

Crowdsourcing for large-scale mosquito (Diptera: Culicidae) sampling

Elin C. Maki, Lee W. Cohnstaedt¹

Abstract—Sampling a cosmopolitan mosquito (Diptera: Culicidae) species throughout its range is logistically challenging and extremely resource intensive. Mosquito control programmes and regional networks operate at the local level and often conduct sampling activities across much of North America. A method for large-scale sampling of two mosquito species using crowdsourcing to network with these local and regional programmes is described. A total of 961 mosquito vector and control districts, health departments, and individual collectors across the United States of America and Canada were contacted in 2011 and 2012 of which 9% positively responded by sending mosquitoes. In total, 1101 unique population samples of *Aedes vexans* (Meigen) and *Culex tarsalis* Coquillett were collected throughout their range in these two countries. *Aedes vexans* outgroup samples were also submitted from Europe and Asia. This is the largest crowd-sourced collection of samples to date.

Résumé—L'échantillonnage de l'ensemble des habitats de moustiques (Diptera: Culicidae) cosmopolites est difficile en terme de logistique et extrêmement coûteux en ressources. Les programmes de lutte contre les moustiques et les réseaux régionaux opèrent au niveau local et conduisent souvent à des activités d'échantillonnage dans la majeure partie de l'Amérique du Nord. En réseau avec ces programmes locaux et régionaux, une méthode d'échantillonnage à grande échelle de deux espèces de moustiques en utilisant la méthode de l'externalisation ouverte (« crowdsourcing ») est décrite. Un total de 961 vecteurs et secteurs de contrôle, les services de santé et les collectionneurs individuels à travers les États-Unis et le Canada ont été contactés en 2011 et en 2012. Ainsi, 9% ont répondu positivement en envoyant des moustiques. Au total, 1101 échantillons de populations uniques d'*Aedes vexans* (Meigen) et *Culex tarsalis* Coquillett ont été recueillis dans l'ensemble de leurs habitats de ces deux pays. Les échantillons hors groupe d'*Aedes vexans* ont également été envoyés à partir de l'Europe et de l'Asie. Il s'agit de la plus grande collection d'échantillons en externalisation ouverte à ce jour.

Mosquito-borne disease field studies are often localised because budgets and logistics limit the scope of mosquito sampling. Information from small studies, while valuable, only informs local management decisions because geographically isolated mosquito populations can be highly variable. For example, vector competence between populations of field-caught mosquitoes has been demonstrated to vary geographically in *Aedes vexans* (Meigen) transmitting Rift Valley fever (Turell *et al.* 2010), *Aedes aegypti* (Linnaeus) transmitting Dengue 2 (Bennett *et al.* 2002), and members of the *Culex pipiens* (Linnaeus) complex transmitting West Nile virus (Vaidyanathan and Scott 2007). However, newly introduced mosquito-borne diseases do not

always remain localised, as was evident by the rapid continental spread of West Nile virus after its introduction in 1999 (Campbell *et al.* 2002; Gubler 2007). Therefore, there is a need for new economic methods to sample mosquito populations throughout their geographic range to better understand and predict the transmission and spread of mosquito-borne diseases on large scales.

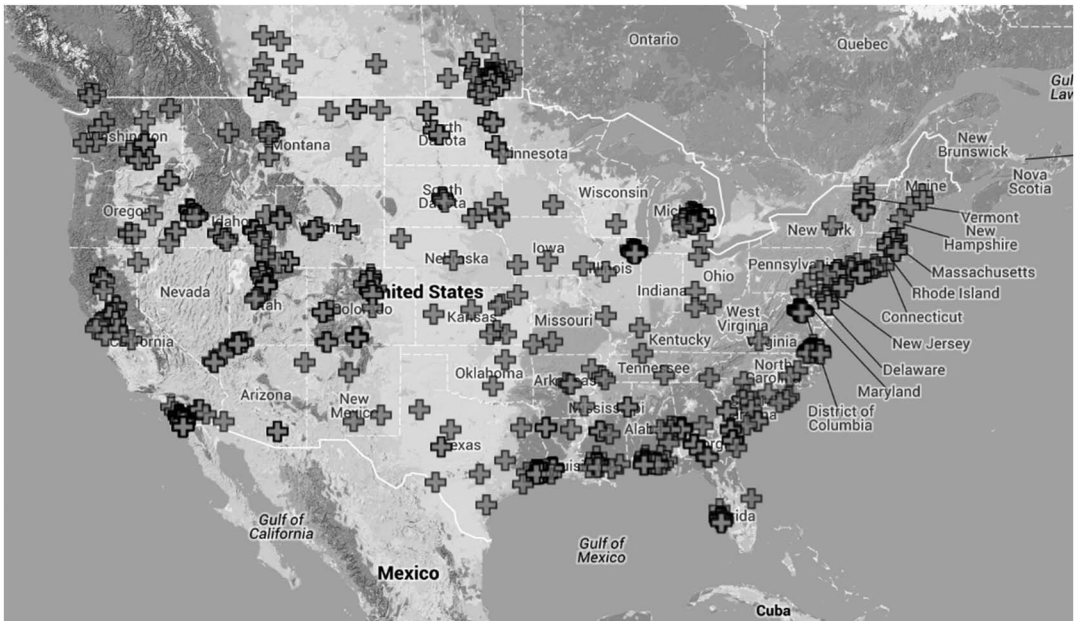
One such method is crowdsourcing. Crowdsourcing is the practice of obtaining needed services, ideas, or content by soliciting contributions from a large group of people and especially from the online community, including via citizen science, which uses untrained volunteers. Crowdsourcing has long been a cost-effective tool to gather data or biological

Received 24 September 2013. Accepted 24 January 2014. First published online 29 May 2014.

E.C. Maki, L.W. Cohnstaedt¹ Center for Grain and Animal Health Research, Agricultural Research Service, United States Department of Agriculture, 1515 College Ave., Manhattan, Kansas 66502, United States of America

Corresponding author (e-mail: Lee.Cohnstaedt@ars.usda.gov).
Subject editor: Kateryn Rochon
doi:10.4039/tce.2014.27

Fig. 1. Distribution map of all North American mosquito samples received in 2011 and 2012. Outgroup samples were also received from South Korea, Japan, Guam, American Samoa, Thailand, and the Netherlands. Symbols are overlaid in areas with greater fine scale sampling. Darker shaded symbols represent multiple collection sites in a small area.



material for large-scale ecology, conservation, or genetic studies for a wide range of organisms, including insects (Schmeller *et al.* 2008; Dickinson *et al.* 2010; Catlin-Groves 2012). This project demonstrates how crowdsourcing can be used to network with local mosquito surveillance programmes to accomplish a large-scale mosquito sampling project with limited resources.

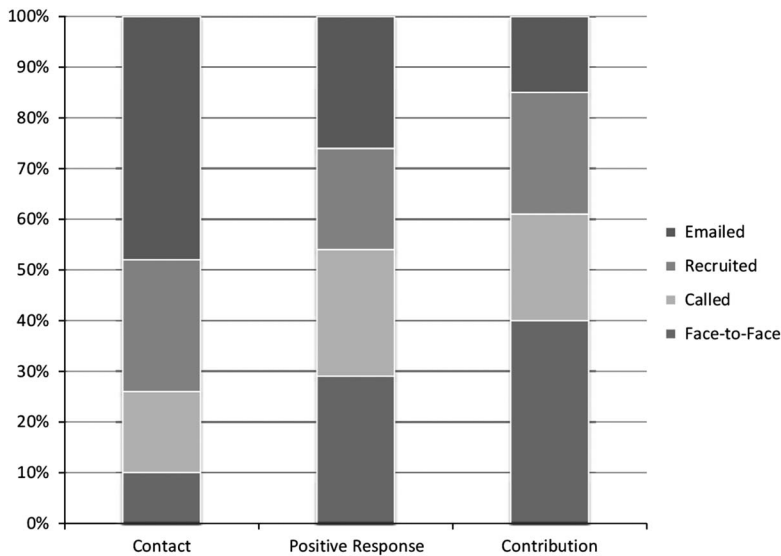
In 2011, contacts were accumulated from multiple sources, including regional and state-wide vector control district contact lists, health department contact information available on the internet, and professional acquaintances. Initial requests for samples were made by telephone or e-mail. People who committed to sending mosquitoes were followed up with an e-mail containing a specific protocol and data collection sheet. Requests were made for at least 50 individual adult female *A. vexans* or *Culex tarsalis* Coquillett mosquitoes. Contacts were provided with sample vials, traps, alcohol, and prepaid mailers on request. Requests for samples were repeated by telephone and e-mail in 2012. After identifying large gaps in the data set in 2011, attempts were made to find untrained volunteers by asking previous contacts for referrals

in 2012. Combining the collections from 2011 and 2012 and targeting poorly sampled areas resulted in thorough coverage of the United States of America. There are highly clustered collections where more intense mosquito monitoring is already occurring near populated areas.

A total of 1101 unique (defined both spatially by at least 5 km separation and temporally by day, Fig. 1) mosquito populations were received from 40 states and outgroup mosquitoes were received from five countries outside of the United States of America and Canada. Overall, 960 individuals were contacted and 110 shipped samples. Most people were contacted by e-mail (48%), although professional acquaintances (face-to-face) had the highest rate of response with 29% of those contacted sending samples. However, the majority (60%) of the total samples received came from individuals unknown to laboratory members (Fig. 2). On average, each responding individual sent ~10 samples.

Although the overall response rate was only 9%, this study demonstrates the feasibility of sampling on a large scale within a limited period of time using crowdsourcing to connect with

Fig. 2. The proportion of individuals by each method that were contacted, responded positively, and the proportion of unique samples received (defined both spatially by at least 5 km separation and temporally by day). Recruited individuals were contacted by others on our behalf. A total of 959 people were contacted. A total of 110 individuals responded positively to the request for mosquitoes and sent 1101 samples.



existing local mosquito control districts. While face-to-face or personal contacts were the most likely to respond and sent the greatest number of samples, a large number of third party contacts were recruited to this project and responded positively. In total, this snowball effect recruited an additional 251 people, or 26% of the total people contacted. These contacts made up a significant portion of those positively responding (20%, Fig. 2). Among the recruited individuals, eight of those positively responding were untrained volunteers or citizen scientists in geographically vital but difficult-to-access locations. These individuals were provided with extra resources, including traps with attractants, and returned unsorted trap catches. Despite the added cost to ship resources to untrained individuals, using citizen scientists in this manner may be a useful method of obtaining samples from otherwise hard-to-reach but vital locations for sampling coverage and considering the high cost of sending an individual to a remote location. Finally, it should be noted that although 84 individuals positively responded in 2011, only 21 positively responded to a second request for samples in 2012, indicating that collection fatigue is highly likely if repeated sampling is necessary.

At the local level, mosquito and vector control districts have the resources and experience to recognise and respond to changes in vector populations. Also, they are the only feasible way to maintain adequate surveillance and control of endemic and introduced diseases and vectors. However, vector control districts are set up by state or local governments and have a mandate to address issues within their state or region while mosquito-borne diseases do not respect these anthropocentrically defined borders. This study demonstrates that crowdsourcing these control districts, as well as others in the field, including untrained volunteers, can be effectively used to accomplish a large-scale sampling project.

Acknowledgements

The authors thank the entomologists and vector biologists who participated in this study (Appendix 1). They also thank Agricultural Research Service employees Bill Yarnell, Kyle Schweisthal, and Darren Snyder for collecting mosquitoes and contacting others. Finally, we thank Christina Mangiapani and Kateryn Rochon for providing edits that significantly strengthened this paper.

References

- Bennett, K.E., Olson, K.E., De Lourdes Munoz, M., Fernandez-Salas, I., Farfan-ale, J.A., Higgs, S., *et al.* 2002. Variation in vector competence for Dengue 2 virus among 24 collections of *Aedes aegypti* from Mexico and the United States. *American Journal of Tropical Medicine and Hygiene*, **61**: 85–92.
- Campbell, G.L., Marfin, A.A., Lanciotti, R.S., and Gubler, D.J. 2002. West Nile virus. *The Lancet Infectious Diseases*, **2**: 519–529.
- Catlin-Groves, C.L. 2012. The citizen science landscape: from volunteers to citizen sensors and beyond. *International Journal of Zoology*, **2012**: 1–14.
- Dickinson, J.L., Zuckerberg, B., and Bonter, D.N. 2010. Citizen science as an ecological research tool: challenges and benefits. *Annual Review of Ecology, Evolution, and Systematics*, **41**: 149–172.
- Gubler, D.J. 2007. The continuing spread of West Nile virus in the Western Hemisphere. *Clinical Infectious Diseases*, **45**: 1039–1046.
- Schmeller, D.S., Henry, P.Y., Julliard, R., Gruber, B., Clobert, J., Dziock, F., *et al.* 2008. Advantages of volunteer-based biodiversity monitoring in Europe. *Conservation Biology*, **23**: 307–316.
- Turell, M.J., Wilson, W.C., and Bennett, K.E. 2010. Potential for North American mosquitoes (Diptera: Culicidae) to transmit Rift Valley fever virus. *Journal of Medical Entomology*, **47**: 884–889.
- Vaidyanathan, R. and Scott, T.W. 2007. Geographic variation in vector competence for West Nile virus in the *Culex pipiens* (Diptera: Culicidae) complex in California. *Vector-Borne Zoonotic Diseases*, **7**: 193–198.
- Valkyrie Piper Kimball, Marin/Sonoma Mosquito District, Cotati, California, United States of America
- Placer Mosquito and Vector Control District, Roseville, California, United States of America.
- Alamosa Mosquito Control District, Alamosa, Colorado, United States of America.
- Sarah Bevins, Colorado State University and the National Wildlife Research Center, United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, Fort Collins, Colorado, United States of America.
- Colorado Mosquito Control, Loveland, Colorado, United States of America.
- John Anderson, The Connecticut Agricultural Research Station, New Haven, Connecticut, United States of America.
- Bob Betts, Escambia County Mosquito Control, Cantonment, Florida, United States of America.
- Wade M. Brennan, Sarasota County Mosquito Management, Sarasota, Florida, United States of America.
- Rosmarie Kelly, Public Health Entomologist, Georgia Department of Public Health, Atlanta, Georgia, United States of America.
- Mark Blackmore and Lauren Smith, Valdosta State University, Valdosta, Georgia, United States of America.
- Jason Kinley, Gem County Mosquito Abatement District, Emmett, Idaho, United States of America.
- Desiree Keeney, Field Operations Manager, Ada County Mosquito Abatement District, Meridian, Idaho, United States of America.
- Ed Burnett, Canyon County Mosquito Abatement District, Nampa, Idaho, United States of America.
- Kirk Tubbs, Twin Falls County Pest Abatement District, Twin Falls, Idaho, United States of America.
- Desplaines Valley Mosquito Abatement District, Lyons, Illinois, United States of America.
- Tom C. Velat, Forest Preserve District of DuPage County, Wheaton, Illinois, United States of America.
- Vanderburgh County Health Department, Evansville, Indiana, United States of America.
- Lyric Bartholomay and Brendan Dunphy, Iowa State University Medical Entomology Laboratory, Ames, Iowa, United States of America.
- Scott Willis and Jill Hightower, Calcasieu Parish Mosquito Control, Lake Charles, Louisiana, United States of America.

Appendix 1

Citations as requested. To address privacy concerns of contributors anyone cited in the appendix was required to opt-in. Not all contributors chose to be cited.

Tanja McKay, Arkansas State University, Jonesboro, Arkansas, United States of America.

Michael Riehle, Frank Ramberg, Department of Entomology, University of Arizona, Tuscon, Arizona, United States of America.

John Albright, Vector Ecologist and Kendra Angel-Adkinson, Assistant Vector Ecologist, Shasta Mosquito and Vector Control District, Anderson, California, United States of America.

Laura Krueger, Orange County Vector Control District, Garden Grove, California, United States of America.

Bruce Kirkpatrick, Alameda Mosquito Abatement District, Hayward, California, United States of America.

Chuck Palmisano, Director, St. Tammany Parish Mosquito Abatement District, Slidell, Louisiana, United States of America.

Kirk Shively, Wildlife Disease Biologist, United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Wildlife Disease Programme, Augusta, Maine, United States of America.

Linda Williams, Country Knitting of Maine, Madison, Maine, United States of America.

Timothy D. Deschamps, Executive Director, Curtis R. Best, Staff Entomologist, Frank H. Cornine III, Field Biologist, Juliana L. Miller, Entomologist, Central Massachusetts Mosquito Control Project, Northborough, Massachusetts, United States of America.

Mary J. McCarry, Biologist, Bay County Mosquito Control, Bay City, Michigan, United States of America.

Michigan Department of Natural Resources, Wildlife Division, Lansing, Michigan, United States of America.

Randall Knepper and William Stanuszek, Saginaw County Mosquito Abatement Commission, Saginaw, Michigan, United States of America.

William W. Stanuszek, Saginaw County Mosquito Abatement Commission, Saginaw, Michigan, United States of America.

Thomas Wilmot, Midland County Mosquito Control, Sanford, Michigan, United States of America.

Cascade County Weed and Mosquito Management, Great Falls, Montana, United States of America.

Shawn Schafer, North American Deer Farmers Association, Turtle Lake, North Dakota, United States of America.

Warren County Mosquito Extermination Commission, Oxford Township, New Jersey, United States of America.

Ary Farajollahi and Isik Unlu, Mercer County Mosquito Control, West Trenton, New Jersey, United States of America.

Mark A. DiMenna, City of Albuquerque, Environmental Health Department, Urban Biology Division, Albuquerque, New Mexico, United States of America.

Amy Isenberg, Environmental Biologist, Rockland County Department of Health, Pomona, New York, United States of America.

Bobbi Jo Kahl, Public Health Sanitarian, Oneida County Health Department, Utica, New York, United States of America.

David W. Gilmore, Environmental Health Director, Oneida County Health Department, Utica, New York, United States of America.

Scott R. Campbell, Arthropod-Borne Disease Laboratory, Suffolk County Department of Health Services, Yaphank, New York, United States of America.

Brunswick County Operation Services/Mosquito Control Division, Bolivia, North Carolina, United States of America.

Craig R. Hicks, Wildlife Disease Biologist, United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, Reynoldsburg, Ohio, United States of America.

Mary K. Daniels, Public Health Entomologist, Ohio Department of Health, Zoonotic Disease Programme, Reynoldsburg, Ohio, United States of America.

Will Reeves, United States Air Force School of Aerospace Medicine, Wright-Patterson Air Force Base, Ohio, United States of America.

Heather Ketchum and Matthew Wegener, University of Oklahoma, Norman, Oklahoma, United States of America.

West Millard Mosquito Abatement District, Delta, Utah, United States of America.

Robert C. Mower, Utah County Mosquito Abatement, Provo, Utah, United States of America.

Salt Lake City Mosquito Abatement District, Salt Lake City, Utah, United States of America.

South Salt Lake Valley Mosquito Abatement District, West Jordan, Utah, United States of America.

Alan C. Graham, Vermont Agency of Agricultural Laboratories, Waterbury, Vermont, United States of America.

Joshua Smith, Fairfax County Health Department, Fairfax, Virginia, United States of America.

Justin Anderson, Department of Biology, Radford University, Virginia, United States of America.

David N. Gaines, Public Health Entomologist, Virginia Department of Health, Richmond, Virginia, United States of America.

Charles Abadam, Jay Kiser, Jamie Durden, and Mindy Russell, City of Suffolk, Virginia, United States of America.

Jennifer D. Pierce and Dreda A. Symonds, City of Virginia Beach Mosquito Control Biology Laboratory, Virginia Beach, Virginia, United States of America.

Elizabeth Dykstra, J.M. Brauner, and S. Kunze, Zoonotic Disease Programme, Washington State Department of Health, Olympia, Washington, United States of America.

Benton County Mosquito Control District, West Richland, Washington, United States of America.

Pete Zani, University of Wisconsin-Stevens Point, Stevens Point, Wisconsin, United States of America.

Culex Environmental Ltd., www.culex.ca, Vancouver, British Columbia, Canada.

Robbin Lindsay and Mahmood Iranpour, Public Health Agency of Canada, Winnipeg, Manitoba, Canada.

Taz Stuart, City Entomologist, The City of Winnipeg, Insect Control Branch, Winnipeg, Manitoba, Canada.

City of Regina, Saskatchewan, Canada.

Heung-Chul Kim, Senior Research Entomologist, 5th Medical Detachment, 168th Multifunctional Medical Battalion, Unit 15247, APO AP 96205-5247, South Korea.

Terry A. Klein, Regional Vector-borne Disease Surveillance Programme Manager Public Health Command Region-Pacific/65th Medical Brigade Unit 15241, APO AP 96205-5281, South Korea.