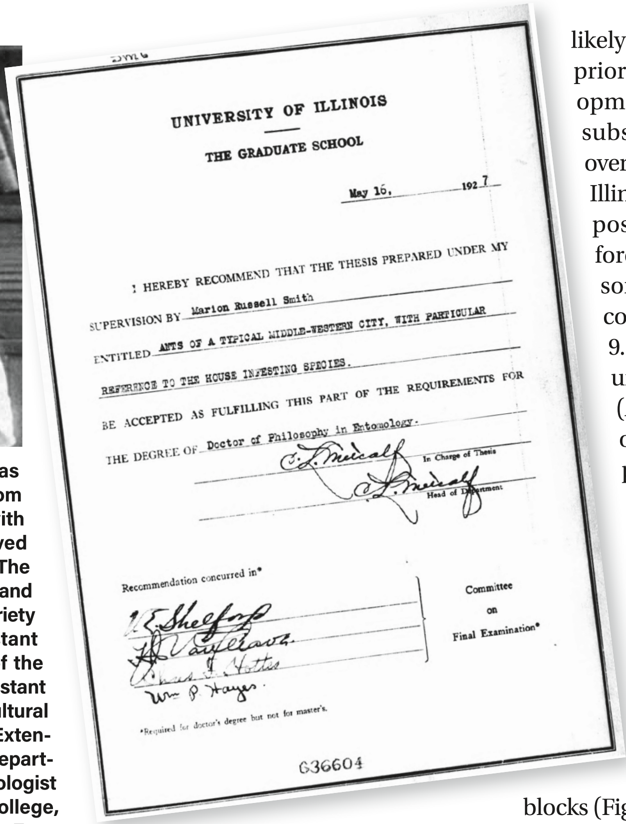
KEYWORDS: Ants, biodiversity, urbanization, pesticide, citizen science

Urbanization can lead to dramatic changes in the composition of insect communities (Raupp et al. 2010). Unraveling the long-term consequences of anthropogenic change for insect populations and communities requires access to detailed historical records to reconstruct patterns of diversity (Parmesan et al. 1999, Roy and Sparks 2000, Suarez and Tsutsui 2004, Kleijn and Raimakers 2008, Chen et al. 2009). For example, careful documentation of floral visitors by Charles Robertson in the late nineteenth century (1888–1891) allowed Burkle et al. (2013) to examine pollination networks around Carlinville, Illinois, and determine that approximately 50% of bee species have been lost over the last 120 years, resulting in a reduction in pollination network structure and function. This research would not have been possible, nor would the scope of the decline and its consequences been so apparent, without the meticulous, high-quality data recorded by Robertson (1927).

Ant species (Formicidae) are frequently the focus of research on biodiversity and conservation in relation to urbanization and ecosystem disturbance (Andersen 1997, Agosti et al. 2000, Lach et al. 2010). Ants are ideal model organisms for such studies because they are dominant elements of many communities and can play key roles relating to ecosystem services and function (Folgarait 1998, Lobry de Bruyn 1999, Ellison et al. 2012, Del Toro et al. 2012). Many species are also sensitive to environmental change (Hoffmann and Andersen 2003). Resources to aid in the identification of ant species are widely available, particularly in urban environments where they are often considered pests, and ant communities can be easily sampled in relatively short periods of time (Agosti et al. 2000). These attributes make ants an attractive group for understanding the impact of long-term land use modification on diversity, composition, behavior, abundance, and community structure (Lach et al. 2010).

Marion R. Smith was a United States Department of Agriculture Agricultural Research Service entomologist who conducted research on ants for nearly 50 years (Fig. 1). After receiving a master's degree from The Ohio State University, he entered the doctoral program in the Department of Entomology at the University of Illinois at Urbana-Champaign. For his doctoral research, he examined the taxonomy and ecology of urban ants in Urbana, Illinois, during the period 1924-1926 (Smith 1927)





UNIVERSITY OF ILLINOIS

THE GRADUATE SCHOOL

May 16, 1927

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Marion Russell Smith ENTITLED ANTS OF A TYPICAL MIDDLE-WESTERN CITY, WITH PARTICULAR REFERENCE TO THE HOUSE INFESTING SPECIES. BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF Doctor of Philosophy in Entomology.

In Charge of Thesis

Head of Department

Recommendation concurred in*

Committee on Final Examination*

*Required for doctor's degree but not for master's.

636604

Fig. 1. (a) Marion R. Smith (1894-1981) was born in South Carolina and graduated from Clemson College in General Agronomy with a minor in Entomology in 1915. He received a Master of Science in Entomology from The Ohio State University in 1917. Between 1917 and 1926, he worked as an entomologist in a variety of capacities, including "Scientific Assistant in the Truck Crop Insect Investigations of the Bureau of Entomology" for the USDA, Assistant Entomologist to the South Carolina Agricultural Experiment Station at Clemson College, Extension Entomologist, North Carolina State Department of Agriculture, and Assistant Entomologist to the Mississippi Plant Board at A&M College, Mississippi. Dr. Smith received his Ph.D. in Entomology from the University of Illinois at Urbana-Champaign, where he was enrolled and worked as a graduate assistant from 1924-1926. Image reproduced from Smith (1983). (b) M. R. Smith's dissertation was supervised by Clell L. Metcalf (Head of Entomology from 1921-1947) and his committee included Victor E. Shelford (Professor of Zoology at Illinois and first President of the Ecological Society of America), H. J. van Cleave (Professor of Zoology), William P. Hayes (Head of Entomology, 1947-1955), and Frederick C. Hottes (visiting scientist at the Illinois Natural History Survey).

(Fig. 1). Smith's dissertation included a three-year study that utilized what would now be called citizen scientists to determine the identity and relative abundance of house-infesting ants. Additionally, he documented the methods used by Urbana residents to control ant infestations and estimated the amount of money expended on ant control city-wide.

Smith's thesis provides a unique opportunity to capitalize on historical data and allow new research to address questions relating to urban ant ecology based on surveys conducted several decades apart. Thus, 87 years after Smith's house-infesting ant survey was conducted, we replicated these survey methods in 2012-2013 with four goals in mind. We wanted to compare the diversity and incidence of ants in houses; compare the identity and cost of methods to control ants; quantify the relative abundance and diversity of ants in urban and natural habitats; and, finally, engage citizen scientists in urban entomology.

Materials and Methods

Study Sites

While historically predominantly prairie, Champaign County, Illinois, also contained a 25.9 km² mixed hardwood forest called "the Big Grove" east and north of where Urbana was settled in 1822 (Stewart 1918, Boggess and Bailey 1964). We identified four study sites that included forest remnants from within or along the edge of the Big Grove (Fig. 2) and likely had similar ant communities prior to their isolation and development. Illinois has experienced substantial land use conversion over the last two centuries. In 1820, Illinois was estimated to be composed of 58.95% prairie, 37.67% forest, and 3.38% water (Anderson 1970). By 1980, Illinois was composed of 80.36% agriculture, 9.73% forest, 5.27% water, 4.64% urban area, and >0.01% prairie (Anderson 1977). Today, 95.1% of the land cover in Champaign County is agricultural land and only 1% is forested (www.agr.state.il.us/gis/stats/landcover/counties/county.php?CNTY=Champaign).

Our residential sampling took place at precisely the same addresses sampled by Smith in 1924-1926. The two perpendicular transects encompass a total of 40 city blocks (Fig. 2). To compare species composition between forested sites with different levels of disturbance, the relative abundance and diversity of ants along this urban transect were compared to the same parameters in natural forested areas. We sampled the ant communities of natural forested areas of similar size, including Busey Woods Nature Preserve, Brownfield Woods, and Trelease Woods, all in Champaign County, IL.

Busey Woods is classified as a disturbed deciduous upland forest and is 239,000 m² in size. This site incorporates a nature preserve with public trails and is a transitional forest that was previously

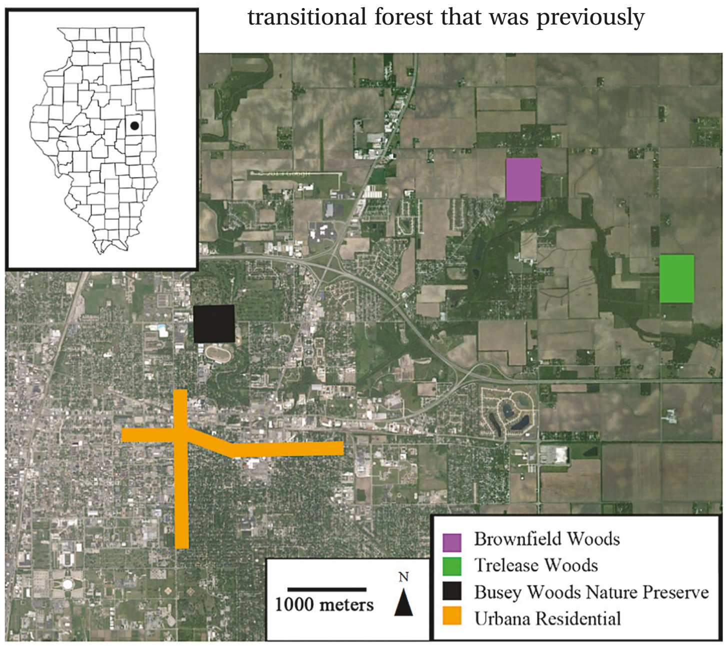


Fig. 2. Locations of the four study sites in relation to each other within Urbana, Illinois. Inset map: approximate location of study sites within Illinois.

a dumping ground for refuse, including household appliances and other debris, until a restoration effort was initiated in the 1970s (Urbana Park District 2011). Brownfield Woods is classified as an undisturbed deciduous upland forest and is 261,000 m^2 in size. It is primarily a mature oak/ash/maple forest with a high, closed canopy and fairly open understory (Buck 2012). Brownfield Woods is surrounded primarily by agricultural land, with houses abutting the north boundary and part of the east side (Buck 2012). Trelease Woods is also classified as an undisturbed deciduous upland forest and is 288,000 m^2 in size. It is primarily a mature oak/ash/maple forest with a high, closed canopy and moderately dense understory. Agricultural land surrounds the woods, with the exception of a prairie restoration (that has been in place for ca. 75 years) on the south side (Buck 2012).

Ant Sampling

Repeat of M. R. Smith's Indoor Surveys. In the summers of 2012 and 2013, with several minor modifications, we replicated M. R. Smith's 1920s methodology to estimate the identity and relative occurrence of house-infesting ants. Prior to 1 May 2012, we contacted 350 residents in the study area and asked them to participate in the Urbana Ant Survey by going door-to-door for in-person conversations or by sending them letters. In addition, whenever permission was granted, we sampled the outdoor ant fauna of their property. Residents were asked in 2012 if a pitfall trap could be placed outdoors in their yard, and in 2013, residents were asked if an outdoor hand sample and leaf litter sample could be collected. This additional sampling was used to characterize the urban ant fauna for comparison with the subset of ants found in houses as well as with the forested sites (see *Urban and Forest Sampling* below). As an incentive to increase participation during the summer of 2013, residents who participated were entered in a raffle for an iPad 2. In 2013, we included five homes that were just outside Smith's original sample area.

As Smith (1927) did, albeit without using the term, we asked Urbana residents to become "citizen scientists" and look for ants present indoors, collect ant/s when they were detected, and fill out a questionnaire every time an ant or ants were spotted indoors. Our methods diverged from his in order to take into consideration modern conveniences and sensitivities. Whereas Smith distributed vials with a killing agent, we developed an alternative approach that obviated the use of toxic material and preserved ant specimens in better condition to facilitate identification. Indoor sampling took place from 1 May to 31 July in 2012 and 1 April to 31 July in 2013. Participants were given a packet containing instructions, one addressed and stamped envelope, a small plastic bag with four pieces of clear tape (6.5 cm x 2 cm), and four collection forms. The instructions described how to collect ants by pressing the adhesive side of a piece of tape onto the ants and then onto the collection form. Afterwards, the collection form (with ants attached) was to be placed in the freezer for preservation until it could be mailed back to us.

Collection forms contained the same questions asked by Smith (1926):

1) Date ant(s) found.
2) How many ants were present? (1-10, 10-150, 150+)
3) What is the food preferred by the ant(s), if observed?
4) Where is the location of the nest, if known?
5) Was any control method used? (Yes/No)
6) What did the control method cost?
7) What control was used (brand and type), and how frequently was it applied?
8) Was the pest control successful? (Yes: 67% or more decline in ants; somewhat: 33-66% decline; no: less than 33% decline)
9) Your name and address, and
10) Any other relevant information.

Urban and Forest Sampling. To survey a disturbance gradient, we compared the composition of the community of house-infesting ants with the ant communities present in the surrounding urban landscape and in three nearby forest patches using pitfall traps (2012), Winkler leaf litter sampling (2013), and visual sampling (2013). In the forested sites, we created five parallel transects 500 m long and at least 50 m apart from the forest edges and each other. Residential study sites were selected by contacting residents (as described above) and obtaining permission to sample ants on their property. Outdoor sampling was conducted contemporaneously with resident sampling indoors.

Pitfall traps consisted of 50 ml plastic centrifuge tubes filled with 12.5 ml water mixed with 10% sodium chloride and one drop of dish detergent (to preserve specimens and break surface tension). Pitfall traps were left open for 72 hours. In residential Urbana, two pitfall traps were placed per house. Pitfall traps were placed >1 m from any wall of the residence and haphazardly located in the front yard of the residence. At

Table 1. Ant species detected in houses by Smith in 1926 and in the current study and the percentage of residences where they were collected. Undetermined species indicates specimen noted as present, but physical specimen not collected.

Species	1926	2012-2013
Tapinoma sessile	15%	27.3%
Lasius alienus	14%	
Camponotus pennsylvanicus	9%	15.6%
Tetramorium caespitum		14.3%
Solenopsis molesta	9%	
Camponotus nearcticus		10.4%
Undetermined species	6%	2.6%
Formica pallidefulva	2%	2.6%
Formica subsericea	2%	
Crematogaster cerasi		1.3%
Formica argentea	1.2%	
Monomorium pharaonis	0.7%	
Camponotus caryae	0.7%	
Crematogaster lineolata	0.5%	
Camponotus castaneus		1.3%
Camponotus americanus		1.3%
Aphaenogaster fulva	0.2%	

Fig. 3. Select commercial products used for ant control in residences in 1926.

the three forest sites, 60 traps per study site were set out along five transects, with an inter-trap distance of 50 m. At Trelease Woods, a second set of traps was placed one week after the first round of sampling because high raccoon activity disturbed >50% of the traps. Visual sampling consisted of collecting ants from the front yard of 77 residences, including from trees, flower pots, garbage cans, lawns, and under stones. Forest transects were visually inspected for ants within and under decaying logs, on tree trunks and the forest floor, and within the shrub layer on vegetation. Winkler leaf litter extractions were used to sample small ants and other invertebrates from soil, twigs, debris, and leaves (Agosti et al. 2000). Five leaf litter samples consisting of 1 L each were collected per site and extracted for 48 hours. In urban sites, litter from 16 houses was combined to create a 1 L sample.

All specimens were sorted in the laboratory using a Leica S6E stereomicroscope and were preserved in 95% ethanol or point-mounted. Ants were identified to genus following Fisher and Cover (2007) and identified to species following Ellison et al. (2012) and AntWeb (2013), and by comparing individuals to specimens from the Illinois Natural History Survey insect collection. Voucher specimens of each species are deposited at the Illinois Natural History Survey insect collection.

Statistical Analysis

We produced sample-based species accumulation curves (Gotelli and Colwell 2001) using EstimateS (version 9.10 for Windows) (Colwell 2013) to estimate the completeness of sampling and the species richness at each site from pitfall data (Colwell and Coddington 1994). Incidence data were randomized 100 times without replacement (Colwell and Coddington 1994) and extrapolated to 80 samples. We calculated 84% confidence intervals to represent a p-value of 0.05 (MacGregor-Fors and Payton 2013). We also calculated similarity indices to compare ant community composition across the different sites and sampling methods (Magurran 2004, Chao et al. 2000).

Results

House-Infesting Species

In 1926, when Smith recruited 414 residents to look for and collect indoor ants from mid-June to late July, 53% reported ants in their house. His survey yielded 12 species and the four most common (i.e., found in 47% of homes that reported ants) were (in descending order of abundance) *Tapinoma sessile* (Say), *Lasius alienus* (Förster), *Camponotus pennsylvanicus* (DeGeer), and *Solenopsis molesta* (Say) (Table 1).

Of the 350 residents we contacted in 2012-2013, 77 participated by returning questionnaires. In 2012, 30 respondents submitted 54 ant samples for identification; and in 2013, 47 households submitted 63 samples. Across both years, 36% of participants (28 houses) reported no ant activity, while 64% (49 houses) collected and submitted at least one ant specimen. A single species was detected in 78% of residences (14 houses) and two species were detected in 22% of residences (11 houses). The eight species reported from residences in 2012-2013 were (in descending order of abundance) *Tapinoma sessile* (Say), *Camponotus pennsylvanicus* (DeGeer), *Tetramorium caespitum* (Linnaeus), *Camponotus nearcticus* (Emery), *Formica pallidefulva* (Latreille), *Crematogaster cerasi* (Fitch), *Camponotus castaneus* (Latreille), and *Camponotus americanus* (Mayr) (Table 1). The four most common species from 2012-2013 were *T. sessile*, detected in 27.3% of all residences, *C. pennsylvanicus*, detected in 15.6% of all residences, *T. caespitum*, detected in 14.3% of all residences, and *C. nearcticus*, detected in 10.4% of all residences.

Control Methods and Economic Impact

Residents used a diversity of products for ant control in 1926, several of which contained similar active ingredients, including oil, arsenic, and pyrethrum (Table 2A, Fig. 3). The most effective control method as reported by homeowners in 1926 was Hoodoo™ paper (Smith 1927). This product, comprising strips of paper impregnated with arsenic, was placed under legs of tables to keep ants from climbing upward. Smith (1927) noted that several control products remained effective for several days or a few weeks before needing replacement (Smith 1927). From 2012-2013, 29.9% of all residents reported using some method to control ants (Table 2B). Most respondents noted their control method(s) worked successfully and reported a >67% decline in ants. The three methods reported to be the most effective were vacuuming or cleaning, Terro® Liquid Ant Bait, and Raid® Ant and Roach Killer.

In 1926, Smith calculated that residents spent between \$0-\$3.80 per block (between \$0-\$50.14 when adjusted for inflation) with an average of \$0.48 (\$6.33 when adjusted for inflation) per household. Smith (1926) wrote that \$0.48 was inadequate for controlling ants in one residence and suggested \$1.00 (\$13.19 adjusted for inflation) would more likely ensure adequate control of ants per residence. In 2012-2013,

Table 2A. Properties and physical nature of control methods used in 1926. Results recorded from citizen response regarding effectiveness. Modified and reproduced from Smith (1927).

Control method	Physical nature	Active ingredient	Mode of action	Satisfactory results	Unsatisfactory results
Hoodoo Paper	Paper	Bichloride of mercury	Repellent	20	1
Swat-the-Fly	Liquid	Oil, unknown constituents	Contact and repellent	8	1
Flit	Liquid	Oil, unknown constituents	Contact and repellent	1	0
Fly-o-San	Liquid	Oil, unknown constituents	Contact and repellent	1	0
Bullock's Ant Exterminator	Liquid	Arsenic 0.016%	Stomach poison	1	1
Kellogg's Ant Paste	Paste	Arsenic 8-9%	Stomach poison	1	0
Fly Tox	Liquid	Pyrethrum	Contact and repellent	4	1
Pyrethrum	Powder	Pyrethrum	Contact and repellent	0	1
El Vampiro	Powder	Pyrethrum, sodium fluoride	Contact and repellent	5	1
Black Flag	Powder	Pyrethrum, sodium fluoride	Contact and repellent	3	0
Peterman's Ant Food	Powder	68% sodium fluoride, 2% sodium silicofluoride	Stomach poison	3	3
Sodium Fluoride	Powder	Sodium fluoride	Repellent and stomach poison	0	1
Borax	Powder	Sodium tetraborate decahydrate	Repellent and stomach poison	7	7
Cenol	Powder		Contact and repellent	2	1
Kerosene	Liquid		Contact and repellent	6	0
Red Pepper	Powder	none	Repellent	1	1
Peppermint Leaves	Leaves	none	Repellent	0	1

Table 2B. Properties and physical nature of control methods used in 2012-2013. Results recorded from citizen response regarding effectiveness.

Control method	Physical nature	Active ingredient	Mode of action	>67% decline in ants	33-66% decline in ants	<33% decline in ants	Price
Vacuum / Towel / Sweeping	Mechanical	None	Physical removal	6	0	2	Varies (Estimate $5)
Terro® Liquid Ant Bait	Gel bait	Sodium tetraborate decahydrate 5.4%	Desiccation, stomach poison	5	0	0	$4.98 / 3 baits
Raid® Ant and Roach Killer	Aerosol	Permethrin (pyrethroid), Pyrethrum, propane	Neurotoxin	4	0	0	$3.98 / 17 oz
Ortho® Home Defense MAX® Perimeter & Indoor Insect Killer	Aerosol	.05% Bifenthrin .0125% Zeta-Cypermethrin	Nervous system	2	1	1	$12.95 / 1 gallon
Terminix® Pest Control	Aerosol	PT-22IL - a-cyhalothrin, PT-P.I. Pyrethrum	Nervous system	1	0	0	? (Estimate $50)
DuPont™ Advion® Cockroach Bait Arena	Gel bait	Indoxacarb	Nervous system, paralysis	1	0	0	$13.63 / 10 baits
Hot Shot® Ultra Liquid Ant Bait	Gel bait	Dinotefuran (Neonicotinoid)	Nervous system	1	0	0	$4.97 / 4 baits
Pest Control Company	?	?	?	1	0	0	? (Estimate $50)
Orkin® Pest Control	?	?	?	0	1	0	$75 / 2 months
Diatomaceous earth	Powder	Silicon dioxide	Desiccation	0	0	1	$9 / 64 oz
						Average	$12.42

residents spent between $0-$75 (Table 2B), with an average of $12.42 per household.

Abundance and Diversity of Ants in Urban and Natural Sites

From urban and natural sites, we collected a total of 10,573 ant workers from 22 genera and 43 species, based on 187 pitfall traps, 20 visual transects, and 20 leaf litter samples across all sites. There were some differences in the ants detected in Urbana between the 1920s and our surveys (Table 3). Notably, our surveys detected more leaf litter species (e.g. *Amblyopone pallipes, Brachymyrmex depilis, Hypoponera opacior, Temnothorax longispinosus*) as a result of the Winkler sampling. A few species conspicuous in M. R. Smith's surveys were not detected in our

Table 3. List of ant species for Urbana, Illinois, reported by M. R. Smith in 1924-26 and detected in the current study by any of the employed methods. Two additional ants detected by Smith, *Linepithema iniquum* (Mayr) and *Tetramorium guineense* (Fabricius) are not included in the table as they were found only in University of Illinois greenhouses and were not established outdoors (Smith 1926). Names reflect current nomenclature. For example, *Formica pallidefulva* was reported as *F. nitidiventris* and *F. schaufussi* by Smith (1926) but were synonymized by Trager et al. (2007), and *Polyergus breviceps* in Illinois is now recognized as *P. montivagus* (Trager 2013).

Species	1924-1926	2012-2013
Stigmatomma pallipes (Haldeman)		x
Aphaenogaster aquia (Buckley)	x	
Aphaenogaster carolinensis Wheeler		x
Aphaenogaster fulva Roger	x	x
Aphaenogaster mariae Forel	x	x
Aphaenogaster picea (Buckley)	x	
Aphaenogaster rudis Enzmann		x
Aphaenogaster tennesseensis Mayr	x	
Brachymyrmex depilis (Emery)		x
Camponotus americanus Mayr	x	x
Camponotus caryae (Fitch)	x	
Camponotus castaneus (Latreille)	x	x
Camponotus chromaiodes Bolton	x	x
Camponotus discolor (Buckley)	x	x
Camponotus herculeanus (Linnaeus)		x
Camponotus mississippiensis (Smith)	x	
Camponotus nearcticus Emery	x	x
Camponotus pennsylvanicus (DeGeer)	x	x
Camponotus subbarbatus Emery	x	x
Crematogaster cerasi (Fitch)	x	x
Crematogaster lineolata (Say)	x	
Formica argentea Wheeler	x	
Formica neogagates Viereck	x	
Formica pallidefulva Latreille	x	x
Formica rubicunda Emery	x	
Formica subintegra Wheeler	x	
Formica subsericea Say	x	x
Hypoponera opacior (Forel)		x
Lasius alienus (Förster)	x	x
Lasius claviger (Roger)	x	x
Lasius neoniger Emery	x	x
Lasius flavus (Fabricius)	x	
Lasius interjectus Mayr	x	
Lasius latipes (Walsh)	x	
Lasius nearcticus Wheeler	x	x
Lasius umbratus (Nylander)		x
Monomorium minimum (Buckley)	x	x
Monomorium pharaonis (Linnaeus)	x	
Myrmecina americana Emery	x	x
Myrmica sp.	x	
Myrmica nr. *evanida* Francoeur		x
Myrmica detritinodis Emery		x
Myrmica pinetorum Wheeler		x
Myrmica punctiventris Roger		x
Myrmica spatulata Smith		x
Nylanderia parvula (Mayr)	x	x
Pheidole bicarinata Mayr	x	
Pheidole pilifera (Roger)	x	x
Polyergus montivagus Wheeler	x	x
Ponera pennsylvanica Buckley	x	x
Prenolepis imparis (Say)	x	x
Solenopsis molesta (Say)	x	x
Stenamma brevicorne (Wayr)	x	x
Strumigenys pergandei Emery	x	
Strumigenys pulchella Emery	x	x
Tapinoma sessile (Say)	x	x
Temnothorax curvispinosus (Mayr)	x	x
Temnothorax longispinosus (Roger)		x
Temnothorax schaumii (Roger)	x	x
Tetramorium caespitum (Linnaeus)	x	x
TOTAL NUMBER OF SPECIES	47	43

surveys, including *Crematogaster lineolata* and a few species of *Formica* and *Lasius*. However, some of these differences likely stem from changes in taxonomy and resources for identification.

The most common species detected in visual surveys and pitfall samples was *Camponotus pennsylvanicus* (DeGeer) (Table 3, Table 4). *C. pennsylvanicus* was detected at similar frequencies at forested (~50%) and residential (53%) sites (Table 5). In contrast, *T. sessile* (the odorous house ant) was relatively abundant at the two disturbed sites (63% at Busey Woods and 67% at residential Urbana), but infrequently collected in the undisturbed sites by pitfall traps (never at Brownfield Woods and 6% at Trelease Woods) (Table 5). In leaf litter extractions, *Temnothorax curvispinosus* was the most common species, found in 100% of the samples (Mayr) (Table 4).

Table 4. Relative abundances, based on percentage of samples in which a species was captured, of most commonly collected ants by sampling method across all sites in 2012-2013.

Rank	Pitfall trap	
1	*Camponotus pennsylvanicus*	49.2%
2	*Tapinoma sessile*	40.1%
3	*Aphaenogaster rudis*	32.6%
4	*Tetramorium caespitum*	28.3%
5	*Lasius alienus*	17.1%
Rank	**Leaf litter sample**	
1	*Temnothorax curvispinosus*	100%
2	*Ponera pennsylvanica*	80%
3	*Myrmica pinetorum*	70%
4	*Lasius alienus*	60%
5	*Myrmica punctiventris*	55%
Rank	**Hand sample**	
1	*Camponotus pennsylvanicus*	100%
2	*Lasius alienus*	85%
3	*Aphaenogaster fulva*	75%
4	*Aphaenogaster rudis*	70%
5	*Myrmica detritinodis*	70%

Four ant species were more commonly detected in the two undisturbed forest sites (*Myrmica pinetorum* Wheeler, *Myrmica punctiventris* Roger, *Stenamma brevicorne* (Wayr), and the seed-harvester ant *Aphaenogaster rudis* Enzmann (Table 5). *A. rudis* was found in more than 50% of undisturbed forest pitfall traps, 33% in traps at disturbed Busey Woods, and only 9% in traps at residential Urbana.

Several species were more abundant in disturbed sites, including *Brachymyrmex depilis* (Emery), *Camponotus castaneus* (Latreille), *Camponotus discolor* (Buckley), *Nylanderia parvula* (Mayr), *Solenopsis molesta* (Say), and *Tetramorium caespitum* (Linnaeus). The introduced *T. caespitum* was found in 69.1% of the traps in residential Urbana and 13.3% of the traps in the disturbed Busey Woods, but it was not detected in Brownfield or Trelease Woods.

Species Richness and Diversity Estimates

Species accumulation curves estimated the highest species richness at disturbed Busey Woods (Fig. 4). The relatively undisturbed Trelease and Brownfield Woods had the fewest species detected by pitfall traps. The species estimates did not reach an asymptote at any site, indicating additional species are likely to be found with more sampling. Species richness estimates for disturbed Busey Woods, residential Urbana, and undisturbed Brownfield Woods were all different from one another (Fig. 4). However, species richness for Trelease Woods was not different from estimated species richness in residential Urbana and Brownfield Woods (Fig. 4). The two least disturbed sites (Brownfield and Trelease Woods) had the greatest number of shared species (19 species, Sorenson's Similarity index = 0.9) in pitfall samples, whereas with leaf litter sampling Busey Woods and Trelease had the highest numbers of shared species (15 species, Sorenson's Similarity index = 0.9).

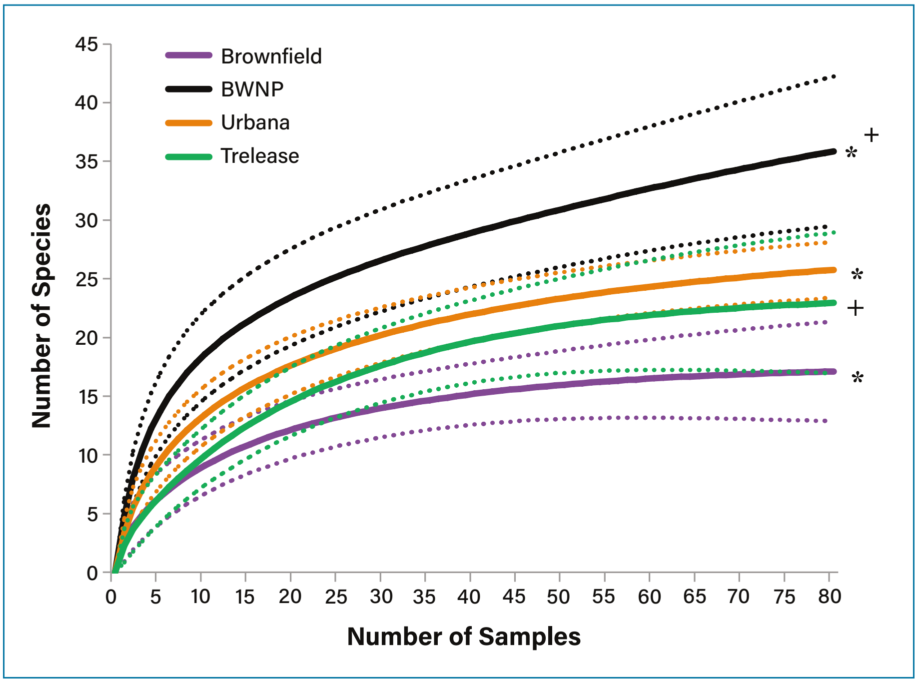


Fig. 4. Number of species extrapolated from pitfall traps at each site in 2012 (with 84% confidence intervals shown as dotted lines). Sites plotted with similar symbols had significantly different estimated number of species (p=0.05).

Discussion

The study of urban ant ecology has a long history, with a particular focus on the species that persist in or are often introduced into urban environments and their interactions with people and their status as indoor or outdoor pests. More recently, the important and often beneficial ecological roles that ants can play in urban landscapes have become a focus for study (Offenberg 2015, Penick et al. 2015, Youngsteadt et al. 2015). We found changes in the species identity and relative abundance of house-infesting ants in Urbana, IL, over an 87-year time period. Overall, fewer ant species were detected in residences in 2012-13 compared to 1926. The most common house-infesting ants in 2012-13 were also detected at higher frequencies than were the most common species of ants in 1926. However, these differences may reflect differences in participant response rates; our results are likely biased against the detection of rare species due to the lower number of responses. The low response rate of participants in our surveys is consistent with a general decrease in survey responses across the U.S. over time (Baruch and Holton 2008, de Leeuw and de Heer 2002). There was a 13% response rate for 2012-2013, with several factors likely decreasing

Table 5. Relative abundances, based on percentage of traps in which an ant was captured, of ant species collected by pitfall traps at all 4 sites in 2012.

Species	Trelease	Brownfield	Busey	Urbana
Amblyopone pallipes (Haldeman)			2.2%	
Aphaenogaster carolinensis Wheeler	5.6%	5.3%	8.9%	
Aphaenogaster fulva Roger	8.3%	10.5%	6.7%	
Aphaenogaster mariae Forel				1.5%
Aphaenogaster rudis Enzmann	52.8%	55.3%	33.3%	8.8%
Brachymyrmex depilis (Emery)			2.2%	8.8%
Camponotus americanus Mayr		2.6%	2.2%	
Camponotus castaneus (Latreille)			17.8%	13.2%
Camponotus chromaiodes Bolton	8.3%		2.2%	
Camponotus discolor (Buckley)				4.4%
Camponotus nearcticus Emery		5.3%	8.9%	2.9%
Camponotus pennsylvanicus (DeGeer)	75%	86.8%	51.1%	13.2%
Camponotus subbarbatus Emery	5.6%	5.3%	24.4%	
Crematogaster cerasi (Fitch)	2.8%		6.7%	
Formica pallidefulva Latreille			2.2%	26.5%
Formica subsericea Say	2.8%		42.2%	17.7%
Hypoponera opacior (Forel)				2.9%
Lasius alienus (Förster)	5.6%	2.6%	51.1%	8.8%
Lasius nearcticus Wheeler			2.2%	
Lasius neoniger Emery	2.8%			23.5%
Lasius umbratus (Nylander)				1.5%
Monomorium minimum (Buckley)				5.9%
Myrmecina americana Emery	2.8%		2.2%	1.5%
Myrmica cf. *evanida* Francoeur	5.6%	13.2%	17.8%	
Myrmica pinetorum Wheeler	11.1%	2.6%	13.3%	1.5%
Myrmica punctiventris Roger	13.9%	31.6%	8.9%	
Myrmica detritinodis Emery		2.6%	2.2%	2.9%
Myrmica spatulata Smith	2.7%		28.9%	
Nylanderia parvula (Mayr)			2.2%	11.7%
Pheidole pilifera (Roger)				1.5%
Ponera pennsylvanica Buckley	11.1%	7.9%	6.7%	4.4%
Prenolepis imparis (Say)	2.8%			
Solenopsis molesta (Say)			4.4%	32.4%
Stenamma brevicorne (Wayr)	2.8%	13.2%	22.2%	1.5%
Tapinoma sessile (Say)	5.56%		66.7%	63.3%
Temnothorax curvispinosus (Mayr)		10.53%	24.4%	2.9%
Temnothorax schaumii (Roger)			4.4%	4.4%
Tetramorium caespitum (Linnaeus)			13.3%	69.1%

the response rate. Contributing factors may include the time frame involved, the demands imposed on participants, and the relative lack of familiarity with the concept of collecting arthropods. We did employ techniques recognized in survey research as positive factors, including advance notice, personalization, follow-up visit or reminder card, economic incentive, and providing postage and university sponsorship (Edwards et al. 2002, Dillman 2000), in an effort to maximize response rate for the Urbana ant surveys.

In his doctoral thesis, Smith (1927) described the methods housekeepers used to control house-infesting ants. His descriptions and language indicated that the people he interviewed were probably present at the house for extended periods during the day. Although there is no specific information on their activities, given the nature of the time period and community, a significant proportion of these people may have been engaged in household activities such as cooking, cleaning, or tending children, which might have allowed them to monitor ant presence and activity more readily than the majority of respondents in 2012-2013. National statistics demonstrate a trend of increasing participation in employment outside the home, particularly by women. Between 1900 and 1920, e.g., the proportion of married women who worked outside the home ranged from 6% to 10%; by 1998, that proportion had increased to 61% (www.pbs.org/fmc/book/2work8.htm). By 2014, both the husband and wife in 47.7% of married-couple families worked outside the home (www.bls.gov/news.release/famee.nr0.htm).

Three species were found in houses both in 1926 and in 2012-13: *Camponotus pennsylvanicus*, *Formica pallidefulva*, and *Tapinoma sessile*. Although all three of these species are native, *Tapinoma sessile*, the odorous house ant, is a common urban pest that exhibits differences in its biology between natural and urban populations (Menke et al. 2010, Buckowski 2011). Consistent with these differences, we found this species to occur at lower abundance in undisturbed relative to disturbed sites. Smith (1928) considered *T. sessile* to be the most important house-infesting ant in Illinois and many other states, including California, the District of Columbia, Maryland, Mississippi, Nevada, and Tennessee.

Differences in the occurrence of two introduced species are worth noting. M. R. Smith found the invasive pharaoh ant, *Monomorium pharaonis*, in households, albeit at low frequency, and in 2012-2013, we failed to find it at all. The absence of *M. pharaonis* could indicate that it has been extirpated from Urbana. A more likely explanation, however, is that this tramp species was not detected in our surveys due to its relative rarity. The pharaoh ant is known to establish colonies in greenhouses, kitchens, and heated buildings such as hospitals; Smith noted that it was restricted to the "business district" of Urbana (Smith 1927). This polygyne species can have hundreds of reproductive females and disperses by budding and fission (Smith and Whitman 1992, Smith 1965). Given its low incidence in 1926, and the substantially fewer sightings documented in 2012-13, we believe that it still occurs in houses in Urbana but that it remains rare. Pharaoh ants have been recorded from at least six counties in Illinois as of 1988, including Champaign County (DuBois and LaBerge 1988).

Another introduced species, the pavement ant, *Tetramorium caespitum*, was the fourth most commonly collected species in residences in 2012-2013; its absence from household surveys in 1926 suggests that it has spread into or increased in abundance in Urbana at some point in the last 80 years. This tramp species was introduced to the United States prior to the nineteenth century and its range has expanded throughout the country (Smith 1965). The pavement ant is nearly ubiquitous in urban habitats in the U.S. It prefers urban, disturbed habitats over natural habitats, and may outcompete native species in urban environments (Uno et al. 2006). This species also enters residences and disturbs landowners (Klotz et al. 2008). It would be worth examining historical records and collections to determine exactly when it became established in Urbana.

Over the past 87 years, chemical control of indoor insect pests, including ants, has changed from broadly toxic inorganic (primarily heavy-metal-containing) compounds, including those containing arsenic, thallium, or mercury, to generally more selective synthetic or "least toxic" compounds often formulated as baits, including the neurotoxic pyrethroids, oxadiazines, phenylpyrazones, and avermectins, the metabolic inhibitor hydramethylnon, and the cuticle-abrading boric acid and diatomaceous earth. Pesticide delivery via baits offers a distinct advantage over older methods in that foraging workers are attracted to the baiting agent and bring the toxic agent directly into the nest, where trophallaxis increases the likelihood of killing the queen(s) and hence the colony. The greater efficacy of baits, as well as the greater selectivity of the active ingredients, may provide an explanation as to why, in Smith's (1927) survey, respondents reported the need to re-apply control chemicals at regular intervals.

Taking into account inflation, there was a greater range of money spent per household for ant control in 2012-2013 than in 1926 (0-$75/house versus $0-$50.14/block). In terms of averages, the 2012-2013 amount spent per household was almost twice as high as that spent in 1926 ($12.42 versus $6.33). However, the money spent per house in 2012-2013 is remarkably similar to the amount Smith predicted would be needed for adequate control in 1926 ($12.42 versus $13.19).

Smith (1927) noted 19 genera and 47 species in the city of Urbana (plus two additional introduced species in greenhouses). In our survey of ants in Urbana and its environs, we recorded 22 genera and 44 species using three sampling methods. The three collection methods yielded species occupying different microhabitats: pitfall traps targeted ground-dwelling ants, leaf litter samples targeted leaf-litter-dwelling ants, and visual sampling targeted ants from several layers, including the ground, fallen logs, and trees. Our findings suggest a possible decline in the overall number of species in Urbana in view of the fact that a number of conspicuous ground-foraging species were absent from our surveys, and we detected four fewer species despite utilizing a greater diversity of sampling methods. Leaf litter sampling detected additional species in 2012-2013 that were not recorded by Smith (1927). We have no way of knowing whether these newly recorded species were present during the time Smith was at the University of Illinois.

The most species-rich genus present in samples collected in both time periods was *Camponotus,* with 8 species collected. *Camponotus* represented 18.6% of the 43 species collected in the entire survey. The genera *Aphaenogaster*, *Lasius*, and *Myrmica* each accounted for 11.6% (five species) of the 43 species collected in the entire survey. These four genera are diverse and dominant species in forest ecosystems, especially *Camponotus* and *Lasius* (Buczkowski 2011, Wilson 1955, Ellison et al. 2012). Half of all *Camponotus* species collected (four of eight species) were detected in houses in 2012-2013, whereas only two of these *Camponotus* species were detected in residences in 1926 (Smith 1927).

Species richness estimators suggest that each of the four areas we sampled contained a subset of ants present in the overall study area. Moreover, each site had a unique assemblage of species, reinforcing the value of preserving even small fragments of native habitat (Gibb and Hochuli 2002). Pitfall sampling revealed the greatest difference between the undisturbed forest and disturbed residential urban site, while the two undisturbed forest sites shared the greatest number of species. However, across all sites, leaf litter sampling revealed that disturbed forest and undisturbed forest had the greatest similarity. Differences in species abundance and richness across these sites either reflect differences in microhabitats or indicate compositional changes between sites over time. Differentiating between these two mechanisms would require a combination of historical sampling and careful documentation of changes in abiotic and biotic conditions through time.

Conclusions

Our survey is one of a relatively small number of re-surveys that take advantage of studies published many decades ago in order to gain insights into faunal change over time. In our case, we had a unique opportunity to document the house-infesting ant species and overall ant species richness in a specific urban area over an 87-year span. Urbana, Illinois, might be unusual in that, as the home of the land grant university of Illinois, it has also been the home of entomologists who have regularly inventoried the local fauna. Repeated sampling in a particular location over lengthy time spans is valuable because faunal responses to environmental change can be difficult to detect in the absence of baseline data or even over relatively short time spans. High-quality re-surveys will be even more important as the need to document species responses to global changes in climate, habitat loss, and the introduction of invasive species increases. For example, a study over 23 years showed that 31 butterfly species typically emerged earlier in the season due to warmer temperatures (Roy and Sparks 2000). Similarly, in a long-term survey of low-elevation butterfly diversity, declines in individual species abundance of butterflies did not appear for 18 years and did not achieve statistical significance until the 25th year of data collection (NAS, 2007). We encourage more entomologists to examine their own departmental archives in the hope of discovering their own M. R. Smith, and make the most of the invaluable and irreplaceable legacy our predecessors have left to us by repeating their work to illuminate how the insect world around us has changed with time.

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