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Mosquito Mapper: a phone application to map urban mosquitoes

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Abstract
This paper presents mosquito mapper: an android phone application created with the goal of giving science-driven citizens the means to monitor mosquito populations in an urban environment. Mosquito mapper allows the recording of mosquito encounters as well as conditions surrounding the encounter. It also features a rudimentary identification tool. The goal of the application is to create a database and construct a map of the encounters free to consult for citizens and scientists. Such database constitutes a necessary first step for the development of useful management strategies addressing potential human health threats induced by mosquitoes. The citizen scientist may voluntarily provide other additional information on the circumstances of the encounter that may contain scientifically useful information. We describe the current features of the application, showcase the limited data gathered so far, then discuss the strengths, limits, potential scientific value and suggest possible future extensions for the application. The original city for which the application was developed is Berlin, Germany, but the application is coded in such a way that it is easily applicable to any urban environment.

Keywords: Phone application, Mosquito, Citizen science, Urban environment, Distribution map

Introduction

Every day, more than 2.5 exabytes of data are generated from internet use (Gantz and Reinsel 2013). Most of these data are generated by the general public and are the target of companies dealing with big data. User-generated data can also be of great use for scientific purposes (Newman et al. 2010). A field of technologically-aided citizen science is now emerging (Silvertown 2009) which can have large scale implications for scientists, policy makers, and the citizens themselves (Dickinson et al. 2010; Reichman et al. 2011). Together, we can use the large amount of data created daily to explore questions that were previously either impractical or impossible to tackle (Van Strien et al. 2013; Cosentino et al. 2014). Citizen science is not a new field, but technological progress especially the development of the internet and the rapid spread of smartphones multiplies the possibilities(Silvertown 2009; Bonney et al. 2014). This endeavour, however, comes with limitations regarding the accuracy of the acquired data (Dickinson et al. 2010; Conrad and Hilchey 2011). These inaccuracies originate from human use but also directly from the monitoring devices but can be tempered with statistical tools on large dataset. (Cohn 2008). Citizen scientists may provide information at a scale virtually impossible to obtain from regular collection and therefore help the scientific community tackle usually difficult questions (Conrad and Hilchey 2011).

Here, we suggest using citizen science to tackle the growing threats posed by mosquitoes. Mosquitoes typically constitute a nuisance in urban environments, a nuisance that may become a threat due to globalisation and climate change as diseases carried by mosquito may spread significantly faster in big centre of urbanisation (Gubler and Clark 1995; Brown et al. 2008). Mosquito-related health issues are usually not linked with developed country. However, the range of disease-bearing mosquitoes such as *Aedes albopictus* (Tiger mosquito) or *Anopheles plumbeus* has increased dramatically to the North (Cunze et al. 2016; Heym et al. 2017) and a country like Germany could see an increase in cases of diseases usually associated with developing countries. A few cases of West Nile Virus infection have been recorded in Germany (Krüger et al. 2001; Cadar et al. 2017). Furthermore, mosquitoes already established in Europe such as *Culex pipiens* and *Culex torrentium* have been shown to be susceptible to West Nile Virus infection (Leggewie et al. 2016). A comprehensive surveillance and

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control plan for mosquitoes is developed in Germany (Becker et al. 2017).

Monitoring the extent to which mosquitoes are encountered in urban environments constitutes a necessary first step for successful management (Hemme et al. 2010). The use of citizen science can provide a quick and cheap way of gathering such information (Cohn 2008; Bonn et al. 2016). Combining citizen science with the virtual ubiquity of smartphones in western urban environments may strike a winning strategy as a means of gaining information regarding the extent of mosquitoes'. The trend of increased urbanisation in developed country (United Nations 2014), closely matched with market penetration of smartphone (GSM Association report 2016) suggests that such application would prove useful worldwide.

Thus, we present Mosquito Mapper, an application whose goal is monitoring encounters with mosquitoes in Berlin. Mosquito encounters happen constantly and carry little information themselves. However, the aggregation of encounters opens the possibility to tackle important questions regarding the dynamic of disease-spreading mosquito within an environmental context (Cosentino et al. 2014). The application uses a simple interface to guide users towards different objectives. From each use of the application, there are several variables that we can access. Ultimately, such user-created database may be useful for drafting urban management policies regarding mosquitoes or be used to cast a "mosquito forecast" in the like of current weather forecast.

Beta release

Mosquito Mapper is readily available on the android store (https://play.google.com/store/apps/details?id=com.sciencetogether.perecastor.mosquitomapper&hl=en). The project is currently in a beta version. The source code for the application is accessible on GitHub (https://github.com/Layninou/MosquitoMapper). The upcoming companion website is accessible at this address (https://layninou.github.io/ScienceTogether/index.html#!/mosquitomapper) but we demand the readers' indulgence here as it is largely a work in progress.

The intended use of the application, that we call an "experiment", follows this scheme: the user opens the application, chooses whether they want to locate or identify an encounter, then follows through the chosen activity. At the end of one activity, the user is asked whether they want to follow with the other option (locate a mosquito if the user just identified one and vice-versa). A guide presenting the application workflow is found in Fig. 1. At the end of the experiment all data associated with the unique experiment ID is confirmed in our database. Data are stored in a JSON objects (JavaScript Object Notation) divided in three branches for questionnaire and location, identification, and pictures.

Mosquito Mapper opens with a page displaying three buttons: "locate", "identify" button, and "information" (Fig. 1). The information button lists the contributors to the project, acknowledges helpers and supplies contact information. The "identify" button brings a user through a short identification key. Finally, the "locate" button brings up the current user's location followed by a short questionnaire. All information provided by users populate the JSON file stored in a database. Users can either locate or identify the encounter, but is encouraged to do both.

Locate activity

By tapping the locate button, users are returned their position, then asked to proceed. The "locate" activity uses the system location service of Android. This service is standard across Android distributions. The application is given access to the location device of the mobile phone (generally not the device's GPS, the application uses various location sources) to provide the user's coordinates. Upon starting the "locate" activity, the application creates an instance of "locate manager" and an instance of "locate listener", then requests an update of the location. The "locate manager" accesses the device's coordinates (or the location of the closest Wi-Fi access or cell tower as a way to reduce the phone's battery consumption) which is displayed to the user. The "locate listener" tracks any change of position of the phone and change the displayed location accordingly. The accuracy of location provided by the application is equal to the accuracy of the mobile device and is usually precise within a range of five meters (Zandbergen and Barbeau 2011). Upon completion of this activity, the last latitude and longitude recorded is given a unique ID and sent to our server.

After recording the encounter, the user is asked a few questions concerning their surrounding environment and to take a picture of the mosquito. By the end of the "locate" activity, the user is asked whether they want to proceed with an identification or end the experiment.

Questionnaire

After the "locate" activity, the user is asked to provide extra information regarding the context within which the encounter took place. The set of answers given is sent together with the location data (Fig. 3). The questions were designed with the help of Ann-Christin Honnen from Swiss Tropical and Public Health Institute, Basel, Switzerland. The set of answers from the questionnaire will help determining the behaviour of the mosquito (e.g.: diurnal or nocturnal), their amount and the likelihood of the encounter. They are complementary to the identification activity to determine whether the encounter recorded took place with a mosquito.

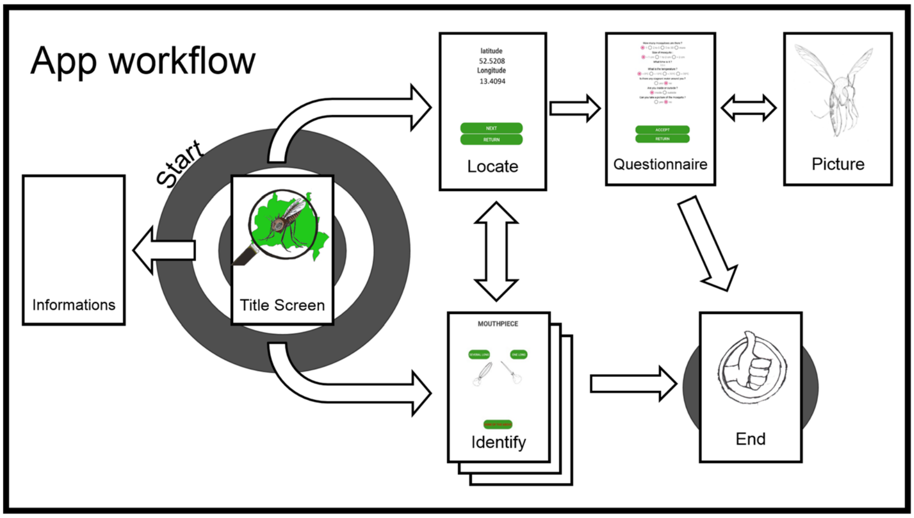

Fig. 1 Application workflow. From the title screen, a user has three choices: starting the "locate" activity, the "identify" activity or explore the information. Information contains the name of contributors and contact information. The "locate" activity returns the user's position followed by a short questionnaire. From there, the user may take a picture of the encountered mosquito, go to the identify activity or end the application. The "identify" activity consists of three pages with simple features to recognise on the mosquito

Identify activity

By tapping the identify button, the user is sent to a simplified identification key (Fig. 2). The goal of this key is to 1) ensure that the encountered organism is a mosquito, 2) estimate broadly which subfamily the mosquito belongs to and 3) determine whether the encountered mosquito is male or female. After this activity, the answers given are tagged with a unique ID and sent to our server. If the locate activity has been performed before, the ID for identification is linked with the one for the location.

Such a low level of identification is acceptable because inner city Berlin is mostly populated by mosquitoes of the genus Culex (Ann-Christin Honnen, *pers.comm*), it also prevents high level of inaccuracy from the user while remaining entertaining, and avoid asking overly complex morphological questions to untrained users (but see planned features). If the user has not completed the "locate" activity, they are asked if they want to.

Pictures

The last question of the questionnaire asks the user to take a picture of the mosquito encountered. By choosing yes, the phone camera opens. Ideally, the pictures taken by citizens could be used later by zoologists as a way to improve species distribution maps although preliminary tests were inconclusive. Pictures are usually large files,

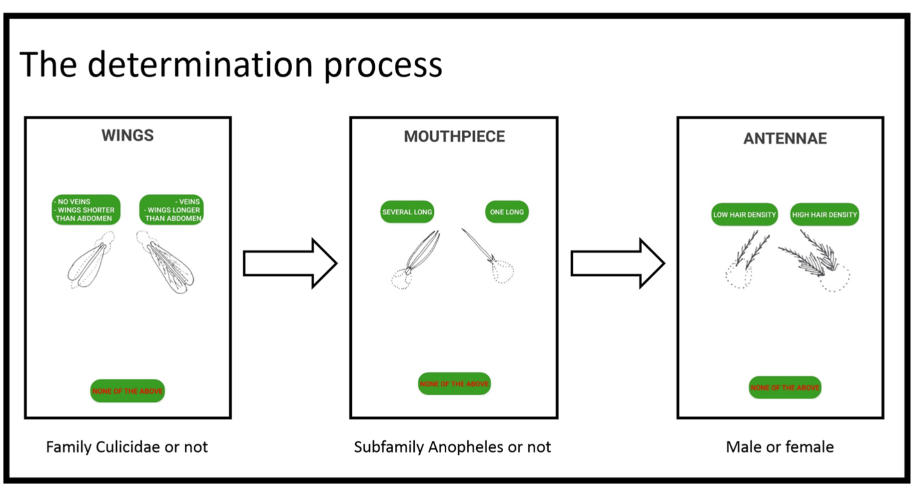

Fig. 2 The determination process consist of three consecutive questions. The first one ensures the encountered animal is indeed a mosquito. The second one helps determining the subfamily of the encounter while the third question aims at determining the sex of the encountered mosquito

which could clutter our database. To reduce the size of images, these are modified locally using a BLOB (Binary Large Object) procedure. This procedure transforms the bitmap image taken with the camera into a bytes object. The BLOB is then sent directly to the server. Image quality is decreased to a quarter of the original picture.

Mosquitoes can be hard to capture on photograph. Especially outside at night when mosquitoes are most active and the lack of external light will affect the quality of image. We recommend taking pictures when the user feel that he or she can take a clear focused picture. Ideally, the insect should be shot on clear flat surfaces: walls, windows or tables. Resting mosquitoes can remain still for long enough for someone to make a clear picture. We expect most shots to be taken shortly after the death of the mosquito as the possibility for a clear pictures are increasing and the fatal event would in many cases occur on a flat surface. This will affect the quality of post-hoc identification. In case of post-fatal pictures, we encourage the user to provide a mean of assessing the size of the mosquito. Ideally a ruler but a thumb or a standard object such as a pen is enough.

Miscellaneous

With this beta release, all information and pictures are sent to a private server, by downloading the application, users agree to provide us with the data and give us the right to store it for scientific purposes. The type of data collected and the moment they are collected is detailed in Fig. 3. They do not contain any personal information. Ultimately, our goal is to make all the data collected freely accessible on a companion website.

First look at the data

We have so far gathered very limited data, most by unknown users around the globe. Despite the app being developed for Berlin, circumstances have prevented us to make a satisfactory field test. The dynamic nature of phone application ensures that more useful data will be collected with time. You can find all the existing data on the website currently under construction at this address: https://layninou.github.io/ScienceTogether/index.html#!/mosquitomapper. On this page, after a short presentation of the app we first show a world map of localisation. It is possible to zoom in and out of the map to focus on a particular place. Then we display the time at which mosquitoes are recorded in a histogram. More questionnaire replies follow and finally the results of identifications are given. We believe the current information to be inaccurate and will wait to have a significant amount of data (>1000 data point) before performing any analysis.

Strengths and limits

Developing a smartphone application for citizens and scientists comes with a suite of strengths and limits that depends to a large degree on variables that are not under our control. First and foremost, the amount of data generated by the application will depend on the number of users. The usefulness of data will also depend on the users. A critical goal of our application is the ability to grossly assess the population dynamic of mosquitoes through time. This requires a regular feed of data. One downside of our application then becomes the possibility of having large amounts of data but distributed in a way that prevents their use for certain types of investigation.

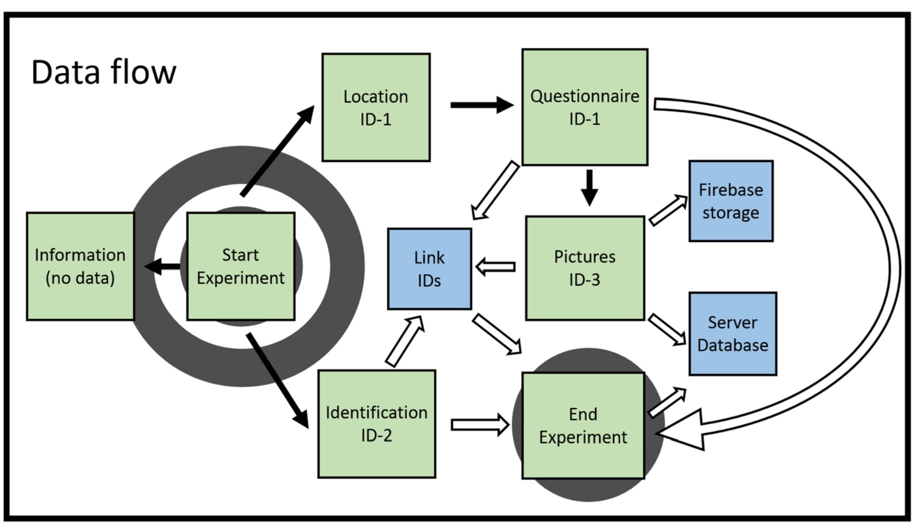

Fig. 3 Data flow of the application. Application activities are represented in green boxes, data holders are in blue boxes. Solid block arrows represents application's workflow while white arrows carry data. Data generated by users carry unique IDs and are linked before being sent to the server. Activities performed alone are not linked. Picture data are sent in two places: a Firebase storage where they can be viewed directly and the server where they are stored as a byte array

For example, it is possible that many data are collected at the end of spring when mosquitoes emerge and very little data afterwards. We will include regular notifications in the final release (see planned features) as a way to mitigate this issue. In its present state, the application relies on the willingness of participants to provide data as well as the introduction of new users.

Inaccuracies also arise because of the inherent difference between the existing data and the true temporal and spatial distribution. This can be overcome through the use of dedicated statistical methods (Fithian et al. 2015). The accuracy of our data will strongly depend on the frequency and the amount of recorded encounters.

The use of our application will probably remain limited to the city of Berlin were we have the capacity to advertise our work on a regular basis to an interested audience. The use of Mosquito Mapper on larger scale, however useful it may be, would rely on time investment from other people.

Developing a smartphone application for big data comes with a lot of uncertainties. Before such endeavour is widely adopted, there is a great possibility that our work produces little useful studies. However, because such application can remain dormant at little to no cost, we believe it offers scientists a great opportunity to study mosquitoes in a way that can be both cheap and efficient. In fact, the strengths and limits described above all rely on the amount of users and their willingness to provide accurate and regular data. All limits eventually turn into strength once a critical amount of users is reached. As such, the value of an application such as Mosquito Mapper can only increase with time, as even low amount of data generated per unit of time will compound into appreciable quantities.

The data collected through the application serve several purposes. For the scientist, GPS data together with the number of recorded encounters plus their time frame can be used to generate dynamic maps of mosquito populations and to predict changes of mosquito populations' sizes for modelling purposes. The pictures constitute a repository that anyone could use to create species distribution maps or compare phenotypes within the same species. Each experiment can then be put in a temporal framework. Ways of using the data that we have not thought of or that do not exist yet may emerge as people use the application. Because of this possibility, we offer free access to all the data collected for anyone.

For the citizen the two main positive outcomes of Mosquito Mapper are the entertaining part of being engaged in citizen science and the future outcome of the database. For example, the predictive maps of mosquito presence could serve as an information tool at the same level as the weather forecast, so that people are informed where not to go if they want to minimise the probability of a mosquito encounter. Finally, the data could be used by municipalities to initiate public health actions in order to reduce mosquito presence.

Few other Android applications have the same goal as Mosquito Mapper. We found three similar educational apps: Caza Mosquitos, ZanzaMapp and Mosquito Alert. Caza Mosquitos is currently only available is Spanish, ZanzaMapp in Italian while Mosquito Alert is available in Spanish and English. The applications are very similar in capabilities and goals. Mosquito Mapper is currently available in English, German, French, Spanish and Portuguese. In our opinion, the main difference between Mosquito Mapper and the other apps lie in the direct and public access to our data so that they can directly manipulate the data if they so desire.

Planned features

The beta release of the application is meant to showcase the possibilities of citizen-driven data collection with the help of smartphones. By trying to make the data collection as easy and fast as possible, our aim is to allow children to take part. As a result, we wish to add features to make the application more "fun" to use. One way to do this is to gamify the application which means adding game-like features that would make using the application more engaging. We envision this process as follows: each use of the application would generate experience points that would lead the user to change levels. We will then add a leader board where users could compare their performance to others. Another direction for gamification will be the addition of badges for certain behaviour such as identifying a certain amount of mosquitoes or with a certain regularity. Developing the application to be more game-like implies various changes to the way the database is currently structured that would make the application more lightweight but would also consume more mobile data.

A big issue of the program is that it consists of a presence-only dataset that is known to suffer from bias (Blossey and Hunt-Joshi 2003; Fithian et al. 2015). Presence-absence datasets are more reliable. Therefore, we will incorporate notifications in the application to encourage users to report places and times when no encounter took place. The downside of such feature is that it may become annoying. The notification shall therefore only trigger rarely (once a week), with the possibility to turn the feature off. Finally, the notification feature may be used to spread timely information or help educate the citizens for example on the differences between mosquitoes and non-biting mites.

Ultimately, we wish to include more precise determination keys. The ability to use more complex keys may be limited to users reaching a certain "level", thus ensuring their willingness to participate fairly. The determination of mosquito species may be difficult and may vary wildly depending on geographical location. As a result, such feature may be limited to a handful of countries.

If a research group or passionate citizens enjoy Mosquito Mapper and want to create an alternative version of this application for another pest or any other organism, the code available on Github contains all the necessary code to easily implement such ideas. These people are welcome to contact us if they need help in this endeavour.

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Availability of data and materials
All non-social data (i.e. location and pictures) will be accessible on a website currently under construction. In the meanwhile, data is accessible through Github (https://github.com/Layninou/ScienceTogether).

Authors' contributions
Camille Guilbaud had the original idea for the application and laid out the original design. He also wrote the main text and created the figures. Théophile Guilbaud wrote the code for the application and organised the database; he also substantially contributed to drafting the manuscript and the figures. All authors contributed critically to the drafts and gave final approval for publication.

Competing interests
The authors declare no competing interests.

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