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Review Paper

Mobile GIS applications for environmental field surveys: A state of the art

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ABSTRACT

Geographical location and object description is an important aspect in field research, regardless of the spatial scale. Throughout time, environmental researchers have been using different tools and methods to determine and record location/description of observations with all limitations on their use. Lately, more and more common digital methods and new technologies have been gaining interest and popularity within the environmental science community. Among those technologies there are mobile mapping devices and applications which have been gaining audience in recent time. dedicated Handheld devices such as consumer-grade GPS (Global Positioning System) dedicated for tourism purposes have been substituted by smartphones and tablets with integrated GPS receiver so that field mapping became much easier and more readily available to a broader audience. Although the possibility of using mobile devices and dedicated applications for field mapping has an increasing trend, there is very little attention dedicated to them in methodology sections of research works. The purpose of this paper is to bring further awareness about such technologies to environmental researchers as they could benefit from using dedicated software available for mobile devices. Such software could ameliorate their workflow, accuracy and quality of data, which can help to achieve better research results.

We briefly present our review result of mobile applications for field mapping as the first global overview within scientific journals. The review includes environmental citizen science apps as a particular example of data collection applications. The comprehensive description of workspace creation for field surveys using ArcGIS Online (Esri, 2019) and Collector for ArcGIS (Esri, 2019a) is presented in this work. This research is conducted using the case study of the limestone mining plant in Poland.

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1. Introduction

Data acquisition is one of the key stages in environmental biology research (Franklin and Miller, 2009). Apart from location sites of plants, fungi and animals, there are many specified attributes describing individuals, whole plant habitats, biotopes and interactions between them. Before the Global Navigation Satellite Systems (GNSS) were developed, and after GNSS receiving devices became cheaper and widely available, researchers could only depend on more traditional approaches like the use of measuring tapes, theodolites, compasses, and paper maps. These traditional tools can provide accuracy, but they have significant limitations. Measuring with tape usually involves two or more people to perform measurements. It also has limited length, so in situations where bigger areas are being mapped, measuring can be problematic. Moreover, a tape can bend under its own weight or because of uneven vegetation covering ground underneath. Total-station theodolite enables measurement on longer distance, even up to hundreds of meters, although a training in order to use the device properly and obtain correct results is required. Additionally, the device can be quite heavy, so in hard terrain conditions, it can pose some problems when changing position. Some devices require at least two people to perform the measurement. Because the prism is sometimes needed, it involves operator of total-station and another person who holds the prism which reflects signal from theodolite. When the survey takes place within larger space, researchers have to rely mostly on their bearings and maps, which could lead to loss of accuracy, due to e.g. complicated topography, insufficient description of site location, lack of characteristic terrain features. In addition, for accurate survey, it is required to have fixed reference points in terrain, but in some cases, they get damaged or moved due to various reasons (Dodd, 2011). An important problem is also the timeliness of background maps if researchers use paper maps or scans in the field. However, very fast development and rising availability of GIS (Geographical Information Systems) and GNSS technology in spatial analyses of environmental and wildlife data triggered the need for change in methods of field work (Sonti, 2015). This change was caused by the introduction of the new types of file recording, increased accuracy of location and enhanced details of data attributes gathered in the field, which led to the increase in field work efficiency, and in consequence, better spatial analysis results.

Nowadays, handheld GNSS devices are one of the basic tools which are being used during the field work by researchers. However, those devices are often designed for tourism or navigation purposes, and their properties do not fit for collecting complex attribute data. Unfortunately, one of the most popular data formats used by GNSS devices for location recording — GPX (GPS eXchange format) makes creating attribute structures impossible. Moreover, such devices are not enabled to work with various user's basemaps and overlays which could be edited in the field. Despite this, there are GNSS devices with software suitable for field surveys, but their prices are high and they are most often used only in geodesy. Currently, there are many GIS solutions - free open source software and programming languages, very specific purposes or multi-purpose mapping applications for mobile devices, and open access data bases which allow performing spatial analysis and field surveys (Jolma et al., 2008; Steiniger and Hay, 2009; Singh et al., 2012; Lindgren, 2017; Fan et al., 2019; Yu et al., 2019). It should be emphasized that the number of GIS mobile applications has increased rapidly in recent years. GPS-equipped mobile devices like smartphones and tablets have also become widespread. The GIS tools that are used in data acquisition have been increasingly benefitting from the citizen science approach, which can significantly affect both the way that projects are designed, and the outcomes that projects achieve (Shirk et al., 2012). Citizen science can be described as public engagement in a scientific project, which produces reliable data and information useful to scientists and policy makers. It is public and open to the same peer review as conventional science *(Gura, 2013)*. Scientists can receive contributions from the public through crowdsourcing, which usually involves large numbers of people in data collection, processing and analysis. Volunteers often contribute to the environment mapping thanks to widespread presence of personal devices with GNSS receivers. Since almost everyone can go in the field and gather data, the possibilities of data collection have become almost endless because field surveys can be carried out in many places simultaneously or throughout the entire year. Regrettably, our review of publications proves that little attention is given to the methodology descriptions of field data collection in research publications despite the fact that the authors are obligated to describe fieldwork methods used within their scientific papers. Therefore, readers don't know whether the use of mobile applications take place. There is a lack of information about the average spatial error of object locations marked using GNSS devices, which results from traveling satellite signals under multiple deformations and environmental factors (Closas et al., 2009), types of mobile applications if used, ways for spatial attribute recordings or data format. This knowledge is crucial for the success of further analysis and conclusions formed by authors or other people who would like to use spatial data in their work, e.g. the precise accuracy is one of the key elements in estimating forest resources (Liu et al., 2016).

Given the low recognition status of mobile applications for environmental data collection in situ, the aim of this paper is to present capabilities and availability of mobile apps as a facilitation of field surveys. In this work, we will provide the basis of GIS field mapping methods and a list of GIS mobile applications with use cases, which are suitable for field collection of environmental data. When choosing the apps, we were looking for complementary systems which allow to collect not only geographical position data, but also many attributes describing research objects in the field and further storage, processing and presentation in situ. We want to show both commercial and open source solutions which can be implemented in different scientific or educational projects. However, we are aware that the proposed collection is not exhaustive due to the fact that there are myriads of different app solutions on the market. In the second part of the paper, we would like to show the methodology of biotic data field surveys using the capabilities of the Collector for ArcGIS (Esri, 2019a) mobile application and ArcGIS Online (Esri, 2019). This study connected with the acquisition of a detailed spatial dataset of eleven groups concerning flora and fauna was carried out as a part of the scientific project "Biodiversity Management Plan (BMP) (Fauna and Flora

International, 2018) for the Kujawy Mining Site in Bielawy Lafarge Cement SA" (Poland), conducted according to World Business Council for Sustainable Development methodology (WBCSD, 2014).

2. Review of field survey GIS applications

2.1. Basis of GIS field mapping methods

Field survey suite usually consist of handheld device which is compatible with mobile mapping software and equipped with GNSS receiver and antenna. GNSS refers to constellation of satellites which provides signals from Earth's orbit with positioning and timing data to dedicated receivers. Then receivers are able to determine their location thanks to transmitted data. Examples of GNSSs include European Galileo, the US NAVSTAR Global Positioning System (GPS), Russian Global'naya Navigatsionnaya Sputnikovaya Sistema (GLONASS) and Chinese BeiDou Navigation Satellite System. Performance of such systems is being assessed according to the following criteria: 1) Accuracy: the difference between a receiver's measured and real position, speed or time; 2) Integrity: the system's capacity to provide a threshold of confidence and, in the event of an anomaly in the positioning data, an alarm; 3) Continuity: the system's ability to function without interruption; 4) Availability: the percentage of time during which a signal fulfils the above accuracy, integrity and continuity criteria. The uncertainty of GNSS measurements depends on number of positions of the navigation satellites, obstacles that affect the reception of signals (tree canopy in a forest, high buildings etc.) and atmospheric conditions. Some of these factors might be avoided thanks to mission planning software (determining position of satellites), while we cannot do almost anything with the influence of terrain and its features (Johnson and Barton, 2004). However, the availability of satellites has become a less important issue due to the fact that nowadays, there are multiple constellations of satellites which are already fully functional or are supposed to be in working order to achieve better accuracy soon. It means that at almost every moment during the day, there are enough satellites "visible" by the receiver in order to obtain high-accuracy measurements because currently, most of the receivers are ready to combine signal from different systems (ESA , 2011). Furthermore, there are systems which can enhance the performance of GNSS, called SBAS - Satellite-Based Augmentation Systems which have regional coverage (GSA , 2019). For example, EGNOS (European Geostationary Navigation Overlay Service) covers Europe, WAAS (Wide Area Augmentation System) is available in North America, and MSAS (Multi-functional Satellite Augmentation System) is present in Japan and surrounding regions. In other regions, SBAS systems are still under development (ESA , 2011a). Devices with GNSS receivers are usually classified according to their accuracy. The highest accuracy can be obtained up to several millimetres using survey-grade instruments. Such surveying equipment is the most expensive, and it consists of antenna (usually on a pole), receiver/controller and dedicated software to process the captured location. Some professional training is usually necessary to be able to use survey-grade GPS correctly. This kind of set is very useful in surveys where accuracy matters, for example, setting up location of a quadrat, or in a general survey in a small area. Mapping-grade GPS have the accuracy up to 1m and they are much more compact because they usually consist of a single handheld device. They are still useful in mapping the location of test areas, determining the location of species within the area of interest. Consumer-grade GPS have the accuracy of about 2−5m (Johnson and Barton, 2004), and smartphones and tablets can be put in this category as well. Currently, multi-constellation GNSS receivers are being integrated within smartphones, which consequently makes precise measurements available to the wide audience. This leads to the situation where a smartphone is an essential tool in many industries where dedicated devices have become obsolete (GSA , 2019a).

The search result of the 'GPS' entry in the Environmental Science journal category in the SCOPUS database shows a steady increase in the use of GNSS devices in research (Fig. 1a). According to recent GNSS Market Report by European GNSS Agency (GSA , 2019a), in 2019, there were 6.4 billion GNSS devices in use, which proves that the technology is used widely. It is expected that this number will be higher, reaching even up to 9.6 billion devices by 2029. The market of GNSS devices is
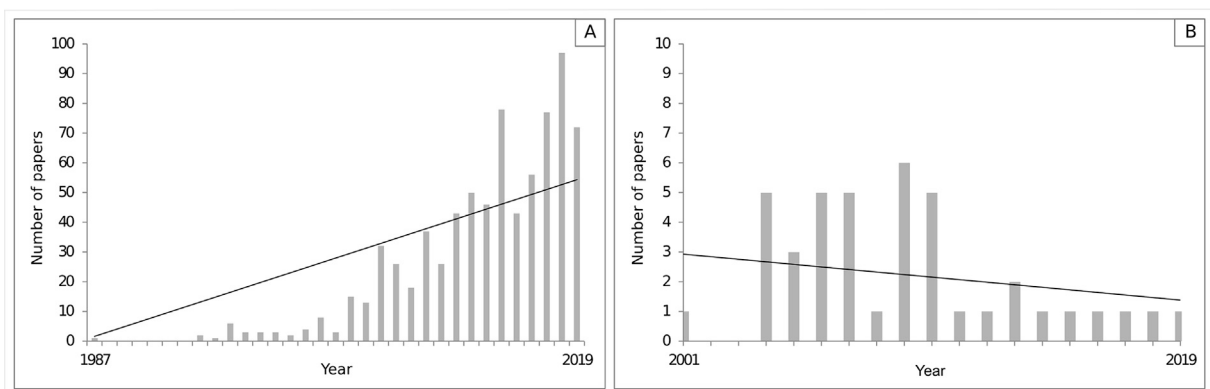

Fig. 1. a. Steady increase in the use of GNSS devices in Environmental Science research; 1b. The use of ArcPad in research papers in recent years.

dominated by smartphones; in 2019, there were approximately 5.4 billion of them, while the total amount of consumer devices with GNSS chips was almost 6 billion. According to the abovementioned report, it is predicted that their share in the market will stay relatively constant, however, there will be more tools like personal tracking devices or low-power asset trackers. Apart from devices and augmentation services (corrections − services directly supporting the GNSS system), there are "added-value services" which comprise all solutions enabled by GNSS, like location-aware apps or navigation systems. In 2019, such services were worth over 80 billion euros of annual revenues. It is expected that they will rapidly increase in the upcoming years, reaching 160 billion euros in 2029 and accounting for more than a half of the total global GNSS revenues. The rapid development of GNSS market is possible also thanks to the advancements in mobile operating systems (OS). Before, handheld devices were running on dedicated OS's which had limited possibility of installing third party software. GNNS devices were equipped with their own software solutions which often had a very limited number of functions and were not always compatible with the desktop of GIS software or they were very expensive. Nowadays, most manufacturers are switching to the most popular mobile OS like Android or iOS. Thanks to that, the current possibilities of software used for mapping in the field are very broad and more and more often available for free.

2.2. Field mapping solutions in environmental studies

In this chapter, we present selected mobile mapping apps. They were chosen according to their features and functionality: seamless and smooth integration with desktop and/or web GIS software, ability to collect various data geometries (points, polylines, polygons) and multiple attributes, compatibility with most popular data formats (Esri shapefile, KML, CSV, geoTIFF). We present the apps which are available for the most popular platforms, as well as the open source software along with the proprietary software, so they would meet needs of most research teams which are looking for mobile mapping solutions. During the review of applications, we used the following sources: Google Play Store, Apple App Store and website of The Tropical Ecology and Conservation Lab of University of Florida (2015).

Collector for ArcGIS is a mobile mapping app developed by Esri (2019a), available for the Android, iOS and Windows platforms. It is a part of the Esri Geospatial Cloud, and it is compatible with the ArcGIS for Desktop (Esri, 2019b) and ArcGIS Online (Esri, 2019). According to the Google Play Store data, it has been installed more than 100 000 times. This app enables offline and online operations in the field, giving the possibility for mapping with the use of GPS measurements or simply by inserting data by hand from a map. The latter is important in the situations when we are not able to use GPS, e.g. when an object we want to map is not directly accessible, so we have to determine its location by surrounding topography. One of the very important and useful features is the ability to create line and polygon features apart from the points, and what is more, these features can have attributes. Collector is compatible with survey-grade GNSS receivers and it is free of charge, however, the app can only be used by the users whose account is connected to an Esri institutional account. In order to start mapping with the use of Collector, the users need a pre-set workspace created with ArcGIS Online, ArcGIS Server (Esri, 2019c) or ArcMap (Esri, 2019d). It is worth to mention ArcPad software (Esri, 2019e) which was developed for Windows Mobile devices, and probably was one of the first mobile mapping apps (Fig. 1b). as the search result of the 'ArcPad' keyword in the SCOPUS database shows high level of ArcPad use in research papers at the beginning of the 21st century. However, there was a significant decline after 2010 probably due to the fact that Windows Mobile for handheld devices started to decline in favor of more flexible OS such as iOS or Android.

Mapit Spatial is a mobile application developed for Android devices by Mapit GIS Ltd (2020). It is a successor to Mapit GIS and Mappad apps, with added new functionalities and brand new data management approach. It is based on Open Geospatial Consortium (OGC) GeoPackage Encoding Standard, where a single file can store vector and raster data simultaneously, together with their attributes (OGC, 2014). This makes data exchange with desktop software much easier and faster. What is more, its users can define the connection to the database within the application itself. However, the users who have already got some data in different file formats are still able to import it into the application because it can read GeoJSON, ESRI Shapefiles, KML, GPX and CSV as well. Files can be imported from internal device memory, but also from FTP servers, cloud file storage services like Google Drive or Dropbox. Mapit Spatial offers the usage of many predefined basemaps sources like Google Maps, OpenStreetMap (OSM), BingMaps or ESRI basemaps. Its users are also able to connect to WMS, WMTS and WFS services of their preference by adding the respective service address, just like in most of desktop GIS software. Moreover, there is also a possibility to use offline custom basemaps by uploading *.mbtiles files to the device memory. Mapit Spatial gives an opportunity to customize the visualization of data overlays, e.g. transparency definition of a layer or custom styles based on attributes of objects within a layer. Data can be collected both in online and offline mode, by drawing objects by hand or by capturing GPS location − it is compatible with some external GNSS devices which can perform measurements very precisely. Apart from the text or numeric attributes, the user can also add a media file (photo, video or audio recording). The application has also enabled a barcode scanner which can be useful for regular surveys of e.g. testbeds. Mapit Spatial can be downloaded for free from Google Play Store, however, the user needs to buy a yearly subscription in order to use all of the features of the app.

QField is being developed by OPENGIS.ch and it is released under the GNU Public License (GPL) Version 2 or above which means that it is free to use and modify. Unlike Collector for ArcGIS, QField does not have any dedicated online platform for sharing and managing data and projects. However, it works smoothly with desktop software QGIS (2019) from which the user shall import a project (workspace) with prepared layers. Because of that, QField does not require creating any account or registration. Data gathered in the field becomes registered within the device memory and later on, it can be seamlessly

imported back to the desktop environment. Developers suggest using dedicated plug-in for QGIS although it is not obligatory for migration of projects and data between mobile devices and PCs. QField can be used in the field in online and offline mode, and we can add new features using GPS position or by hand. Moreover, it is possible to use external GNSS receiver through a third-party application. The application is compatible with most of the popular geodata formats like Shapefile or TIFF. It is also capable of reading data from WMS or WFS services (The QField Project/OPENGIS.ch, 2019). QField is available only on the Android platform and so far, it has been installed more than 100 000 times.

Open Data Kit (ODK) (2017) is a suite of open-source tools for data collection and management. It includes components of a broad system consisting of forms specifications, programming libraries and APIs (Application Programming Interface). ODK software is released under Apache 2.0 Licence, which means that the source code can be used for both free and proprietary software. The standard ODK Collect app enables collecting data in the field with questionnaires including photos and geographical location. However, it is possible to record only a single latitude and longitude point position (Open Data Kit, 2017). The ability to record other kinds of geometries (polyline, polygon) is provided by other apps, e.g. GeoODK (GeoMarvel, 2017) or OpenMapKit (American Red Cross, 2019). In order to create a survey form, we need to predefine it first in the software called ODK Aggregate. Later on, the user can synchronise these two to manage the collected data. There are other applications which are based on the ODK and they provide forms with geodata collection, for example KoBoToolbox (2019). KoBoToolbox consists of a website component and a mobile component - KoBoCollect. On the website, the users are able to prepare a form and deploy it. The form can be shared as a website and can be filled out from any device. When deployed for an Android app use, it can be used in the field without the Internet connection. KoBoToolbox is free of charge for any kind of users, however, humanitarian organisations can have unlimited number of submissions and data storage. For other users, these are limited. Apps which are based on the ODK have the possibility to export data in formats such as CSV or KML and they are mostly available for Android devices.

SW Maps is a free app available on Android, developed by Softwel (P) Ltd. (2018). It offers recording data through GPS (it allows recording points, lines and polygons as well as our tracks in terrain) or by drawing on a map. When recording geodata, the user can add attributes in form of a text, numerical values, options (we can create a list of selectable values), photos, audio and video files. SW Maps can be used together with survey-grade, connecting via Bluetooth or USB. Moreover, it provides additional information about GPS status and a sky plot with the currently visible GNSS satellites. It also has compass tools which can be helpful for orientation in the terrain. This app is able to read such file formats as KML, ESRI Shapefile, GeoJSON, GeoPackage, online tiles (e.g. WMTS), online data from WMS, and it can export its projects and gathered data as KMZ, Shapefile, GeoJSON, GeoPackage, CSV, spreadsheets in XLS/ODS, and media files. Data are exported into device memory, however, we can also send files to the cloud, to another person via the 'Share' option or upload it to an FTP server. SW Maps works in both online and offline mode. In the app, it is possible to define templates for projects, which can be useful when similar surveys are repeated. Also, the developers provide desktop software for project template creation called SW Maps Template Builder. SW Maps itself is not associated with any desktop or online GIS platform, however, thanks to compatibility with many data formats, it gives possibility to work on gathered data in different desktop software environments. SW Maps has been downloaded more than 100 000 times from Google Play Store.

Locus GIS is a free Android app developed by Asamm Software (2019). It supports data formats such as ESRI Shapefile, KML and GPX. The app provides a different kind of basemaps (some of them are paid), but we can connect to WMS as well as upload own basemap from the local storage. We can import ready-made layers from device internal memory or file storage services (Dropbox or Google Drive). Also, we can create new layers from scratch or with the use of a template. The process of creating new layers proceeds in a similar way like in desktop GIS software. The users have the possibility to define the name of the layer, encoding, geometry type, reference system (EPSG codes work well), attribute columns with their types (text, integer, decimal, date, yes/no, and list), label, and symbology. Layers are being exported to ESRI Shapefile by default and projects can be saved to QGIS project format (QGS). Locus GIS has a module presenting GPS status and compass. The app offers the connection with external GNSS receiver via Bluetooth. The users have the possibility to perform distance and area measurements on a map. By now, LocusGIS has been downloaded from Google Play Store more than 10 000 times.

Global Mapper Mobile is a free app for iOS and Android developed by Blue Marble Geographics (2019). This application lets its users gather data through GPS and by drawing features on a map. Despite being free of charge, it requires proprietary software — Global Mapper, where the user has to prepare Global Mapper Mobile Package (GMMP) for the use in the field.

Mobile Data Collection is a mobile app for collecting data in the field developed by GIS Cloud (2019). In order to be able to collect data, the user first needs to prepare a form with dedicated Map Portal. GIS Cloud is an online system which consists of aforementioned Map Portal along with Map Editor, Map Viewer and Crowdsourcing. The system is available for free as trial, and the subscription is required in order to get all features. Mobile Data Collection can be used on iOS and Android devices.

Mobile mapping apps are useful when surveying some limited area, but what can researchers do when they need to collect data over a vast area e.g. country or continent, or to conduct long-term monitoring? Long-term and large-scale surveys are not possible without large financial resources and some areas are sometimes not easily accessible for everyone. In such cases, a phenomenon called *citizen science* comes in handy. Volunteers help in research of various aspects of environment e.g.: species distribution (including invasive ones), behaviour and habitat monitoring, occurrence of seasonal events like tree leaf out (McKinley et al., 2017). Renowned global datasets like GBIF (Global Biodiversity Information Facility, 2019) or The Red List of Threatened Species very often incorporate records obtained thanks to citizen science (Wood et al., 2015; Chandler et al., 2017). When it comes to citizen science, there is a related term called Volunteered Geographic Information (VGI) (Goodchild, 2007) and it refers to citizens who volunteer in creating geographical information. It concerns a special kind of data which was

reserved for a long time only for national agencies. Environmental citizen science can be now realised on a worldwide scale thanks to dedicated mobile applications. These apps are diverse - some of them cover the whole biodiversity of the Earth, while others are focused on a given kingdom, genus or species. Below, there are some examples of mobile apps involving citizens in environmental data collection, including geographical localisation:

iNaturalist is an app which enables the identification of species from different kingdoms. Thanks to user community, the application's entries are verified. The community ensures that data is reliable, but it also gives the opportunity for fellow users to gain knowledge about species from around the world. iNaturalist is a joint initiative of California Academy of Sciences and National Geographic Society (2019). The app is available for free for Android, iOS and it is also accessible through the web page: https://www.inaturalist.org/.

Pl@ntNet (Joly et al., 2016) is a similar application to iNaturalist although it is dedicated solely to plants. Thanks to the pattern recognition, the algorithms and visual search engine, it enables automatic plant species recognition. Pl@ntNet is able to recognise a plant through a photo of an entire individual and its organs — leaves, flowers, fruits or bark. Entries are being validated through collaborative tools IdentiPlante and PictoFlora by Tela Botanica association members. Apart from recording the photos of plants, Pl@ntNet gathers the location of given registered individual. Gathered and validated data can be used to enrich other global datasets like GBIF. The platform is available as mobile app for iOS and Android, it can be accessed from desktop via: https://plantnet.org/.

Spipoll is a pollinator insects identification app, created by the French National Museum of Natural History (le Muséum National d'Histoire Naturelle) and the Office For Insects And Their Environment (Office Pour les Insectes et Leur Environnement, OPIE). The aim of the application is to collect photos of insect-plant interactions in a standardised manner. The users are asked to take pictures of flowers, leaves, entire plants and their surroundings. Photos shall be taken during 20 min time frame in order to capture flower 'visitors.' Insects are identified by the Spipoll community (de Flores and Deguines, 2012). In the event of more complicated cases, the entries are verified by the Museum staff. Currently, the application is available in French and the identifications of insects are meant to take place within France's territory. Spipoll's platform is accessible through the website: https://www.spipoll.org/.

eBird is an online citizen science project managed by the Cornell Lab of Ornithology which focuses on avians (Sullivan et al., 2009). It enables its users to document data on bird distribution, abundance and habitat use. Birders can enter the information on where, when and how they went birding, filling out the checklist of birds that they had heard or seen. The eBird mobile app allows offline data collection in the field. The website provides an exploration and a summary of data as well as data entry. eBird is a worldwide database with more than 100 million bird sightings each year entered by its users. Thanks to the data entry through the checklists, the information is gathered in a structured way and moreover, the errors are minimised because unusual entries are reviewed and validated by experts. eBird is comprised of local, national and international partners' networks, and collaborates with them for regional data entry portals, outreach, engagement and local impact. The application is available for desktop through the website: https://www.ebird.org, and for Android and iOS devices.

Apart from specialised mobile mapping applications, citizen science can be realised through conventional tools. For example, Brown et al. (2018) implemented a public participatory mapping project in New South Wales, Australia to identify and map koala (*Phascolarctos cinereus*). Instead of developing a new application from scratch, they have based it on Google Maps API. More examples of citizen science data collection apps with described development process can be found in the paper by Teacher et al. (2013).

2.3. Use cases of mobile mapping applications

Unfortunately, the authors of methodological parts of scientific publications do not mention the applications used despite the increasing popularity of online applications. Most frequently, mobile mapping applications that are described in literature are custom developed apps for very specific purposes or surveys. However, the literature does not include much information about multi-purpose mapping software for mobile devices, which was presented in the first part of the chapter 2.2. Below, we would like to show some use cases of both types of mobile apps for environmental mapping: the use of Collector for ArcGIS for mapping of the bumble bees (*Bombus*) in the Upper Mississippi River National Wildlife and Fish Refuge (Turton, 2017); the support for mapping the suitable habitat of endangered species of bats (Gibbs and Epplin, unknown); the mapping of invasive plant species in terrain as in situ validation for remote sensing data (Müllerová et al., 2017). Mapping of invasive species through mobile apps can serve not only scientific purposes, but also public safety, e.g. the mapping of hogweed species, which are potentially harmful for people in direct contact, can be made through Mobile Alert Smart M.App developed by Hexagon Geospatial. When local governments have accurate data, they are able to precisely localise a dangerous plant and destroy it (Fleming, 2019). Using the data collected by the Leafsnap Mobile App and citizen science approach, Kress et al. (2018) determined the expansion range of native and exotic plants. Due to the increasing risks for Oak species in California, which include disease, overgrazing and urbanization, Lindgren (2017) developed the Oak Tree Mapper mobile app. GISCloud mapping software found its application useful for local authorities and scientist who could use it for mapping the emerald ash borer (*Agrilus planipennis*) infestation in Maple Grove community in Minnesota, USA (GISCloud, 2019a). The same suite was used by arborists in Sweden to create and maintain the tree inventory (GISCloud, 2019b). WeForest organisation implemented GISCloud for their reforestation action in Zambia (GISCloud, 2019 c). Thanks to the need of giving the means of monitoring mosquito populations in an urban environment to science-driven citizens, an Android phone app was created (Guilbaud and Guilbaud, 2017). In order to maintain the sustainable food systems in cities, Arrington et al. (2017) conducted analyses of

ecological and demographic dynamics of urban foraging in the USA through user-generated geo-demographic, landscape-level, and species richness trends data from the web and mobile application Falling Fruit. VGI mobile mapping apps, GPS tracking and questionnaires are more often used to implement sustainable environmental policies within green urban areas and protected sites such as national parks and Natura 2000 (Korpilo et al., 2018; Barros et al., 2020; Kim et al., 2019; Muñoz et al., 2019; Jurado Rota et al., 2019). Long-term ecological research (Criscuolo et al., 2018) and forest trees measurements (Fan et al., 2019) have also started to be supported by common mobile devices equipped with GIS apps.

## 3. Collector for ArcGIS as a mobile solution for biodiversity field mapping

3.1. Case study of opencast limestone mine

In this section, we would like to show our experience with the use of Collector for ArcGIS (Esri, 2019a) mobile application and ArcGIS Online (Esri, 2019) for biotic data field surveys, which could be treated as a model for researchers. The goal of testing mobile app capabilities was connected with one of the main purposes of our working group - the acquisition of a detailed spatial dataset of flora and fauna as a part of the scientific project "Biodiversity Management Plan (BMP) for the Kujawy Mining Site in Bielawy Lafarge Cement SA" (Poland). During 2016−2017, as part of a grant awarded by Lafarge Cement S.A. company, a group of scientists from the Faculty of Biology of the Adam Mickiewicz University in Poznań (Poland) con-ducted field studies in the area of the Kujawy Mining Plant in Bielawy (Fig. 2). The aim of the project was to develop the BMP for the area under strong anthropogenic pressure - an open-cast limestone mine, including a 500 m buffer zone. Under the conditions of mining operations, an environmental inventory of the following groups of organisms was carried out: vascular flora of terrestrial habitats, vascular aquatic flora, mosses, algae, butterfly, orthopterans, odonates, fish, amphibians, birds and mammals. Plant communities were also inventoried. Each individual occurrence site, in addition to recording of the location, required describing their characteristics in the field. For all groups of organisms, there were over 100 attributes in total. As an example, for the vascular flora of terrestrial habitats, the following attributes were collected: species name, abundance, habitat type, collection date and author of an inventory, and the global ID. The map in Fig. 3 shows the distribution of habitat types used for the inventory of vascular plants of terrestrial habitats in the mine area. The occurrence of some groups of organisms was mapped not only as a set of points, but also as polygons and transect lines. In the whole mining plant area, the scientists gathered 47 507 points which represented vascular plants of terrestrial habitats (Fig. 4). To achieve this goal, the Esri solutions - ArcGIS Online and Collector for ArcGIS were used. ArcGIS Online is an online platform that allows storing vector and raster spatial data, creating workgroups, giving group members specific permissions (to browse, edit or share data; group administration), conducting simple spatial analyses online and creating maps. A very important function of this app is the ability to create a workspace that can be used in the field working with the Collector for ArcGIS app. The workspace based on a set of vector layers created in GIS software and basemaps enables field data collection on layers with a personalized attribute template. In addition, a dictionary can be created for each attribute in the database. It allows to select a specific feature from the drop-down list in the field, e.g. species name. A well-prepared workspace, after the export to Collector for ArcGIS on a mobile device (in our case it was a tablet iPad Air2), enabled reliable work without the access to the Internet. Since our research was carried out in the open-pit mine, where the depth reaches 120 m below ground level and there was no Internet connection, it was crucial to able to collect the data regardless of the network availability. After each data collection, re-searchers were required to send the dataset to ArcGIS Online via the Internet. Thanks to this approach, the project leader and

Fig. 2. Study area of the lime stone mine.
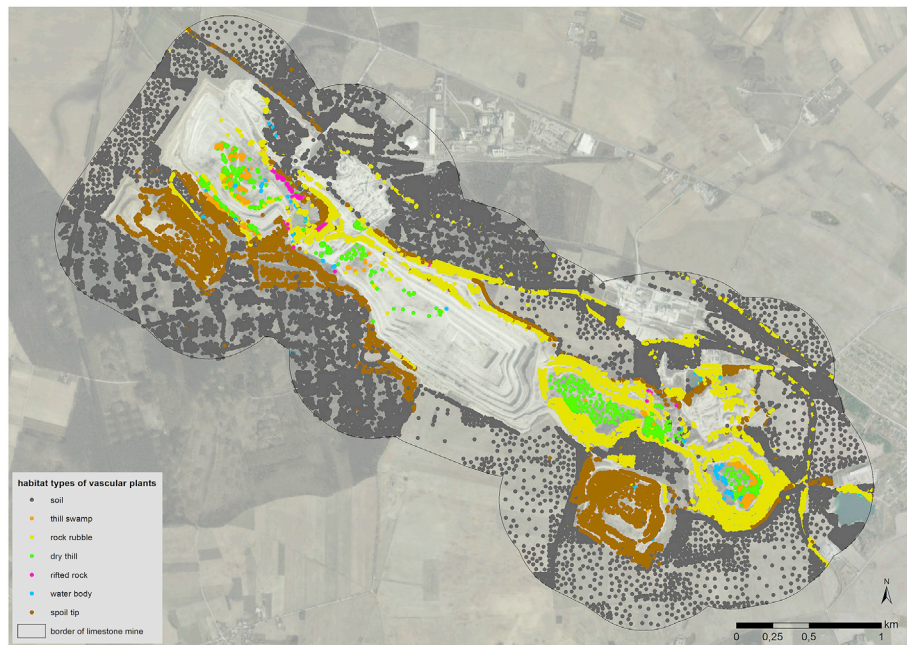
Fig. 3. The distribution of habitat types of vascular plants of terrestrial habitats in the mining plant area.

Fig. 4. The distribution of all location sites of vascular plants of terrestrial habitats in the mining plant area.

the entire team were able to perform up to date reviews, analyses and evaluations of data from other researchers who were working on other groups of organisms. Furthermore, the determination of some parameters required certain information about topography, land cover and the presence of other groups of organisms during field surveys to work more efficiently. The possibility of sharing data gathered in the field between researchers gave them the possibility of creating maps of individual species distribution and vector layers with such data facilitating the inventory of another groups of organisms. This approach was possible because there are many relationships between the occurrence of plant and animal species at various stages of their lives. Fig. 5 shows the distribution of four selected plant species that mutually determine the occurrence of specific
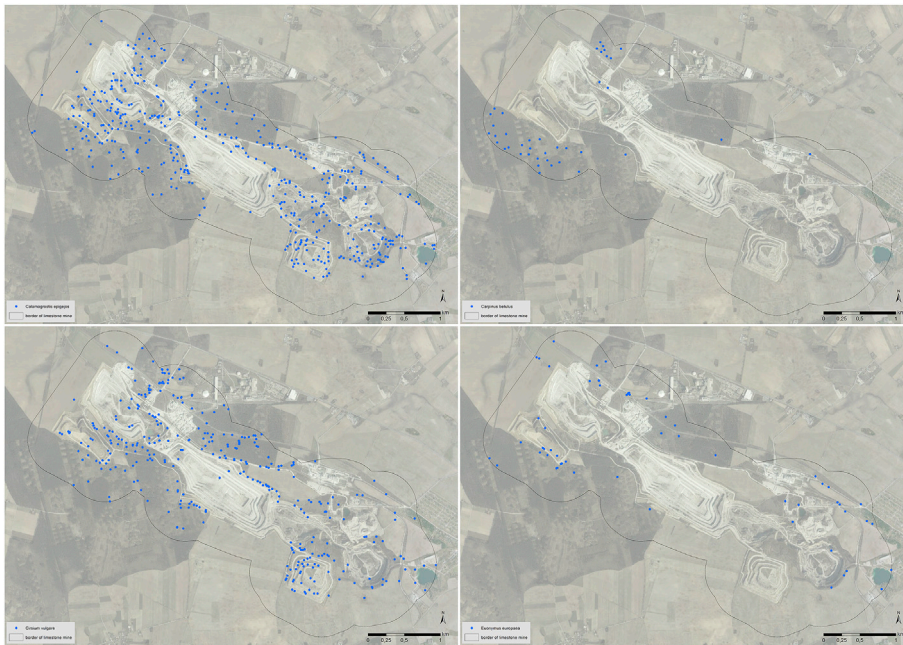
Fig. 5. The distribution of 4 plant species in the mining plant area as a co-occurrence factor of another groups of organisms.

animal species. For our mining area, these were the following examples of relationships: *Calamagrostis epigejos* and *Phaneroptera falcata*, *Carpinus betulus* and *Coccothraustes*, *Cirsium vulgare* and *Fringilla carduelis*, *Euonymus europaea* and *Yponomeuta cagnagella*.

4. Discussion

The essence of mapping plants, fungi and animals is to recognise the distribution of the given species. The quality of studies on distribution patterns rely on many factors, which may or may not be independent from a researcher. Apart from the circumstances like terrain accessibility, skills, competences and thoroughness of a researcher, the field work methods, research methods and spatial data decide about gathered data quality and value of final results. However, it is the aim of the research that implies methods in scope of field work spatial accuracy. In the case of research conducted in Bielawy mining plant, the aim was to fully recognise the number of species and their localisation with the best approximation to the real situation. For that reason, there was a need to develop a method enabling collection of biotic data in form of points, lines and polygons, and allowing to monitor constantly data quality, along with flow of data between researchers over the course of project realisation. It is important to mention that the data series was open and during every stage of the project, it was possible to make corrections regarding attributes and localisation of observations. Such approach enabled, for example, species determination, which was not possible to perform in the field. However, during the fieldwork, it was unavoidable to face significant methodological problems. Delineation of polygon location and range for multiple species was often infeasible. In such cases, the problem was resolved by marking the point anywhere within boundaries of the observed species range. In effect, the point representation of localisation of species occurring frequently is undervalued in relation to the ones that are much less abundant, with a significant influence of the dispersion of point observations. The optimal solution would be a classification of aerial photos, regarding habitats and land use. Such approach would enable delineating polygons, to which a species that occurs evenly in given polygons would be added. Undoubtedly, Collector for ArcGIS and other mobile mapping applications bulleted in this work give specific functionalities regardless the applied methods and allow the elimination of common problems among researchers, i.e. the expiration of the basemaps and the need for their calibration if researchers use tourist-class GPS devices and paper maps or scans in the field.

5. Conclusions

GNSS technology has been well known to environmental scientists since the last decade (Johnson and Barton, 2004; Rutter, 2007; Hauptvogel et al., 2010; Dodd, 2011) and since then, they have been using them with success. Although some of them still seek for solutions to ameliorate data collection workflow as described by Toczydlowski (2017), the new mobile mapping devices and apps might be the answer to their problems. We listed the apps which are the examples of mobile mapping solutions, taking into account our experience with Collector for ArcGIS from the case study. In our work, we have

observed that despite the fast growth in number of mobile apps and rising interest in them, the number of scientific papers containing information about them is rather limited. The reason behind this might be the fact that authors do not always carefully describe the field methods. Consequently, we are not able to tell if they use the new tools and approaches. There is much more attention given to the citizen science mapping apps than to regular mapping apps in scientific research, probably due to the fact that the citizen science initiatives are largely managed by multi-institutional organisations, so it is obvious that they have to describe results both at the educational and methodological level. On the other hand, scientists are not aware of the existing new tools and still use classical methods based on the analogue approach or they use GNSS devices which do not allow to adjust them to individual needs of a given field work. We have to acknowledge that in the near future, with the rising usage of mobile apps, the descriptions of digital methods and tools will become more exhaustive. This thesis can be supported by the fact that the apps have increasingly become open to users, facilitating the development of researchers' own fieldwork methods. Furthermore, the new tools, which have taken steps to revolutionise spatial data acquisition appeared. For example, there are Unmanned Aerial Vehicles (UAVs) in the field of the environmental biology (Nowak et al., 2018). On the other hand, it is increasingly popular to reuse ad reprocess data from other scientists' works. It is possible thanks to the dedicated on-line databases such as GBIF (2019) which are based on Access to Biological Collection Data (ABCD) standard (2017). However, transferring data to such databases requires caution when describing data and metadata acquisition methods - information crucial for prospective users. The abovementioned facts give hope that in the nearest future, there will be more emphasis put on the description of the field work methods within scientific publications.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gecco.2020.e01089.

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