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Global Mosquito Alert:

Building Citizen Science Capacity for Surveillance and Control of Disease-Vector Mosquitoes

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Executive Summary

According to the World Health Organization (WHO), there are over 500 million cases of mosquito-borne illnesses such as Zika, yellow fever, chikungunya, dengue, malaria, and the West Nile virus each year. Proactively managing these diseases requires acquiring information on the current and predicted presence and distribution of disease-vector mosquitos, including information on adults, larvae, and breeding habits. But traditional monitoring methods cannot always deliver information on the desired scale and resolutions required and often fail to engage or educate the public. Citizen science, a process where the public contributes to scientific research, can augment information from other sources to help researchers, government officials, and the general public understand and manage risks.

In May 2017, the Woodrow Wilson International Center for Scholars worked with the European Citizen Science Association (ECSA) and the United Nations Environment Programme (UN Environment) to host a workshop to discuss the use of citizen science for coordinated mosquito-vector monitoring. This workshop culminated in the formation of the Global Mosquito Alert Consortium (GMAC), the first global platform dedicated to advancing citizen science to tackle mosquito monitoring. GMAC will be an open, common set of protocols and toolkit that is augmented with modular components created to meet both global and local research and management needs. Each protocol associated with the Global Mosquito Alert Consortium will be structured around a common list of "core" fields. These fields may be augmented by additional information collected by local projects. A toolkit will list the protocols, supporting technologies, and resources such as guidance on volunteer management, information on working with decision-makers including public health agencies and pest managers, and lesson plans for bringing citizen science into educational environments. Data associated with the Global Mosquito Alert Consortium will be made available through the dynamic UN Environment platform Environment Live.

The future of citizen science lies in coordination and partnership. The Global Mosquito Alert Consortium seeks to leverage the activities of existing citizen science projects to dramatically improve local, national, supra-national, and global research and management of disease-vector mosquitos. GMAC also hopes to become a model for coordination and partnership that emerging consortia of citizen science projects tackling other challenges can leverage and improve.

With the growth of citizen science comes the challenge of coordinating people, projects, and data. These challenges also present an opportunity. Through the use of data and metadata standards and other mechanisms to promote interoperability, data can support multiple research questions, allowing citizen science to help address ever-grander issues and problems on local, regional, national, and global scales.

Global Mosquito Alert:

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Introduction

"The benefits we obtain from the citizens' participation by sending their observations and reports using the mobile app not only help us to do better as professionals but it's also a way to involve the community in the work and actions that we develop from the public agencies."

– Lidia Fernandez, Public Health Agency, City of Barcelona, discussing the citizen science project Mosquito Alert.[1]

In 2016, the first detection of locally transmitted Zika virus in the continental United States exposed fractures in the way the U.S. monitors and combats disease-vector mosquitoes – fractures that are found in mosquito control mechanisms throughout the world. These mechanisms are often patchworks of uncoordinated surveillance and control strategies governed by counties and cities with limited funding and little information sharing across jurisdiction.[2] They are easily overrun by fast-moving invasive mosquito species with far fewer scale-dependent constraints. In the face of this problem, an active public has often proved critical to mosquito surveillance, and a growing number of citizen science initiatives have been rising to bolster weak defenses. Recent work suggests that citizen science may well be positioned to "revolutionize mosquito-borne disease surveillance worldwide."[3]

There are already a small handful of citizen science projects engaged in mosquito-vector monitoring. The Mosquito Alert project, based in Spain, has been using expert-validated citizen science reports for research, surveillance, and management of tiger mosquitoes and yellow fever mosquitoes since 2014. In spring 2017, the US-based GLOBE Observer Mosquito Habitat Mapper was launched to help volunteers around the world find and map mosquito breeding sites. Most recently, Zanzamapp helped generate news of mosquito presence, density, and distribution during the fall 2017 outbreak of chikungunya in the Lazio Region of Italy. Zanzamapp researchers are now working with stakeholders including municipal leaders, doctors, science teachers, and the public at large to understand how the project could be used in a longer-term surveillance system.

All of these projects help targeted populations or local communities monitor vectors in ways that make sense to them. All have similar requirements regarding the need to understand and engage a range of stakeholders, including motivating volunteers and working with decision-makers. And if these projects collect compatible or interoperable data, information from each can be combined to support national and global scale research, decision-making, and vector control. But realizing the full potential for citizen science mosquito monitoring requires a global network to support and promote communication, collaboration, and mutual support.

With this in mind, the Woodrow Wilson International Center for Scholars, the European Citizen Science Association (ECSA) and the United Nations Environment Program (UN Environment) organized a workshop to bring together citizen science projects from around the world focused on disease-vector mosquitoes, along with topical experts in vector monitoring, citizen science, public health and data management (Appendix A). Participants travelled from Cyprus, Denmark, Germany, Hong Kong, Italy, the Netherlands, Spain, the United Kingdom, and the United States, including Puerto Rico. The goal of the workshop was to develop a common vision for engaging the public as partners in monitoring and combatting disease-vector mosquitoes. The outcome was the formation of a new Global Mosquito Alert Consortium (GMAC).

The collaborative vision advanced by workshop participants is: *"The Global Mosquito Alert Consortium is a new citizen science initiative that aims to leverage networks of scientists and volunteers for the global surveillance and control of the mosquito species known to carry the following diseases: Zika, yellow fever, chikungunya, dengue, malaria and the West Nile virus. Global Mosquito Alert will be an open, common set of protocols and toolkit that is augmented with modular components created to meet both global and local research and management needs."*

The Global Mosquito Alert Consortium agreed to develop and advance four canonical data collection protocols involving citizen scientists. To promote research on national, supra-national, and global scales, each protocol will be structured around a common list of "core" data types or fields. These fields may be augmented with additional information collected by different citizen science projects to suit local monitoring and control needs. In addition to these protocols, a toolkit will list and link to interoperable data collection technologies that support each distinct protocol. The toolkit will also contain resources including guidance on volunteer management, information on working with decision-makers including public health agencies and pest managers, and lesson plans for bringing Global Mosquito Alert into educational environments.

To promote research on national, supra-national, and global scales, each protocol will be structured around a common list of "core" fields.

This consensus document reports on the outcomes of the April 2017 workshop and subsequent discussions, and details the shared future agenda of the Global Mosquito Alert Consortium.

Vector Surveillance, Control, and Citizen Science

Managing vector mosquito populations involves two main tasks:

1. Surveillance, or monitoring the presence and distribution of the populations including through proxy variables, and improving the knowledge on the behavioral and functional ecology of the species (from habitat selection to biting activity); and,

2 Control, implementing initiatives focused on the reduction of populations. This includes raising awareness to minimize the proliferation of breeding sites- e.g., small water containers in private areas- and, in public spaces, applying treatments repeatedly on known breeding sites such as storm drains and urban fountains to avoid the development of the larvae into adults. Control can be guided by citizen input or based on accumulated knowledge about the main risk areas in a given city, municipality, or other territory of interest.

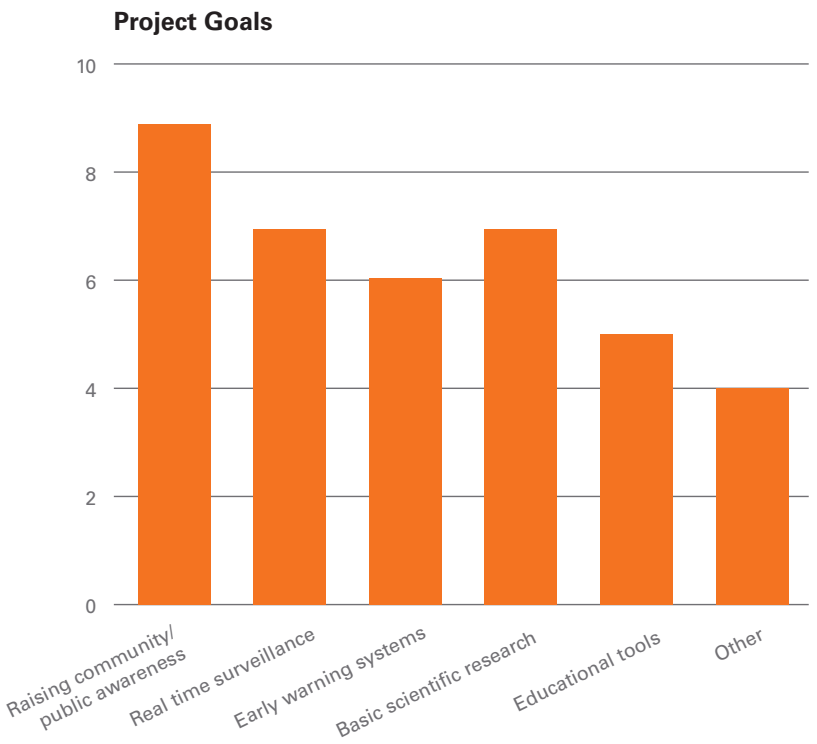
Citizen science can support both vector surveillance and control. Using new technologies like smartphones and the Internet, volunteers can detect and monitor vector species at large regional scales that would be impossible to capture through traditional monitoring methods. In areas where species are known to reside, citizen science data can be used in real-time incidence maps. This is especially true in large cities where epidemiological risks are higher, so that control becomes more cost-effective and manageable. If participation is high, the resolution can also be high enough to be useful for epidemiological control. For example, if diseased individuals are present, a mosquito-free zone needs to be created to avoid contact between the mosquitoes and infected individuals, especially in the viremic phase when the disease can be transmitted.

Breeding grounds for mosquitos include pools not being cared for, rain water containers, and other small water containers under plant pots for instance.

One important goal of citizen science is to educate the public and raise awareness.[4] Knowledge is also a key component of vector management, as the public is needed to engage in prevention measures to augment and amplify municipal control. Finally, citizen science for mosquito monitoring can also advance scientific research. Because citizen science supports data collection at unprecedented spatial and temporal scales, including on private land that may not be accessible to researchers in some jurisdictions, species are often detected in unexpected areas or regions far away from their core distribution area.[5]

Many of the citizen science projects already engaged in mosquito monitoring have multiple goals (Figure 1). Depending on the risk status of a region, citizen science can be implemented differently, putting more weight, for example, on surveillance or control actions, or on raising awareness by different channels including through social networks, media, web pages, mobile applications (apps), and educational or volunteering training programs. If sustained over the years, citizen science can provide high quality massive datasets to model vector species distributions and predict health risk, as well as to quantitatively assess the effectiveness of various control strategies. Opportunities also exist to link mosquito distribution data to information on abiotic factors, such as climate and weather; and, to information on human health, including reports of mosquito-borne disease.

Figure 1. Results from a pre-workshop survey



Results from a pre-workshop survey of 12 existing projects reveal a range of goals. Most common are raising awareness, conducting real-time surveillance, and supporting basic scientific research. "Other" goals include educating government officials and supporting the open data movement.The authors are not currently aware of citizen science projects that are also obtaining data on volunteer health, though many consider this the logical next step.

Global Mosquito Alert Data

The April 2017 workshop was convened to help coordinate the existing projects with e-infrastructure, networks, and communities that utilize citizen science for mosquito monitoring, surveillance or control. Each project, while employing a similar approach to involving the public, has slightly different goals and uses slightly different methodologies. Still, many activities converge around four types of protocols that support a diversity of monitoring activities. Key requirements for each individual protocol, as well as common shared fields, are described below.

Four Canonical Protocols for Global Mosquito Alert

Global Mosquito Alert supports and endorses four canonical monitoring protocols: (1) Real-time vector mosquitos; (2) Larvae or breeding sites; (3) Bites or nuisance; and, (4) Biodiversity specimens or DNA. Each protocol is designed with a small set of common, "core" elements to be captured by all data collection partners participating in the global consortium. Each project is also encouraged to build on these core protocols to collect additional information relevant to local, regional, or national needs.

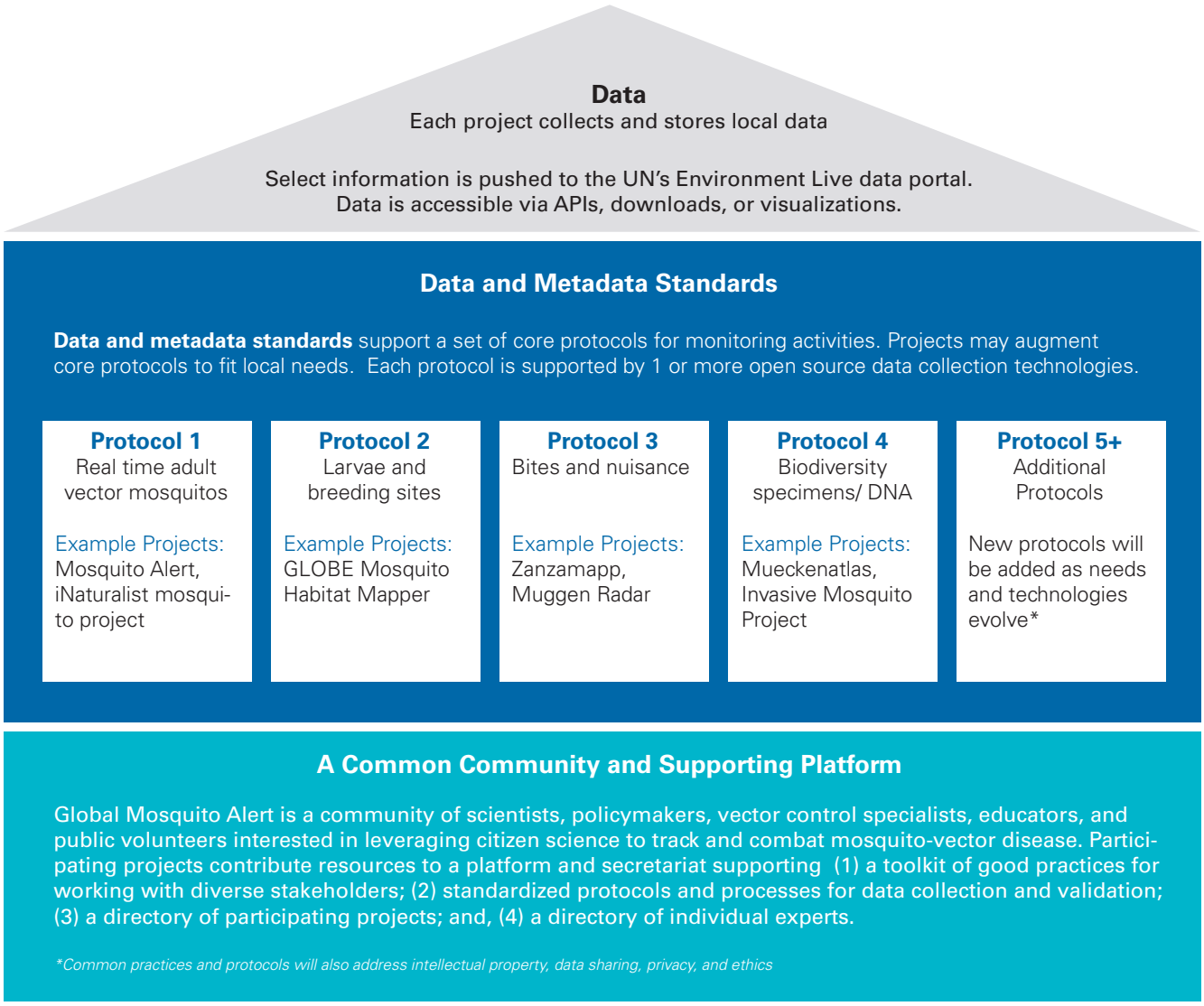
The four protocols, an initial list of key elements for metadata documentation, are based on the ongoing activities of different citizen science projects monitoring vectors at local, regional, national, and global scales. These protocols are presented as an initial, minimum set of requirements, and will be refined and finalized over time. As the Global Mosquito Alert Consortium continues to grow a key challenge will be ensuring that the common core data collection and documentation protocols are compatible with existing domain-specific standards, such as Darwin Core for Biodiversity monitoring, and general standards, such as those advanced by the International Organization for Standardization (ISO).

Protocol 1: Real-time targeted vector mosquitos. Data will be submitted in real time, through a mobile application or another web interface, with timestamp and geolocation. A notification system should alert participants to new vectors in their area. Alternately, in the "extreme" citizen science version volunteers could submit their written observations via postal mail. Core tasks and data collection protocols include *record of the targeted species; picture(s) or sound profiles of the targeted species*; information on sampling effort; and, notes. Adult mosquitoes located with this protocol can lead to a specimen for protocol 4 (see data integration below).

Protocol 2: Larvae and breeding sites. Data submission as in Protocol 1. Core tasks and data collection protocols include *record of breeding sites*, including *site category, habitat description*, and *genus identification; designation of location as public or private; information on sampling effort;* and, *notes.* Larval data can also lead to a specimen for protocol 4 (see data integration below).

Protocol 3: Bites/nuisance. Data submission as in Protocol 1. Core tasks and data collection protocols include quantifying the nuisance caused by mosquitoes (the *number of mosquitoes buzzing around and/or biting an individual)* over a period of observation; the *location* of the observer, *designation of location* as indoor or outdoor; *sampling effort* as reported by the observer (could include start and stop time logged by the application or other method); and, *notes.* Ideally bites/nuisance data can provide an entry point to protocol 1 (see data integration below).

Protocol 4. Biodiversity specimen/ DNA. Data (specimens) will be submitted via postal mail. Participants should receive notifications when their specimens arrive, and when new vectors are identified in their area. Core tasks/ data collection protocols include *specimen or DNA; pictures* (e.g. protocol 1 or 2); *sampling effort;* and, *notes.* Ideally *Biodiversity specimen/ DNA* data can result from participants following any of the previous protocols facilitating sample tracking and return of results to the user (see data integration below).



Data Integration Protocol. Protocols 1-4 will be integrated such that they complement each other when implemented together. Adult and larval mosquitoes located with Protocols 1and 2 will often result in the collection of actual specimens, and these may then be submitted under Protocol 4. Bite and nuisance reports under Protocol 3 will often lead to reporting under Protocol 1 (and specimens under Protocol 4). Specimens collected under Protocol 4 will often be accompanied by reports under Protocols 1 or 2. Although each protocol will be capable of standing on its own (and thus may be implemented independently of the others), special attention will be paid to ensuring interoperability and supporting integration, including through a mechanism for sharing participant and reporting identifiers across protocols, and for otherwise facilitating participants' use of the full suite of protocols together.

Protocols 1-4 will each be supported by a canonical data collection platform, as described in depth below. This initial list of protocols may be augmented to reflect new science and technological innovations in monitoring, or the practices of new citizen science projects that wish to join Global Mosquito Alert. In addition, it will be critical to link data on vectors with epidemiology data, for example through human genomic-based surveillance (Box 1).

Box 1: Digital Genomic Surveillance of Mosquito Vectors

During epidemics of vector-borne pathogens such as dengue, chikungunya and the recent Zika epidemic that plagued a host of countries from 2015 to 2016, one critical type of information has been limiting: genomics data—to precisely characterize the infectious agents and vectors at stake in viral outbreaks and determine their evolutionary rate. In the future, greatly increasing the capacity to sequence, in real-time, massive quantities of human and non-human genomic samples—for example, the DNA snippets present in human blood or in mosquitoes – will become increasingly crucial for four reasons: 1) to detect and track the presence of viruses such as Zika in specific human and non-human populations (e.g. mosquitoes); 2) to determine how host immune response to viruses; 3) to better identify potential diagnostics and their efficiency over time; and, 4) to assess the immune response to vaccines or treatments.

How can the GMAC help scale the need for genomics data? What if research teams had been able to bring portable genomics sequencers closer to the afflicted populations before outbreaks begin, for instance with Zika on the northern coast of Brazil? What if, in the future, these researchers were able to simply transmit their skills to other citizens, who would then be equipped with the power to identify the source of new epidemic outbreaks from Zika to dengue, malaria or potentially to other pathogens such as Salmonella or avian flu? If generated in near real time, crowd-sourced genomics data could become an indispensable tool in epidemic surveillance. Several teams of researchers in the USA, Switzerland and the UK are now ready to use genomics data collected on site and shared through the cloud to feed open-source virtual and visual maps that track where and how viruses are spreading, allowing not only early warning of pending pathogen outbreaks, but also enabling scientists to study when and how pathogens are mutating as they spread.

A shared metadata documentation system

The four protocols listed above are designed to collect data about a vector, as well as metadata about the data collection effort, including sampling effort and the time and location of data collection. While data collection protocols will vary as described above, documentation in the form of metadata should be consistent across all Global Mosquito Alert projects. For example, the same terms should be used to describe *sampling effort* in each of the four protocols.

As with protocols for data collection, protocols for metadata documentation will involve a common core of required elements that various projects can build upon. For example, while it is expected that all projects using the Larvae/breeding site protocol will collect metadata that designates a location as public or private, some projects using this protocol may also wish to collect information such as the exact address of a larvae/breeding site.

Benefits and challenges to interoperability

Together, the four canonical protocols and underlying common data model will enable interoperable data collection by multiple project partners. This will allow information to have impact in and beyond the immediate context of data collection. For example, a volunteer using the Zanzamapp application to track mosquitos in Rome could help local authorities understand the effectiveness of municipal control efforts. The same data point could be aggregated up into national-scale data sets and used by epidemiologists to understand the spread of vectors linked to epidemics such as chikungunya. And that same data point could also be leveraged in global scale research on, for example, the relationship between topography or weather and mosquito distribution.

Shared metadata will also allow for integration of data between the four protocols that has the potential to leverage participation between methods, enhance data value and improve citizen engagement. For example, a record resulting from a photo or a sound recording of an adult (protocol #1) or a larva (#2) documents a specific specimen and that specimen could be used for genetic analysis (protocol #4). The shared metadata and unique identifier from the originating record will allow a consistent link to downstream results. For instance, a genetic analyses (see box 1) could be returned as a linked result back to the original sample record. This will simultaneously ensure data quality and communication directly with the volunteer who collected the specimen, not only informing the volunteer of their contribution, but also allowing them to ask a question or comment on the findings.

Developing a common data model

The process of finalizing the four data collection protocols and shared metadata documentation system will lead to a common ontology and data model for citizen science vector monitoring. Building this ontology and data model will require the following steps:

1. Finalizing the four main data collection protocols for collecting different types of vector data, including both data and metadata fields.
2. Compiling a list of relevant standards and ontologies used in and beyond citizen science in machine-readable format.
3. Crosswalking the four data collection protocols and relevant standards and ontologies, resolving any disagreements.
4. Leveraging an initiative such as the Statistical Data and Metadata Exchange (SDMX) standard,[6] finalize an ontology and data model for citizen science vector monitoring. The final data model should be usable in geospatial and semantic web formats. In addition, the four protocols should be documented in a form that is easy for new citizen science projects to find and implement, and published on the websites of existing Citizen Science Associations based in the United States, Europe, and Australia[7] and on the Global Mosquito Alert platform.

Developing a common set of data policies

The Global Mosquito Alert Consortium will develop a common set of data policies that each participating partner must agree to. These will include common policies for:

1. **Intellectual Property.** The Consortium will agree on a single set of compatible, standardized, free, and open source software licenses for software code (e.g. General Public Licence (GPL). All leading partners responsible for developing and maintaining a canonical app will agree to use one of these licenses. The Consortium will also agree on a single set of compatible, standardized, and open licenses for vector data (e.g., Creative Commons). As with licenses for software code, different observations may contain different licenses, and different components of an observation may contain different licenses. For example, some citizen science projects currently using the Creative Commons framework could use the CC0 designation to waive copyright to the data record, while licensing volunteer photos as CCBY (e.g., recognizing that volunteers have copyright of their photographs, and deserve attribution). From a legal standpoint, it will be important to consider different treatment of copyright in different jurisdictions, such as the United States and the European Union.
2. **Privacy Policies.** Some research suggests that citizen science is a context where volunteers often prioritize ideals of openness and responsible sharing over extensive privacy protections.[8] Working closely

with volunteers to understand their preferences in the even more specific context of mosquito monitoring, The Consortium will agree on a common set of data policies describing the steps that each partnering project will take to protect the needs of their volunteers in regard to privacy and attribution. For example, The Consortium may decide that all publically-accessible open data should be stripped of Personally Identifiable Information (PII). Alternately, The Consortium may decide to add an additional, optional field such as "Username" to acknowledge and attribute volunteer contributions.

3. **User Agreements.** The Consortium will develop and host three types of user agreements: agreements between The Consortium and partnering projects; agreements between the consortium and end users of the data; and, agreements between individual projects and their volunteers. These agreements will codify and enforce key intellectual property, privacy, and other policies to ensure legal interoperability of GMAC data. They will also protect the rights of citizen science projects, volunteers, to ensure that the data is understood and used by a broad range of stakeholders under mutually agreed-upon terms.

A web-based platform will publish key information on GMAC data including the finalized data model, associated protocols, and common data policies. This platform will also host and coordinate additional technologies and tools, including mobile apps for data collection, processes for data validation, and platforms for data access and visualization. The platform and toolkit will also include resources listing effective practices for using data, visualizations, and other outputs to communicate with stakeholders including private- and public-sector decision-makers, the scientific research community, public media outlets including online and broadcast media, and different public groups.

A Common Platform for the Global Mosquito Alert Consortium

Shared technology for data collection

Consortium partners anticipate that most data collection campaigns will leverage Smartphone technology. The Global Mosquito Alert Consortium will encourage the use of three "canonical" open source mobile applications for consortium data collection and sharing as follows:

1. Android & iPhone app for real-time vector mosquitos.
2. Android & iPhone app for larvae/ breeding sites.
3. Android & iPhone app for bites/ nuisance.

Supporting three canonical apps will help ensure interoperability through working code. Still, despite the seeming ubiquity of Smartphones these tools are still not accessible to all. For the partners located in rural and developing areas without smartphone access, a paper-and-pencil option will also be made available. In addition, an SMS-adaptation of the open source mobile applications could be developed for areas with cellular access, but low smartphone penetration rate.

A single leading partner will develop each open source application. Each leading partner will be responsible for maintaining the application itself, as well as developing and maintaining documentation to support appropriation by other consortium partners. A leading partner will also be responsible for developing and maintaining APIs to promote data sharing. This federated model is designed to promote interoperability while also supporting maintenance over time. Each app will have a common technical architecture, capable of collecting the same types of information via structured and unstructured fields and pushing the information to databases and end users. Further, all apps in The Consortium will collect and document observations using the same Globally Unique Identifier (GUID) system.

Other consortium partners will be encouraged to adopt these platforms directly or build upon the open source code to customize these platforms according to a project's specific needs. Customizations may include applying unique branding, for example in line with a specific citizen science project; translating the app instructions and protocols for use in different countries; and, expanding the common core data collection protocol to collect additional types of information.

Shared strategies for data validation

When public volunteers collect data through citizen science, researchers often leverage a range of data validation processes to ensure fitness for use in research and decision-making. Global Mosquito Alert will take a two-pronged approach to ensuring data quality, developing a common set of validation process with supporting tools, and engaging, growing and maintaining a network and directory of active experts and advanced citizen scientists willing and capable of verifying citizen science data.

Existing citizen science mosquito monitoring initiatives validate observations in a number of ways. Experts in local projects may conduct field assessments. Researchers working on local, regional, or national scales may conduct photo-based validation, or molecular-based validation through DNA barcoding. Researchers are utilizing social-network methods to simultaneously promote engagement and help citizens collect, identify and validate photo observations. Based on the existing work of consortium partners, Global Mosquito Alert will refine and endorse a handful of different and complementary data validation strategies. In addition to standardized processes, The Consortium will also leverage or develop standardized tools to support validation. For example, where possible, experts around the globe will encourage the use of the same dichotomous keys to identify species and the same pictorial keys used to determine morphology. Where global dichotomous keys are not appropriate, localized material will also be used.

In addition, The Consortium will cultivate a hub for a growing body of data validation experts to help support individual projects. The consortium will both recruit and maintain a directory of experts that projects will be able to consult. As many types of expertise will require knowledge of local conditions, such as species distribution in a certain area as related to weather patterns or extensive networks with traditional ecological knowledge of the area, most experts will need to be recruited on the local level. Other experts may be able to validate data from any geographic area or scale. Finally, the program will leverage social networking between experts and advanced amateur citizen scientists in order to further scale the pool of experts with relevant local knowledge through education.

Shared processes for data access, analysis, and visualization

The data collected through Global Mosquito Alert will be supported and stored by a consortium of data and information providers. This federated data collection and storage will also be supported and coordinated through Environment Live, the dynamic UN knowledge platform which is designed to collect, process and share the world's best environmental science and research. Built and maintained by UN Environment, the platform provides real-time open data access to policymakers and the general public, using distributed networks, cloud computing, big data and improved search functions. Validated data collected by Global Mosquito Alert partners will be made openly available through Environmental Live to support scientists addressing a range of research questions in fields ranging from biology and biodiversity monitoring to epidemiology and public health.

Global Mosquito Alert will implement a standardized analytical process for monitoring the spread of vectors over time, combining vector information with other relevant data sources, and reporting information to a range of stakeholders. This process requires the following activities:

1. Identifying a common baseline for global occurrence and distribution of species such as Aedes aegypti and Aedes albopictus.
2. Beyond initial data validation, developing a process for cross-validation between different citizen science projects, especially using specimen-based protocols.
3. Developing a process for quantifying change that may be applied to local, regional, national, and global scales.
4. Determining other relevant types of data, for example on climate or population, and corresponding data sets.
5. Develop a platform for integrating the data collected, validated and analyzed through Global Mosquito Alert with other relevant datasets such as remote sensing data.
6. Develop a platform for visualizing data, including vector data and other relevant data, on local, regional, national, and global scales.
7. In addition to on-demand visualizations, determine the additional data and information needs of researchers, policymakers, citizen scientists, and other stakeholders monitoring and eradicating disease-carrying mosquitos, including documentation on data sources and modeling/ prediction needs.
8. Determine the desired frequency of aggregated reporting, and the parties responsible for reporting on an ongoing basis.

Data analysis, visualization, and aggregated reporting will leverage UNEP's Environment Live platform to the greatest degree possible.

Project Directory

Lastly, GMAC will compile and publish a directory of projects that support citizen science mosquito monitoring

consistent with Global Mosquito Alert. This directory will be developed so a prospective partner organization in (for example) a small town in Brazil can find and leverage existing efforts, including local deployments that may already be happening. This directory will also help coordinate and disseminate changes and feedback on the existing common protocols. The Global Mosquito Alert Consortium Directory should leverage and be compatible with existing platforms like SciStarter.

Stakeholder engagement within and beyond the scientific research community

Scientific Researchers

An inherent goal of Global Mosquito Alert is to facilitate scientific research on disease-vector mosquitoes. This research is valued for its own sake, and also for its potential to support vector control and disease management. Adhering to a number of key principles can maximize the utility of the data produced by consortium members for research and policy alike.

First, GMAC data should not only be openly available to the public, but should also be made easily accessible on a timely basis. This includes ensuring that data is well-documented and distributed in standardized formats like CSV or JSON. For some protocols, the best distribution will be through an API (Application Programme Interface) that gives researchers access to data as soon as it is generated or with only minimal delay. It should be possible for researchers to access raw, disaggregated data, although processed data may also be helpful.

Second, data should be archived regularly to facilitate reproducible research. In other words, it should be possible for researchers to obtain the same data that a previous researcher obtained on a given day, even if the underlying database is changing. This can be easily done through an open repository like Zenodo. Mosquito Alert, for example, sends a snapshot of its data every day to Zenodo, in addition to making the latest data available through an API and sharing data with Environment Live.

Third, data should include information on any validation that has been completed, for instance through an audit trail visible at the record level, on sampling effort (if available), on the software (including version) and/or the hardware used in data collection. As much as possible, the protocols should standardize these items, such that data quality and sampling effort can be compared across datasets on equal or similar terms. For instance, if sampling effort data makes use of anonymization cells, the same cells or compatible cells should be used across protocols. Data on collection software is especially important in order to avoid biases caused by changes in algorithms. Thus, it should be possible for researchers to easily link a given observation to a particular version of the code for the mobile phone application that was used in its collection. Similarly, it should be possible to link an observation to the phone model (and thus sensor quality) used in its collection.

Fourth, the collection of data from traditional or other, non-citizens-scientist sources should be encouraged, and this data should be made available or its location clearly identified so that is can be used for cross-validation of the citizen science data. For example, to the extent possible, contemporaneous ovitrap data should be made available along with citizen science data, and in such a way that the two can be easily compared.

Fifth, while the preceding points envision independent analysis of raw data by researchers who are not necessarily connected to the Global Mosquito Alert Consortium, the Consortium should also develop and fit a set of statistical models and carry out other relevant analysis using the data generated by each protocol. These models should produce valid and useful results for a variety of questions and these results (including raw estimates) should be shared openly in the same manner as the raw data. Thus, for example, it should be possible for someone modeling the spread of a given disease to easily access mosquito prevalence estimates generated by The Consortium. In addition, the code for these models should be made available with a free and open source license and in a manner that tracks version changes and facilitates sharing and improvement (e.g. via Github). The Consortium should also consider developing a set of libraries for common statistical software (e.g. R, Python, or Julia) to facilitate the analysis of the data discussed here.

Sixth, there should be regular communication with researchers in the fields most likely to use this data, with citizen scientists involved in its generation, and with additional stakeholders, in order to anticipate what information is useful or of greatest interest. Involving these stakeholders not just in data collection, but in the selection of research questions and analysis of data should be encouraged. It should be possible for researchers using the data to easily communicate back to project managers with any suggestions or problems they encounter.

Beyond the scientific research community stakeholder engagement requires the allocation of resources for communication, including through community building and education. Because of this a suite of digital training modules should accompany each common protocol, divided by audience or users. In addition to (1) scientific researchers, there are five additional audiences or users in the success of this consortium: (2) the public; (3) expert validators; (4) the media; (5) vector managers; and, (6) policymakers. Each of these stakeholders will have a different set of criteria for interacting with citizen science projects, and The Consortium will develop outreach materials including training modules for each of these targeted audiences. The following requirements for each module are the result of early brainstorming and should be considered a work-in-progress.

Engaging the public (citizen scientists)

Citizen science projects engage and educate public volunteers through training. Training modules should communicate the scope of the project, the science, the public health relevance and protocol of the program for primary, secondary, college and adult learning. NASA's Project Globe, a collaborator of the GLOBE Mosquito Habitat Mapper, has extensive experience with integrating this type of information for teachers of K-12 audiences for The Consortium to draw from. Other elements that would ensure an effective educational and training experience for the public may include:

- Certification (Massive Open Online Course or MOOC-like) for participation in The Consortium.
- Badges to encourage and "gamify" collecting mosquito data.
- Data visualizations to demonstrate effort and impact of participation.
- A well designed feedback loop including individual record notifications, individual news feeds displaying local activity, aggregated results of ongoing data analyses, participant stories, and participant acknowledgement or recognition.
- Usage reports, including near real-time rankings demonstrating the popularity of each protocol across different geographic regions.

Expert Validators

Each protocol will attract a different set of experts, from epidemiologists to entomologists. The criteria for this training module should include:

- Validation protocol for the validators, including how to ensure they are in fact credentialed enough for participating in this expert network. One way to resolve this would be to identify professional networks that already vet participation and require the validators be a part of that professional network (example: The World Health Organization).
- Information on a discussion board where validators can contribute to discussions on difficult to resolve photos/samples.
- In addition, engagement on the platform itself will encourage the observers to learn how to identify the mosquitoes they document, and as their expertise grows, graduate into a new pool of volunteer identifiers working together with other expert validators.

The Media

To reduce the risk of misinterpretation and disinformation surrounding such an ambitious and global program, an effective media toolkit should be developed. Expert public health communicators should be consulted on what vocabulary to use when discussing citizen science data to ensure public trust in the data and wide participation in the project. Niche communications networks should be included, perhaps targeting outdoor magazines, DIY-bio community, and medical journals. The media toolkit should be translated into local languages where the pilot protocols are centered and adjusted based on culture.

Vector Managers

Existing projects often struggle to communicate effectively with local managers responsible for vector control. Clear communication materials need to be drafted in an effort to gain the trust and support of the governing bodies responsible for combating and tracking mosquitoes. This type of educational material should use technical language suited to vector control. An effective mechanism noted among existing projects was the ability for vector managers to share information between geographic districts that covered the best practices and pitfalls. The managers were more likely to engage with a citizen science project if they could be guaranteed secure and private communication. Notably, vector managers' needs for effective outreach can be facilitated by social media promotion of such citizen science efforts using live feeds of records or localized summary updates for ongoing project results.

Policy Makers

Another goal of the Global Mosquito Alert Consortium is to demonstrate that public health protection requires participation from the public to enhance early-warning systems and that the technology to enable their participation already exists. These early-warning systems are designed to be extremely rigorous in data quality assurance and control to provide information to decision-makers and policy makers in local, regional and national governments that is as granular and accurate as possible. Therefore the training materials for policy makers should emphasize the immediate skepticism they will bring to the data that emerges from these four protocols perhaps focusing on the data validation process and metadata documentation. Note that many of the steps taken to make data valuable to the scientific research community will also be required to make data valuable to public health agencies.

Resource Model for Participating in the Global Mosquito Alert Consortium

Considering the distributed nature of the project we will need to seek funding for the core e-infrastructure and the human resources dedicated to maintaining and coordinating this infrastructure and building the community. A key question observed was how this consortium could be locally supported and implemented but coordinated globally. A potential resource model is to ask for contributions from local nodes towards a global fund for coordination. For example, as local nodes pursue their own funding to develop the materials and resources for their local context they could write in their grant proposals a section for contributory fees to supporting this project, effectively paying dues. This resource model would need to have a set of general standards for participation and contribution.

Conclusion: Next Steps and Priorities

At the time of writing, the Global Mosquito Alert Consortium is an emerging initiative engaging in proof-of-concept activities.

Between 2017 and 2018, the Wilson Center will work with a NASA DEVELOP team in a proof-of-concept data integration combining data from three mosquito monitoring citizen science projects with NASA Earth Observations in areas such as weather and elevation. This proof-of-concept data integration will help demonstrate the feasibility and value of a coordinated global approach for advancing research and supporting decision-making.

This project may also expose critical data gaps to be addressed through local deployments, and technical hurdles towards coordinating monitoring and integrating data.

In parallel, members of The Consortium will build an online presence on the UN Environment Community of Practice website and other platforms. Language and a logo for participating in the Global Mosquito Alert Consortium will continue to be developed and refined. Leaders will also compile a communication package for finding funding, including finalizing individual project node descriptions (Appendix B), statistics, vision and mission statements, background information, and analysis of relevance to scientific research and policy.

While consortium partners are predominantly based in the United States and Europe, a number of partners are pilot testing local deployments in Central America, South America, and Africa. For example, Mosquito Alert has been piloted in Puerto Rico and Columbia, while Muggenradar is investigating partnerships in Rwanda and other African countries. More support is required to support these local deployments, and to understand how technology can be customized to local needs and to build a truly global network.

Within and beyond the context of mosquito-vector monitoring, the future of citizen science lies in coordination and partnership. The Global Mosquito Alert Consortium seeks to leverage the activities of existing citizen science projects to dramatically improve local, national, *supranational*, and global research and management of disease-vector mosquitos. GMAC also hopes to become a model for coordination and partnership that emerging consortia of citizen science projects tackling other challenges can leverage and improve.

ENDNOTES

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Appendix A: Workshop Attendees

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Appendix B: Consortium Partners

The European Citizen Science Association (ECSA): a non-profit association set up to encourage the growth of the Citizen Science movement in Europe, covering over 28 countries across the European Union and beyond. https://ecsa.citizen-science.net/

The Wilson Centre's Science and Technology Innovation Program (STIP): The Wilson Center, chartered by the U.S. Congress as the official memorial to President Woodrow Wilson, is the nation's key non-partisan policy forum for tackling global issues through independent research and open dialogue to inform actionable ideas for the policy community. https://www.wilsoncenter.org/about-the-wilson-center

UN Environment: is the leading global environmental authority that sets the global environmental agenda, promotes the coherent implementation of the environmental dimension of sustainable development within the United Nations system and serves as an authoritative advocate for the global environment.http://web.unep.org/about/who-we-are/overview. Environment Live provides UN Member States with open access to information and knowledge on the environment at the global, regional and national levels. It supports Environmental Policy through Foresight, Outlooks and Assessments and providing Capacity Building for countries to achieve the Goals of Agenda 2030 and Sustainable Development. Environment Live provides up-to-date information for citizen-science, communities of practice and impact stories and case-studies on the environment and people. https://uneplive.unep.org/what

The Globe Observer Mosquito Habitat Mapper: is a NASA-sponsored project that is the result of the combined efforts of an extended team that includes the Institute for Global Environmental Strategies (IGES); NASA Goddard Space Flight Centre, Langley Research Centre, and Jet Propulsion Laboratory; Space Science Applications, Inc. (SSAI); the GLOBE Implementation Office (GIO), GLOBE DIS and Brooklyn College. It is part of the Mosquito Challenge Community Campaign (MCCC) focused on demonstrating the usefulness of citizen science data for combatting Zika in Brazil and Peru. For more information contact - rusty_low@strategies.org

The Invasive mosquito project: is a classroom based citizen science project that links educators and citizen scientists with local expertise to monitor mosquitos using do-it -yourself oviposition traps. The project aims to educate kids (kindergarten through high school) about their role in protecting oneself, their family, and their pets from mosquito-borne diseases. The website contains lesson plans, PowerPoint presentations, quizzes, and basic information for teachers. For more information contact: http://www.citizenscience.us

Muggenradar (Mosquito Radar): is the first community-based project for collecting information about mosquito activity and biting nuisance in the Netherlands. Muggenradar is a surveillance instrument initially launched to investigate mosquito activity during winter. The public are encouraged to submit data, photographs and mosquito specimens for identification. http://www.muggenradar.nl

Mosquito Alert: is a citizen science platform based in Spain with the aim of uniting citizens, scientists and public health managers in the fight against mosquito-borne diseases. With the Mosquito Alert app anyone can report tiger mosquitoes *(Aedes albopictus),* yellow fever mosquito *(Aedes aegypti),* and their breeding sites. Reports are validated by a team of entomologists and information is passed in real-time to relevant public health agencies as well as the public in general. http://www.mosquitoalert.com/en

ZanzaMapp – Sapienza Università Di Roma: is a citizen science platform that allows citizens to report the presence of mosquitoes and check real time information on mosquito presence and activity. It helps institutions, government bodies and universities to work together on controlling mosquitos. http://www.zanzamapp.it/

MosquitoWEB— Instituto de Higiene e Medicina Tropical: – is a community-based monitoring program focused on the early detection of invasive mosquito species (e.g. *Aedes albopictus* and *Ae. aegypti*) in Portugal, as well as on the update of native species' distribution and activity. http://www.mosquitoweb.pt

CitizenScience.Asia: brings together Citizen Science projects and practitioners in Hong Kong and across Asia. The goal of the community is to promote the concept of citizen science and to facilitate dialogues between researchers, citizens and communicators across different projects in the region. Participating projects include DIYbio Hong Kong and their Hong Kong Barcode project, the crowdfunded BauhiniaGenome project, and the Hong Kong participants in the Mosquito Alert project. For more information, please contact- citsci@s01ut10n.com.

**The Mosquitoes in Hawai`i Project:** has citizen scientists focused on documenting, identifying and eliminating invasive mosquitoes *(Aedes, Culex)* in Hawai`i and is powered by the *iNaturalist* social network platform from the California Academy of Sciences. Participants share identifiable photographs by creating biodiversity records with the *iNaturalist* app. Records are peer-reviewed online by a growing group of volunteers guided by professionals. Research grade observations conform to Darwin core standards and are sent to the Global Biodiversity Informatics Facility. App includes a machine learning algorithm to suggest potential identifications. For more information see: https://www.inaturalist.org/projects/mosquitoes-in-hawaii.

The Three Mosquiteers: is a pilot citizen scientist initiative aimed at raising awareness regarding vector borne diseases, vector ecology and management of native and non-native mosquitoes in Cyprus. It is primarily designed for children aged 7-18. For more information please contact: Angeliki.Martinou100@mod.uk

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