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SCIENTIFIC NOTE

CITIZEN SCIENCE AS A TOOL FOR MOSQUITO CONTROL

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ABSTRACT. In this paper, we share our findings from a 2-year citizen science program called Mosquito Stoppers. This pest-oriented citizen science project is part of a larger coupled natural-human systems project seeking to understand the fundamental drivers of mosquito population density and spatial variability in potential exposure to mosquito-borne pathogens in a matrix of human construction, urban renewal, and individual behaviors. Focusing on residents in West Baltimore, participants were recruited through neighborhood workshops and festivals. Citizen scientists participated in yard surveys of potential mosquito habitat and in evaluating mosquito nuisance. We found that citizen scientists, with minimal education and training, were able to accurately collect data that reflect trends found in a comparable researcher-generated database.

KEY WORDS *Aedes albopictus,* citizen science, natural-human systems, public engagement

Environmental citizen science projects are those where lay persons engage with experts in authentic environment-related research endeavors (Dickinson et al. 2012, Jordan et al. 2015). Outcomes from these types of collaborations include data, research publications, collaborative learning, conservation goal attainment, and possibly increased community capacity to deal with environmental issues (Bonney et al. 2009a; Gray et al. 2012, 2016; Jordan et al. 2012a, 2016). Citizen science has transformed fields where data needs are vast and beyond that which experts can address individually, such as ornithology (Bonney et al. 2009b) and invasive plant detection (Crall et al. 2012, Jordan et al. 2012b).

The Asian tiger mosquito, *Aedes albopictus* (Skuse) is a nonnative species found in California and throughout the southern and eastern USA (Kraemer et al. 2015). This species is a major biting pest throughout its range (Moore and Mitchell 1997) and particularly difficult to control because of its ability for larval stages to grow in very small, transient water-filled spaces such as in trash, tires, and other human environmental manipulations (Unlu et al. 2011). While this species is only of moderate concern as a disease vector in the northeastern region of the USA, it is a competent vector for pathogens such as Zika, chikungunya, dengue, eastern equine encephalitis, West Nile, and yellow fever (Kraemer et al. 2015). Indeed, models support the notion that under explicit, but highly possible conditions, *Ae. albopictus* could result in significant disease outbreaks in densely populated areas of the temperate USA (Manore et al. 2017). Equally as important, however, is that *Ae. albopictus* is a highly bothersome biting best (Moore and Mitchell 1997). Information about *Ae. albopictus* breeding and biting habits in urban environments is, therefore, valuable.

Previous research has shown that researcher access to *Ae. albopictus* larval habitats is difficult because populations of these mosquitoes tend to be found in privately owned spaces, and species presence and absence is highly variable across a fine spatial scale (Unlu et al. 2011, LaDeau et al. 2013, Becker 2014). This inability for researchers to gain access and to survey sites creates a need for citizen engagement in this type of research. Citizen scientists can study their own yards without ownership concern, and represent a larger workforce when compared to the expert workforce. This type of research might best fit a contributory model of citizen science (Shirk et al. 2012), where scientists establish the research question and then engage the public in data collection support as citizen technicians to the research.

Effective mosquito control requires spatially explicit knowledge about where the mosquitoes deposit eggs and where nuisance populations are greatest. Given that these data are difficult to collect at the relevant spatial scales, this study explores the accuracy and potential spatial extent of citizen scientist–generated data to meet these needs. More specifically, we tested the efficacy of a citizen science project with West Baltimore, MD, residents who aided researchers in the collection of *Ae. albopictus* distribution data. Engaging these individuals also served a 2nd goal for the researchers, which was to promote learning and behavioral change with respect to contributions to *Ae. albopictus* spread (e.g., proper trash handling techniques and reducing opportunities for standing water). Below we describe our project and detail the efficacy of the citizen data. We conclude with suggestions for those seeking to engage citizens in mosquito control efforts.

Mosquito Stoppers (hereafter MS) is part of Take Back the Block, a community beautification and science program established for West Baltimore,

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Table 1. Instructions outlines for participation. Each citizen scientist completed 1–4 data-collecting tasks designed to quantify *Aedes albopictus* habitat and population levels in their own yard by collecting data on mosquito habitat and nuisance. Data were turned in monthly, and each record included an address and specific date. As a part of their tasks, all participants were given descriptions and photos of *Ae. albopictus* and other common mosquitoes.

Task	General description
Define and quantify a list of potential breeding habitats[1]	• Monthly location (street address) where data were being collected and the specific date(s) of data acquisition during that month. • Develop a list of potential breeding habitats for mosquitoes in their yard or area surrounding their living space. • Note outdoor temperature and whether water was present for each date-specific record. To collect data: Participants were given an image of potential breeding sites and were told that these habitats can include natural and manmade water sources (trash, tires, play structures, potted plants, etc.).
Nuisance data as a proxy for understanding adult distribution	The protocol prompted that while encounters with mosquitoes differed from day to day, participants were to think about nuisance in general and do the following: • Take data monthly from June to August and to focus on the previous 2 wk from the date of collection. • During each data collection session note how often they spent time outdoors (i.e., beyond a 30-min period) and for how long, whether mosquito-related nuisance affected time outdoors, whether they encountered mosquitoes indoors, and how many complaints they had regarding mosquitoes outdoors near their place of residence. • They were then to go outside and note time to 1st mosquito encounter. Participants rated the experience as "just fine," "irritating," or "intolerable." Using these data, we created a visual comparison with the expert-collected data (see Fig. 1).

[1] In 2014, participants were given petri dishes and droppers in the event that they felt they could count wrigglers (larvae and pupae). This was discontinued in the following years because no one completed this step. Participants were also given the opportunity to "Spot the 1st Mosquito of the Year!" by noting the date that they 1st saw an *Ae. albopictus*.

MD, residents. Activities of this program include community gardening, park cleanups, local surveying, multigenerational discussions (school children, teachers, parents, and grandparents), learning basic advocacy principles, and data gathering and visualization. Because the authors, who were funded as researchers by the National Science Foundation to study the impacts of the citizen science programs, are not members of the West Baltimore community, groups listed in the acknowledgements were essential to integrating the project into the community.

The MS program was established to help meet the scientific goals of the project, which were 1) to determine how different neighborhoods in West Baltimore vary in terms of mosquito nuisance and abundance and 2) to determine the extent to which the removal of mosquito immature habitats contributes to reduced mosquito abundance. The latter is currently ongoing, so we discuss here only results for the former goal.

We recruited for this project using 2 means: 1) distributing flyers and packets to all partners and 2) setting up tables at local block parties, neighborhood events, and community street fairs to sign up participants and distribute materials. Citizen science training included an information packet explaining the protocol, which was also available via weblink (baltimoremosquitoes.weebly.com), or attendance at 2 workshops if they were interested in more information. Because slightly less than half of our participants attended the in-person workshops, we were able to compare responses of those who attended in-person trainings versus those who worked from the paper materials only. We describe here data gathered from 2014 and 2015, which were analyzed in to determine how citizen-gathered data compared to expert data.

In 2014 and 2015, we recruited 70 citizen scientists out of 170 individuals who received an information packet. Fifty-three percent of those recruited completed data collection (37 individuals). Of those 37, we had 10 individuals collect data repeatedly either over the 2 years or in different locations within the same year. All participants that submitted data earned $100 for project participation.

Data describing the 1st mosquito of the year were submitted mostly in year 1. Seven of the 37 participants submitted data; 2 of these sightings were in late March, which is unlikely given the typical emergence time of *Ae. albopictus* (although overwintering is a possibility). Two other mosquitos were described as brown, 1 was described as crawling on an arm, and 2 were described as biting in a mosquito-like fashion and having black-and-white markings, which could be *Ae. albopictus*. Given the lack of consistency with what we would expect of *Ae. albopictus*, with the exception of 2, we decided to discontinue this measure. In most cases, description of the 1st-of-the-year *Ae. albopictus* was indeterminable. It was clear that a series of photos or flyers were

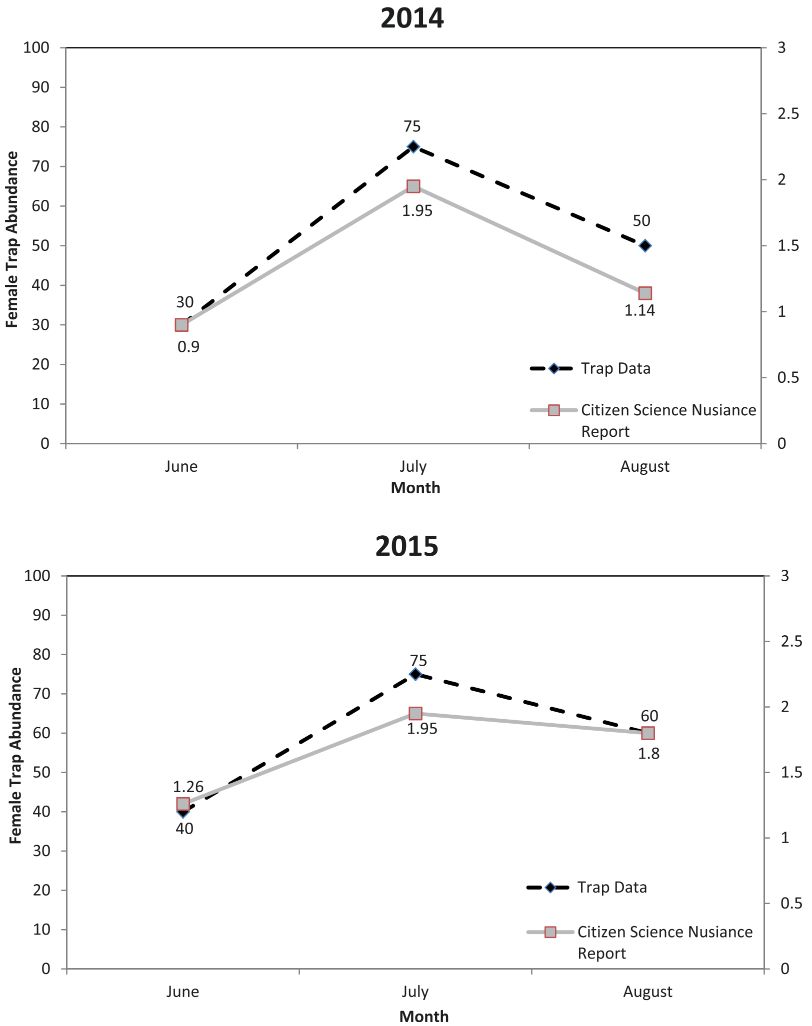

Fig. 1. Dashed lines refer to adult trap data. BG Sentinel traps were deployed with octenol baits and dry ice to attract host-seeking adult mosquitoes. Two traps were deployed at least 25 m apart on 12 blocks across 5 neighborhoods. Traps were deployed for 2 consecutive nights, with catch bags removed and batteries and lures recharged after 24 h. This protocol was followed every 3 wk from May to November. All mosquitoes collected were enumerated and identified to species. The solid lines refer to the citizen science nuisance data, which were collected according to the description in Table 1.

not sufficient for individuals to make reliable identifications.

All 37 individuals provided evidence of potential larval habitat in their study areas (see Table 1 for full protocol). These took the forms of flowerpots, sidewalk holes, persistent yard puddles, structural issues (e.g., failing gutters or leaking faucets), and trash. We did not have analogous expert-collected data collected in these yards for specific comparison but these reports are consistent with what is known from the literature.

We found striking similarity between expert-collected data and participant nuisance patterns, which suggests that citizens were reliable measures of relative abundance and nuisance (Fig. 1). For example, we found that both data sets peaked in July for both years, but in August of 2014, we found a greater decline in abundance/nuisance. We also found no difference between those who met with project personnel and those who worked with packets in terms of project accuracy (the groups were evenly divided). However, those individuals who remained with the project were all trained in person. It is hard to discern whether these were the type of participants who were highly engaged at the beginning, hence attending the in-person sessions, or whether the session influenced their continued participation. No one worked from the web link.

In summary, our data support the notion that citizen scientists can collect reliable data on adult distribution trends with minimal training. Individuals also were able to identify a number of larval habitats.

Less reliable, however, were measures of larval presence and when the 1st *Ae. albopictus* emerged for the season. These data support a dual function of engaging citizens in scientific data collection about environmental issues. First, participants were able to provide data at a finer scale than often produced by scientists, and 2nd, this project encouraged increased compliance with best practices for invasive *Ae. albopictus* control. This dual impact from citizen science has been noted several times with more pleasant flora and fauna species (see Dickinson et al. 2010). In this project, we found that participants were able to be engaged in a project that focused on pests and often around undesired places (e.g., trash). This finding is particularly notable given the difficulties with engaging resident participation/action in urban areas or in pest management studies. While not all individuals were motivated to learn more about mosquitos, many seemed driven by the need to improve the places where they lived (Jordan Sorensen, LaDeau, Biehler; unpublished data). The threat of the Zika virus (in 2016; therefore out of the scope of these data) had intensified this concern (published elsewhere). Concerns about health and the spaces where people live have been shown to be important motivations in citizen science.

Beyond vector control, this project helped residents to collaborate and articulate social concerns. In blocks where individuals reported lower socioeconomic status (SES), individuals were twice as likely to report negative attributes of their neighborhood as those from neighborhoods with higher SES. These attributes most often included increased larval habitats (Dowling et al. 2013, LaDeau et al. 2013). Furthermore, time spent outside differed among groups, meaning different levels of exposure to *Ae. albopictus* (Jordan et al., unpublished data). Prior to engaging in this project, participants reported levels of social responsibility regarding social-ecological issues similar to that of individuals not engaged. After participation, however, differences resulted between the not-engaged and the engaged group, with those who were engaged reporting higher levels of social responsibility (Jordan et al. 2016). Overall, when compared to the cost of paying undergraduate or research personnel to collect these data, fees for the citizen scientists were relatively low (recall $100 per participant).

On a broader note, this project may represent an important progression between citizen science projects that are contributory (e.g., researcher driven) to those that are more collaborative (e.g., stakeholder driven; see Shirk et al. 2012 for greater description). Collaborative-type citizen science projects tend to engage participants longer and more intensely. The group of individuals who persisted in our project was ready to continue the research and their training. With more intensive engagement, it is possible that these individuals could handle more difficult tasks such as larval sampling or spotting the 1st mosquito of the year.

In conclusion, we suggest that citizen science could be an important asset in the study of and fight against mosquitoes as invasive pests and disease vectors. Engagement can vary but with very little intervention, participants can provide reliable data. Next steps for this work include testing the social-ecological effects of breeding habitat removal.

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