

Chapter 6

Geographical Information Systems in Modern Citizen Science

Laia Subirats
Eurecat, Spain

Joana Simoes
GeoCat, The Netherlands

Alexander Steblin
Eurecat, Spain

ABSTRACT

This chapter shows how citizen-science initiatives have been known to exist for a long time, but only recently they were further enhanced thanks to technological and societal developments, such as the availability of mobile devices, the widespread use of the internet and the low cost of location devices. These developments shaped the geographic information system (GIS) world as it is known today: a group of technologies that allows retrieving, storing, analyzing and sharing spatial information, by people who are not necessarily GIS professionals. This chapter starts with a general background about GIS, adding then more detail in topics of particular relevance in the context of citizen science. The rest of the chapter is focused on reviewing and classifying the use of GIS in citizen-science initiatives; and some use cases are described in order to provide practical examples of the use of these technologies for solving specific spatial problems. The chapter closes with a brief discussion of the future of GIS in citizen science, in the light of current technological trends.

INTRODUCTION

Citizen science has a great focus in environmental issues such as pollution, habitat and biodiversity (Castell et al., 2014; Uhrner et al., 2013), and thus it has an eminent geographic component. The phenomena that concern citizen scientists do occur in a certain place and at a certain scale, and they are often interrelated with other phenomena that are also linked to places and scales. GIS is the “glue” which

DOI: 10.4018/978-1-5225-0962-2.ch006

Geographical Information Systems in Modern Citizen Science

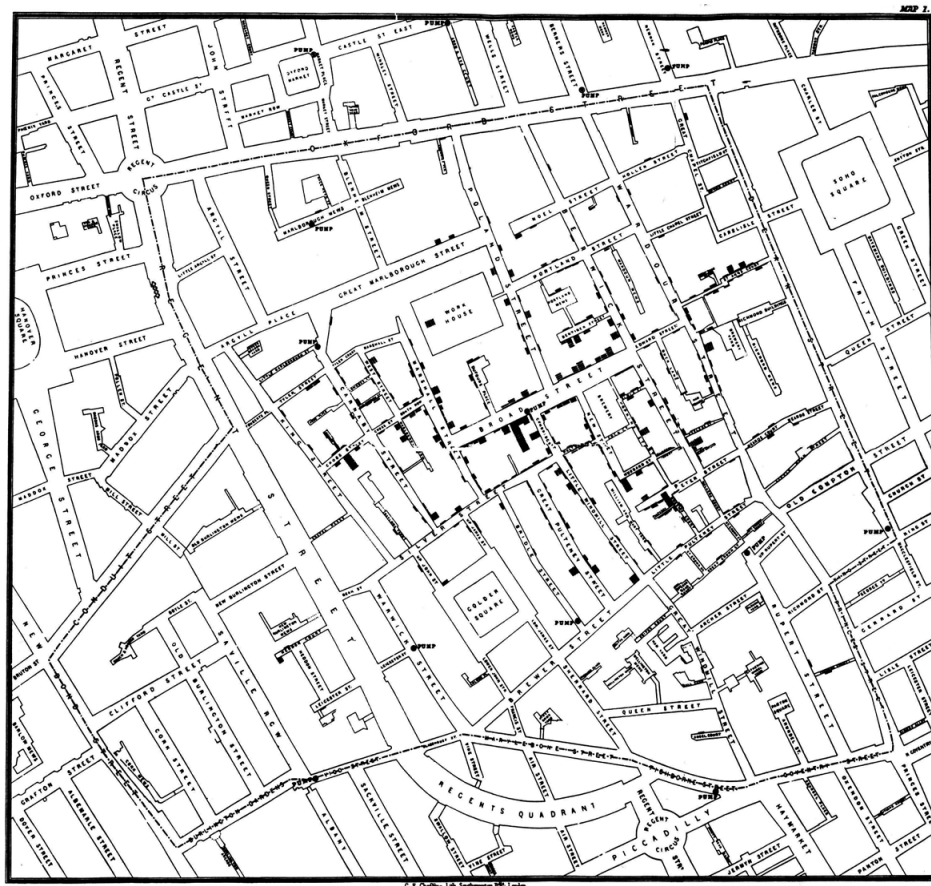
enables us to relate these different places, scales and phenomena in a system where the information can be effectively stored, managed and analyzed.

Scientists have been known to use spatial analysis for a very long time. In 1854, British epidemiologist John Snow (Goodchild, 2007), plotted the reported cholera deaths onto a street map (a technique similar to what is currently called a *mash-up*), in order to find out the source of the infection: the public water pump on Broad Street.

Although this early example already illustrates the application of GIS principles to solve a societal problem, it was not until recently that the use of GIS became generalized among the citizen science community, along with other communities. Undoubtedly, modern GIS developments such as interoperability, the growth of Free and Open Source Software (FOSS) and digital Volunteered Geographic Information, amongst others, have played an important role for this widespread technology adoption. These aspects are discussed within the “Background” section, which aims at familiarizing the reader with GIS technologies. Unfortunately it would be too ambitious to provide a complete introduction to GIS

Figure 1. Original map by John Snow, depicting the clusters of cholera cases in the London epidemic of 1854

Drawn and lithographed by Charles Cheffins (Snow, 1854).



Geographical Information Systems in Modern Citizen Science

in the scope of this chapter, so the authors focused instead in the most recent events, and in particular in those technologies, movements and ideas which are more relevant in the context of citizen science.

The rest of the chapter is entirely devoted to describing and understanding the use of GIS in citizen science projects. The next section, “GIS in the Context of Citizen Science”, starts with an extensive list of citizen science GIS projects, and it aims to showcase the diversity of citizen science applications powered by GIS, as well as exposing common aspects across many of them. The following section elaborates a bit more about these commonalities across infrastructures, by proposing a Citizen Science GIS taxonomy. This is followed by a description of use cases, where the use of GIS is portrayed with more detail, within real-world, well-defined, citizen science problems. These use cases are examples, and they were chosen based on their representativity, as well as on the availability of information about those projects.

The last section is more practical, and it provides a set of recommendations on how-to setup a typical GIS infrastructure for a citizen science project. Finally the authors close the chapter with some general conclusions and an overview of GIS trends which could impact the development of citizen science in the upcoming years.

Although not all citizen science relates to GIS, there is an important overlap between the two areas and it could be stated that there is also a positive feedback, in the sense that citizen scientists are not only contributing to GIS, but also pushing for its use and contributing towards its development. Apart from demonstrating that GIS technologies can support the development and further enhancement of citizen science projects, the objectives of this chapter were to understand and describe which are these technologies, and “why” they are relevant, which in turn can help us to understand “why” they were adopted by citizen scientists.

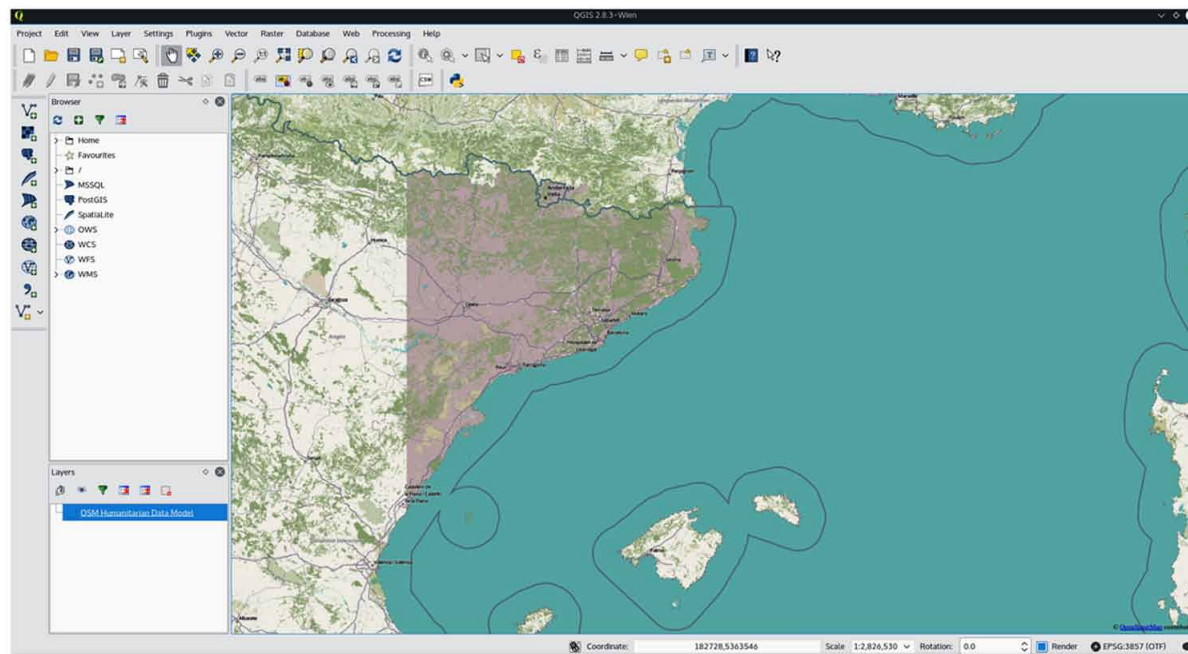
BACKGROUND

Although GIS has been erroneously described as a *container of a map in a digital form*, it is actually much more than that (Longley et al., 2005). A more complete definition of GIS would be *an integration of data, hardware, and software designed for management, processing, analysis and visualization of georeferenced data* (Neteler & Mitasova, 2008).

In recent years, GIS has evolved from being a highly specialized niche area, restricted to a group of experts, to a technology that most people use to manage different aspects of their lives (Neteler & Mitasova, 2008). This may include trivial tasks such as searching for a restaurant nearby, navigating through a road network, or even locating a missing or stolen phone.

Nowadays most GIS users use software that runs either on their desktop, or on the web (Longley et al., 2005); in fact, these usage patterns can be used to derive the two main categories of GIS: Desktop GIS and Web GIS. Desktop GIS has been around since the mid 90s, and provides rich functionality to the end user, which includes viewing, querying, updating and analyzing spatial information and related data. The applications are normally large, and they may be referred as “fat” clients. QGIS (<http://qgis.org/en/site/>), gvSIG (<http://www.gvsig.com/en>) and GRASS (<http://grass.osgeo.org/>) are examples of desktop GIS that run in Windows, Linux or OS X. Spatial libraries such as GDAL/OGR (<http://www.gdal.org/>) are the backbone of desktop GIS.

Internet GIS, or web GIS, sometimes also referred as web mapping, or Geoweb, has developed significantly in the last two decades. The architecture of internet GIS is two tiered, comprising a server,

Geographical Information Systems in Modern Citizen Science*Figure 2. Screenshot of the user interface of a Desktop GIS (QGIS)*

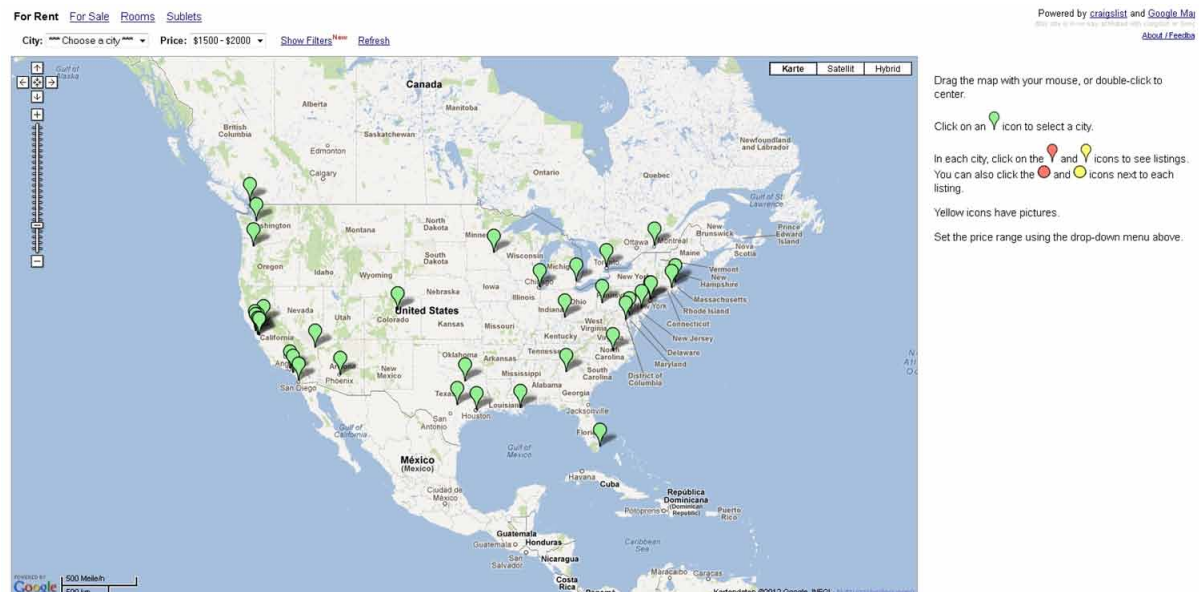
which runs on a computer server and can handle multiple requests, and a range of networked clients (Longley et al., 2005). These clients can be as simple as a web page, as the most complex functionality is built into the server, and thus they are referred as “thin” clients. This kind of architecture has the potential for a very large user base with a very low cost per user, and unsurprisingly it has an important role in supporting public participation.

The first generation of web mapping can be dated to the late 90s, and it was based on simple HTML protocols that delivered mostly static maps, and resulted in a poor user experience (Minghini, 2014). In the following ten years a second generation of web mapping arrived, based on DHTML, Java and ActiveX, which resulted in websites with increased interactivity (e.g.: MapQuest, Yahoo! Maps). During this period, many organizations (in particular from the public sector) entered the GeoWeb 1.0, and server side products were developed, including the Free and Open Source alternative for serving maps, MapServer (<http://www.mapserver.org/>). The delivery of spatial data over the web was increasingly more sophisticated, but a number of factors still limited its diffusion; these were basically the complexity in developing applications, the limited bandwidth and the cost of the base cartography (Minghini, 2014). This limited the number of people who developed applications, and delegated most users to a passive role; a top-down approach was a key characteristic of this generation of web mapping.

The Web 2.0, with the advent of technologies such as SOAP, AJAX and APIs, together with hardware improvements such as the low cost of GPS receivers, was the driving force behind the Geo Web 2.0. The third generation of web mapping is iconically represented by Google Maps (<https://www.google.com/maps>), which arrived in 2005. The rise of the mapping APIs, which ease the development of map websites and at the same time give access to base data, allowed a large community of users to create and share spatial information (Minghini, 2014). The birth of the APIs is associated to the Google map platform, which was reverse engineered by hackers, in order to create *mash-ups*, applications that integrated the

Geographical Information Systems in Modern Citizen Science

Figure 3. HousingMaps (Rademacher,2005) overlaid Craigslist records on a map; it is considered the first mashup



map layers from Google, together with information from other services and data. Shortly after, Google released a public API and it was quickly followed by other competitors (e.g.: MapQuest, Yahoo!).

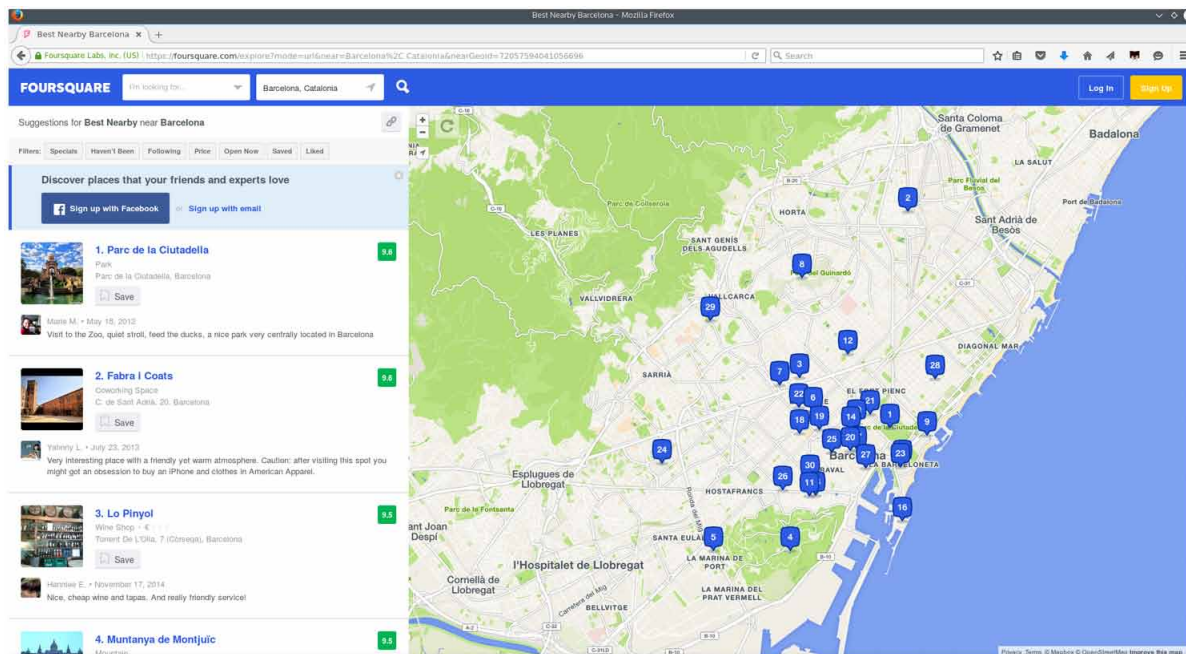
The most recent web mapping clients are independent from the server-side applications, and can consume different services provided by servers. They support browsing maps (e.g.: zooming, panning), and layer interaction (e.g.: switching layers on/off) out-of-the-box. OpenLayers (<http://openlayers.org/>) is the most well-known and widely used web mapping client; it was developed with the idea of providing a Free and Open Source alternative to the Google Maps client, and it is entirely written in JavaScript, providing a rich experience in most modern browsers, without any server side dependencies. OpenLayers 3 includes the latest HTML5 and CSS3 features, and it supports 3D virtual globe capabilities through the use of WebGL.

As OpenLayers capabilities increase, it tends to become more difficult to use. Leaflet (<http://leafletjs.com/>) was released in 2010, with a main focus on developing mobile-friendly applications, and it has attracted a lot of attention since then, mostly due to its simplicity, performance and usability. Its objective is not to provide such advanced functionality as OpenLayers but to satisfy the basic needs of the majority of the users. This approach may explain its popularity, which is showcased by its adoption by major websites such as FourSquare, Pinterest, Flickr and OpenStreetMap.

Unlike the traditional approach to GIS, where professional cartographers would use complex desktop GIS and deal with advanced concepts and functionality, sometimes perceived as “boring”, the GeoWeb 2.0 introduced techniques which enabled a more pleasurable and effective user experience, attracting a more casual and far wider usage of geographic information. This new approach is summarized in the term *neogeography*, coined by Eisnor (2006) to describe the non-professional practice of mashing up multiple sources of geographic information. Citizen science shares this aspect of the GeoWeb 2.0, of including non-professional scientists, voluntarily participating in a scientific project.

Geographical Information Systems in Modern Citizen Science

Figure 4. Screenshot of the FourSquare website, powered by Leaflet (Foursquare, n.d.)



STANDARDS AND INTEROPERABILITY: WHY DO THEY MATTER?

Standards are technical documents, that define interfaces and encodings that can then be used by developers to implement applications that use these interfaces and encodings (Open Geospatial Consortium, n.d.a). They are very important, because they are the way to guarantee that data collected by different applications and different use cases is interchangeable, and that different services can talk to each other. This is particularly relevant in crowd-sourced initiatives where there are a lot of players involved, in different places, who may even use different devices. It is important to enforce standards, in order to ensure that these data will be discoverable, viewed, accessed and integrated, or else there is the risk to create data silos.

In the case of the geospatial community, two organizations have played a key role in setting a well-defined standardization framework: the Open Geospatial Consortium (OGC) and the International Organization for Standardization (ISO), and in particular its technical committee 211 (ISO/TC 211).

The ISO/TC 211 was first established in the mid 90s, and it was set to define a structured set of standards to describe georeferenced objects and phenomena. Among others, it created the ISO 19115 (International Organization for Standardization, 2003), which defines a schema for describing geographic data (metadata) and the 19119 (International Organization for Standardization, 2005), which identifies and describes the architecture patterns for services interfaces used for geographic information.

The OGC was also established in the mid 90s, mostly focusing on interoperability through standard development, but also featuring a compliance program with the goal of providing resources, tools and policies, for improving software implementation in compliance with these standards. The idea behind developing standard-based products, is that these products should work together effortlessly, without

Geographical Information Systems in Modern Citizen Science

further debugging. As of 28th February 2016, there are 46 OGC standards, listed on their official website (Open Geospatial Consortium, n.d.a).

OGC Web Services (OWS) is a set of standards created for use in web applications; they include the Web Map Service (WMS), the Web Feature Service (WFS) and the Web Coverage Service (WCS). These standards enabled the development of vendor-agnostic server side products, which serve vector and raster data. MapServer and GeoServer are examples of such products. They also enabled the development of vendor-agnostic web mapping clients, which can combine different types of server-side services, as is the case of OpenLayers.

The Catalog Service for the Web (CSW) is another OGC standard, which is used to expose a catalog of geospatial records over the internet. These services support the publishing and searching of metadata about geospatial data, services and related information. They also support the discovery and retrieval of metadata (harvesting). The CSW profile must be consistent with the core metadata elements defined by ISO 19115 and its XML implementation given by ISO/TC 19139. The services metadata elements must be consistent with ISO 19119.

The Sensor Web Enablement (SWE) OGC standards (Open Geospatial Consortium, n.d.b), enable developers to make all types of sensors and sensor data, discoverable, accessible and usable through the web. These standards are very generic, and although they provide all the needed functionality for crowdsourcing campaigns, they also provide unnecessary functionality for this particular context. With the goal of simplifying the application of these standards to citizen science projects, the Citizen Science Observatory (<http://www.citizen-obs.eu/>), a network of five EU sponsored citizen observatory projects, has compiled a set of best practices and made them available on a GitHub repository. The “SWE4CitizenScience” (Citizen’s Observatory, n.d., Higgins, 2016) is a remarkable effort for enforcing the interoperability in crowdsourcing campaigns, at the same time it eases the application of these standards in the context of citizen science.

Although OGC specifications are the golden standard for interoperability of geographic information, they are sometimes overlooked by the neogeography community (including citizen scientists), due to its complexity and relative obscurity (Minghini, 2014). This explains why the birth of the GeoWeb 2.0 relied mostly on APIs, rather than on OGC standards, which were available much earlier and could have enabled the same type of applications. Nevertheless, most Free and Open Source GIS relies heavily on OGC standards, and its level of popularity has been responsible for a wider adoption of standards, and thus an increasing interoperability among the GIS community.

The Role of Free and Open Source GIS

The term “Free Software” (use interchangeably with “Free and Open Source Software”) was coined by Richard Stallman in 1984 (Stallman & Gay, 2009). It is based on the idea of guaranteeing to the users four basic freedoms, which are designed to promote software evolution (e.g.: bug fixing, capabilities improvement):

- The freedom to run the program, for any purpose.
- The freedom to modify the program to suit their needs (which requires access to the source code).
- The freedom to redistribute copies of the program, either free of charge, or subject to a fee.
- The freedom to distribute modified versions of the program, so that the overall community can benefit from their improvements.

Geographical Information Systems in Modern Citizen Science

These freedoms are enforced by a method called *copyleft* (Stallman & Gay, 2009), which is implemented through a family of software licenses. The first *copyleft* license was the GNU General Public License (GPL), written by Richard Stallman in 1984, and in its unmodified form it still dominates the FOS community.

The access to the source code is particularly relevant in GIS, because some algorithms are complex and it may be important to review them, in order to understand them (Neteler & Mitasova, 2008). Proprietary software falls short in terms of examinability of algorithms, but also in the distribution of newly implemented models, since the original software is required to run the model (Steiniger & Hay, 2009). Bug fixing and feature improvement are another consequence of the FOS model. Although the average user may not be able to solve bugs and improve features, there are a number of people who can do this, and the overall community can support them by testing and issuing bug reports, and then benefit from the improvements. FOSS development tends to be very dynamic, and sometimes it evolves quicker than proprietary software.

It is important to dissociate “free” software from “free of cost”, as FOS can be distributed for a fee, and software that is *gratis*, may not guarantee the four basic freedoms to the user. Likewise, it is important to not mistake FOSS with “Open-source” software, as this definition does not specify if the source code can be modified and distributed.

In recent years the paradigm of FOSS development has taken root in the GIS community, resulting in the creation of several very sophisticated software projects that implement the different components of a complete GIS stack (Steiniger & Hay, 2009); ranging from map server applications (e.g.: MapServer, GeoServer), and spatial database management systems (e.g.: PostGIS), to desktop GIS (e.g.: QGIS, GRASS, SAGA) and web mapping libraries (e.g.: OpenLayers, Leaflet). These days FOS GIS have nothing to envy from proprietary systems, both in terms of functionality and ease of use. Unsurprisingly, all these features at zero cost and supported by a vibrant community have resulted in a rising uptake of FOS GIS among different user groups, including universities, public authorities, private companies, journalists and non-profit organizations.

According to Steiniger and Bocher (2009), the rise in popularity of free GIS tools can be measured using four indicators. The first one is the number of projects started, which is exposed on the number of entries added to the website FreeGIS.org (featuring 356 entries, on 27th February, 2016). The second indicator is the increasing financial support to FOS GIS projects, given by governmental organizations. GRASS, gvSIG and Jump are examples of projects which received such funding. The third indicator is the rate of downloads of FOS GIS software. Steiniger and Bocher (2009) mention as an example, SAGA GIS, which experienced an average increase of downloads in its documentation section, between 2005 and 2008, from 700 to 1300 per month. The fourth indicator is the increasing number of use cases of FOS GIS software (for instance those documented on Ramsey (2007)).

The Open Source Geospatial Foundation, OSGeo, (<http://www.osgeo.org/>) was created in 2006, driven by the need of a public representation of the FOS GIS community (Steiniger & Bocher, 2009). Since then it has led important initiatives such as publishing a journal, hosting a number of software projects, founding an education and curriculum committee, donating Sol Katz award to individuals who have demonstrated leadership in the FOS GIS community and organizing its yearly international conference, FOSS4G. The FOSS4G conference in Seoul, in 2015, has attracted 562 attendees from 48 different countries (Brovelli & Raghavan, 2015). The presentations include research talks, software development reports, and business case studies, and there is also space for user group meetings, developer workshops and software demonstrations.

Geographical Information Systems in Modern Citizen Science

Overall, the FOSS paradigm fits very well with the citizen science paradigm, since both are bottom-up initiatives; thus it does not come as a surprise that the citizen science community has been deeply involved in FOSS and vice-versa (Okolloh, 2009).

Volunteered Geographic Information

The term Volunteered Geographic Information (VGI) was created by Goodchild (2007), to describe the widespread engagement of large numbers of private citizens, often with little in the way of formal qualifications, in the creation of geographic information. It is important to note, that this approach of using citizens as sensors is opposed to the top-down approach taken for centuries, where this would be a role reserved for official agencies (e.g. mapping agencies).

Although some VGI themes such as land use, or soil classification may require sophisticated mapping skills, others activities such as collecting place names and geographic features are much less demanding, and have been widely adopted in citizen science initiatives. Technology improvements, which resulted from the advent of Web 2.0, and the low cost of GPS devices, contributed for enabling the collection of rigorous geographic information, without requiring an advanced knowledge in topics such as coordinate reference systems. Ushahidi (<http://www.ushahidi.com/>) is a good example of a platform that eases the process of *activist mapping*, a blend of activism, journalism and geographic information. It provides a user-friendly user interface, through which citizens can submit their local observations (using phones or computers) and a backend where it stores this spatio-temporal information. The aggregated results are then displayed in a web page. Ushahidi has been at the core of many citizen science initiatives (Meier & Brodock 2008; Liu et al., 2010).

The “democratization” of data collection, has also been associated with a “democratization” in the access to datasets, expressed by the Open Data philosophy (Auer et al., 2007). In line with Open Hardware, Open Software (see section “The Role of Free and Open Source GIS”), Open Content and Open Access, it expresses the idea that data should be freely available to everyone to use and republish as they wish, without any type of constraints. Although there is a very clear association between bottom-up datasets (for instance OpenStreetMap, n.d.), that is traditionally not the case with top-down, governmental datasets. Nevertheless, in recent years there has been an increasing pressure from citizens and communities, in order to promote the release of official data with open licenses. The governments, the United Nations and the European commission have responded to this effort with initiatives such as Data.gov (<https://www.data.gov/>), OpenDataBCN (<http://inspire-geoportal.ec.europa.eu/>), the FAO GeoNetwork (<http://www.fao.org/geonetwork/srv/en/main.home>) and the INSPIRE geoportal (<http://inspire-geoportal.ec.europa.eu/>).

The reactions to hurricanes Irene and Sandy, that recently affected the US, illustrate the use of *public data for public good*; i.e.: they show how the combination between VGI and Open Public Data can provide a critical, updated, information, which can potentially save lives. Hurricanes have always been a major concern, in particular around central and North America, and they often left a trace of destruction and death. For instance it is estimated that hurricane Galveston, which affected Texas in 1900 has provoked around 8000-1200 deaths; sixty three years later, hurricane Flora, which affected Florida has taken a death toll of 7,193 (Wikipedia, n.d.). The difference nowadays, is that more than 50% of American adults use social networks, 35% have smartphones and 78% are connected to the Internet (Loukides et al., 2013). For both citizens and local authorities, the internet turns into a two-fold pool for resources: in one hand for submitting information and on the other for receiving data about the hurricane.

Geographical Information Systems in Modern Citizen Science

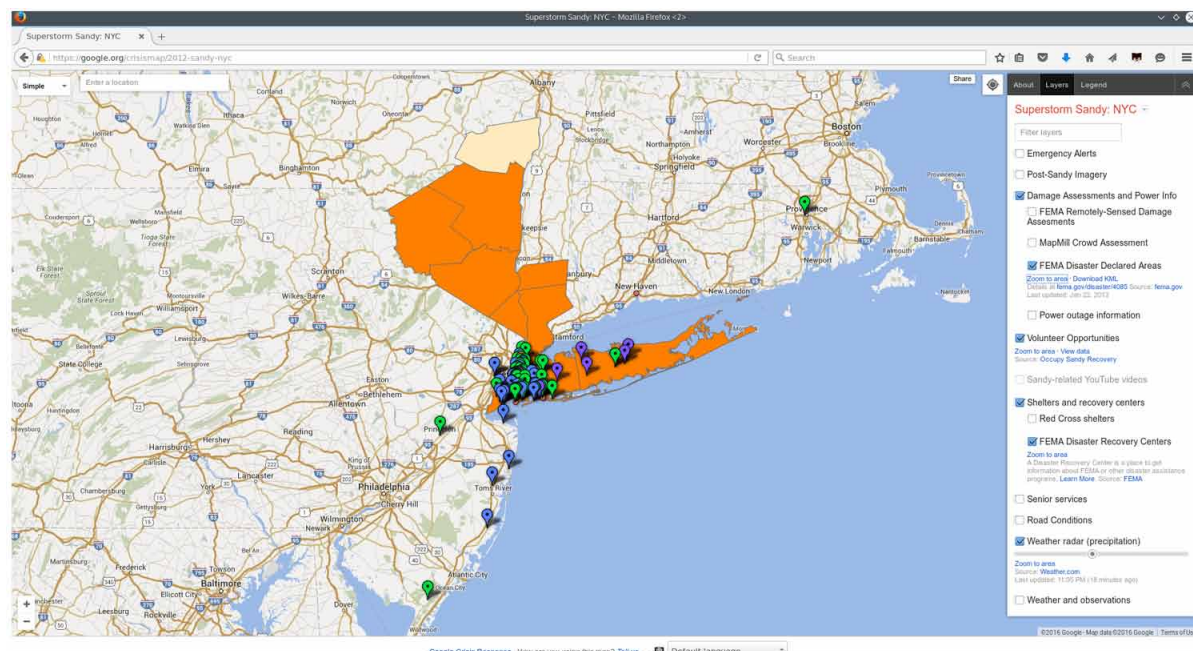
The “Google Crisis map for Hurricane Sandy” (Google Crisis Response, 2012) is an interactive map which predicts the future of the “Frankstorm” in real-time; this impressive mashup is fed by public Open Data (e.g.: government weather data), as well as social data gathered by citizens (e.g.: location of volunteering opportunities, location of shelter and recovery centers). During the hurricane, this map was used by a large number of individuals for instructing other people about what to expect, and what to do.

Likewise to what happened during hurricane Irene, during hurricane Sandy there was a huge pressure from citizens towards local authorities regarding the release of official information about the hurricane. The New York City and the U.S. federal government decided to publish all their evacuation plans as open data, and apart from publishing their official evacuation maps, they also enabled the community to develop their own mashups and apps. By releasing open data, these organisms acted as a platform for public media, civic entrepreneurs and nonprofits to enable people to help themselves and one another at a crucial time (Loukides et al., 2011).

On the other hand, by acting as a network of connected sensors, citizens can share the effects of the hurricane in real time, providing local and regional authorities unprecedented insights into what is happening. The city of Maryland has taken a deliberate step towards promoting and organizing this VGI and invited their citizens to share and view hurricane data throughout the state (<http://gopi.maryland.gov/>). For this purpose they used a web tool and free mobile app, seeclickfix (<http://en.seeclickfix.com/>), that allows citizens to report neighborhood issues to local authorities. The app uses phone GPS in order to collect georeferenced information, which is later aggregated in maps.

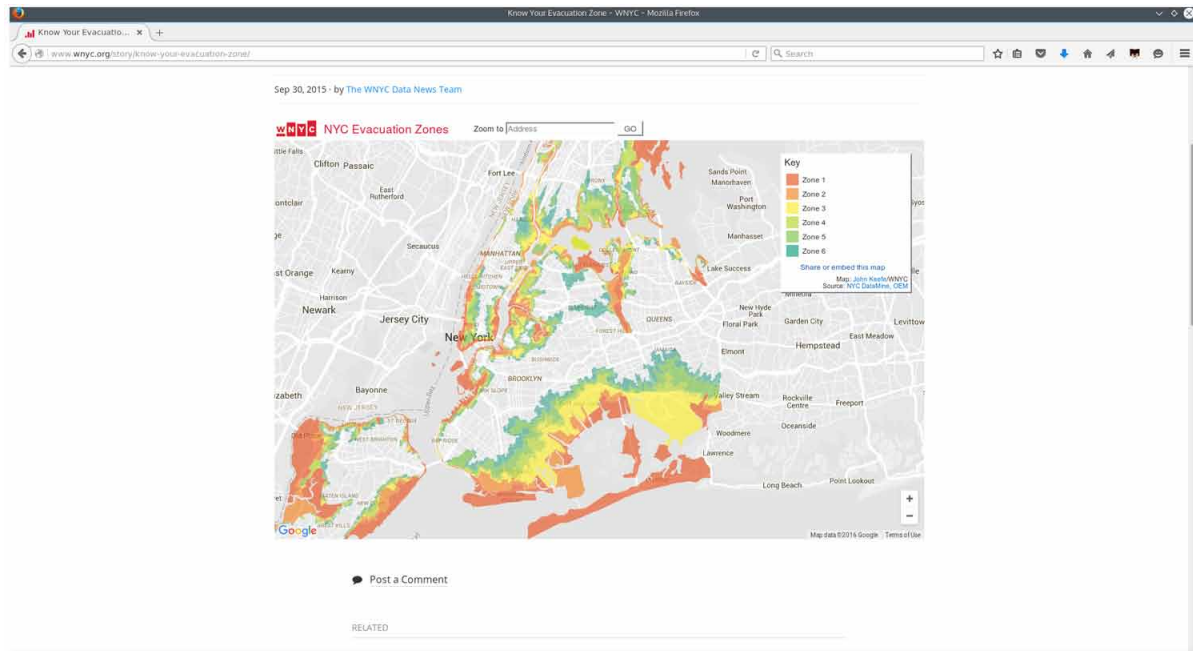
Official data (for instance administrative maps) is still important and relevant for GIS, as it provides extremely accurate information, with a consistent degree of coverage. Nevertheless, this data is costly

Figure 5. Google Crisis Map for Hurricane Sandy, showing emergency alerts, FEMA disaster declared areas, the location of volunteer opportunities, shelters and recovery centers (Google Crisis Response, 2012)



Geographical Information Systems in Modern Citizen Science

Figure 6. Evacuation zones map, produced by WNYC data news editor John Keefe (The WNYC Data News Team, 2015)



to produce, and often takes a long time to create it. Most applications demand data availability and up-to-date information, and they are turning to *unofficial* sources, such as OSM, Twitter or other examples of VGI. This information may not be as accurate as the official versions, but it is extremely updated, it may cover some themes or geographical areas that are not covered, and can provide a great complement to official information. Public authorities are also understanding this and they are incorporating it, or using it to improve their own datasets.

In the early nineties, the Map Science Committee of the National Research Council issued a report describing the concept of National Spatial Data Infrastructure (NSDI); among other things it introduced the notion of *patchwork*, the idea that mapping agencies should no longer attempt to provide uniform coverage of the entire country, but instead they should provide standards and protocols, under which groups of individuals may emerge a global coverage, with varying detail, according to their needs (Goodchild, 2007). This directive provides the perfect ground for nurturing VGI under an official data infrastructure, and it exposes the growing interest of public authorities in this type of bottom-up data.

GEOGRAPHICAL CITIZEN SCIENCE

As mentioned in the “Introduction” section, a great deal of the information collected through citizen science projects has a geographic component. The intersection between citizen science and VGI is often called *Geographical Citizen Science*, a term coined by Haklay (2013) to describe citizen participation in scientific projects which involve the collection or analysis of geospatial information. Although geographic information can be, and still is, collected accurately using non digital technologies (e.g.: *paper* maps),

Geographical Information Systems in Modern Citizen Science

citizen cyberscience is the branch of citizen science which takes advantage of GIS and of the Web 2.0, and thus it will be the focus of this chapter.

Geographical citizen science volunteers can be classified according to their role (Haklay, 2013). While active volunteers contribute consciously to the observation or analysis, passive volunteers normally behave as “observation platforms”, without being actively engaged in the data collection process. An example of such behaviour would be an user that carries a phone with an app, which records location tracks.

Geographical Citizen Science can also be classified according to the explicit nature of geographic information (Haklay, 2013). While some activities are directly aimed at collecting geographic information (for instance the location of an observation of a species), in other citizen science activities this information can be collected unintendedly, as it may be the case of some geotagged pictures.

As citizen science projects often target geographically spread observations, and thus require a large, often sparse, network of volunteers, VGI results in an extremely attractive approach for supporting those projects.

GIS in the Context of Citizen Science

GIS has been at the core of many citizen science initiatives. As in many VGI projects, citizen scientists use the internet as their primary communication channel, and thus web GIS is their privileged tool to share spatial information. Unsurprisingly there are already some initiatives that provide general resources and information such as the citizen science association (CSA), the European citizen science association (ECSA) and the Australian citizen science association (ACSA). These global initiatives demonstrate that citizen science is building a momentum across the world.

In addition, there are guidelines for successful web mapping applications in citizen science, such as Newman et al. (2010). Moreover, an increasing number of initiatives use mobile-based applications to enhance public participation and engagement in citizen science (Brovelli et al., 2015).

This section lists different citizen science initiatives which make use of GIS, detailing a few use cases. It also analyses some aspects of the use of GIS in citizen science and provides generic guidelines, which the authors consider useful when starting a project.

Examples of GIS Enabled Citizen Science Projects

In order to illustrate better the current GIS trends within citizen science it has been collected a list of citizen science projects which have presence in diverse research areas. Some projects have been selected from the Barcelona city council’s citizen science booklet (Barcelona City Council, 2016). These projects cover different topics such as zoology (“Atrapa el Tigre”, iNaturalist, JellyWatch, NatureWatch, Sea-Watchers UrbanGene), air quality (Safecast), water quality (Citclops, EyeOnWater, Riunet, SecchiDisk), ornithology (eBird) and coral health monitoring (CoralWatch). There are different types of entities behind these initiatives, including universities (in most cases), local associations, companies, research centers, and public authorities. Most of these initiatives use web mapping and rely on OGC standards.

“Atrapa el Tigre” (<http://atrapaeltigre.com>), promoted by Centre for Advanced Studies of Blanes of the Spanish National Research Council (CEAB-CSIC), was created to survey and monitor the population of the Asian tiger mosquito (Kampen et al., 2015). The project includes a database where it stores all the data related to this species, a service to serve these data, and an interactive web client with a map, where it displays the information to the final user. Figure 7a) presents a screenshot of the web mapping client.

Geographical Information Systems in Modern Citizen Science

The map features colored markers displaying different information, depending on the probability of a mosquito being the target species. The samples are grouped by clusters, and when clicking on a cluster, it zooms to its bounds. Each cluster features the number of samples associated to it. Clicking on a sample triggers the display of a pop-up menu with the photo of the mosquito, along with the answers to some questions that help to identify the tiger mosquito, and whether this sample was validated by an expert.

Citclops (<http://citclops.eu>) is a research project which focuses on assessing the color, transparency and fluorescence of the sea (Ceccaroni et al., 2015). This project also includes a database where it stores all the information related to watercolor (measured in Forel-Ule (FU) units), a service to serve these data, and an interactive web client with a map where it displays the information. Figure 7b) shows a screenshot of the web mapping client, featuring a map with different color markers, which correspond to different FU colors; the number and color of the cluster indicates the average FU color for the samples in that cluster. More information about the Citclops objectives and how GIS technologies contribute to achieve these objectives are detailed in the “Use Cases” section.

Figure 8 shows screenshots of the web mapping clients of the CoralWatch and eBird projects.

CoralWatch (<http://www.coralwatch.org>) was developed by the University of Queensland, with the objective of quantifying coral health (Alabri, 2010). The CoralWatch website presents an interactive map

Figure 7. Web mapping clients of the a) *Atrapa el Tigre* and b) *Citclops* projects

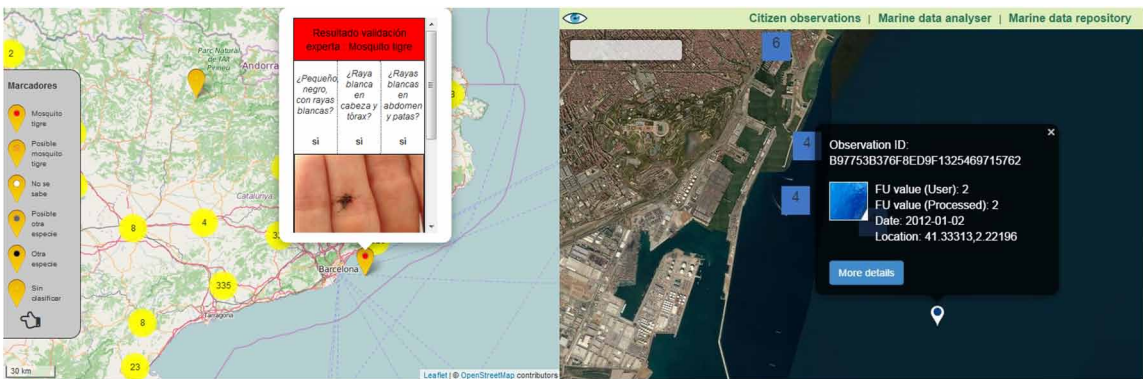
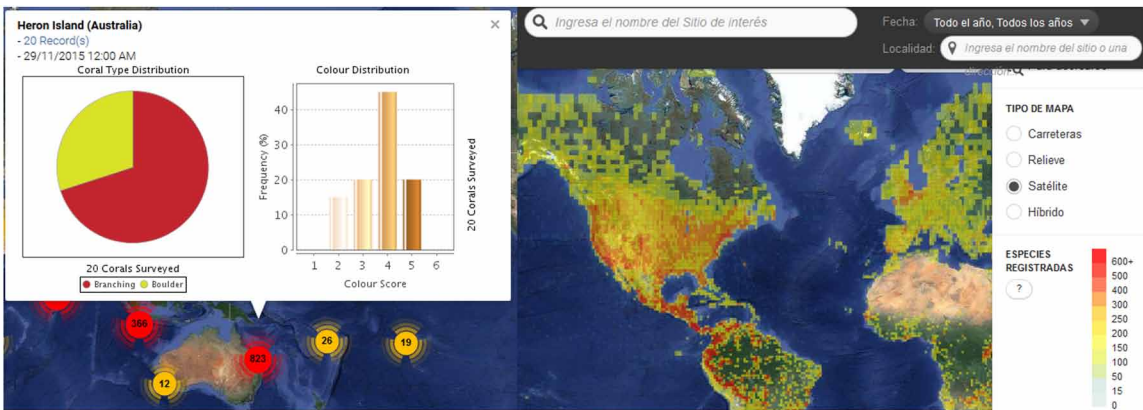


Figure 8. Web mapping clients of a) *CoralWatch* and b) *eBird*



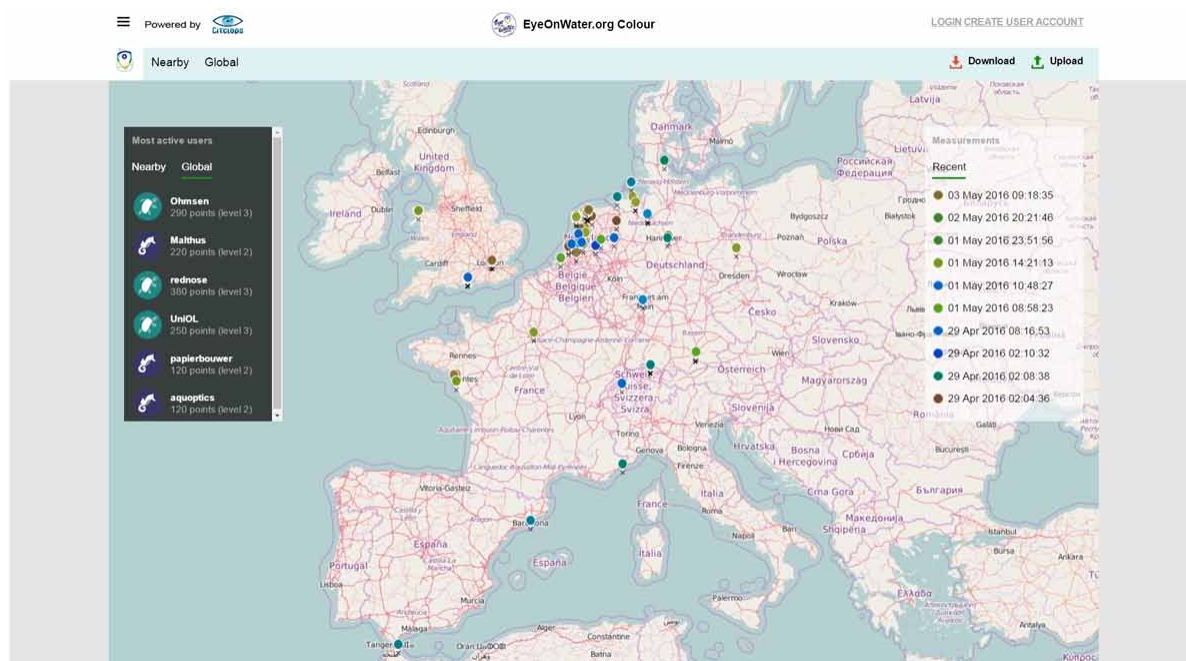
Geographical Information Systems in Modern Citizen Science

featuring calculated clusters of corals (Figure 8a). The numbers associated with the clusters indicate the number of samples, and the color scale depicts the number of samples. When clicking on a cluster, some additional information is displayed (the number of analyzed colors, a pie chart featuring the coral type distribution and an histogram with the color distribution). Clicking on the survey details will extend the information to each of the records in the survey. More information about the backend technologies of CoralWatch is given at the use cases section.

The eBird project (<http://ebird.org>) is an initiative of the Cornell Lab of Ornithology (National Audubon Society), with the objective of monitoring birds (Sullivan et al., 2009). The project, which started in 2002, presents a website with an interactive heatmap of the number of registered species. The web application offers different ways of plotting the distribution of the birds: by region, hotspots (Figure 8b), by species, bar charts (e.g.: explore the bird population distribution, according to the time of the year, or the location), line graphs (explore different metrics of species observations in a region or location) and a submission map, sighting submissions from people across the globe, are displayed in real time.

Figure 9 shows the web mapping application of EyeOnWater (<http://eyeonwater.org>) developed by Citclops / MARIS. The underlying motivation for this project was to assess the color and clarity of natural waters, and the physiological state of *Ulva* (Sea Lettuce). The website, launched in 2015, displays an interactive map with the different observations of FU color, the users who submitted them, and the most recent observations. The color of the samples indicates the Forel-Ule color of the observation. Lists of the most active users and most recent observations complement the information on the map. When clicking on a user, its observations are automatically displayed. One of the most interesting aspects of this project is the application of user engagement techniques. For instance, scoring citizens who submit observations, ranking them, and rewarding the most active data collectors with a special status, that can range from Jellyfish to Neptune.

Figure 9. Web mapping client of EyeOnWater



Geographical Information Systems in Modern Citizen Science

Figure 10. shows the web-mapping application of iNaturalist (<http://www.inaturalist.org>), a project started in 2008 by the California Academy of Sciences. The idea behind this initiative is to share observations of animals and plants. The map displays the observations of different species (in grey circles) and supports filtering by different parameters (e.g.: observation, species, identifiers and observers). The most recent samples are listed on the side of the map.

Naturewatch (<http://naturewatch.org.nz>) was developed by the New Zealand Bio-Diversity Recording Network Trust, with the purpose of monitoring nature (e.g.: Botany, Entomology, Ecology, Ornithology, Phenology and Zoology). The web mapping interface is similar to the one used in iNaturalist. As in iNaturalist, it supports filtering by observations, species, identifiers and observers. When clicking on an observation on the map, a photo of the observation is displayed, along with the observer and the respective research grade.

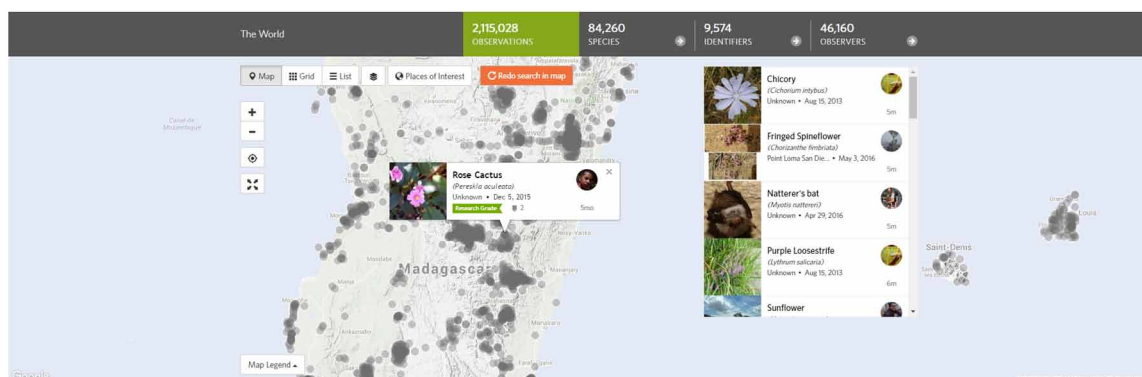
JellyWatch (<http://www.jellywatch.org>), developed by the Monterey Bay Aquarium Research Institute, is a project whose aim is to monitor jellyfish. The web mapping application shows the locations of jellyfish around the world, along with the information about other marine organisms. The different species of jellyfish are represented by different icons.

Riunet.net (www.riunet.net) was developed by the Freshwater Ecology and Management Research Group, of the Universitat de Barcelona, with the objective of evaluating the ecological quality of river ecosystems. The website features an interactive map plotting the distribution of the different ecological samples of a river. Figure 11 shows a screenshot of Riunet, featuring the markers that indicate the ecological status of the river. When clicking on a sample, a pop-up is automatically triggered, displaying additional information (a photo, the observer's name, and the description of the different parameters measured in the sample).

Safecast (<http://safecast.org>) was started in 2011, by the Momoko Ito Foundation; its main concern is to monitor radiation and air quality (Yasuhiko, 2014). The project's website shows the level of radiation and air quality collected by sensors. The amount of radiation in a zone, is depicted by a color scale. When clicking on one sensor, the evolution of the radiation for that sensor is displayed.

Figure 13 shows screenshots of the web mapping clients of Seawatchers and Secchi Disk projects. Sea watchers (<http://www.observadorsdelmar.cat>) was developed by the Institute of Marine Sciences of the Spanish National Research Council (ICM-CSIC) with the purpose of monitoring the current state of seas and oceans (Azzurro et al., 2013). The Secchi Disk study (<http://www.secchidisk.org>), started in

Figure 10. Web mapping client of iNaturalist



Geographical Information Systems in Modern Citizen Science

Figure 11. Web mapping client of Riunet.net

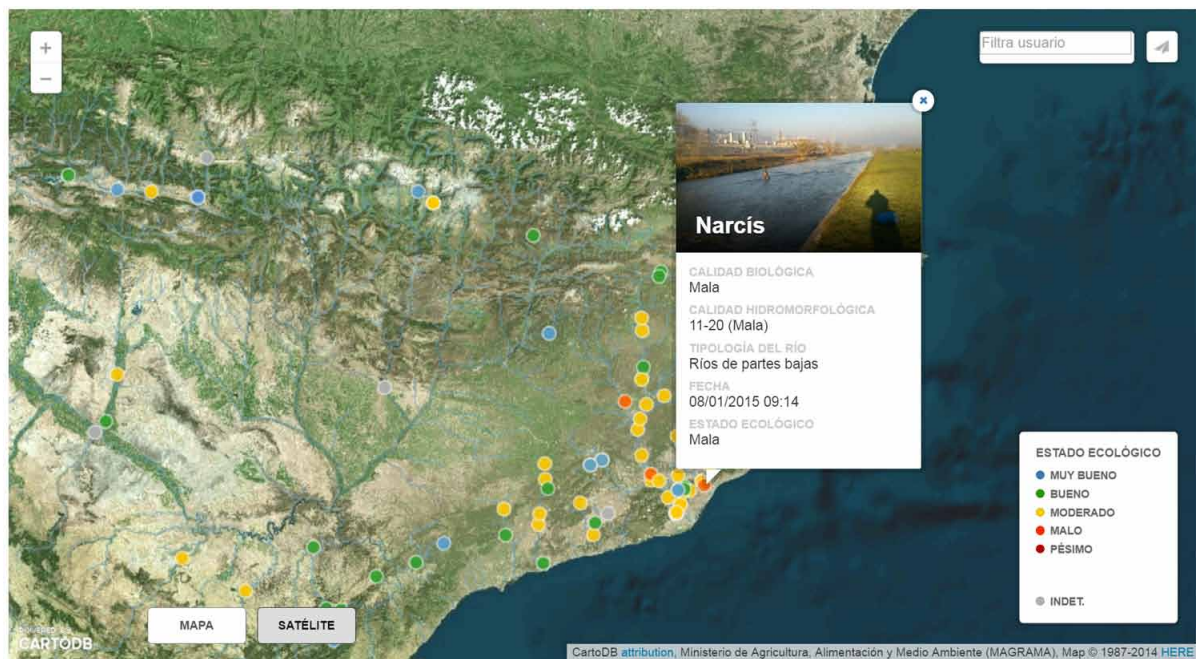
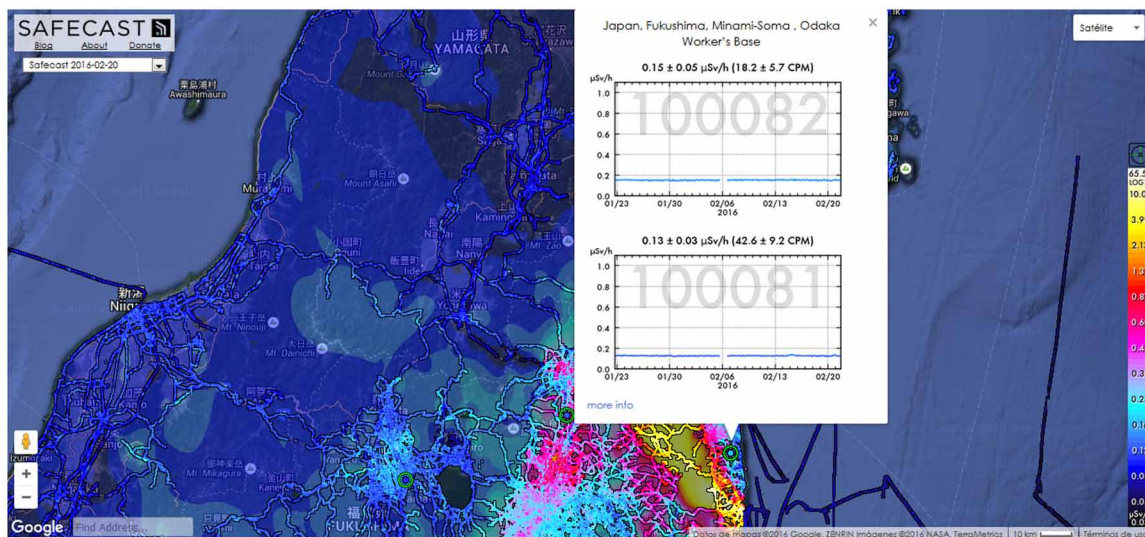


Figure 12. Web mapping client of Safecast



2013, focuses specifically in monitoring changes in the marine phytoplankton. In Seawatchers the different colors indicate different species, while in Secchi Disk indicate the different levels of transparency.

Urban Gene (<http://urbangene.epfl.ch>) was developed by the École Polytechnique Fédérale de Lausanne. The overall idea of this project was to assess the current state and dynamics of biodiversity, and to identify ecological, socioeconomic and socio-demographic factors that may influence dispersal, gene

Geographical Information Systems in Modern Citizen Science

Figure 13. Web mapping clients of a) Seawatchers and b) Secchi Disk project



flow and adaptation of plant and animal species in urban areas (Joost et al., 2014). The developed web mapping application (in Figure 14), displays clusters of species, along with an indication of the number of samples on each cluster. The backend of UrbanGene is described in more detail in the use cases section.

Classification of Citizen Science Projects

Any type of citizen science project based on GIS demands a high level of interaction between the citizen user and the technological platform provided by the project. Thus there is a requirement to enable a kind of access door, or gateway, in order to exchange the generated knowledge between two sides, users and GIS platform. Through this entrance there is a dataflow in both directions. The direction from the user to the platform firstly generates all the necessary information required by the project such as the samples, registers, observations or sensor data and secondly receives user requests for access to this information. The direction from the platform to the user responds to requests for information by downloading, view-

Figure 14. Web mapping client of Urban Gene



Geographical Information Systems in Modern Citizen Science

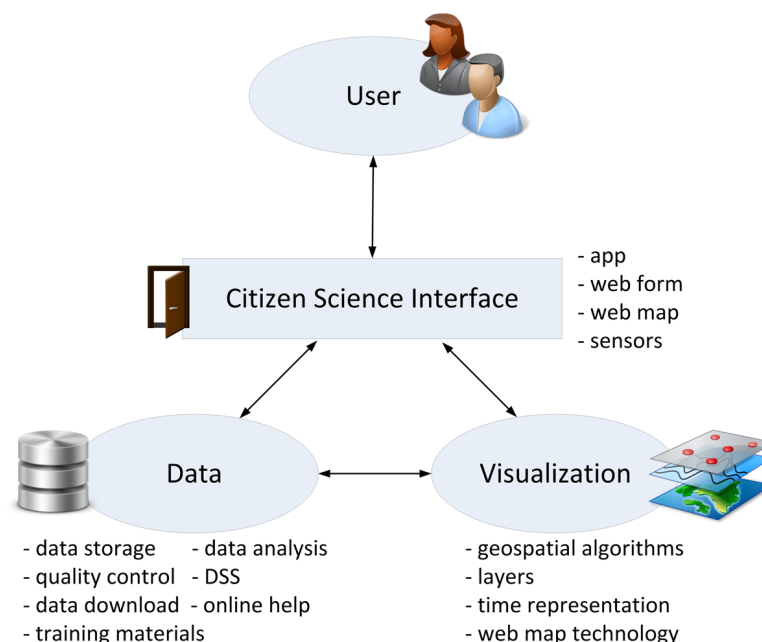
ing or analysis. Examples of information request could be downloading raw data, samples display on a web map or data analysis by generating reports or graphs. This “door” can be interpreted as a citizen science interface. It is the first things a user sees, when he/she joins a citizen science project. Moreover, this interface could provide more than one access door. This gateway could take the form of an app, web map, web form or sensors. Some of them can generate, display data or both.

As can be noted, all interaction between citizens and GIS platform is carried out through this interface. Therefore, this interface has to be fit, as much as possible, for an audience of non-experts. The usability and user experience are very important aspects to consider when designing this type of interface. The tools provided to citizens should be very easy to use, understandable and intuitive. In this way it can be assured a higher user engagement, universal acceptance of the initiative pursued by the project and a wide dissemination of its results. All of this will eventually lead to a more pronounced impact on both scientific and citizen level.

Despite their differences, citizen science projects based on GIS share something in common. On one hand they share the interface that has been mentioned above. And on the other hand they share the actions performed through this interface that are the interaction with data and its visualization. In Figure 15 a summary of the interrelation between these elements is displayed.

Figure 15 shows that first of all, the only interaction door between the user and the technology platform in question is the citizen science interface. Analyzing the structure below the interface in greater depth, one will notice that it is formed by two large blocks: data and visualization. The data block represents all actions, components and technologies that have some relation to it such as data input, data storage, data analysis, etc. The visualization block represents the actions, components and technologies related to the graphical presentation of the data or results after its analysis through web mapping, clustering and layer display techniques, etc.

Figure 15. Concept components used by citizen science projects



Geographical Information Systems in Modern Citizen Science

The next two sections contain a more detailed explanation of these two groups citing several examples of technologies and citizen science projects. Note that this classification does not attempt to make a technology separation, but concepts (in this case, data usage and data display concepts) to which different types of technologies are applied.

Visualization-Driven Classification

The analyzed projects are grouped according to the following classification topics: geospatial algorithms, layer display, representation of time and web technology.

Clustering data points according to its location is a common interpretation of collected data used by GIS technologies. In citizen science, there are several initiatives that cluster samples such as *Atrapa el Tigre*, *Citclops* and *CoralWatch* (Alabri, 2010). Other common geospatial algorithms include the calculus of point trajectories, for instance used in *Citclops - Barcelona World Race 2014-15* initiative (Ceccaroni et al., 2015), heatmaps (e.g.: *Safecast*) and the generation of new samples by clicking in the map, which it is shown in Figure 14 (UrbanGene, Joost et al., 2014).

The organization of information in layers, which supports combining different thematic units in a single view, is a core feature of GIS. In citizen science initiatives, there are several projects which take advantage of this approach to expose important information, such as *Atrapa el Tigre*, *Citclops*, *iNaturalist* and *Seawatchers*.

Time is an important variable in citizen science, which unlike space does not have a standard native support in GIS, but can be represented with different strategies. Some web mapping applications represent the time dimension with widgets such as a calendar (*Citclops*) or a time slider; others support time filtering (*Atrapa el Tigre*, *Citclops*, *iNaturalist* and *Sea watchers*). Finally *eBird* is an example of a web mapping application which displays information in real-time.

Web mapping clients, can also be classified according to the map service they use. Many citizen science initiatives use Bing (*Citclops*), while others use OpenStreetMap (*Atrapa el Tigre* and *UrbanGene*), Google Maps (*iNaturalist*, *NatureWatch*, *Sea watchers* and *Secchi Disk study*) or *CartoDB* (*Riunet*).

Web Mapping Application Classification

Newman (2010) presents another classification, based on web map application features and the role they support. These features include: data entry, quality control, data download, analysis, decision support, training, and technical support.

Data entry can be achieved by entering data forms (*Citclops*), an app (like *Secchi Disk study* or *Citclops*), sensors (*Citclops*, *Citi-Sense*, *Omniscientis*, *Wesenseit*) or by interactively clicking on the map (*UrbanGene*).

Quality control can be performed in different ways, by specific algorithms (*Citclops*), by assigning a reputation to the user who collects the sample (*EyeOnWater*), or through expert validation (*Atrapa el Tigre*).

Data download is generally not supported in citizen science projects (although some of them such as *EyeOnWater* have this functionality). Most of them do not allow the download of the complete dataset, and not even of a subset.

Geographical Information Systems in Modern Citizen Science

Regarding data analysis there are several factors that can be displayed:

- Calculate the number of contributions per year by project. In iNaturalist and NatureWatch you can see the total number of contributions, species and observers.
- Create project statistics as charts. This is done in some projects such as CoralWatch.
- Report the most frequently reported species. Projects like NatureWatch and iNaturalist show the most recent found species.
- Display and reward the member with the most contributions. For example EyeOnWater display most active users in one side of the screen. Others like NatureWatch and iNaturalist enable to look for observers and rank them according to the number of observations.
- Display and reward the project with most contributions. Projects like NatureWatch and iNaturalist rank the species according to the contributions when clicking to the species tab.

Decision support is not supported in most projects. They lack functionality such as activating early warning email alerts, defining locations of interest for early alerts, defining species of interest for early alerts or creating predictive models. Citclops offers decision support capabilities in a module called 'Citclops Data Explorer'.

Regarding training materials, there are plenty of them in most initiatives, such as online videos or tutorials.

Although online help is implemented in most initiatives, telephone support is a more difficult functionality to find.

Use Cases

In order to demonstrate the diversity of GIS technologies and how they can be applied in the context of citizen science, the authors selected a few use cases, in which the underlying technologies were disclosed. The next paragraphs contain a detailed description of each use case.

Citclops

Citclops is a European project (2012-2015) that was developed under the umbrella of FP7. This project was led by Eurecat, with the collaboration of the following institutions: Spanish National Research Council (CSIC), Carl von Ossietzky Universität, Oldenburg, Royal Netherlands Institute for Sea Research, Kinetical Business SL, TriOS Mess, MARIS, Noveltis SAS, Coastwatch Europe and Deltares. The Citclops project aims to develop systems to retrieve and use data on seawater color, transparency and fluorescence, using low-cost sensors combined with people acting as data carriers, contextual information and a community-based Internet platform. GIS technologies have an important role in this context, because they allow the visualization, analysis and interpretation of collected data.

As a result, a decision support system named 'Citclops Data Explorer' has been developed, which provides several interfaces to visualize collected data: the citizen observations, the marine data analyzer and the marine data repository (Ceccaroni et al., 2015). For each interface different GIS technologies are used. The citizen observations' interface, allows citizens to visualize the observations collected through the "Citclops-Citizen water color monitoring" app. It enables the user to share his/her localization and see the samples nearby. The marine data analyzer is aimed at a more advanced user. In this case, it is

Geographical Information Systems in Modern Citizen Science

shown more in-depth information regarding the state of seawaters, such as the historical state of bathing waters, seawater color obtained from the satellite data and historic weather data. The data in this interface can be graphically visualized in time series plots. Finally, the marine data repository allows a more extensive search and data downloading according to different parameters.

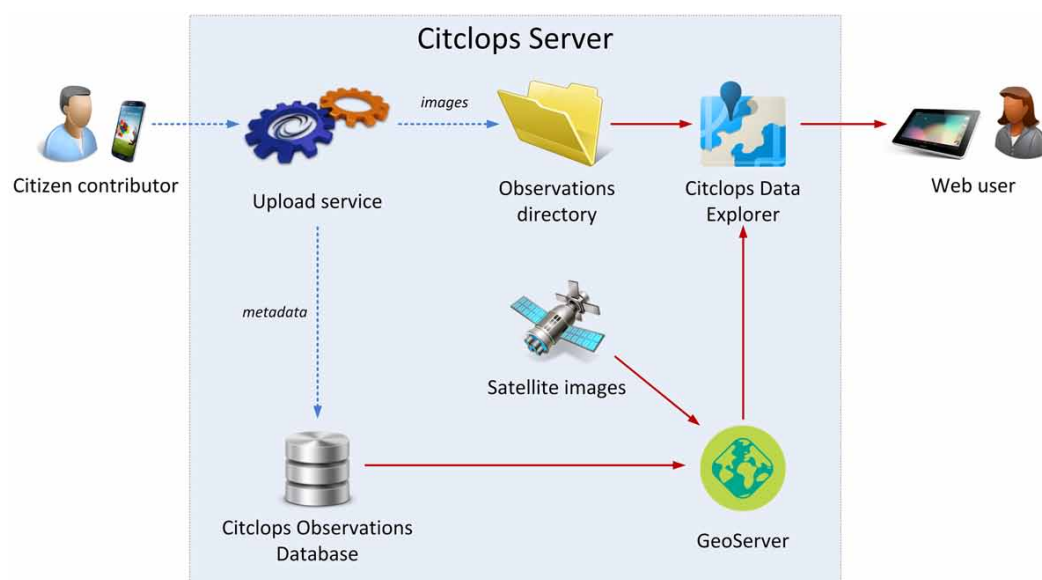
To develop these interfaces several GIS technologies have been used such as Bing Maps and Leaflet for the front-end and Geoserver, PostgreSQL and PostGIS for the back-end. GIS technologies were used mostly for visualization, storage and delivery of information while other technologies have been applied for developing different features (for instance Octave for quality control and Python language with Flask framework for data upload).

Figure 16 shows the general diagram of the internal structure of the Citclops server, with its components and dataflows. The arrowed lines indicate the flow of the observation data. Dotted lines depict the paths, when an observation is being inserted into the Citclops Server; solid lines depict the paths, when viewing the observation-data through the Citclops Data Explorer (Ceccaroni et al., 2015).

During the insertion action the citizen can provide his or her observation through the “Citclops-Citizen watercolor monitoring” app or the web form available through the Citclops’ website. Both components are connected to the Upload service located on Citclops Server. This service has been developed in Python language using Flask framework. Once the sample reaches the server it is split in two parts; the graphical part (watercolor images) goes to a dedicated directory and the information part (geospatial and description metadata) goes to the PostgreSQL database where the PostGIS extension has been activated.

During the viewing process the citizen uses the web-based Citclops Data Explorer. The backend part of this component is based on GeoServer, which also uses the same database to read the metadata, in order to locate the observations’ markers (with watercolor images taken from the dedicated directory) on the map. A part of the color samples GeoServer also serves the available satellite images with watercolor processed data. These samples have been collected through Medium Resolution Imaging Spectrometer

Figure 16. Application components and data-flows in the Citclops Server



Geographical Information Systems in Modern Citizen Science

(MERIS) instrument, which has been launched by the European Space Agency (ESA) onboard its polar orbiting Envisat Earth Observation Satellite.

The frontend part of the Citclops Data Explorer is based on Bing maps, using the satellite view layer. The interactive map was developed using the javascript library Leaflet. In order to show the watercolor samples contributed by citizens, GeoServer returns the messages with information on their location, metadata and a link to the image. This information is then added to the web map by the Leaflet API. MERIS satellite images are also included as layers. Besides visualizing time series, the user can also query a color image by date, using a calendar.

EyeOnWater

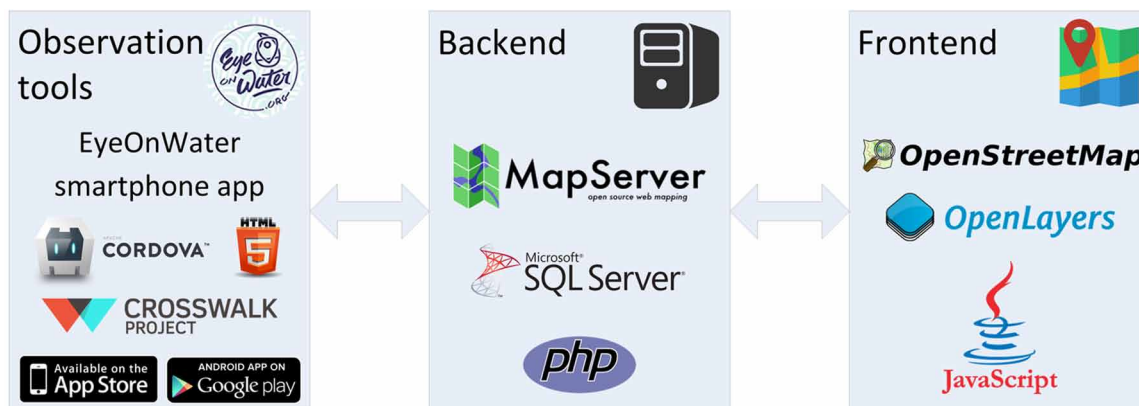
This project was born during the execution of the Citclops project. It is an evolution of the results obtained in Citclops, counting with several improvements. These improvements include progress on the issues of usability, user experience and user engagement.

The idea and functionality remain more or less similar. The concept involves the collection by citizens of watercolor samples through the smartphone app and the visualization and analysis of these samples on the web map.

As for the technologies used in this project, a summary of components is shown in Figure 17. The backend includes MapServer where the use of WMS and WFS standards is made. The PHP language is used for functionality unrelated to the maps. The data storage part uses SQLServer database. The Frontend includes OpenStreetMap for web mapping and OpenLayers 3 stack for the API interaction. Javascript is also used for the GUI web elements.

In the case of the mobile application it has been developed in the project for various purposes, such as observing color or transparency of the water. The tools that have been used for its development are Apache Cordova framework with Crosswalk project and HTML5.

Figure 17. EyeOnWater components



Geographical Information Systems in Modern Citizen Science

CoralWatch

In the case of CoralWatch the technologies used are slightly different, but the architecture remains similar. Figure 18 describes in detail, the architecture and components used in this project.

On the backend side, CoralWatch integrates Java based tools. On the web server the Apache FreeMarker template engine is used to generate HTML output based on templates and changing data. PostgreSQL with PostGIS, is the selected database engine. A different aspect in this case here is the use of PL/R Statistical processing, which performs statistical analysis of coral data to determine whether a bleaching event has occurred. In addition the CoralWatch server includes a component called “Integration tools”, which consist of correlating the CoralWatch data with other data repositories using an ontology. Finally, there are one or more connectors to provide the ability to send samples using the smartphone.

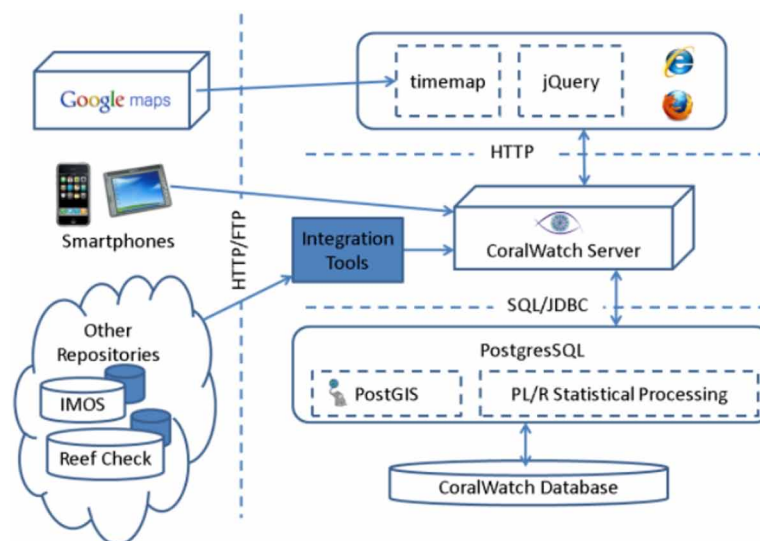
On the frontend side there is an interesting combination of Google Maps API and TimeMap javascript library. On one side the Google Maps enables the geospatial representation, and on the other side, the TimeMap allows the integration of spatial and temporal objects into a map and a timeline.

As a final result, a simple but effective citizen science tool has been implemented, which gives the ability to report information regarding the status of corals and visualize the results in very intuitive way.

UrbanGene

In UrbanGene the authors found similar technologies and a similar structure of the solution. On the backend side two main elements have been detected; the web server, which is developed in PHP, and data storage based on the PostgreSQL/ PostGIS stack, which adds support for geographic objects allowing location queries to be run in SQL.

Figure 18. CoralWatch system architecture extracted from Alabri (2010)



Geographical Information Systems in Modern Citizen Science

The part of the frontend uses a fairly standard combination consisting of OpenStreetMap to enable the geospatial representation, Leaflet API to enable the data web visualization and jQuery UI library to manage some user interactions like the drag & drop (Joost et al., 2014).

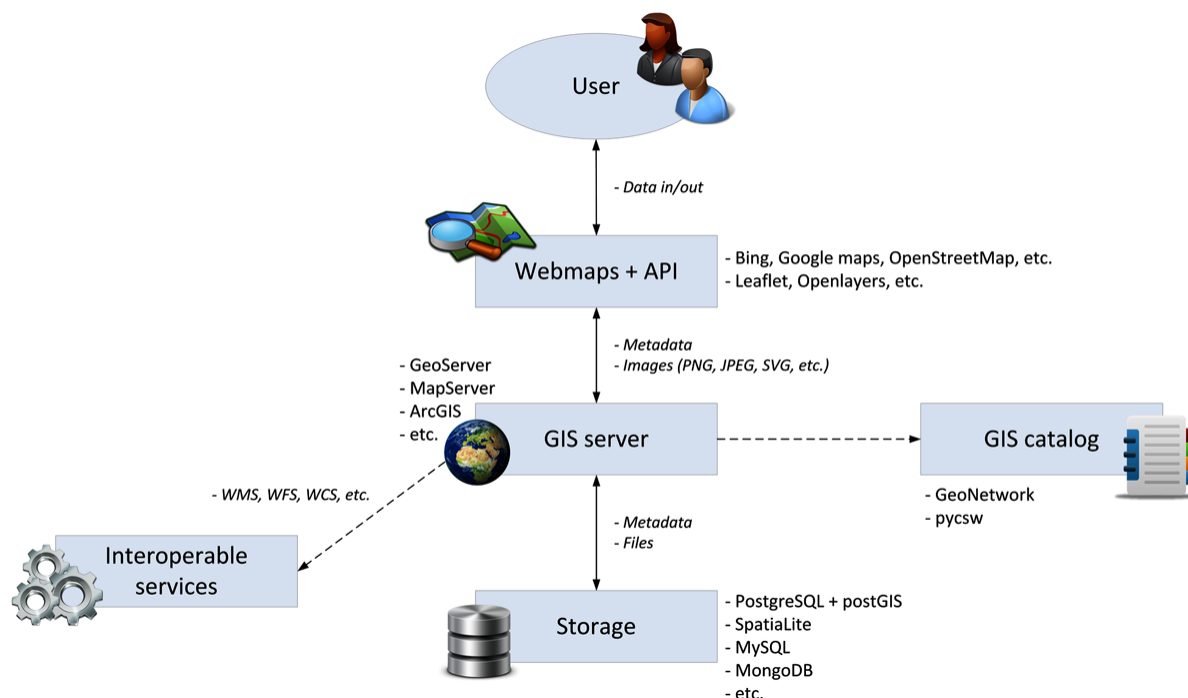
GIS INFRASTRUCTURE FOR CITIZEN SCIENCE

After reviewing all these solutions, one can ask the question: “which technology should I use for my citizen science project?” In this section the authors compare different GIS technologies in order to support a more informed decision regarding these options. To help understanding the comparison made in this section, the reader may refer to Figure 19, where a summary chart of all components is presented.

The first step could be to choose a map server, to provide the base maps. There are several popular options such as Google Maps (proprietary), Bing Maps (proprietary), MapQuest (proprietary), OpenStreetMap (ODbL), Here (proprietary) and Apple Maps (proprietary). In case you need to show high-resolution satellite maps, Bing Maps provides a resolution slightly higher than other solutions. Apart from this, one could also use an OGC standard (e.g.: WMS, WFS, WMTS) to access maps served by a non-proprietary server (or even choose to serve them).

The next step is to choose a web map API for data web visualization. As stated earlier in the “Background Section” the most well-known web map APIs are Leaflet (BSD-2-Clause license) and OpenLayers (FreeBSD license). As mentioned before, Leaflet has the advantages of being simple and easy to use, having a good look and feel, being light, offering mobile support and having a good performance. On

Figure 19. General GIS architecture within a citizen science project



Geographical Information Systems in Modern Citizen Science

the other hand, OpenLayers supports all WebGIS protocols, has a better documentation and community support. It is also a more mature and tested project, it features more map controls, it has better integration of projections, and in most cases plugins are not needed.

The next step would be to decide in which database, the data and the images should be stored. Most citizen science initiatives use PostgreSQL (PostgreSQL license) because of the PostGIS extension (Citclops, CoralWatch and UrbanGene). PostGIS is a spatial database extender for PostgreSQL object-relational database. It adds support for geographic objects allowing location queries to be run in SQL. It should be noted that there are other databases with spatial extensions such as MySQL (GPL version 2), MongoDB (GNU and AGPL), Oracle Spatial (proprietary) or SQLite (public domain) with SpatiaLite extension, but they are not nearly as popular.

The next step would be to choose a server to publish the produced information to the web. Most initiatives use a GeoServer (GPL license) (Citclops, Brovelli et al., 2014, Castell et al., 2014) to share, process and edit geospatial data. Others use Mapserver (X/MIT license) that supports the creation of spatially enabled internet applications (Fritz et al., 2012). There are many other solutions, both free and open source (e.g.: MapGuide Open Source), as well as proprietary (e.g. ArcGIS server).

Finally, there is the option of publishing the created services in a Geospatial web catalog, which can be consulted and used in an interoperable way through the CSW standard (see “Standards and Operability: Why They do Matter”). In this manner it enables open access to geo-referenced databases and related metadata generated by the citizen science projects. The most widely used application to catalog these services and manage spatially referenced resources is GeoNetwork (GPL license) (<http://geonetwork-opensource.org>). It provides powerful metadata editing and search functions as well as an interactive web map viewer (Fritz et al., 2012). In addition there is another application that has similar functionality; pycsw is an OGC CSW server, which allows for the publishing and discovery of geospatial metadata, providing a standards-based metadata and catalogue component of spatial data infrastructures. Both solutions are FOSS and run on all major platforms.

Quality Control in GIS Enabled Citizen Science Projects

Quality control is another aspect which should be considered when building a GIS infrastructure for citizen science. The information collected within the framework of a citizen science project is usually freely and voluntarily provided by users and the tools used in this process are also distributed in an open and public manner. This can lead to the situation where users can send erroneous, incomplete or inappropriate information. To ensure the minimum quality of provided samples and prevent the collapse of citizen science platform is advisable to integrate a layer of quality control within the project's architecture.

There are different techniques to check and ensure the incoming data to the system. But first of all it should be decided which data will be controlled and why. For example, in case if the samples are images reported by a mobile application, the quality of what has to be analyzed? If the image actually contains the sample/subject to be analyzed or not? If metadata of the image is complete or not? If the coordinates where the image has been taken are correct or not? The possibilities are multiple and are directly related to the context of the project.

There is a brief mention of quality control in the “Web mapping application classification” section. For example, one of the techniques used in the Citclops project to filter the citizen observation data consists in a software module which analyzes the images collected via app and computes the water color (Novoa et al. 2014 and Novoa et al. 2015). In this way it becomes possible to compare the results that

Geographical Information Systems in Modern Citizen Science

have been reported manually by the citizen on the one hand and calculated by the algorithm on the other hand (Ceccaroni et al., 2015). Another quality control process used in the Citclops project consists in collaborative techniques. In this case there is a functionality implemented in the user interface that allows to flag images that do not correspond to the water (Ceccaroni et al., 2015). The same type of technique has been detected in the web viewer of EyeOnWater project.

But one of the most complete designs of quality control module has been observed in the COBWEB project. The quality assurance (QA) is one of the key components of its system architecture and is provided on several levels through the QA workflow service which have been developed basing on Business Process Model and Notation (BPMN) and the OGC's Web Processing Service (WPS) standard. Very interesting approach used in this solution consists of seven pillars that mark the topology of quality assessment in citizen science (Higgins, 2016).

CONCLUSION AND FUTURE DIRECTIONS

In citizen science it is very important to promote user engagement and user participation. Modern GIS technologies enable citizens to visualize, collect and analyze geospatial data in a user-friendly way. Because of the high level of graphical feedback of GIS interfaces, they produce a high engagement with the end user of citizen science projects. As a consequence, GIS technologies used in citizens science projects create a unique user experience which empowers the end users to use them more, and provide more valuable information for this type of projects. In certain parts of the world, the majority of citizens are equipped with smartphones, which enables them at the very least, to be passive contributors to citizen science projects, and a great deal of them has a presence in social networks, an extremely powerful tool for sharing information; the citizen science community has taken advantage of these favorable conditions, by creating mobile apps that collect and display georeferenced information; these apps have the effect of increasing user engagement, encouraging them to contribute to these citizen science initiatives.

Interoperability is a key property of citizen science projects because information generated by these projects should be reusable and exchangeable. Moreover, the aggregation of new types of information and results is much easier. Therefore, with interoperability, citizen science initiatives can provide more holistic information to the user. With the objective to contribute to interoperability, some standards such as WMS, WFS or WCS were created and promoted by international institutions such as OGC. Standards such as the Sensor Observation Service (<http://www.opengeospatial.org/standards/sos>), or SWE are particularly relevant for those citizen science projects in which GIS information is collected through sensors, in raw data format. When combined with web mapping APIs, the backend - normally a spatial database - gives support to the visualization of sensor data. Thus, this type of information generated by sensors, is on one hand more understandable for citizens, and on the other hand more interoperable and easy to analyze by researchers.

As the citizen is the main actor in a citizen science project, the initiatives aim to support an open participation and easy access to the tools. Through these tools the delivery of new information to the project (such as new samples or observations) and its future visualization and analysis (such as reports) have become of a global and universal usage. Nowadays the access to this kind of technology is extended to most people, both in terms of cost and ease of use.

There are technological trends that could have a positive impact in GIS, supporting further expansion and improvement of citizen science; one of these trends is Big Data. This trend refers to a transi-

Geographical Information Systems in Modern Citizen Science

tion, supported by cloud, mobile and social technologies, which is leading us to a *data-enabled* world (Loukides et al., 2013). However, this growing availability of data does not come without challenges. The four V's of Big Data, attempt to summarize some of these challenges: volume, velocity, variety and veracity; a fifth V has also been mentioned: value (Xu & Yang, 2014). Citizen science projects often use data collected by sensors, sometimes with a low latency, which can be near real-time. The low latency, combined with the bottom-up nature of these projects (run by sometimes large groups of volunteers) means that these datasets have the potential to become huge. Thus velocity and volume may already be a challenge for citizen scientists, and will most certainly be one in the future, as more people join the initiatives and larger time series datasets accumulate. Scalability and distributed operations have been successfully implemented in the NoSQL world, but GIS still tends to rely on single computers and relational databases (Xu & Yang, 2014). Nonetheless there are already some attempts to give support to Big Spatial Data, for instance by extending the Hadoop framework (Aji et al., 2013), and it is expected an increasing developing activity on this area, in the near future.

The variety and veracity aspects, on the other hand, are well-known challenges in citizen science projects, which do not mean they have been fully addressed. The variety of data is a constant in citizen science projects, as they often mix environmental information with other elements (for instance societal), in a range of different formats that are related to the way this information was collected. At least to some extent, this aspect has been successfully addressed by the use of interoperable standards, such as those from OGC or ISO. Finally, the last v ("veracity") is a common concern for VGI projects, where there are different degrees of trustworthy. One solution could be to enforce embedding the degree of quality in the metadata, and to display it on the map, but this type of approach is not yet generalized, and it still lacks standard support. Although the quality of data, and in particular OpenData, is already a concern there is still a lack of strategies to approach it, and this aspect is expected to get some attention in the near future. This attention should be translated first in sets of best practices, and eventually in standards related to quality control.

As we have seen through this chapter, citizen scientists accumulate the role of both, data creators and data consumers. Nowadays, empowered by modern technologies, they contribute to the generation of often large and complex datasets, which they may want to relate with existing large and complex datasets (e.g.: from social networks, sensors), that share common spatial attributes. Big Data technologies are key to unlock the consumption of this information, and extract value from it. Thus, as it happened before with other modern GIS developments, citizen scientists could be among those who would benefit from Big Spatial Data support.

As both GIS and citizen science are rapidly evolving fields, it is very difficult to predict exactly how they will be in the future, but looking at the current synergies, it is very likely that they will keep evolving together.

REFERENCES

- Aji, A., Wang, F., Vo, H., Lee, R., Liu, Q., Zhang, X., & Saltz, J. (2013). Hadoop GIS: A high performance spatial data warehousing system over mapreduce. *Proceedings of the VLDB Endowment*, 6(11), 1009–1020. doi:10.14778/2536222.2536227 PMID:24187650
- Alabri, A. (2010). Enhancing the quality and trust of citizen science data. *IEEE eScience 2010*.

Geographical Information Systems in Modern Citizen Science

Auer, S., Bizer, C., Kobilarov, G., Lehmann, J., Cyganiak, R., & Ives, Z. (2007). *Dbpedia: A nucleus for a web of open data*. Springer Berlin Heidelberg.

Azzurro, E., Broglio, E., Maynou, F., & Bariche, M. (2013). Citizen science detects the undetected: The case of *Abudehduf saxatilis* from the Mediterranean Sea. *Management of Biological Invasions*, 4(2), 167–170. doi:10.3391/mbi.2013.4.2.10

Barcelona City Council, Citizen Science. (2016). *20 projects to promote the city*. Retrieved from: https://issuu.com/bcnlabcienciaciudadana/docs/lilibret_icub__v.eng_

Brovelli, M. A., Dotti, L., Minghini, M., Pancaldi, M., & Zamboni, G. (2014). Volunteered Geographic Information For Water Management: A Prototype Architecture. *International Conference on Hydroinformatics*.

Brovelli, M. A., Minghini, M., & Zamboni, G. (2015). Public participation in GIS via mobile applications. *ISPRS Journal of Photogrammetry and Remote Sensing*.

Brovelli, M. A., & Raghavan, V. (2015). Reflections on FOSS4G Seoul 2015. *Directions Magazine*. Retrieved from: <http://www.directionsmag.com/entry/reflections-on-foss4g-seoul-2015/455554>

Castell, N., Kobernus, M., Liu, H. Y., Schneider, P., Lahoz, W., Berre, A. J., & Noll, J. (2014). *Mobile technologies and services for environmental monitoring: The Citi-Sense-MOB approach*. Urban Climate.

Ceccaroni, L., Velickovski, F., Steblin, A., & Subirats, L. (2015) Citeclops: data interpretation and knowledge-based systems integration. *Environmental Information Infrastructures and Platforms Workshop*.

Citizen's Observatory. (n.d.). *swe4citizenscience*. Retrieved from: <http://github.com/opengeospatial/swe4citizenscience>

Eisnor, D. (2006). *What is neogeography anyway?* Retrieved from: http://platial.typepad.com/news/2006/05/what_is_neogeog.html

Foursquare. (n.d.). Retrieved from: <https://foursquare.com/>

Fritz, S., McCallum, I., Schill, C., Perger, C., See, L., Schepaschenko, D., & Obersteiner, M. et al. (2012). Geo-Wiki: An online platform for improving global land cover. *Environmental Modelling & Software*, 31, 110–123. doi:10.1016/j.envsoft.2011.11.015

Goodchild, M. F. (2007). Citizens as sensors: The world of volunteered geography. *GeoJournal*, 69(4), 211–221. doi:10.1007/s10708-007-9111-y

Google Crisis Response. (2012). *Superstorm Sandy: NYC*. Retrieved from: <http://google.org/crisismap/2012-sandy-nyc>

Haklay, M. (2013). Citizen science and volunteered geographic information: Overview and typology of participation. In *Crowdsourcing geographic knowledge* (pp. 105–122). Springer Netherlands. doi:10.1007/978-94-007-4587-2_7

Geographical Information Systems in Modern Citizen Science

Higgins, C. I., Williams, J., Leibovici, D. G., Simonis, I., Davis, M. J., Muldoon, C., & O'Hare, G. et al. (Manuscript submitted for publication). Citizen OBServatory WEB (COBWEB): A Generic Infrastructure Platform to Facilitate the Collection of Citizen Science data for Environmental Monitoring. *International Journal of Spatial Data Infrastructures Research*.

International Organization for Standardization. (2003). *ISO 19115:2003 - Geographic information - Metadata*. Retrieved from: http://www.iso.org/iso/catalogue_detail.htm?csnumber=26020

Joost, S., Baumann, R., Ertz, O., Ingensand, J., Widmer, I., & Rappo, D. (2014). *A participatory WebGIS platform to support biodiversity inventory in the Geneva cross-border area*. Third Open Source Geospatial Research & Education Symposium (OGRS), Espoo, Finland.

Kampen, H., Medlock, J. M., Vaux, A. G. C., Koenraadt, C. J. M., van Vliet, A. J. H., Bartumeus, F., & Werner, D. et al. (2015). Approaches to passive mosquito surveillance in the EU. *Parasit Vectors*, 8(1), 9. doi:10.1186/s13071-014-0604-5 PMID:25567671

Liu, S. B., Iacucci, A. A., & Meier, P. (2010). Ushahidi Haiti and Chile: next generation crisis mapping. *ACSM Bulletin*, 246.

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2005). *Geographic Information Systems and Science*. John Wiley & Sons.

Loukides, M., Warden, P., Watters, A., & Croll, A. (2013). *Big Data Now - Current Perspectives from O'Reilly Radar* (A. Noren, Ed.). O'Reilly Media.

Meier, P., & Brodock, K. (2008, October 23). Crisis mapping Kenya's election violence: Comparing mainstream news, citizen journalism and Ushahidi. *iRevolution Blog*.

Minghini, M. (2014). *Multi-dimensional geoweb platforms for citizen science and civic engagement applications*. PhD thesis.

Neteler, M., & Mitasova, H. (2008). *Open Source GIS: A GRASS GIS Approach* (3rd ed.). Springer. doi:10.1007/978-0-387-68574-8

Newman, G., Zimmerman, D., Crall, A., Laituri, M., Graham, J., & Stapel, L. (2010). User-friendly web mapping: Lessons from a citizen science website. *International Journal of Geographical Information Systems*, 24(12), 1851–1869. doi:10.1080/13658816.2010.490532

Okolloh, O. (2009). Ushahidi, or 'testimony': Web 2.0 tools for crowdsourcing crisis information. *Participatory Learning and Action*, 59(1), 65-70.

Open Geospatial Consortium. (n.d.a). *Open Geospatial Consortium*. Retrieved from: <http://www.opengeospatial.org/>

Open Geospatial Consortium. (n.d.b). *Sensor Web Enablement (SWE)*. Retrieved from: <http://www.opengeospatial.org/ogc/markets-technologies/swe>

OpenStreetMap. (n.d.). *Copyright and License*. Retrieved from: <http://www.openstreetmap.org/copyright>

Pycsw. (n.d.). Retrieved from: <http://pycsw.org/>

Geographical Information Systems in Modern Citizen Science

- Rademacher, P. (2005). *HousingMaps*. Retrieved from: <http://www.housingmaps.com/>
- Ramsey, P. (2007). *PostGIS case studies*. Retrieved from: <http://www.refrations.net/expertise/white-papers/postgis-case-studies/>
- Simonis, I. (2015). *Citizen Observatories: A Standards Based Architecture*. EGU General Assembly 2015, Vienna, Austria.
- Snow, J. (1854). *On the Mode of Communication of Cholera* (2nd ed.). Retrieved from http://matrix.msu.edu/~johnsnow/images/online_companion/chapter_images/fig12-5.jpg
- Stallman, R. M., & Gay, J. (2009). *Free Software, Free Society: Selected Essays of Richard M. Stallman*. Paramount, CA: CreateSpace.
- Steiniger, S., & Bocher, E. (2009). An overview on current free and open source desktop GIS developments. *International Journal of Geographical Information Science*, 23(10), 1345–1370. doi:10.1080/13658810802634956
- Steiniger, S., & Hay, G. J. (2009). Free and open source geographic information tools for landscape ecology. *Ecological Informatics*, 4(4), 183–195. doi:10.1016/j.ecoinf.2009.07.004
- Sullivan, B., Wood, C., Iliff, M., Bonney, R., Fink, D., & Kelling, S. (2009). eBird: A citizen-based bird observation network in the biological sciences. *Biological Conservation*, 142(10), 2282–2292. doi:10.1016/j.biocon.2009.05.006
- The WNYC Data News Team. (2015). *Know Your Evacuation Zone*. Retrieved from: <http://www.wnyc.org/story/know-your-evacuation-zone/>
- Uhrner, U., Grosso, G., Romain, A. C., Hutsemekers, V., Delva, J., Kunz, W.,... Ledent, Ph. (2013). Development of an Environmental Information System for Odour using Citizen and Technology Innovative Sensors and Advanced Modelling. *CEUR Workshop Proceedings*.
- Wikipedia. (n.d.). *List of deadliest Atlantic hurricanes*. Retrieved from: https://en.wikipedia.org/wiki/List_of_deadliest_Atlantic_hurricanes
- Xu, C., & Yang, C. (2014). Introduction to big geospatial data research. *Annals of GIS*, 20(4), 227–232. doi:10.1080/19475683.2014.938775
- Yasuhiko, A. (2014). Safecast-Radiation Risks. *The Asia-Pacific Journal*, 11.