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Ecologists, educators, and writers collaborate with the public to assess backyard diversity in The School of Ants Project

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Abstract. Citizen science can generate data that would not exist otherwise while increasing public scientific literacy. However, the quality and use of citizen science data have been criticized in the recent ecological literature. We need an approach that advances eco-evolutionary understanding, achieves education goals and incorporates public participation into as many aspects of the scientific process as possible. We collaborated with public participants to make new discoveries about the distribution and ecology of ants while informing the next studies that participants and scientists might perform together. We implemented the School of Ants (SoA) program in which participants sample ants that are identified by taxonomic experts. Using a comprehensive framework that meets the needs of multiple agents, we also developed outreach materials about ant biology, collaborated with educators to incorporate SoA into classroom science, and launched an international SoA module in Italy. In the first 17 months, SoA volunteers collected ants at 500 unique sites across the USA-including all 50 states and Washington, D.C. To address concerns about the validity of citizen scientist-derived data, we conducted a ground truthing trial that confirmed that trained and untrained volunteers were equally effective at collecting ants. Data from SoA samples indicate that ant diversity varies across wide geographic scales and that there can be high levels of native ant diversity where people live. SoA volunteers collected 7 exotic and 107 native ant species. Although exotic ants were common, ants native to North America occurred in ~70% of all sites. Many of the ants common in backyards were species that tend to be very poorly studied. For example, citizen scientists documented a range extension of more than 2000 miles for the Asian Needle Ant, *Pachycondyla chinensis*. Using SoA data as a starting point, we collaborated with a science writer to produce a free, interactive iBook about the common ants in North America; the book included distribution maps such as that for *P. chinensis* informed by participant collections. Moving forward, we plan to leverage this existing framework to address more complex ecological and evolutionary questions in partnership with our public participants.

Key words: ants; citizen science; distribution; diversity; public participation in scientific research; urban ecosystems.

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Introduction

Although historically underappreciated relative to the ecology of protected areas, ecological dynamics in cities and other human-dominated landscapes are likely to influence populations, communities and ecosystem processes across entire landscapes. Humans are integral to these dynamics, especially those that occur where people live and work. Consequently, we are becoming increasingly aware that engaging non-scientists in the scientific process can not only increase public scientific literacy (Bonney et al. 2009, Cronin and Messemer 2013), but also generate scientific data that advance ecological knowledge and could exist in no other way (e.g., Silvertown et al. 2011, Hulcr et al. 2012).

Citizen science is broadly defined as an organized scientific endeavor that includes participation from professional scientists and the public (Dickinson and Bonney 2012). It is deeply rooted in the historical origins of science (Miller-Rushing et al. 2012) and has long contributed to the advancement of ecological theory. For example, the first analysis of predator-prey cycles by Vito Volterra depended on data collected by fishermen (Scudo 1971). More recently, citizen science has emerged as an increasingly popular tool for understanding the structure and dynamics of ecological communities over broad spatial ranges while educating non-scientists about local ecology (Dickinson et al. 2010). Recent technological advances have led to the development of many citizen science programs in ecology, ranging in scope from long-term, broad-scale biodiversity monitoring (e.g., Schmeller et al. 2008), to short-term biodiversity surveys of targeted taxonomic groups or ecosystems (e.g., Hulcr et al. 2012) to the use of applications on mobile telephones to monitor the dynamics of species invasions or plant phenology (Graham et al. 2011).

Although citizen science projects often generate large datasets with benefits for professional scientists and the public (Dickinson and Bonney 2012), multiple challenges of the citizen science approach to scientific inquiry have been identified in the recent ecological literature (e.g., Crall et al. 2010, Conrad and Hilchey 2011 and references therein). These criticisms fall under three broad categories. First, organizational challenges include lack of public interest in citizen science projects (Conrad and Daoust 2008), funding issues (Whitelaw et al. 2003), and limited outreach opportunities which allow professional scientists and participants to interact (Milne et al. 2006). Next, data collection issues are among the most frequently criticized aspects of citizen scientist projects (Bradshaw 2003, Gouveia et a. 2004, Royle 2004, Conrad 2006, Nerbonne et al. 2008, Fitzpatrick et al. 2009, Crall et al. 2010, 2011, Kremen et al. 2011, Farmer et al. 2012). Specifically, controlled studies have demonstrated that citizen scientists can have increased variability in data collection relative to experts (Farmer et al. 2012, but see Miller et al. 2012), which could lead to an increased likelihood of errors. Citizen scientists tend to measure abundances poorly, and abundance estimation is a major source of this among-participant variability (Foster-Smith and Evans 2003). Lack of taxonomic training additionally leads to higher rates of misidentifications, especially at the species level, which is often the taxonomic level of interest (Kremen et al. 2011). Finally, concerns have arisen related to the way that scientists use data generated by their citizen scientist partners. Data management problems primarily emerge with respect to data accessibility (Crall et al. 2010) and a lack of consistent data management protocols among researchers (Dickinson et al. 2010, Kelling 2012). Furthermore, professional scientists are often mistrustful of the conclusions drawn from citizen scientist-derived data, because researchers have not accounted for the data collection problems described above (Crall et al. 2011). Some of these issues related to data quality and use have been addressed using data validation (Galloway et al. 2006, Bell 2007, Fitzpatrick et al. 2009, Kremen et al. 2011, Bonter and Cooper 2012); unfortunately, these error analysis techniques are not incorporated into most citizen science projects (Crall et al. 2010).

A final challenge with citizen science relates to the outcomes for public participants. Benefits for participants can vary considerably, even within the same project, and no citizen science project will perfectly meet the needs of all participants. However, citizen scientist projects should ideally provide opportunities for participants to be involved in and learn about as many aspects of science as possible. Participants in citizen science

projects are particularly well poised to begin by learning existing knowledge and then to join scientists in making new discoveries.

With these challenges in mind, we developed and implemented the School of Ants (SoA) citizen science project, in which participants sample ants in their backyards and sidewalks. The motivations for this project were twofold: (1) we wanted to increase scientific knowledge about the diversity and distribution of ants across a broad spatial range, and (2) we wanted to provide opportunities for the general public to learn about and participate in understanding the ecology where people live and work. Ants are widespread and diverse (Dunn et al. 2007), commonly associate with humans and their structures (Klotz et al. 1995, Menke et al. 2011), and are an ecologically important group across various spatial scales and multiple habitat types (Folgarait 1998, Dostál et al. 2005), making them ideal focal organisms to meet both of these goals.

Here, we first detail our methods with a particular focus on the challenges of data quality in citizen science projects. Next, we describe the results to date in terms of (1) the diversity and distribution of the ants most commonly collected by SoA participants; (2) collaborations with formal educators and international scientists who used SoA as a vehicle for collaborative learning; and (3) the development of outreach materials, paying particular attention to the creation of 'Dr. Eleanor's Book of Common Ants'—an accessible and interactive guide for general audiences about the ants most frequently collected by SoA participants.

Methods

Protocol

Data collection.—We provided step-by-step instructions on our website. To follow the SoA protocol, participants placed cookie pieces on index cards in two different habitat types: (1) a green space, defined as a vegetated area, such as a lawn, garden or forest; and (2) a nearby paved space, defined as an impervious surface, such as asphalt, concrete or cobblestones. Within each habitat type, $n = 4$ stations were placed within ~30.5 cm of one another. Each bait station consisted of one quarter of a Pecan Sandies cookie (Kellogg, Battle Creek, Michigan, USA), placed on a white card (~8 × 13 cm) labeled 'green' or 'paved'. Pecan Sandies have been commonly used in ant ecology since the early 1990s (e.g., Human and Gordon 1996), because they contain protein, carbohydrates and lipids, thus providing an attractive food source to multiple ants. After one hour, participants placed cards, cookies and any ants attracted to the baits into individual labeled plastic bags and then put the bags in a freezer (http://schoolofants.org/sites/default/files/soa-images/dyi_ant_kit.pdf).

Data entry.—Participants were guided in data collection by a table provided on the protocol sheet. Citizen scientists entered data into online forms on the SoA website (http://www.schoolofants.org/) to register as an official participant of the SoA project. Data included (1) the specific location where baiting occurred; (2) habitat characteristics of green and paved spaces; and (3) abiotic conditions during baiting trials. After data entry was completed, the participant was assigned a unique confirmation code that served as a reference number for the sample.

Sample submission.—Participants submitted samples by mailing completed collections to a regional SoA processing center (currently, there is one at North Carolina State University and another at the University of Florida, housed in the labs of project PIs). The associated confirmation code linking collection data to the sample accompanied each submitted sample.

Sample processing.—Teams of trained undergraduate students (see below) and laboratory assistants received the samples at regional processing centers. Depending on the volume of incoming samples, processing teams included 1 lab manager and 1–4 trained undergraduate students. The processing teams isolated ants from debris and cookie crumbs and sorted ants to morphospecies. Green samples were pooled, as were paved samples; within each habitat x sample combination, one specimen from each unique morphospecies was point-mounted and labeled with collection data and a unique barcode. All other ants were stored in 95% ethanol. Ethanol-preserved samples were stored in the permanent collections of each regional processing center. During the initial phase of the project (when sample volume was high, July 2011–September 2012) this resulted in 40–60 person hours per week. Later, fewer samples

resulted in a reduction to 20–30 person hours per week in the summer and 8–10 hours per week in the winter.

Point-mounted specimens were sent to regional ant taxonomic experts, who we subcontracted to provide or confirm ant identifications at the species level. These taxonomic experts entered species determinations directly into the online database. The specimens were then returned to regional processing centers for permanent storage alongside ethanol-preserved specimens.

Data retrieval by participants.—Once identifications were entered into the database, collection sites and species names appeared on our online interactive 'Ant Map' (http://www.schoolofants.org/map).

Data management

We build the SoA website on a backbone of a PHP MySQL database in a Drupal environment. The specimen-level database was informed by Darwin Core standards (http://rs.tdwg.org/dwc/index.htm) to ensure the integrity and broad utility of ant distribution data. The taxonomic framework of the project was imported from Antweb (http://www.antweb.org/; August 2011), but maintained the flexibility to note nomenclatural changes or uncertainties in species identifications.

Validating ant collections by citizen scientists

It is very common for trained undergraduates to collect samples that are used in published ecological papers. For studies of insects-such as ants-this training includes basic field and laboratory identification skills and field sampling techniques specific to insects. Our sampling protocol is simple, and the technical identification skills are needed after participants mail their samples to processing centers. However, participants still set out cookie baits and collect ants using only the information provided on our website. We examined the error associated with using untrained participants using a ground truthing trial. The SoA ground truthing trial was conducted on the campus of North Carolina State University (Raleigh, NC). Two groups collected data: (1) 'untrained participants' (undergraduate students in an Ecology course), who used only the information provided on the SoA website to collect ants using the SoA protocol; and (2) 'trained participants', undergraduate members of the SoA team from Dr. Rob Dunn's laboratory group. Importantly, both groups were sampled from the same population (NCSU undergraduates). Both groups used identical methods and collected ants from the same sites from 15 April to 9 May 2013. We compared the number of ant species collected by trained and untrained participants, and used a Spearman correlation of rarefied species accumulations for each group to examine how these results were related to trained or untrained status. We used Primer-E v.6 to perform rarefied species accumulation analyses and SAS v.9.3 to conduct Spearman correlations.

Public outreach

We used multiple approaches to provide opportunities for the public to learn about the SoA project. First, we frequently developed outreach materials for formal public outreach events (Appendix: Table A1), including: brochures describing the SoA project, 'trading cards' for common ants, a pictorial dichotomous key for the most common ants collected by SoA participants, Dr. Eleanor's Book of Common Ants (Box 1, Fig. 1; Spicer Rice 2013) and a short video on the SoA website showing children using the SoA protocol to sample ants (http://www.youtube.com/watch?v=gMg55LTJ6gQ). We also formed partnerships with teachers to develop curriculum based upon SoA (Box 2, Figs. 2 and 3). Finally, we collaborated with scientists in Parma, Italy to develop an international SoA module (Box 3, Fig. 4).

Results

Citizen science participation in the SoA Project

Description of participants.—Between 13 July 2011 (when the website was published online) and 2 May 2013, there were 35,994 total visits to the SoA website (Fig. 5). Most visits were from people in the United States (84.9%). The most common US region of origin was the South Atlantic, with 9,832 (33.1%) total visits (Fig. 5a). Additionally, the website has been accessed from 132 different countries. There were also 1,170 visits from other North American countries (Fig. 5b), especially Canada (73.5% of NA visits outside the USA). Finally, there were >5,000

Box 1

Backyard ecology for the masses: Dr. Eleanor's Book of Common Ants

How do we get people excited about the ecology of species living in their own backyards? One approach is to give the public opportunities to collect and observe species through citizen science projects. We employed this approach through the SoA project. The next step towards achieving this goal was to provide people with information about the natural history of the species that they collected through the SoA project. Therefore, we contracted a professional science writer to compose vignettes about the ants most commonly collected for the SoA project-those ants that people were most likely to interact with in the course of their daily lives.

The book is titled Dr. Eleanor's Book of Common Ants (Fig. 1) and is available free online as an interactive iBook (https://itunes.apple.com/us/book/dr.-eleanors-book-common-ants/id634057983?mt=11). Features of the iBook include photographs, distribution maps (based upon SoA collections and literature accounts) and natural history stories about each featured species. There are also interactive features, which include a photo gallery, short videos, and links to the global SoA map and a glossary. The flexibility of this format allows us to update the iBook as more data accumulate through the SoA project. For example, new versions are currently being developed that focus on the ants of New York City, Chicago and North Carolina, respectively. This book will help (we hope) direct participants toward particular questions about ants that they might study on their own in addition to those questions which we, as scientists, frame.

visits from people outside North America (Fig. 5c).

From July 2011 to December 2012, we logged 814 total kits. Of these, 599 kits (74%) from 500 unique sites (Fig. 6) were usable and were

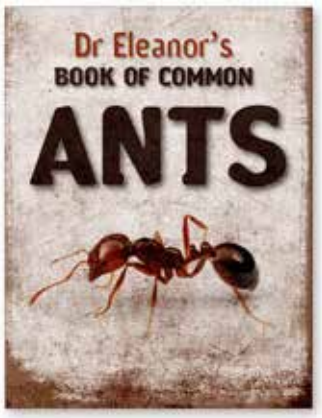

Fig. 1. Cover of the interactive iBook based upon the most commonly collected ants from the SoA project.

included in the dataset described below. During registration, we surveyed participants about how they found out about the SoA project. Approximate 55% of Project participants answered; of those, most respondents found out about SoA from media coverage (including traditional media, social media, and blog posts) of the project, the SoA website, or a school network (e.g., a listserv for parents; Fig. 7). The cities with the greatest number of samples were Chicago, IL (149 samples), Raleigh, NC (143 samples) and New York City, NY (34 samples).

Data validation: Results from ground truthing

To address concerns in the literature about the accuracy of untrained vs. trained workers in collecting ants, we conducted ground truthing trials which showed that the collections of untrained and trained collectors were highly correlated (Fig. 8; Spearman correlation: $P < 0.0001$, $r^2 = 0.9376$).

Assessment of the diversity and distribution of the ants most commonly collected by our citizen science partners

Ant diversity.—We detected a wide range of ant species across North America using the SoA protocol. Across 500 sites (Fig. 6), we found 7 exotic ant species and 107 native ant species. While we do not appear to be encountering new exotic species (Fig. 9), rarefaction curves indicate that additional sampling will continue to encounter more native species, even given the

Box 2

Teachers and scientists collaborate to bring SoA into the classroom

There are many aspects of the SoA project that make it an ideal vehicle for meeting the needs of formal science educators. First, the School of Ants protocol is simple, inexpensive and modifiable based on the specific learning needs of a classroom. Additionally, in order to extend the experience for students and educators, SoA educational materials encourage discovery through inquiry-based learning.

SoA is promoted through media coverage, writing on our blog (www.yourwildlife.org), local outreach events and school visits (Appendix: Table A1). Interactions with educators and the School of Ants were initiated, in the majority of instances, by the educators themselves through our website or email. Our team consistently receives email inquiries from educators expressing interest in the project through the SoA dedicated email address and to our broader Your Wild Life email list. From the initial contact, we reply with the pertinent information to answer the educators' questions and then, with their permission, include them on our list of interested educators to continue to update with news related to our citizen science projects. All future related curricula are available at education.yourwildlife.org and cross linked at ants.yourwild life.org.

However, there are many aspects of formal classroom education that we-as scientists-did not know. Therefore, we formed partnerships with local teachers to develop classroom modules inspired by the SoA citizen science project. As a first step towards meeting the goal of developing curricula, we hosted a workshop for local K-5 teachers about the SoA project. The workshop was held at the North Carolina Museum of Natural History in February 2013. Teachers first collected ants outside the museum with the help of the SoA scientific team (Fig. 2). Next, they used a pictorial dichotomous key that was developed specifically for SoA to identify their ants back at the museum (Fig. 3). Members of the SoA scientific team helped the teachers work through identifications. Finally, the teachers and scientists discussed the possibilities and challenges of using the SoA project as an inspiration for classroom curricula.

After the workshop, SoA scientists and local educators worked together to develop SoA learning modules for formal classrooms. While not explicitly part of the SoA protocol used for data collection, students were encouraged to ask their own questions about diet preference and the abundance of ants. We developed a flexible curriculum, allowing students to additionally explore a multitude of other variables that further promote exploration and observation of natural and built environments. These modifications to the standard SoA collection protocols allowed students to both ask questions about their local environment and to personally connect ecology to their lives with place-based learning benefits.

To reach a broader audience of students, we have focused efforts on developing several three-day course modules that will be available free of cost for teachers on our website, education.yourwildlife.org. In the Spring and Summer of 2013 we tested our first course module based on a modification of the School of Ants protocol at a residential gifted high school program in Mississippi. When we have finished and fully vetted the prepared elementary and middle school modules they will be available for download on our educator resources page at education.yourwildlife.org. These curriculum development efforts allow elementary school teachers with limited exposure to scientific research to feel confident teaching life science in their classrooms.

current protocols (Fig. 9). Exotic ants were common across a broad geographic range, occurring in 333 (66.7%) of all sites that we sampled. Within sites with exotic species present, 90.7% only had one exotic species. The most common exotic ant collected using the SoA protocol was *Tetramorium caespitum* complex (a group that is in taxonomic flux and includes the

Fig. 2. Dr. Eleanor shows local teachers how to collect ants in the field during SoA teacher's workshop.

Fig. 3. Local teachers use SoA pictoral dichotomous key to identify ants collected during SoA teacher's workshop.

morphologically indistinguishable *T. caespitum, T. tsushimae,* and *T.* sp. E), which was detected at 242 sites (48.4% of all sites). The other exotic ant species collected in this study were *Linepithema humile, Solenopsis invicta, Nylanderia flavipes, Pachycondyla chinensis,* and *Lasius niger*. Ants native to North America accounted for 65.6% of all records, with at least one native ant species present in 349 (69.8%) of all sites sampled using the SoA protocol. The most common native ant species was *Monomorium minimum*, which was found in 96 sites (19.2% of all sites). Thirty-eight native species were only found at a single site (35.5% of all native species), while 17 native species occurred in ≥10 sites (15.9% of all native species). Exotic and native species co-occurred in 181 sites (36.2% of all sites; Figs. 6 and 10).

Ant distribution.—Our findings to date indicate the diversity of those ants attracted to food baits varies across wide geographic scales and that there can be high levels of native ant diversity where people live. Here we highlight results for three cities that have been particularly well sampled, Chicago (Figs. 10 and 11a), Raleigh-Durham (Figs. 10 and 11b) and New York City (Figs. 10 and 11c). Samples from Chicago and New York City included some sites with only native ants, some with only exotic ants, and sites with both native and exotic ants (Fig. 11a, c). In contrast, native ants were found at all sites sampled in Raleigh-some with and others without exotic species present (Fig. 11b). Although present in all three cities, the *T. caespitum* sp. complex was most prevalent in Chicago (found in 78.5% of all sites in Chicago, compared to 38.2% and 32.2% of all sites in NYC and Raleigh, respectively; Fig. 10). We also found many native ant species in our pilot study in Parma, Italy. *Tetramorium caespitum* (s.l.) was the most com-

Box 3

School of Ants goes global: International module of SoA in Parma, Italy

The Italian module of SOA arose from a scientific question: "Can ants sampled by citizen scientists be a useful model to study how human impact is shaping the urban ecosystems in Italy?" Previous research in other countries suggested that ants can be effective indicators of ecosystem responses to anthropogenic activities (e.g. Andersen and Majer 2004). Additionally, recent studies of ants in Italian agro-ecosystems (Castracani and Mori 2006, Santini et al. 2007) and an urban reserve (Castracani et al. 2010) suggested that using ants as bioindicators of ecosystem health can be quite effective in Italy. Adapting the SoA project to study Italian ants using citizen science was thus a promising approach to addressing this scientific question.

As a first step towards implementing the Italian module of SoA, we conducted a small-scale trial of our modified protocol at selected schools in the city of Parma (44°48′ N, 10°19′ W). Specifically, we visited 6 primary school classes and 2 secondary school classes at six different sites (working with a total of 211 students and 8 teachers) from October 2011–May 2012. We trained our citizen science partners to use a modified SoA protocol. We provided students with 12-mL plastic vials filled with ~4 mL of cookies. Pecan Sandies were not available in Italy, so we used the ingredients of Pecan Sandies to bake our own cookie baits. All samples were processed by the staff of the Myrmecology Lab at the University of Parma. Finally, ant specimens were identified to the species level (Hölldobler and Wilson 1990, Bolton 1994) by staff in the Myrmecology lab, with consultation from ant taxonomic expert, Dr. Fabrizio Rigato (Natural History Museum of Milan, Italy).

Using this methodology, we collected thirteen species, which were all native in Italy. As in the US SoA, the *Tetramorium caespitum* species group was the most commonly collected ant across all sites (Fig. 4).

We also engaged the Italian public through multiple outreach events, stories in news outlets, and blog posts (Appendix: Table A2). Additionally, we developed outreach materials for formal public outreach events. To date, our outreach materials include a coloring book on morphology and biology of ants, a "memory game" with photographs and explanatory sheets of the most curious ants of the world, a pictorial dichotomous key for the most common ants collected in Parma and related sheets on their natural history, a guide to build an home-made insect aspirator.

monly collected species in Parma, present all six sites (Fig. 4).

Surprising discoveries.—In addition to increasing our understanding about the diversity and distribution of ants broadly, the SoA project can be a vehicle for discovering new biological information about individual species. In the first phase of the SoA project, we made two particularly compelling discoveries with the help of our citizen scientist partners. First, a group of 5th graders in the Young Naturalists Day Camp participated in SoA in Winston-Salem, NC. Their samples included *Aphaenogaster miamiana*, an ant species previously thought to be restricted to more southern and eastern ranges of North America. We have begun follow-up investigations of the genetic diversity of *A. miamiana* to further investigate this finding. Similarly, invasive Asian Needle Ants (*Pachycondyla chinensis*) was considered to be restricted (in its NA range) to the Southeastern USA. However, SoA volunteers collected this problematic invader as far away from its presumed range as Washington and Wisconsin. We wrote a blog post about this discovery (http://www.yourwildlife.org/2012/08/amateur-scientists-discover-asian-needle-ant-has-expanded-its-range-by-thousands-of-miles-unnoticed/) and are intensively investigating its invasion.

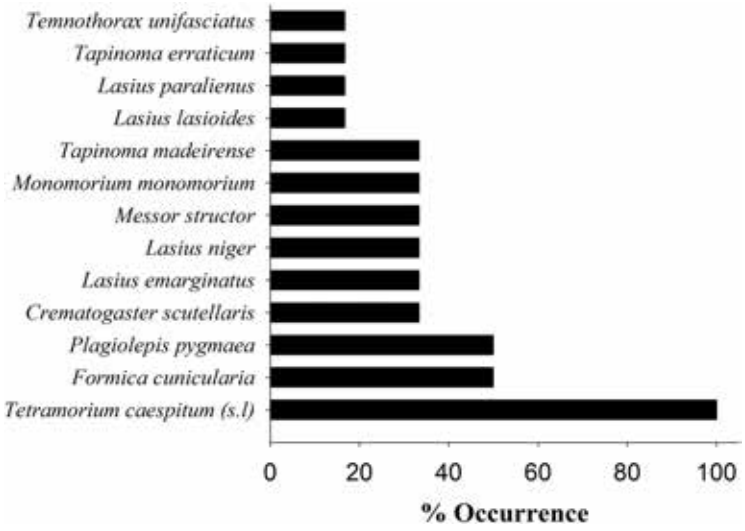

Fig. 4. Occurrence of ant species collected in Parma, Italy (%; $n = 6$ sites) using an adapted version of the SoA methods.

Discussion

Summary: progress to date

In less than 1.5 years, we have made substantial progress in meeting our goals for the School of Ants citizen science project. We have generated rigorous data about the diversity and distribution of the ants that live in backyards and cities, engaged the public in the process of science and the ecology around them, and developed both outreach materials for public audiences and curricula for classrooms based upon the SoA project. Moving forward, we have multiple educational and scientific goals for the next stage of this project.

Insights into the diversity and distribution of North American ants

Our protocol provides a powerful tool for understanding the diversity and distribution of the ants that live around people and are attracted to human-derived food. Using this protocol, our citizen science participants collected not only exotic ants, but also a diversity of native ants in their backyards and sidewalks (Figs. 9, 10, and 11). Furthermore, our data suggest that more extensive sampling will lead to the collection of more native ant species (Fig. 9). Because they are often behaviorally dominant and have broad diet and nesting preferences (Holway et al. 2002), it is generally assumed that ant assemblages in human-dominated habitats will be comprised mostly of exotic ants. We did find exotic ants, and they were often the most common ants we collected. However, our data—collected across a broad geographic range in North America—suggest that the ants that live where people live and work are more complex than has been previously assumed.

There were also interesting differences among the cities that were most intensively sampled using the SoA protocol. Raleigh-Durham supported a diverse and relatively even ant fauna compared to the other cities. Furthermore, native ants were more common than exotic ants in most of the samples from Raleigh-Durham (Figs. 10 and 11). In contrast, our samples from Chicago were dominated by one exotic ant species-*Tetramorium caespitum* sp. gr. (Figs. 10 and 11). This result may be driven by collections near Chicago's Metra Transit (Fig. 10). Nonetheless, our data suggest that ant communities can be quite simple in some urban environments. New York City was sampled less intensively than the other two cities, but supported more native species than might be predicted for the most urbanized city in North America (Fig. 10). In addition to being less urbanized than the other two cities, Raleigh-Durham is also further south, and has a milder climate. Follow-up studies that assess the interaction between climate and urbanization could help to disentangle these

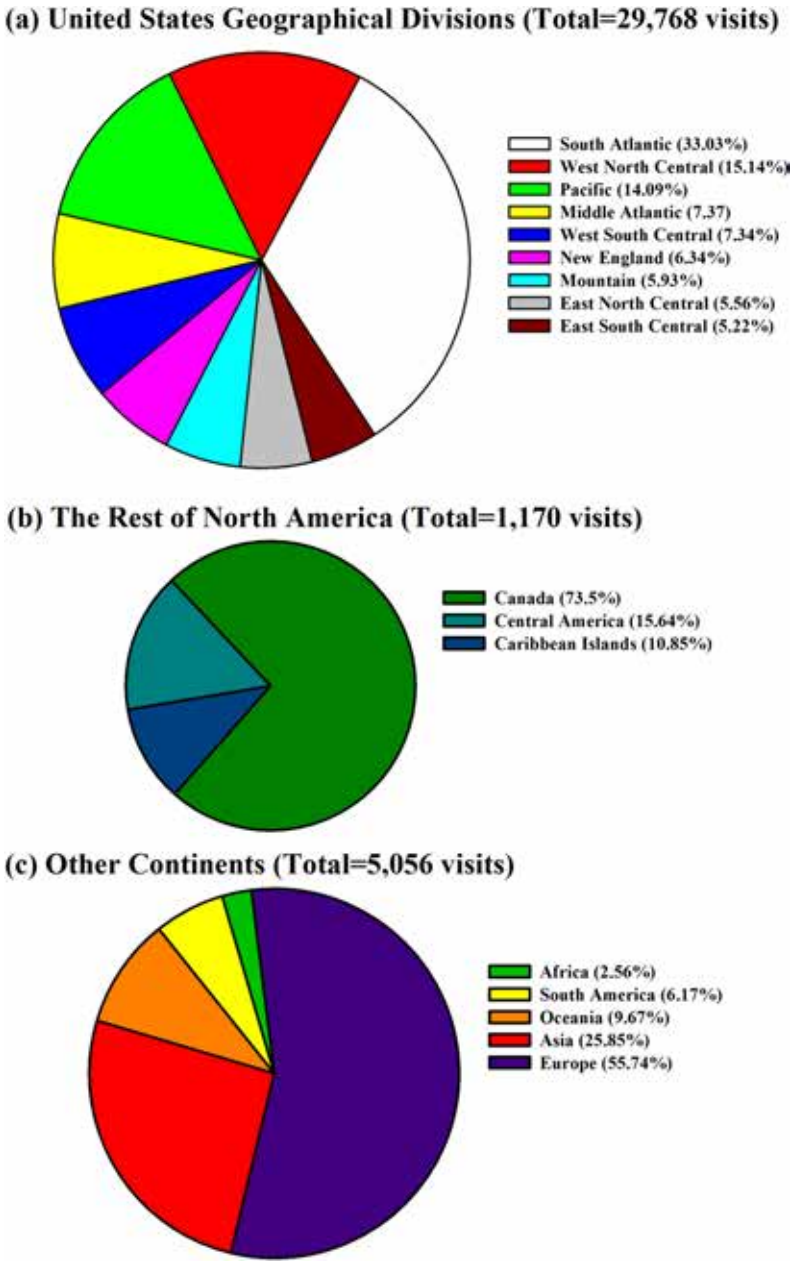

Fig. 5. Percentage of visits to the School of Ants website from (a) Geographic divisions within the USA (b) the rest of North America and (c) across other continents globally.

patterns and lead to a greater understanding of the relative importance of multiple ecological factors to the distribution of ant diversity within and among North American cities.

How does SoA address criticisms of Citizen Science?

Merits and challenges of simple protocol.—A simple protocol reduces potential errors in data collection and invites broad participation, but requires that we focus on a subset of the ant community. Our samples consider only those ants that forage on the ground, are attracted to cookie baits, and are able to find baits. While this protocol cannot be effective in assessing whole communities, it is appropriate to our goals, since

Fig. 6. Map of the distribution of School of Ants collection sites across the continental USA. Each circle represents a unique collection site, and the size of each circle describes the total number of ant species collected per site using SoA methods. Ants per site ranged from 1 to 12. Geographic Divisions are noted on the map, as defined by the United States Census Bureau. Samples from Alaska and Hawaii were still being processed at the time of publication, and are therefore not denoted on this map.

we are particularly interested in the species richness of ants that interact with humans in daily life. Moving forward, we seek to build on this protocol by using our network of participants to ask questions in which they can perform not only observations but also experiments.

Better taxonomic certainty: the role of experts.—As described above, previous studies have demonstrated that non-scientists have a particularly difficult time identifying species, largely because they lack training in recognizing key traits for species-level identifications (Kremen et al. 2011). However, identifying North American ants can be a challenge even for ant biologists not

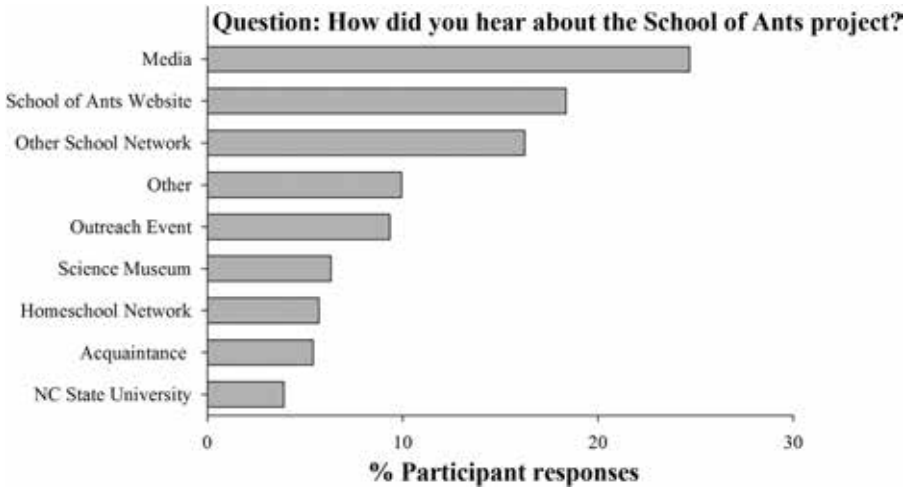

Fig. 7. Summary of participant responses about how they found out about the SoA project.

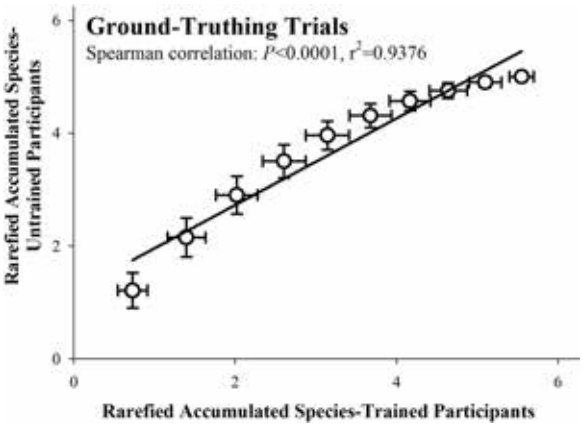

Fig. 8. Correlogram of the accumulated species collected by trained and untrained participants. Untrained participants were undergraduate students in an introductory Ecology course at North Carolina State University (NCSU). Experts were trained undergraduates in the Dunn lab at NCSU. Rarefaction curves were constructed independently for novices and experts using observed species counts and 10,000 iterations. We then plotted the number of accumulated species for untrained participants against the number of accumulated species for trained participants. Error bars represent ±1 SE of the mean.

specialized on a particular region or taxon. Perhaps ten ant biologists in the U.S. would be comfortable identifying all of the ants we encountered in the School of Ants samples. We addressed this issue by investing in the skills of regional taxonomic experts for identifications. This approach allows us to have much greater confidence in the data that is generated from the SoA project than is common for citizen science projects. Adding the extra step of consultation with taxonomic experts does mean that processing samples takes much longer than most non-scientists expect and increases costs of the project. However, the benefits in terms of data quality outweigh these costs.

Data validation.—Many of the criticisms of citizen science are based upon concerns about the errors associated with having untrained participants collect field data (Bradshaw 2003, Gouveia et al. 2004, Royle 2004, Conrad 2006, Fitzpatrick et al. 2009, Crall et al. 2010, 2011, Kremen et al. 2011, Farmer et al. 2012). To address these concerns, we conducted ground truthing trials to assess the efficacy of participant collections. These trials demonstrated that trained and untrained participants were equally effective at collecting ants using the SoA protocol. While unsurprising, these results provide important confirmation of the accuracy of citizen science ant collection using the SoA protocol.

Public outreach and interest.—One criticism of citizen science projects is that they fail to reach broad audiences and therefore garner public interest (Conrad and Daoust 2008). We took this challenge very seriously. We entered into partnerships with local museums so that we could talk to museum visitors about SoA during outreach events (Appendix: Table A1). We also visited schools and gave tours to both teacher and student groups to increase awareness of the project (Appendix: Table A1). We also collaborated with web designers to create a user-friendly website that we update regularly. Finally, we developed outreach materials to increase the reach and visibility of SoA. Most notably, we worked with a science writer to produce a book about the natural history of the ants most commonly collected by SoA participants (Box 1).

Funding.—Another issue associated with citizen science projects is the difficulty in attaining funding (Whitelaw et al. 2003). This issue is even more important for projects like ours, in which experts (both taxonomists and science writers) are contracted to contribute to the success of the project. SoA was part of a broader NSF-funded project aimed at understanding the diversity and distribution of North American ants and has received supplementary funds from diverse sources (including, for example, Burroughs Wellcome fund) to supplement our initial goals. Additionally, we can now leverage the data generated by this initial, labor (and expert) intensive phase of the SoA project to move to a second phase more focused on discrete, participant-led experimental approaches to understanding ant ecology, evolution and diversity (see below).

Future elaborations: scientific goals

Scientifically, we have multiple, specific goals for the future of the SoA project. First, we plan to continue collecting samples from our citizen scientist partners to gain a better understanding of the distribution of ants across US regions that are currently undersampled. We are especially

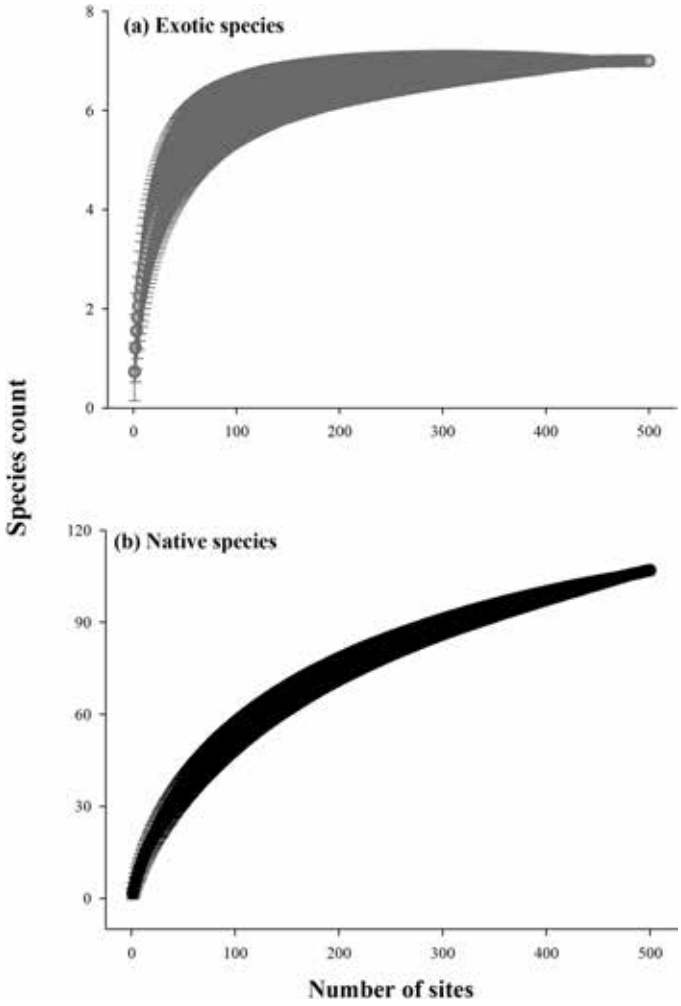

Fig. 9. Rarefaction curves constructed using the observed species counts of (a) exotic and (b) native ants per site (n = 500 sites) and 9,999 iterations. There were a total of 7 exotic ant species and 107 native species collected across all sites. Rarefaction curves were constructed using 9,999 iterations and error bars represent ±1 SD.

interested in expanding our knowledge of the diversity of native ants in the USA. Ultimately, we plan to use SoA data to inform ecological models that can help facilitate the advancement of basic ecological theories.

International.—Similarly, we plan to foster the growth of SoA projects in multiple countries globally. Our early success in Italy demonstrates that the modular nature of this project is adaptable to the needs of researchers and citizen scientists in different countries, and we already have partners in Australia piloting additional modules.

Public participation in experimental design.—We would also like to involve our citizen science partners in designing and conducting simple manipulative experiments across broad spatial scales. This approach to conducting science has the potential to generate important data, but also to teach the general public about the process of science in practice.

Future elaborations: educational goals

Formally, we plan to continue collaborating with local educators to incorporate the natural history of ants and other arthropods into life science curricula for students ranging from K-12 to align with the Next Generation Science

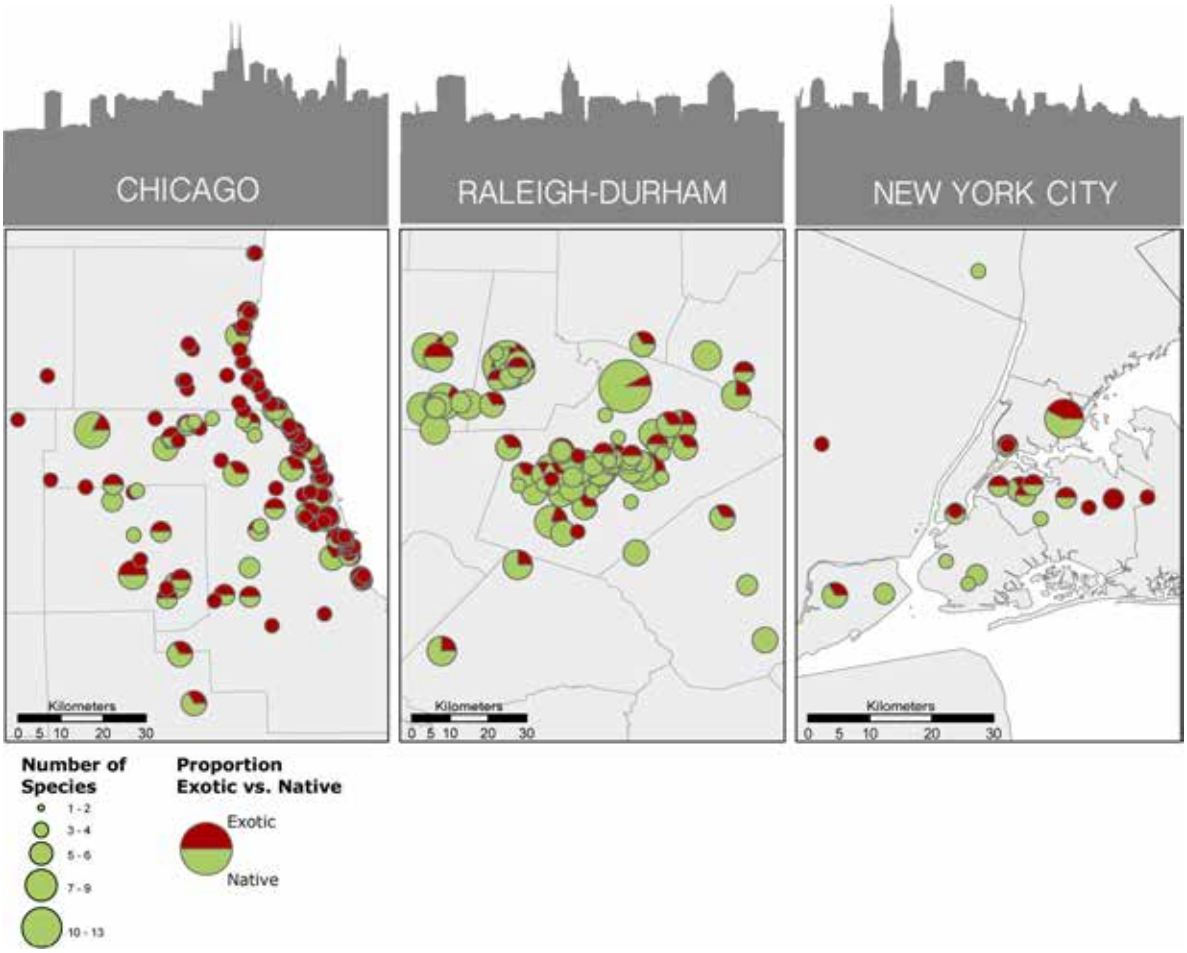

Fig. 10. The relative prevalence of exotic and native ants in Chicago, Raleigh, and New York City. As in Fig. 5, the size of each circle represents the total number of ant species collected at each site. Proportions of exotic to native species are indicated by the shading of the circles. The proportions of native ants are depicted in green, while the proportion of exotic ants are red.

Standards (http://www.nextgenscience.org/search-standards). Connections with collaborators that were established through the SoA teacher workshop in February of 2013 continue to produce new and innovative ways to incorporate ants in the elementary school classroom.

We have also formed collaborations with university instructors to incorporate ant ecology, citizen science and the SoA project into introductory undergraduate science courses (University of FL College of Agriculture and Life Sciences). In association with these classes we are evaluating learning gains associated with SOA and other citizen science activities. Specifically, we are addressing the question of whether active participation in these projects (vs. only learning about the subject in the classroom) increases retention of knowledge about the biology of the organisms and ecosystems involved. Further, we are conducting focus groups with participants to better understand how non-scientists' perceptions of science may change as a result of participating in a citizen science project.

Outside of the classroom, we also have goals for informal science education. Our primary goals are to encourage participation in science-based activities to increase scientific literacy, and specifically in relation to our project, to recruit participants to SOA so we can disseminate more information about our results to a wider audi-

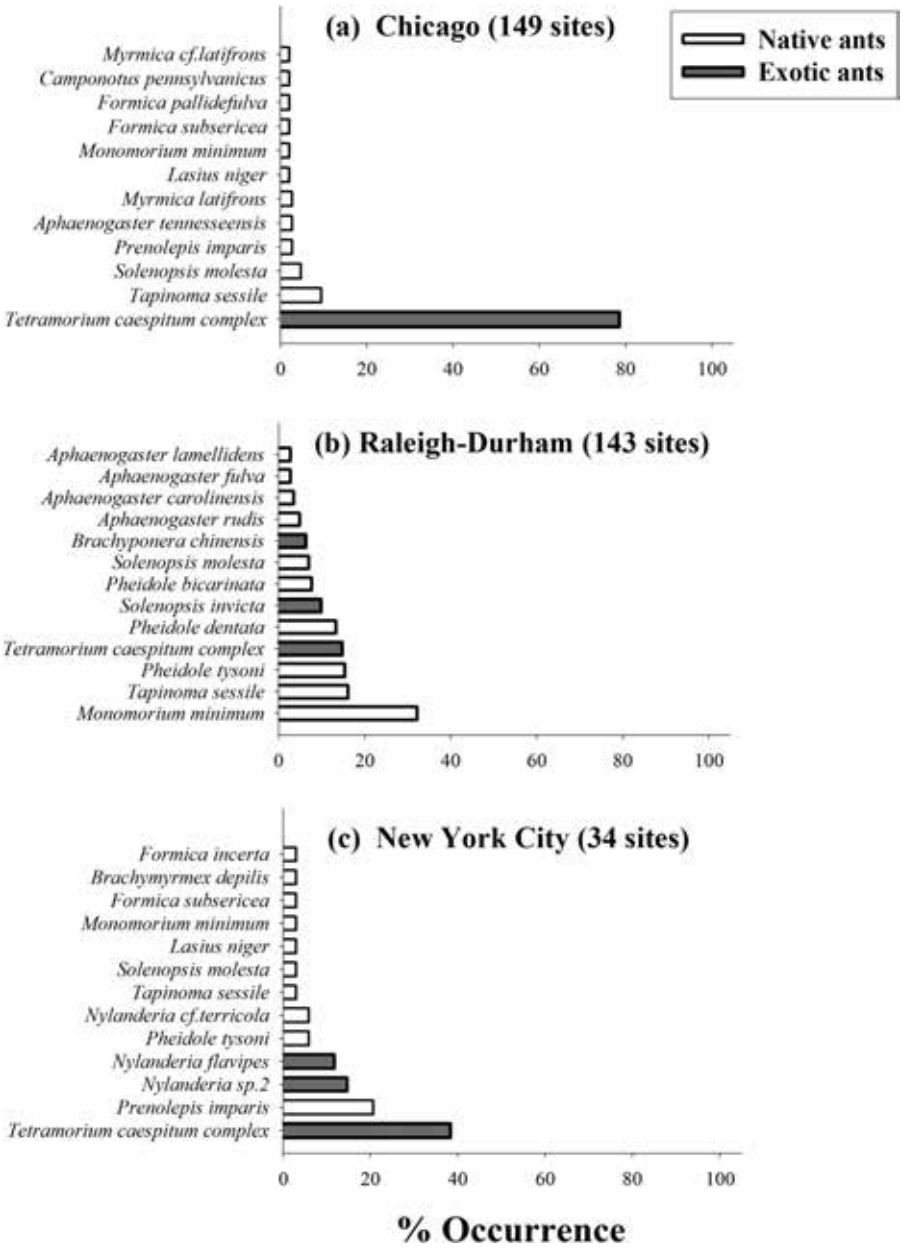

Fig. 11. Occurrences of the most common ants in (a) Chicago, (b) New York City, and (c) Raleigh-Durham. Gray bars represent exotic species and white bars represent native species.

ence. In order to do this we will continue speaking at public events such as science cafes, museum events and science events.

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Supplemental Material

Appendix

Table A1. Description of the outreach activities to-date for the School of Ants project in the USA.

Date	Outreach category	Description of outreach activities	Description of visitors
Sep 2010, 2011, 2012	Museum event (North Carolina Museum of Natural Sciences, NCMNS)	Annual BugFest: School of Ants (SoA) team set up and worked at a display booth (as described above). In 2012, we also highlighted Dr. Eleanor's Book of Common Ants.	~36,000/yr adults and children; event was free and open to the public
Mar 2011	Museum event (NCMNS)	Presentation at NCMNS staff meeting: School of Ants project leaders presented background, aims and protocols of the SoA project to museum staff. Potential outreach collaborations were also discussed.	~50 adults-event was limited to people who volunteered or worked at the NCMNS
Mar 2011	Museum event (NCMNS)	Poster Presentation: SoA project leaders won 1st prize in a science-communication poster competition for their presentation about the project .	~100 visitor; including museum staff, university faculty, grad students, undergrads and the general public
Apr 2012	Museum event (NCMNS)	24-hr Grand opening of the Nature Research Center (NRC): SoA team presented a display table about North American ants; showed visitors specimens of common ants, talked to visitors about ant natural history, backyard ecology, and the SoA project and protocol; gave visitors outreach materials (e.g. brochures, trading cards).	~70,000 adults and children; event was free and open to the public
Apr 2012	Museum event (NCMNS)	NRC grand opening gala: Ant experts worked at SoA display booth (as described above).	Several hundred adults; Black-tie private event attended by Friends of the NCMNS
Apr 2012	Museum event (Morehead Planetarium and Science Center)	Science Café, School of Ants: SoA project leaders discussed the SoA project informally at a local, organized Science Café (http://www.moreheadplanetarium.org/index.cfm?filename=current_science_forums.html&fuseaction=page)	~75 adults; event was free and open to the public.
Sep 2012	Museum event (Florida Museum of Natural History, FLMNH)	Opening of Water Exhibit: SoA FL team presented a display table (as described above) at the opening of a new exhibit	~400 adults and children; event was free and open to the public.
Sep 2012	Museum event (FLMNH)	Ask a scientist event: SoA FL team presented a display table (as described above) and answered questions about ant biology and behavior	~50 adults and children; event was free and open to the public.
Dec 2012	Museum event (NCMNS)	E.O. Wilson visit and launch of Citizen Science Center: SoA team presented a display booth (as described above). We also highlighted Dr. Eleanor's Book of Common Ants.	Hundreds of adults and children.
Jan 2013	Museum event (NCMNS)	2013 Science Online Conference opening reception: The SoA Team set up and worked at a display booth as described above. Also included discussing backyard biology, ant ecology and SoA with science communicators from all over the world.	400 adults; all visitors attended the 2013 Science Online Conference.

Table A1. Continued.

Date	Outreach category	Description of outreach activities	Description of visitors
Feb 2013	Museum event (NCMNS)	Darwin Day Celebration: The SoA team set up and worked at a display booth as described above. This event additionally included i-pads loaded with Dr. Eleanor's Book of Common Ants and a contest to give *Forelius pruinosus*, one of the most common ants collected by SoA citizen scientists, an official common name.	~4,000 adults and children; event was free and open to the public
Mar 2013	Museum event (NCMNS)	BEST (Biotechnology, Engineering, Science and Technology) fest: The SoA team set up and worked at a display booth as described above. Also included an i-pad loaded with Dr. Eleanor's Book of Common Ants, the *F. pruinosus* naming contest, and a remote display of ants under the scanning electronic microscope at NCSU (with a live feed to a technician who manipulated specimens, measured body parts, and answered questions).	6,760 adults and children; event was free and open to the public
Sep 2011	School visit	Presentation at NCSSM High School: SoA team members presented information about ant biology and the SoA project to a high school science class and guided students in performing SoA protocols on school grounds.	30 high school students and 1 teacher
Apr 2011	School visit	Presentation at Cedar Creek Middle School: SoA team member presented information about the SoA project to a "Girls in Science" class and guided students in performing SoA protocols on school grounds.	20 middle school students and 2 teachers
Sep 2011	School visit	Presentation during Cary (NC) Home School Science Fair: SoA team member presented information about the SoA project to students, parents and advisors at Science Fair and guided students in performing SoA protocols in a local park.	~100 home school parents and children
Jun 2011	School visit	Presentation at Chapel Hill Planetarium: SoA team member presented information about the SoA project to students at the Chapel Hill Planetarium's after-school program and guided students in performing SoA protocols on Planetarium grounds.	150 elementary school students
Sep 2012	School visit	Presentation to UFL Undergraduate Entomology Club: SoA project leader (AL) presented information about the SoA to undergraduate students in an intramural entomology club.	25 undergraduate students

Table A1. Continued.

Date	Outreach category	Description of outreach activities	Description of visitors
Nov 2012	School visit	Presentation to second grade classes at Fred Olds Elementary School: Presented a short powerpoint about the SoA project and helped students to perform SoA protocols on school grounds.	60 elementary school students and 2 teachers.
Jun 2011	Teacher training workshop	Hands-on teacher training workshop at Duke Forest Warming Chambers: Members of the SoA team gave teachers a tour of the experimental warming chambers at Duke forest and provided training about using the SOA project in their classroom.	30 High School teachers from across NC selected as Climate Change Fellows
Feb 2013	Teacher training workshop	Day-long workshop to teachers from Orange County (NC) schools: SoA team members trained teachers to collect & identify ants, and discussed ways to incorporate ants into NC life science standards (K-5).	13 teachers (each with ~20 students)
Jul 2011 Sep 2011	Blog post	Myrmecos: Alex Wild first featured the SoA project on his blog in July 2011 and then wrote a blog post with photographs and descriptions of his experiences as a SoA participant. (http://myrmecos.net/2011/09/18/enrolling-in-the-school-of-ants/)	Myrmecos a popular blog about ants and other arthropods from a science writer with ~4900 followers on Twitter.
Jul 2011 Aug 2011	Blog post	Wild about Ants: Roberta Gibson featured the SoA project on her blog in July 2011 and then wrote a blog post with photographs and descriptions of her experiences as a SoA participant. (http://blog.wildaboutants.com/2011/08/16/school-of-ants-update-ant-ecology-lesson/)	Wild on ants is a blog about ant natural history and science. Its Facebook page has 102 likes, and Roberta Gibson has 56 followers on Twitter.
Oct 2011	Blog post	The Dragonfly Woman, Chris Goforth wrote a blog post with photographs and descriptions of her experiences as a SoA participant. (http://thedragonflywoman.com/2011/10/17/school-of-ants/)	The Dragonfly Woman is a popular blog about citizen science and aquatic insects from a science writer with ~700 twitter followers.
Aug 2011 Mar 2013	Online feature	Wired Science: Danielle Venton wrote an online feature for Wired Science describing the SoA project and providing details about becoming a SoA participant. School of Ants was again featured on Wired Science when Bruce Sterling described the project in March 2013.	Wired Science is a popular venue for science writing, with ~925,000 Twitter followers and ~16,500 likes on Facebook.
Aug 2011	Online feature	North Carolina State University Bulletin: David Hunt wrote an online feature for the NCSU Bulletin describing the SoA project.	The NCSU Bulletin publishes articles and announcements related to the academic activities of faculty, students and staff of North Carolina State University.

Table A1. Continued.

Date	Outreach category	Description of outreach activities	Description of visitors
Jul 2012	Online feature	Chicago Tribune: In response to questions following a print/online article about the SoA project (see below), Jessica Morrison and James Janega posted a Q&A primer about the project and collecting ants more generally.	With circulation that is among the top 10 of all daily newspapers published in the United States, the Chicago Tribune is the main source for print news in the Chicago metropolitan area.
Oct 2011	Online/print newspaper	Raleigh News and Observer: Sabine Vollmer wrote an article about kids participating in research at NCSU through the Your Wild Life projects (including SoA). The experiences of a 6-year old boy who participated in SoA were highlighted.	The second largest daily newspaper in North Carolina, Raleigh News and Observer serves the Raleigh-Durham-Chapel Hill region. It has a daily circulation of ~175,000 and a Sunday circulation of ~210,000.
Jul 2012	Online/print newspaper	Chicago Tribune: Jessica Morrison wrote an article about the SoA project and a related undergraduate project in Chicago inspired by SoA.	See above.
Jul 2011	Podcast	Scientific American's 60-second science: Karen Hopkin described the SoA project and encouraged citizens to participate in this minute-long segment.	Scientific American has an active online voice in science writing and podcasts. It has ~575,000 followers on Twitter and 268 likes on Facebook. 60-second science is a daily feature on the Scientific American website.
Jul 2012	Radio	WGN Radio 720: Kristin Decker interviewed project co-PI, Andrea Lucky, about the SoA project.	WGN Radio 720 is a news radio station serving the Chicago area.
Sep 2012	Radio/podcast	WUWM Radio 89.7: Mitch Teich reported about the discovery of Asian Needle Ants in Wisconsin, which was found using SoA protocol and extended the known range of this species far west of where it had been previously known.	WUWM Radio 89.7 is the National Public Radio station for the Milwaukee, WI region.
Jul 2011	Other outreach event	Presentation to "Girls in Science" summer camp group: A member of the SoA team presented information about careers in science and explained the SoA project at a camp focused on encouraging young girls to pursue science. Girls were guided students through SoA protocols at local campgrounds.	30 middle school girls from rural counties of NC
Apr 2012	Other outreach event	USA Science and Engineering Festival: The SoA team set up and worked at a display booth (as described above) in a large Expo Hall.	~150,000 adults and children-event was free and open to the public
Feb 2013	Other outreach event	Florida State Fair-Tampa: Members of the SoA presented a display booth during the 2013 FL State Fair in the Agriculture Hall of Fame. Visitors learned about local insects that are helpful and harmful, and we introduced to SOA as well as other Citizen Science projects relating to insects.	Approx. 50,000 adults and children

Table A1. Continued.

Date	Outreach category	Description of outreach activities	Description of visitors
Feb 2013	Other outreach event	Orange County Math and Science Night: Members of the SoA set up and worked at a display booth that included the SoA materials described above. Additionally, we gave teachers, students and parents scientifically accurate coloring pages of common insects, provided visitors with both Spanish and English versions of the SoA protocol, and projected live ants onto a SmartBoard with a digital microscope.	Several hundred teachers, students, and parents
Mar 2013	Other outreach event	Meeting with coordinators of education and outreach for the NYC Botanical Gardens: Members of the SoA team met with coordinators to discuss the SoA project and ways that it could be incorporated into the citizen science and education efforts at the NYC Botanical Gardens	2 education and outreach coordinators

Table A2. Description of the public outreach events to-date from the SoA module in Italy.

Date	Outreach category	Description of outreach activities	Description of visitors
Academic year 2011–2012	School project	Students of Corridoni Elementary School, Albertelli Elementary School and Newtown Secondary School were involved in sampling ants using SoA protocol in their school yards and in other part of the town.	~150 students and 5 teachers were involved in the project
Academic year 2012–2013	*School project*	Students of Corridoni Elementary School, and Parmigianino Secondary School were involved in sampling ants using SoA protocol in their school yards and in other part of the town. Sampling Kits were distributed to students to sample ants in their summer holidays locations	~ 80 students and 4 teachers were involved in the project
23 April 2012	Blog post	Myrmecos: Alex Wild hosted a blog post of Rob Dunn about the SoA project in Italy and his experience in catching ants with the help of young Italian students. (http://myrmecos.net/2012/04/23/the-mystery-of-the-italian-ants/)	Myrmecos a popular blog about ants and other arthropods from a science writer with ~4900 followers on Twitter.
30 April 2013	Online/print newspaper	Gazzetta di Parma: Licia Gambarelli wrote an article about the SoA project in Parma. The concept of SoA as a citizen science project was highlighted and the SoA event during Europe Week 2013 was presented.	The largest daily newspaper in Parma. It has a monthly circulation of ~38,600.

Table A2. Continued.

Date	Outreach category	Description of outreach activities	Description of visitors
9–13 May 2012	Other outreach event	Europe Week 2012 (Parma): Event organized by EFSA (European Food Safety Authority). The Italian SoA team involved the citizens to sample ants at the University Campus using the SoA kits and protocol.	~ 60 people; the event was free and open to the public
12 May 2013	Other outreach event	Europe Week 2013 (Parma): The Italian SoA team involved the citizens to sample ants at the Ducal Park using the SoA kits and protocol. Free kits were then distributed to sample ants in private gardens.	~ 300 people; the event was free and open to the public