The Vanishing Firefly Project: Engaging Citizen Scientists with a Mobile Technology and Real-Time Reporting Framework*

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ABSTRACT

Fireflies are a unique part of the natural landscape at a global scale. Urban development and changes in the landscape can negatively affect firefly distribution and abundance. Assessment of firefly abundance through counts of bioluminescence flashes provides an environmental quality indicator that can be easily observed and quantified by citizen scientists. Researchers at Clemson University, collaborating with resources managers, educators and teachers initiated the Vanishing Firefly Project to engage citizen scientists with the following goals: (1) Science Inquiry-Engage citizens in scientific practices to understand the impacts of urbanization on environmental quality; (2) Service Learning-Increase the skill of citizens in making critical, scientific and informed decisions through community and service activities; (3) Sustainability-Protect natural habitats through effective land and resource management practices and (4) Stewardship-Provide opportunities for citizens to participate in environmental and sustainability studies and activities.

The project began in 2010, and was initially a Field Day located in Georgetown, South Carolina, USA. Since then, the project has grown from a single day event, to a statewide field survey, and now a global event in 2014. The 2010 efforts were local and to realize our goals would require increasing citizen science participation from one location in South Carolina to a regional scale. Several issues were to be addressed that varied from technology development, data quality and management, citizen scientist training and motivation for

volunteers. Our initial technology framework consisted of a single Google Docs webform that allowed users to submit their firefly counts, but we had no ability to engage volunteers during and after the initial submission. The technology framework at this time (2014) now consists of an iOS app, Android app and a webform that submit firefly counts, firefly behavior, ambient light measurements (iOS and Android app only) and habitat type to a real-time reporting and geospatial data management system. Our efforts have leveraged social media platforms including Facebook, Twitter and YouTube to support training, education and engagement. This paper describes project activities focusing on how our technology framework has developed and matured to increase the scope, reach and capability of citizen scientists participating in the Vanishing Firefly Project.

Categories and Subject Descriptors

H.2.8 [Database Management]: Database Applications—*scientific databases, spatial databases and GIS*; K.8.1 [Personal Computing]: Application Packages—*data communications, freeware/shareware*

General Terms

Human Factors, Design

Keywords

Fireflies, Vanishing Firefly Project, iOS, Android, GIS, Citizen Science

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1. INTRODUCTION

Citizen science is the collection or the analysis of data by volunteers and non-specialists in support of a scientific project, and are increasing in scope and number [6][15][18]. The scientific fields impacted include archeology, cartography, biology, genetics, astronomy, mathematics and others [6][16]. One of the oldest projects is the Christmas Bird Count started in 1900 where 56,623 volunteers counted nearly 70

million birds at more than 2,000 locations during the 2004-2005 sampling event [2]. Increasingly, citizen science projects are proving to be an effective means of environmental data collection, which is enabling the ability to collect data at geographic scales not possible in previous decades [9].

Fireflies (Coleoptera: Lampyridae), sometimes called lightning bugs, produce bioluminescence to attract mates or even prey [1][20], and they can be easily observed during the spring and summer[7][13]. However, many adult citizens have inquired about the recent rarity of firefly flashes, which are perceived as having been ubiquitous in their childhood. Such interest has provided environmental science educators an opportunity to use fireflies as a charismatic and easily observed educational tool that can reach citizens of all ages [5][8].

Environmental indicators are used to communicate information about the health of ecosystems and the impacts of human activity to school children, the general public, and government policy makers [4][19]. These indicators can reflect biological, chemical, and physical aspects of an ecosystem, and firefly abundance is correlated with the availability of suitable habitats [11][17]. Firefly habitat can be significantly impacted by changes in land use patterns, and indiscriminate use of insecticides, fertilizers and pet waste in lawns can kill many non-target insects, including fireflies[10][11][12]. Strong, bright artificial light can outshine firefly flashes and interfere with mating behavior [20]. All these factors work in concert to reduce the quantity and quality of habitat, thus reducing the abundance of fireflies.

The Internet, smartphone applications and data and information technology are increasingly a critical component to citizen science programs [16][21]. These technologies can support a robust and data intensive project that can reach a global audience when social media technologies are integrated into an education and outreach program. This paper summarizes the development of a real-time geospatial framework and two smartphone applications (apps). The apps enable the collection of firefly counts and measurement of ambient light. They then report the observed and collected data to an online mapping application.

2. PROJECT BACKGROUND

The combination of civic concerns and the value of fireflies as an educational tool led to the development of Clemson University's Vanishing Firefly Project¹[3]. Firefly surveys have been promoted worldwide as citizen-science projects [8][14]. The Clemson Vanishing Firefly Project, which began in 2010, is a collaborative effort by researchers from Clemson University, land and resource managers from Hobcaw Barony Nature Reserve, educators from Hobcaw Barony Discovery Center, teachers from local schools, and leaders of local nonprofit organizations. The Clemson Vanishing Firefly Project was composed of two service-learning activities each year: (1) a Firefly Field Day and (2) a South Carolina Statewide Firefly Survey. Both activities occurred in May or early June during the peak season of firefly activity in coastal South Carolina. The Clemson Vanishing Firefly

¹http://www.clemson.edu/public/rec/baruch/firefly_project

Project has four primary project goals: (1) Science Inquiry-Engage citizens in scientific practices to understand the impacts of urbanization on environmental quality; (2) Service Learning-Increase the skill of citizens in making critical, scientific, and informed decisions through community and service activities; (3) Sustainability-Protect natural habitats through effective land and resource management practices and (4) Stewardship-Provide opportunities for citizens to participate in environmental and sustainability studies and activities.

In 2013, the project was awarded funds to support a Creative Inquiry effort at Clemson University. The Creative Inquiry program provides funding to support undergraduate student participation in a research project working with faculty advisors. Several students participated through the 2013-2014 academic school year where students were engaged in ecological analyses, mobile phone app design, software programming, database design and administration, social media outreach and citizen science education. Their efforts culminated in participation in at the EPA P3 (People, Prosperity and the Planet Student Design Competition for Sustainability)² competition. The team was awarded an "honorable mention". The result of the student involvement in the project realized the launch of the 2014 survey with an integrated framework of software, databases and educational content to support citizen science engagement at a global scale.

3. DATA COLLECTION WORKFLOW

The Vanishing Firefly Program data collection and visualization framework is composed of four overarching components: (1) data collection and mapping applications including an iOS app, an Android app, webform and web mapping application; (2) a web service layer that processes data submissions and web mapping data requests; (3) an Apache HTTP Server and map server enabling, WMS cached tiles (GeoServer) and (4) PostgreSQL and PostGIS data infrastructure to support GIS raster data and firefly counts (Figure 1). The system is running on a distributed network of servers hosted at Clemson University and Amazon Relational Database Service (RDS).

3.1 Data Collection

The firefly observation data consists of three applications that support citizen scientist data collections. The primary technologies are iOS and Android applications that are available for download from the iTunes Store and Google Play, respectively. The smartphone apps use GPS for data collection location. The third application supporting citizen science data collection is a webform that collects user inputs and geocodes a user submitted address prior to data submission. The smartphone apps and webform submit data to the database in real-time. The data are immediately available for visualization on the firefly web map.

3.1.1 Client Applications: Smartphone Apps

Our initial technology framework in 2011 consisted of a single Google Docs webform that allowed users to submit their firefly counts, but we had no ability to engage volunteers during and after the initial submission. These data were

²<http://www.epa.gov/p3/>

Figure 1: Overarching software architecture supporting the Vanishing Firefly Project.

downloaded from Google and entered into a GIS and deployed online using ArcGIS API for Flex³. Our program did not use social media at the time and we did not collect contact information from volunteers, as a result we did not have any mechanism to engage volunteers after their initial data submission. Given our objectives to grow the program we pursued the development of a smartphone app to serve as handheld data collection instrument. An iOS app was first developed for the 2013 census. This app formed the foundation for further development of the smartphone as the primary data collection instrument for volunteers in the field. Objectives for 2014 included: (1) improve the usability; (2) update and improve the training module; (3) integrate data submission with real-time visualization framework and (4) develop a comparable Android app.

Plans to develop an app started in March 2012. The project team drew up the initial design of an iOS app and development progressed through 2013 resulting in the first version of the app, called Firefly Flash Counter in the spring of 2013. Firefly Flash Counter was available at iTunes for the firefly census during the Firefly Field Day, 2013 and was used to collect approximately 700 citizen scientist submissions that summer.

This app formed the foundation for further development of the smartphone as the primary data collection instrument for volunteers in the field. Discussions after the 2013 field day resulted in several modifications and improvements in the app. First, it was found that, despite a training session during the field day, the name Firefly Flash Counter confused participants who counted flashes instead of fireflies.

³<https://developers.arcgis.com/flex/>

A decision was made to change the name to simply Firefly Counter. Additional objectives for 2014 included: (1) improve the usability; (2) update and improve the training module; (3) integrate data submission with real-time visualization framework and (4) develop a comparable Android app. To accomplish these objectives, a tutorial was added to the app instructing the volunteer on various types of fireflies, the number of habitat areas was increased, and a function was added providing the ability to save firefly count records locally on the phone until Internet access was available. Easy links to the Twitter and Facebook accounts of the Firefly Count Project were also added. A link to a map shows the location of the citizen scientist when the count was taken, but also a map showing counts submitted by other citizen scientists. By the spring of 2014, to reach more potential participants, an Android⁴ version of the app was developed and made available on the Google Play Store. By design, both iOS⁵ and Android apps provide a similar look-and-feel.

Figure 2 highlights the multiple functions of the app. The first (upper leftmost) screenshot is the opening screen and allows volunteers to take a tutorial or review past submissions. The client is also able to view a map showing where the count was taken. In the tutorial, users are shown how to "make a circle with their hand" forming a small tunnel through which they view fireflies. They then proceed to the next step that simulates a counting event. A screen with varying green flashes, representing fireflies as they might be seen during an actual counting event is used for the simu-

⁴<https://play.google.com/store/apps/details?id=edu.clemson.firefly>

⁵<https://itunes.apple.com/us/app/firefly-flash-counter/id648413169?mt=8>

lation, which lasts for ten seconds. These simulated flashes appear and disappear in varying locations on the screen. In past years, there was confusion from volunteers about how to count. The overall objective is to count fireflies and not multiple flashes from a single insect. The latter leads to inflated numbers and overestimates the actual number of fireflies in a given location. The second screenshot shows the results of a tutorial exercise.

Tutorials were designed to emphasize the counting of a single flash from one firefly and to standardize the data collection methods. Additional tutorials and instructional videos were made available on YouTube⁶ including one directed towards children and the other adults. Although these were not integrated into the phone apps, this could be an area of improvement for the programming phase after the 2014 census. In the tutorial, the user reviews a series of potential flash patterns that they may encounter while taking counts. Timing and pattern of flashes is unique for a given species, thus the user is presented a series of animations for four possible flash patterns including single, double, triple, and J-shaped flash.

The third screenshot displays the counting screen. Users touch the screen each time they see a different firefly. Data collection is limited to 60 seconds and volunteers are encouraged to use the census methods learned in the tutorial module. A user initiates the data collection module. A large button is made available and the volunteer can tap in sightings as they perform the census. Once the census is complete there are additional data elements that are requested including: (1) type of fireflies seen based on the flash patterns reviewed in the tutorial module (4th screenshot); (2) general habitat type (5th screenshot) and (3) ambient light level measurement using the smartphone camera. Next steps of the data collection workflow include entering comments (6th screenshot), review of the GPS position and data submission. If Internet is not available, the app will store the census record and allow the user to submit at a later time. The 7th screenshot displays pending and submitted reports generated on this phone. The 8th and final screenshot displays the map on which this and other census reports have been taken.

3.1.2 Client Applications: Webform

The original data collection instrument was a Google Docs webform that was limited in scope and functionality. Additionally, there were no automated processes to enable geocoding of the user submitted address, which led to a fragmented data management infrastructure as the smartphone app data were stored in a MySQL database and webform data were stored on Google during the 2013 census. Beginning in the winter of 2013, the MySQL database was moved over to a PostgreSQL database and a new webform developed that could be used across all screen sizes from desktop to mobile phone⁷. The webform writes to the same database as the smartphone apps enabling all count data to be entered into the same database after census submission. The user submitted address is geocoded prior to insertion into the

firefly database using The Google Geocoding API⁸. This updated architecture has consolidated all data into a single database enabling real-time reporting and improved data management. Overall, data input elements were similar to the smartphone app including firefly counts, habitat type and flash pattern. After submission the volunteer is directed to an educational survey and to the Firefly Real-Time Map.

3.2 Data Visualization

Visualization is an important feature for engaging citizen scientists [15][21]. Allowing volunteers to explore their data submissions in real-time was a primary goal of the 2014 census event. Previous firefly census events offered little incentive to keep citizen scientists engaged in the project as there were no applications allowing volunteers to explore their data submission(s) and the submissions of other project volunteers until several days after the close of the census event. Past census efforts involved downloading submissions from the respective databases and geocoding the webform data. Data from all application clients needed to be aggregated into a common data set followed by data verification. This was a slow process and our program in the past years was not supporting data collection beyond a single nightly event, thus by the time the data were made available on the web interest in the project had noticeably decreased.

A web mapping application was developed using the Open Source Javascript library, Leaflet⁹. The objectives for this application were to provide volunteers a real-time view of their data submission and overall activity of the project¹⁰ (Figure 3). Unlike past firefly census events, we decided to accept data during the entire summer of 2014 where in past years the focus of the project had been on a single event over a three hour time frame. Users are able to view multiple data layers including their firefly count immediately after data submission and the historical 2013 census event. Basemap data include MapQuest-OSM Tiles and MapQuest Open Aerial Tiles¹¹. Additional base layer data services are available including Hydric Soil Rating¹², Ecoregions Level II¹³ and 2012 County Population Density¹⁴. These three base layers were identified to align with environmental factors that may relate to firefly abundance. Legends are available for each of these base layers.

⁸<https://developers.google.com/maps/documentation/geocoding/>

⁹<http://leafletjs.com/index.html>

¹⁰<http://firefly.clemson.edu>

¹¹Data services are made available for use under MapQuest Platform web services that is publishing OpenStreetMap® data (<http://developer.mapquest.com/web/products/open/map>)

¹²A soil formed under conditions of saturation, flooding, or ponding during the growing season to develop anaerobic conditions in the upper part. (http://www.soilinfo.psu.edu/index.cgi?soil_data&conus&background)

¹³Ecoregions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources. (http://www.epa.gov/wed/pages/ecoregions/na_eco.htm)

¹⁴http://www.census.gov/popest/data/historical/2010s/vintage_2012/index.html

⁶<https://www.youtube.com/channel/UCkqGZJ3Y2IUgzwNagiZ9ow>

⁷<http://firefly.clemson.edu/webform>

Figure 2: Tutorial and educational modules for the smartphone app available in iOS and Android versions.

Figure 3: Vanishing Firefly Project real-time reporting map on June 26, 2014.

```
{
  "Time"      : "2014-02-12 14:20:05",
  "Latitude"  : 37.33233141,
  "Longitude" : -122.0312186,
  "Count"     : 101,
  "Comments"  : "Bad Data. SNOW DAY!!",
  "Luma"      : 0,
  "Habitat"   : "Back yard, grass",
  "Types"     : [
    "5",
    "6"
  ],
  "Address"   : {
    "Street"   : "2522 West Georgia Road",
    "City"     : "Piedmont",
    "State"    : "South Carolina",
    "Country"  : "United States",
  }
}
```

Figure 4: Example of a webform application JSON data object as submitted by a user.

4. INTERFACES

A requirement for the 2014 census event was a consolidated set of web services to support data submissions by citizen scientists and visualization applications. Our team developed and deployed a relatively simple set of interfaces to: (1) enable a consolidated interface for submissions from the clients to the database and (2) support visualization of firefly counts and other GIS data (Figure 1).

4.1 Interfaces: Database Service

A PHP - JavaScript Object Notation (JSON) Database Service acts as a middle man between the the smartphone and webform to the database, and is running on an Apache HTTP Server. The smartphone apps and webform submit functions use the URL of the Apache HTTP Server to POST the count data. When the service receives a data submission in a JSON format from the smartphone apps or the webform it first checks to make sure all the required data fields (Latitude, Longitude, Time, Count, etc.) are present (Figure 4). Requirements vary depending on the data submission client. If an error is found, the client is notified and the database insert does not proceed, alternatively, an error free submission is processed and the data are submitted into the PostgreSQL firefly database. The source code for the PHP JSON Database Service is located on GitHub¹⁵.

4.2 Map Service

A PHP - GeoJSON Map Service supports visualization of the Firefly census counts on the Leaflet web mapping application. The map service queries the firefly database and dynamically builds a GeoJSON Feature Collection¹⁶ based on year of the census for each for each HTTP request (Figure 5). At this time, 2014 and 2013 census data are available. The firefly leaflet map application passes an argument of year (for example, 2014); this argument is used to filter data from the PostgreSQL database query to show only records for that particular time period. PHP functions are

```
{ "type": "FeatureCollection",
  "features": [
    { "type": "Feature",
      "geometry": { "type": "Point",
        "coordinates": [-82.307277862059, 34.815195850129] },
      "properties": { "habitatname": "Backyard, grass",
        "habitat": "1", "time": "2013-06-11 01:08:57+00",
        "datetime_formatted": "June 11, 2013 at 01:08:57am",
        "count": "111", "id": "846",
        "latitude": "34.815195850129", "longitude": "-82.307277862059",
        "luma": "0", "comment": "", "ident": "",
        "geom": "0101000020E61000000115C470AA9354C0CA116E5658684140",
        "id": "846" },
      { "type": "Feature",
        "geometry": { "type": "Point",
          "coordinates": [-82.096321536305, 34.889839002895] },
          "properties": { "habitatname": "Backyard, grass and shrubs mix",
            "habitat": "3", "time": "2013-06-11 01:15:30+00",
            "datetime_formatted": "June 11, 2013 at 01:15:30am",
            "count": "13", "id": "845",
            "latitude": "34.889839002895", "longitude": "-82.096321536305",
            "luma": "0", "comment": "", "ident": "",
            "geom": "0101000020E610000002615CE212A8654C0D411943EE6714140",
            "id": "845" }
        ]
    }
  ]
}
```

Figure 5: Example of a GeoJSON data object showing two firefly census records.

used to convert the raw query output into a GeoJSON object. The GeoJSON data are parsed by the firefly web map application to create point data on the map in the form of marker(s), and attributes are available through the use of InfoWindows by clicking on markers. The source code for the PHP GeoJSON Map Service is located on GitHub¹⁷.

4.3 WMS Tile Caches

We deployed the Open Source map server GeoServer to enable custom base layers, discussed previously in the section "Data Visualization". GeoServer is a Java-based software that allows users to view and edit geospatial data using Open Geospatial Consortium (OGC) standards¹⁸. Specifically, we are using the caching service of GeoServer that runs as a proxy between the firefly map client and the map server (GeoServer), caching tiles as they are requested by the client. This greatly improves client base layer drawing performance and reduces the processing load on the server(s).

5. DATABASE: POSTGRESQL

PostgreSQL¹⁹ serves as the primary database for the firefly data and web map base layers with each running on a separate server. Each PostgreSQL instance has the PostGIS extension installed, which supports geographic objects and enables location queries to be run in SQL²⁰. The shp2pgsql data loader was used to import the base layer shapefiles directly into PostgreSQL and made available as WMS tile caches through the map server.

Firefly census submissions are a vector (point) data and a custom database model was developed (Figure 6). The *Entries* table is the primary data table where the PHP JSON

¹⁵<https://github.com/whitedl/vanishingfirefly>

¹⁶GeoJSON object will contain a geometry object and additional parameters. A feature collection represents a list of features (<http://geojson.org/geojson-spec.html>).

¹⁷<https://github.com/whitedl/vanishingfirefly>

¹⁸<http://www.geoserver.org>

¹⁹<http://www.postgresql.org/>

²⁰<http://postgis.net>

Figure 6: Firefly database model for census data submitted by smartphone apps and webform.

Database service writes the majority of the incoming data object submission. There are subtle differences between the smartphone app and webform submissions as the webform data object will not have a "luma" data element. The "id" column is an auto increment primary key and the geometry, "geom" column, for each record is generated by a trigger. All data are projected in the WGS84 coordinate reference system (CRS). The *Habitats* table is a look up table for the "habitat" column in the *Entries* table. The smartphone app and webform submit a data object with an integer value for habitat where there is only one habitat type per submission. The "ident" column records the type of client used and for smartphones will record the operating system version and hardware platform.

The citizen scientist is asked to document the observed flash pattern(s). This helps the firefly team estimate species distributions during the census. Flash patterns are documented in the smartphone apps, YouTube videos and other media. Multiple species may be observed and are submitted by the client applications as an integer(s). The *Types* table is a look up for *Types_Selected* that has foreign key to the *Entries* table.

An entry into the *Addresses* table is a requirement for webform submissions. Given the errors that can occur with geocoding, the table allows for the original address entry to be saved and geographic coordinate accuracy verified at a later time. *Address* has a foreign key to the *Entries* table.

A quality control flag column will be added to the *Entries* table starting in July 2014. This will allow for the ability to remove potentially erroneous data from the firefly web map and alert data managers to potential submission errors. The flagging mechanism will be based on a combination of factors including time of submission, total count submitted and location of submission.

6. CONCLUSIONS

At the time of this writing (September 6, 2014), a total of 2,703 counts were submitted since May 31, 2014 for a total of 46,255 fireflies counted where each submitted firefly count is one hundred or less. Submitted counts greater than one

Table 1: Summary Census Observations by Platform

Client	# of Counts	Total Count	Mean
iOS	1872	30903	17
Android	617	11685	19
Webform	214	3667	17

hundred will be verified independently. A detailed summary by client application is provided (Table 1). The latest version of the Firefly Project framework is a marked improvement over past years. We have reached a greater geographic distribution with citizen scientists participating from seven countries including USA, Canada, Columbia, Luxembourg, Germany, Italy and Qatar. The smartphone app was designed to improve training, help the volunteer keep track of the survey time period (60 seconds) and standardize the data collection process and workflow, thus improving data quality. The webform although improved will need further enhancements such as integrating a standardized training module. Additionally, we have a small number of users who may be making repeated counts over time, which suggests a high level of engagement with the project. Overall, the data management framework is superior and provides opportunities to increase citizen scientist involvement and allows the research team to further our educational and research priorities.

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