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

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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

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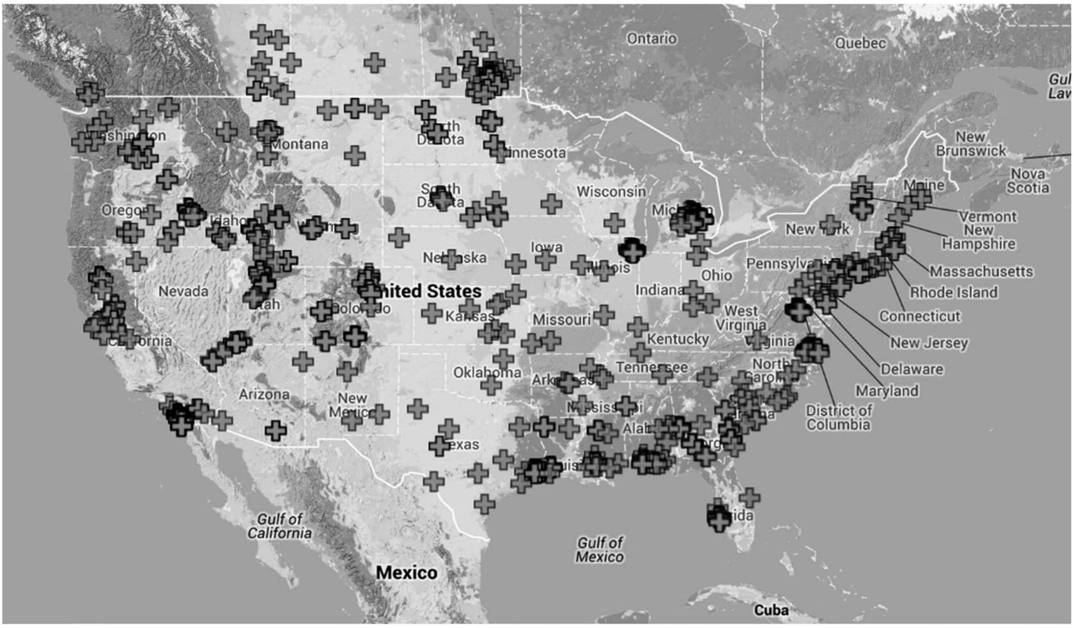
Fig. 1. Distribution map of all North American mosquito samples received in 2011 and 2012. Outgroup samples were also received from South Korea, Japan, Guam, American Samoa, Thailand, and the Netherlands. Symbols are overlaid in areas with greater fine scale sampling. Darker shaded symbols represent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



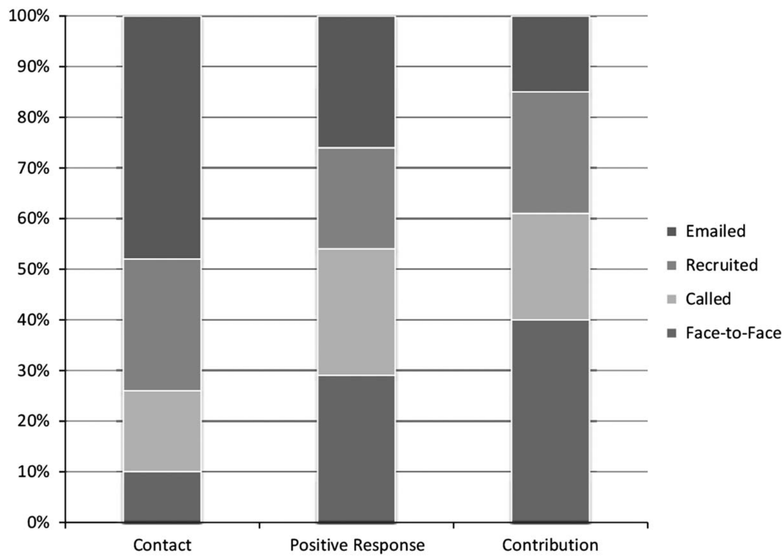
material for large-scale ecology, conservation, or genetic studies for a wide range of organisms, including insects (Schmeller *et al.* 2008; Dickinson *et al.* 2010; Catlin-Groves 2012). This project demonstrates how crowdsourcing can be used to network with local mosquito surveillance programmes to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

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Appendix 1

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