Management of Biological Invasions (2015) Volume 6 in press

Special Issue: Alien species related information systems and information management

Information Management CORRECTED PROOF

Trying to engage the crowd in recording invasive alien species in Europe: experiences from two smartphone applications in northwest Europe

Tim Adriaens[1]*, Michael Sutton-Croft[2], Katy Owen[2], Dimitri Brosens[1], Johan van Valkenburg[3], Dave Kilbey[4], Quentin Groom[5], Carolin Ehmig[6], Florian Thürkow[7], Peter Van Hende[8] and Katrin Schneider[9]*

[1]*Research Inst. for Nature and Forest (INBO), Department of Management and Sustainable Use, Kliniekstraat 25, B-1070 Brussels, Belgium*
[2]*Norfolk County Council, Environment Section, County Hall, Martineau Lane, Norwich, NR1 2DH, Norfolk, Great Britain*
[3]*Nederlandse Voedsel- en Warenautoriteit, Nationaal Referentie Centrum, Postbus 9102, 6700 HC Wageningen, The Netherlands*
[4]*University of Bristol Computer Centre, 5 Tyndall Avenue, Bristol BS8 1UD, Great Britain*
[5]*Botanic Garden Meise, Bouchout Domain, B-1860 Meise, Belgium*
[6]*University of Potsdam, Germany*
[7]*UMGEODAT Umwelt- und GeodatenManagement GbR, Mansfelder Straße 56, D-06108 Halle/Saale, Germany*
[8]*Proximus, Dept. Marketing and Communication, Koning Albert II-laan 27, B-1030 Brussels, Belgium*
[9]*Coordination Centre for Invasive Plants in protected areas of Saxony-Anhalt at UfU – Independent Institute for Environmental Issues, Gr. Klausstrasse 11, D-06114, Halle/Saale, Germany*

E-mail: tim.adriaens@inbo.be (TA), michael.suttoncroft@norfolk.gov.uk (MS), katy.owen@norfolk.gov.uk (KO), dimitri.brosens@inbo.be (DB), j.l.c.h.van.valkenburg@minlnv.nl (JV), d.kilbey@bristol.ac.uk (DK), quentin.groom@br.fgov.be (QG), carolin.ehmig@gmail.com (CE), info@umgeodat.de (FT), Peter.vanhende@proximus.com (PV), katrin.schneider@ufu.de (KS)

**Corresponding authors*

Received: 30 October 2014 / Accepted: 16 February 2015 / Published online: 10 March 2015

Handling editor: Stelios Katsanevakis

Abstract

New technologies such as smartphone application software (apps) are increasingly used to reach a wider audience on the subject of invasive alien species (IAS) and to involve the public in recording them. In this paper we present two of the more recent smartphone applications for IAS recording in northwest Europe, the RINSE *That's Invasive!* app and the *KORINA* app. We present an overview of available smartphone apps for IAS recording in Europe and address issues of data integration, data openness, data quality, data harmonisation and database interoperability. Finally, we make some recommendations for future app design.

Key words: biological recording, citizen science, early warning, app, data management, technology

Introduction

Engaging volunteers in data collection around the natural environment and biodiversity, also known as citizen science, is increasingly driven by technological developments (Bonney et al. 2009; Roy et al. 2012). Indeed, the advance in communications technology over the past decade has been one of the reasons citizen science has flourished (Silvertown 2009). One well established method for data collection is the use of smartphone applications for recording. The increasing availability of smartphones and other web-enabled mobile equipment with built-in GPS for precise positioning represents an evolution in data collection (Newman et al. 2012). Smartphones have also revolutionised the way citizen scientists are recruited, engaged and retained (Graham et al. 2011) and provide opportunities to link science with society (Teacher et al. 2013).

Their wide geographical reach and ability to collect data more efficiently and accurately are clear advantages of smartphone apps (Teacher et al. 2013). Compared to website-based recor-ding, which is still important for online record submission, smartphone apps can increase the likelihood of photograph submission which makes data verification easier. Also, the

disadvantage of having to manually enter a locality and the potential for error this task creates (i.e. relying on users to accurately enter grid references) is overcome by the detailed geolocation smartphones can provide. Furthermore, data from such devices can be quickly uploaded to an online database, avoiding the potential for errors in data transcription and the loss of data forms (Crall et al. 2011). Apps also facilitate real-time recording or, in case the recording is performed off-line until connection is available, with a short time lag between the observation and reporting. This renders app data valuable for early warning purposes and for conducting IAS management programs.

The use of mobile phones in environmental observations was predicted to be widely applied to data gathering and has become increasingly practical and widespread (Sutherland et al. 2010). Although in some countries smartphone uptake is still low, according to GSMA (2014), by 2020, smartphones will account for 70 % of all mobile connections worldwide. Smartphone penetration (the percentage of the population owning and using a smartphone) in 2020 should be around 75 % both in Europe and the United States. Information technology advancements, including smartphones, are currently exhibiting rapid convergent evolution. Consequently, consumers can now conduct an array of different tasks with their smartphone that would formerly have required multiple different devices. Today, smartphones are the most important convergent end-user devices, with users seeking experiences that are intuitive, seamless, and entertaining. Many online recording programs have anticipated this evolution and developed dedicated smartphone applications for environmental citizen science and recording.

Swift reporting and validation are key to any early warning and rapid response programme (Caffrey et al. 2014; Genovesi et al. 2010; Genovesi and Shine 2004; NOBANIS 2010; Wittenberg and Cock 2001) and the value of engaging citizens in such programmes has been demonstrated (Scyphers et al. 2014). Furthermore, up to date, accurate and reliable IAS distribution data are used in horizon scanning, predictive modelling, risk assessment and other activities underpinning management strategies for biological invasions (Groom et al. 2015). Therefore, unsurprisingly, a number of management programs for IAS have developed smartphone applications (apps) in recent years (Table S1). Most of the smartphone apps used for IAS recording enable the user to easily submit a photograph alongside some additional information, most critically a geolocation obtained via the device's built-in GPS receiver. This greatly enhances the accuracy of the records compared to some of the more classical mapping and monitoring projects, which often use data at lower resolutions (e.g. grid squares). The geo-referenced pictures are subsequently used to verify the information provided (verified citizen science sensu Gardiner et al. 2012). Furthermore, mobile phones have managed to infiltrate parts of the globe where other infrastructure is absent (Kwok 2009). The importance of mobile reporting is expected to increase in the future. For example, during a two year pilot study (2011–2012) on early warning for IAS in Belgium using the online platform http://www.waarnemingen.be and http://www.observations.be (Adriaens 2014) the proportion of observations performed with dedicated smart-phone apps (as opposed to website-based recording) increased from 3 % to 8 % (N = 6,335) and this percentage is still increasing (unpublished data).

In this paper we present two recent smartphone applications for IAS recording in northwest Europe, the RINSE *That's Invasive!* app and the *KORINA* app. We briefly present an overview of the projects behind the development of these applications, the species they comprise, their technical specifications, functionalities and a description of the records they generated so far. We will discuss the strengths and weaknesses of the applications and discuss potential improvements based upon the data collected so far, user surveys and experiences since their launch. With regards to the future development of IAS smartphone applications in Europe we present an overview of available smartphone apps and address issues of data integration, data openness, data quality and database interoperability.

Two smartphone applications for IAS recording in northwest Europe

RINSE That's Invasive! *smartphone application*

The RINSE project (Reducing the Impact of Invasive Non-Native Species in Europe http://www.rinse-europe.eu) sought to improve the management of IAS in the 2 Seas Region (Figure 1), a global invasion hotspot, with large numbers of non-native species and IAS reported (Gallardo et al. 2013; Zieritz et al. 2014) and a level of invasion that is amongst the highest in Europe

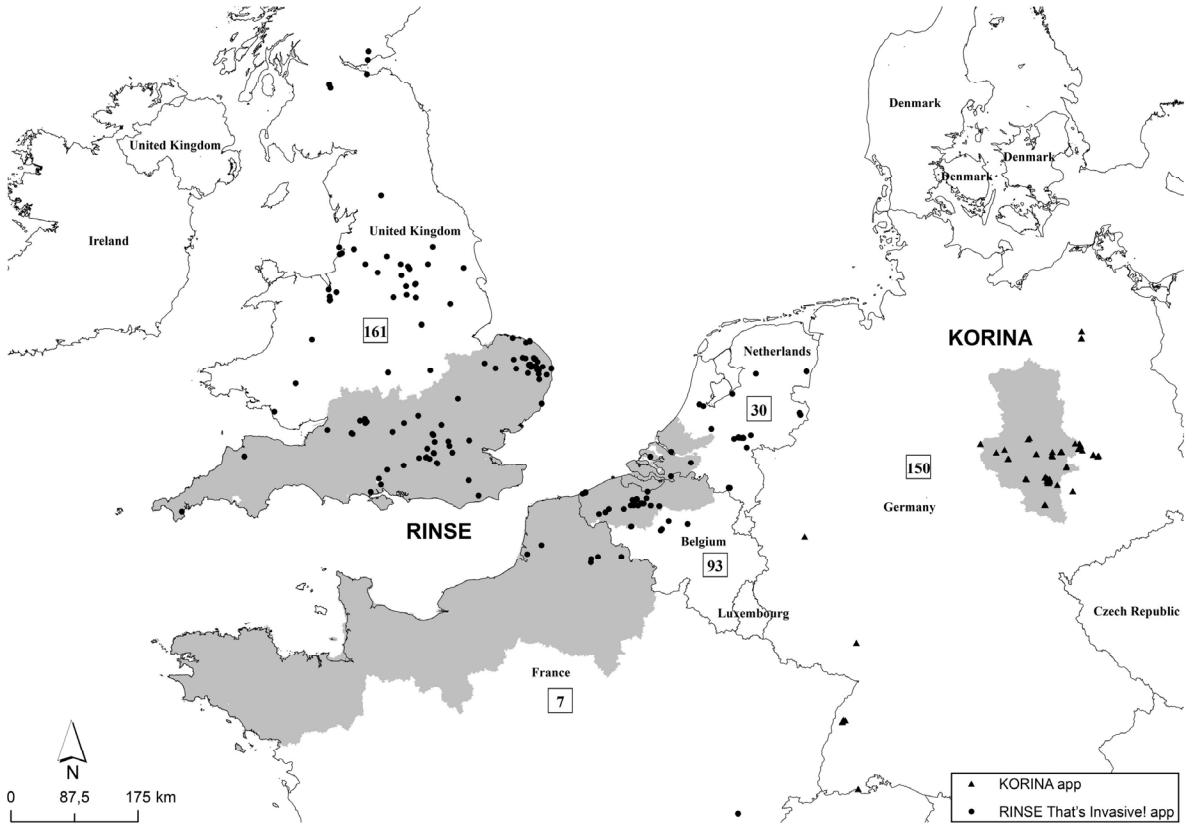

Figure 1. Non-native species data retrieved from the RINSE *That's Invasive!* (dots) and KORINA (triangles) smartphone apps in the period June 2013 - January 2015 and April - December 2014 respectively, with project areas (grey) and number of records per country (boxes). Distribution data used here are in tables S4 (*That's Invasive!*) and S5 (KORINA).

(Chytry et al. 2009). The project developed a smartphone application for iOS and Android named "*That's Invasive!*". The app collects geo-referenced photographs of a selection of priority IAS and uploads these with some additional information to the online recording platform iRecord (NBN, http://www.brc.ac.uk/irecord/). To facilitate ease of use and maximize participation, a limited list of 36 of the "worst" species was chosen, rather than a much larger list of all invasive species in the RINSE region (Table S3). It included a mixture of known alert list species which were not present or had limited distributions in the partner countries, as well as established species with ongoing management or research in the RINSE region.

The use of the app does not require registration in order to maximise outreach and user- friendliness. This has the disadvantage that some records are without an observer name (recorder name "anonymous"). To ensure that the data are useful to species management programs, users are required to take a photo of the observed species and to specify an abundance scale (Table S2). GPS location services are unaffected when a data network is lost and observers are able to store their observations until they get to an area with better connectivity. The location can be confirmed by manually checking a map on the smartphone and relocating the location marker on the map if necessary. The app includes fact sheets of the species with country-specific information on invasion history, distribution, impact and identification. Each IAS on the app has a gallery of photographs to browse; a list of key features and characteristics to look out for and a section on confusing species which may be similar in appearance.

That's Invasive! was launched in 2013 in the UK by issuing a press release. This generated significant local interest, with the app featuring on TV and radio news reports. A few months later, it became available in the French, Belgian, Dutch and, more recently, the German iTunes store. Promotion outside Great Britain has hitherto been relatively limited. After a trial period (2012-2014) and a survey of user satisfaction (2014), adjustments to the app were ordered, including improvements to the translations, increased functionality (e.g. bulk upload of data), availability for an increased number of devices (e.g. smartphones with newer Android and iOS versions, Fairphone) and some technical improvements (e.g. greater accuracy of GPS localisation). Version 2 will introduce social media integration and user reports (how many records submitted, how many verified etc.).

So far only 291 records were submitted through the RINSE app. These originated both from iOS (63 %) and Android (37 %) devices. These data were gathered by 39 different recorders, the majority of which (32 recorders) recorded no more than 5 records (excluding anonymous records). Eighteen recorders (47 %) only used the app once for recording. Sixty five percent of the records had no recorder name ("anonymous") and thus originated from non-registered users. Overall, 76 % (221 records) of the data could be verified based on the picture. The majority of the records (98 %, 285 records) supplied information on abundance or plant cover, as this is obligatory information. Missing data, such as an occasional missing abundance scale or the lack of a photograph with a record are probably due to submission error or server malfunction. Some records showed indications of field management, such as "caught and removed", "some areas have been managed" and "being controlled". Although the app is available in French, most records were received from Great Britain, Belgium and the Netherlands (Figure 1).

KORINA *smartphone application*

The Coordination Centre for Invasive Plants in protected areas of Saxony-Anhalt (KORINA, http://www.korina.info) aims to prevent plant invasions, establish an early warning system and enhance control of invasive plants in protected areas (Schneider 2010; Schneider and Hormann 2012). The project developed a mobile application to help record sightings of invasive alien plants in an easy, fast and accurate manner and with sufficient quality for verification (Schneider 2014). The app has three main features (Table 1, table S2). First, the FUND screen allows for recording a new sighting of an invasive plant. The species list contains an extensive number of non-native plants (Table S3). The app obliges users to upload a photo to the KORINA Atlas website, with information on the plant cover (in square meters). Second, the KARTE screen shows a map of recorded locations of non-native plants within a radius of 1 km from the observer location. Here, clicking on the locations displays information with species name, date of record and the cover of the plant. Third, the INFO screen shows a menu which includes information about selected invasive plants through a link to the KORINA website. It also contains help information on how to use the app and references to the system.

The project website was launched in 2011 and included an online database of the distribution of non-native plants, a mapping tool and additional information (ecology, distribution, best practices for management, the legal framework, literature references). The database was designed to facilitate rapid response by various bodies after new non-native plant incursions and to implement coordinated actions against some of these species. This online database holds 74,441 records of non-native plants in Saxony-Anhalt from 1687 to now, mostly from the plant database of the state Agency for Nature Conservation of Saxony-Anhalt. It also contains sightings from citizens reported via phone, the app or the internet, KORINA-recordings, student recordings and records from volunteer mapping of protected areas, collected since 2010. Forty percent of these (29,915 records) represent point data with a geo-location.

So far, the KORINA project has yielded 7,770 records of non-native plants. The majority of those (98 %, 7,620 records) originate from KORINA-recordings and the desktop online recording through the project website. As the *KORINA* smartphone app has only recently been launched the number of records originating from the app is still small and currently represents only 2 % (150 records) of the data collected. Other reasons for the low number of records could be a low degree of smartphone use among conservationists and the comparatively low population density of Saxony-Anhalt (110 citizens/km²). For 2015 the development of an identification tool for non-native plants and similar looking native plants is planned. This tool will be integrated both in the app and on the website.

Table 1. Specifications and functionalities of the RINSE and Korina smartphone applications for IAS recording.

	That'sInvasive	**Korina**
Project	RINSE	Korina
Projects website	www.rinse-europe.eu	www.korina.info
Developer	NatureBureau, Bristol	UMGEODAT, Halle
Development cost	20,262 €	21,405 €
Launch date	July 2013 (iOS) and September 2013 (Android)	May 2014 (iOS) and September 2014 (Android)
Number of downloads since launch	350 times on iOS and 320 times on Android	362 times on iOS and 77 times on Android
Number of species	36	111
Number of records since launch	291	150
Number of recorders since launch	39	12
Taxonomic scope	Plants, animals	Plants
Target audience	anyone	anyone
Fact sheets	Yes (integrated)	Yes (linked)
Image gallery	Yes	Yes
Photo sent with records	Obligatory	Obligatory
Registration required	No	Yes
Help function	Yes	Yes
Geographic scope	2 Seas region (parts of France, Belgium, The Netherlands, Great Britain)	Saxony-Anhalt, Germany
Possibility for off-line recording	Yes	No
Languages	English, French, Dutch	German
Operating system	iOS, Android	iOS, Android
Validation	Yes	Yes
Data put on Gbif	Planned	No
Gbif License	To be determined (CC0, CC-BY or CC-BY-NC)	-
Data model	National Biodiversity Network (NBN) data model	KORINA data model
Data sent to	iRecord with manual import in waarnemingen.be, waarneming.nl and observations.com	KORINA data system (PostgreSQL)

Smartphone apps for recording invasive species in Europe

In recent years, a multitude of apps for IAS recording has become available in Europe and many more are likely to be developed for species groups currently lacking specific apps. We screened the Google Play and Apple store for invasive species smartphone apps and listed their country of origin, the project they are embedded in, the development team, the database used for data upload and further references (Table S1). As we focused on dedicated IAS apps, apps designed to record all species such as Artenfinder (http://www.artenfinder.rlp.de), iObs (http://waarneming.nl), Obsmapp (http://obsmapp.org/), Webobs (http://webobs.org/), Record Wildlife Pro (http://www.recordwildlife.co.uk) and iSpot (http://www.ispotnature.org), were not comprehensively reviewed here and therefore not included in this overview. However, these apps probably yield a lot of the non-native species records in northwest Europe. For example, the total number of records reported through the Belgian online recording platform http://www.waarnemingen.be increased from 800,000 in 2009 to 1,6 million in 2013. The number of observations of non-native species in the same period was on average 3 % of all records and showed a similar increase from 27,000 to 50,000. Of those, about 10 % were performed with the smartphone apps Obsmapp or Webobs (unpublished data).

All of the apps for invasive species recording are free but not all of them are available for both Android and iOS platforms. Their functionality is very similar, as all of them allow for pictures with embedded GPS location data to be uploaded, which implies that the data collected can be verified. The number of species included in the apps varies, with some meant for reporting of a single species (e.g. Ambrosia Scout, Ambrosia Melder, Ambrosia alert and the SMARTER Ambrosia Reporter for *Ambrosia artemisiifolia* L.; Ash Tag for Ash dieback (*Chalara fraxinea* T. Kowalski 2006); JKC for Japanese knotweed (Fallopia japonica (Houtt.) Ronse Decr.); Leafwatch for Horse-chestnut leaf miner (*Cameraria ohridella* Deschka and Dimić, 1986); Tigatrapp for tiger mosquito (*Aedes*

albopictus Skuse, 1894). Other apps are designed for thematic groups (e.g. AquaInvaders for 26 aquatic non-native invasive species including 12 fish species; iWaterplant for invasive macrophytes) or taxonomic groups (e.g. iRecord Ladybirds, Korina and PlantTracker for non-native plants). Apps are available for reporting IAS in terrestrial, freshwater and marine environments (e.g. Sealife Tracker for marine invasives). In terms of geographical coverage, most of the current European apps for recording invasive species (including *That's Invasive!* and Korina) have a (north) western European scope. The IUCN MedMIS app for recording invasive aquatic species in Mediterranean Marine Protected Areas, Plantas Invasoras for reporting invasive plants in Portugal and Tigatrapp for tiger mosquito (*A. albopictus*) represent the only apps outside northern Europe. The SMARTER Ambrosia Reporter is pan-European.

In some cases there is overlap in the target species of the apps so observers have a choice among different apps for the same purpose. For example, for recording Ambrosia (*A. artemisiifolia*) there are several apps to choose from in Germany (KORINA app, Ambrosia SCOUT) and the Netherlands (Ambrosia Alert, Ambrosia Melder). When recording invasive plants in the Netherlands and Belgium, observers have a choice between apps for biological recording of all species (Obsmapp, iObs) or dedicated IAS apps such as *That's Invasive!* or iWaterplant. Some apps (SMARTER Ambrosia Reporter) address the variation in requirements by allowing the user to choose several recorder applications to suit their level of knowledge (van Valkenburg and Odé 2014).

Data on IAS occurrences recorded through apps are used in management and response programmes, thereby mobilizing human and financial resources. Therefore, to prevent wasting resources, verification is key. For scientific application, verified citizen science, e.g. through validation of photographs by experts, has also been shown to be more cost effective than traditional science (Gardiner et al 2012). Improving the level of interaction around data validation (e.g. through social media integration) could be beneficial for participant retention and volunteer involvement. Volunteers can also be trained in data validation to ensure ongoing validation. Most websites (e.g. iRecord) also provide the functionality to registered users to download the data they submitted. When running citizen-science recording schemes, providing such feedback is key in retaining involvement and improving recording rates.

Issues of database interoperability and harmonisation

The launch of the *That's Invasive!* app in the Belgian part of the RINSE region (Flanders, Northern Belgium), raised several issues. Flanders is a relatively small area and its biological recording landscape is dominated by a single system (waarnemingen.be/observations.be). This system has its own dedicated smartphone applications (iObs, Zostera b.v., Obsmapp, Alex Kwak and WinObs, Ies Meulmeester) for recording any species including non-natives and IAS. The governing, non-governmental, organisation was therefore reluctant to promote another application to volunteers active in survey schemes that had no link with their systems. Even if the set of species were more limited and the target audience different from the classical biological recording community, the app was perceived as either a useless addition which contributed to fragmentation of the biological recording scene, or as competition for an already existing initiative.

At a workshop where the app was promoted to municipalities, the manager of a giant hogweed eradication program in West Flanders commented that app data going onto the British iRecord system was unpractical, as it placed an extra burden on the coordinators of control programs to collate data on the target species from several sources. To solve this, RINSE partners decided to work towards a data exchange agreement, which comprises periodical transfer of the RINSE app data to the observado.org data system (including waarnemingen.be/waarneming.nl domains) and input in these databases through an XML streaming service. The first trial of transferring the data onto the Belgian system succeeded in 2014.

The way forward with smartphone applications for IAS recording in Europe

Technological developments

User demands in terms of accessibility are high and user interactions are expected to be intuitive and quick. This requires the functionality of the app to be kept simple, streamlined and to-the-point. It compels project teams to think thoroughly about both app objectives and design (Roy et al. 2012). Data recording is usually based on pressing icons rather than typing, and the number of data entry fields to fill is very limited. Further drawbacks include elevated development costs, exclusion of people that do not have access to or do not want

to use technology and loss of data through low mobile connectivity in some regions (Roy et al. 2012).

Smartphone technological advances occur swiftly with many future applications in ecological research (e.g. Teacher et al. 2013). Smartphone cameras are rapidly advancing both in terms of photo quality, embedded information and the possibilities for safe data storage (e.g. in the cloud through the use of built-in Wi-Fi in the camera or a memory card with built-in Wi-Fi). Smartphones and digital cameras that have built-in GPS and mobile internet access display convergent evolution. Also, the speed of image capturing is increasing, with smartphones that have the ability to automatically start recording images when taken out of the pocket. This opens possibilities of filming mobile organisms (e.g. birds) before they can get away. Also, on cameras, there is an evolution towards higher quality video which would allow post-hoc editing of the desired stills. This could extend the possibilities of acquiring high quality pictures through video editing, by choosing a video still most suitable for verification. Waterproof smartphones already enhance the recording of underwater species and habitats. Furthermore, some of the current restrictions of smartphones limiting their use in citizen science surveys (e.g. small screen, limited amount of additional information) might disappear with the expected increase of "phablets", smartphone and tablet hybrids.

The future of smartphones is likely to include an increased number of built-in or external sensors (Tweddle et al. 2012; Teacher et al. 2013) and augmented reality, extending the possibilities of classic smartphone apps. A well-known example making use of external sensors is iBats, an app which connects a bat detector to a smartphone during standardized bats surveys (Roussos et al. 2012; Jones et al. 2013). Operationally, voice and gesture control could enhance the speed of data input and improved battery performance would allow more data to come in. This will increase the amount of information obtained from records and photographs, for example through the inclusion of environmental variables such as temperature, light and weather. Higher speed networks (3G, 4G) will also drive such data growth (GSMA 2014). These developments could potentially benefit our knowledge of invasive species ecology but also represent a growing challenge to the capture and storage of data, as well as the design of citizen science programs.

Project management

An important aspect to consider when producing apps is the sustainability of funding and continuity of the data management. The *That's Invasive!* and *KORINA* app differ markedly in that respect. RINSE was a short term project (2012–2014) with limited funding. *KORINA* is embedded in a longer term management project at regional level, which however also has to apply for new funding on a regular basis (Schneider 2014; Schneider and Hormann 2012). Finding money for the creation of an app can be straightforward, as funding agencies and programs favour this style of innovative technology-for-all, although securing continuous investment in app promotion and maintenance, which is essential for recruitment and retention of participants, might be more of a challenge.

The adopted European Regulation on the prevention and management of the introduction and spread of IAS stresses the importance of involving the public in invasive species recording and management (European Union 2014). Apps for invasive species recording have the potential to do exactly that. When designed intelligently, these applications should also be able to engage an audience outside of the biological recording community. Therefore, smartphone applications also have potential added value in terms of awareness raising but this is yet to be quantified. Users of smartphone apps for recording invasive species might possess more awareness of biological invasions.

However, engaging a group of citizens and retaining their interest clearly requires more than a recording tool. Roy et al. (2012) refer to volunteer confusion and fatigue due to an overabundance of projects following new technological advances. Also, with the general inclination towards "use once and throw away" in the app market, data gathering has a tendency to become increasingly opportunistic (e.g. 19 % of the observers recorded less than 5 records with the RINSE app), which in time could render the data of lower scientific value (e.g. site occupancy modelling, species distribution modelling). Stimulating volunteers and providing continuous feedback is therefore an essential part of any citizen science survey (Science Communication Unit 2013).

Graham et al. (2011) highlighted a potential for conflict between technology and the desire to escape into nature which could limit participation in environmental citizen science. Therefore, smartphone apps should be only one of the tools

used when conducting citizen science surveys. Moreover, collaboration with existing citizen science groups and establishing new ones remains essential.

The design of smartphone applications for IAS recording requires careful consideration of the objectives of the app, the target audience and a thorough understanding of the biological recording community and recorder needs in the target region. There is also a need to constantly evaluate, revise, and refine mobile tools based on what users are willing to do, what they can do with confidence and what they expect in return, whilst also meeting the data requirements of the scientific community (Graham et al. 2011). The proliferation of apps means designers and invasion managers continuously need to find new ways of engaging their target audience and improving user experience. People are spending more time than ever with their apps, but certain app categories such as social networking show a greater increase than others (Nielsen 2013). Apps for invasive species recording could build upon such trends, taking into account the target audience. For example, adding gamification (i.e. the use of game thinking and game mechanics) or an element of social media interaction to the data collection and the record validation might be useful, to combine recording with awareness raising and improve user engagement with certain audiences. However, apps developed for citizen science projects need to balance the need to generate quality data with usability. This should be addressed by understanding the needs of the specific users throughout the planning and development process (Teacher 2013). Version 2 of *That's Invasive!* will introduce social media integration.

Data management

The experience of promoting the *That's Invasive!* app, which primarily communicates with the UK iRecord system, exposes an important issue on data integration. With the multitude of apps for recording invasive species now available in northern Europe (Table S1), each acting at different geographical scales and embedded within projects with their own geographically distinct regions, the compilation of invasive species data by managers and scientists represents a growing challenge. Managers need all available data for the area they manage in one place. Scientists and decision makers working within the framework of the European IAS Regulation often need data on a larger e.g. pan-European scale. Allowing app data to be deposited in open data repositories can partly solve this issue as far as scientific application of the data is concerned. For rapid response programs these open data repositories are less practical, as they currently hold no possibilities to issue alerts whenever new data come in. Yet in theory, verified data originating from apps could be published on GBIF (GBIF 2014) or a similar network immediately. From the moment the data is published an automated alert could be sent to all who are subscribed for that specific taxon in a specified area.

We recommend that smartphone applications build on internationally agreed data standards such as the Darwin Core or ABCD for occurrence records and the Audubon Core for multimedia recordings. This could help considerably in data validation and exchange between data systems. The RINSE *That's Invasive!* app e.g. uses the NBN data model (Copp 2004) (Table 1). This has proven useful in providing compatibility and ease of transfer with another mainland European system. Issues of data verification, the use of existing ratified data models and data quality should be addressed in a functional analysis phase. Appropriate metadata (e.g. NBN metadata standards, GBIF metadata profile (GBIF 2011)) should be provided alongside the data to ensure end-users fully understand the data. Furthermore, we advocate app operators to provide validated data to open data repositories in order to maximize sustainability of data storage, functionality and application of the data. This can ensure greater potential for their use in horizon scanning, species distribution modelling, risk mapping and other scientific activities underpinning management strategies for biological invasions. Efforts could be undertaken to create a common platform or to promote an existing one (e.g. DAISIE, EASIN) for uploading data originating from apps, or for mirroring validated data into a single, easy to use web service. Data repositories and international organisations such as GBIF, TDWG (TDWG 2014), GEO BON (GEO BON 2014) and EU BON (EU BON 2014) may have an important role to play in the creation of standards and software to make this possible.

Some data repositories for biodiversity observation data have the ability to store an image (or other media file) of the organism together with its associated data. Such large repositories of verified pictures could be an important resource in the future, just as herbaria and museum collections are now. However, presently it is easy for data to become separated

from their evidential photograph because intellectual property rights tend to force this division. Copyright prohibits copying of images, but doesn't protect the data they contain. An example of good practice is iNaturalist.org where users can choose between six different Creative Commons licenses to share their data and images. Other websites vary; some equivocate leaving the situation unresolved, while at least one other explicitly splits the licensing of data from images.

At present, most smartphone apps have been designed to record only the presence of an invasive species, although some permit documentation of the coverage or abundance of the recorded species. However, none of the apps currently available allow follow-up of recorded management measures or recording absences on previously visited locations. The KORINA website allows such absences to be documented, and this possibility is planned for inclusion within the Korina app.

If the app is part of a temporary project it is important to plan how to continue performing necessary technical updates such as making adjustments for different devices and mobile operating systems and continuing record verification after the project finishes. Sharing data to multiple platforms is one way to better ensure data persistence and security. Another partial solution is to develop volunteer-led recording schemes where volunteers are trained for data verification. This way, as a project ends and records continue to arrive, validation work can more easily be taken over by others. Care should be taken to determine the picture copyright (e.g. by mentioning this in the terms and conditions). It must be made clear on the app that all images taken are licensed openly, otherwise passing them on for management elsewhere may not be legal.

Conclusions

The use of smartphone applications can generate verified geo-referenced records which can complement professional monitoring schemes and yield high quality data useful for early warning, rapid response programs and the execution of management schemes. A wealth of smartphone applications for recording invasive species has become available in Europe in recent years, most of which have a (north)western European scope. Efforts should be undertaken to create a common platform for uploading data originating from apps or mirroring validated data into a single, easy to use web service. Major networks such as GBIF, TDWG, GEO BON and EU BON may have an important role to play in the creation of standards and software to make this possible. We recommend that project managers designing new smartphone applications for recording should:

- Make certain that the data collected is suitable for the purposes (e.g. early warning, rapid response, management, research) it is intended for;
- Take into account the target audience and understand the biological recording community and recorder needs and motivations;
- Ensure that applications generate data in a standardized format and feed into central record collection systems;
- Address issues of data verification, the use of existing ratified data models and data quality in a functional analysis phase;
- Ensure sustainable funding or think of other solutions for technical updates, data verification and retention of participants after the project ends;
- Invest in volunteer management and interaction with users e.g. through feedback on survey campaigns and control actions;
- Communicate to users why their records are useful and how they may be used;
- Inform users about issues of intellectual property rights of records and associated media files so that this does not restrict further usage;
- Horizon scan technological advances to improve the functionality of apps.

To make the most of smart mobile technologies we still need to address some of the technical, legal and social issues that they raise. Yet, we expect rapid evolution in the field of mobile applications for biodiversity recording and look forward to their full integration into the IAS management landscape.

Acknowledgements

The RINSE *That's Invasive!* app was funded through the EU Interreg 2 Seas project RINSE, which was co-funded by the European Regional Development Fund. We thank the other RINSE partners who have been actively working in app development, fact sheet translation, app promotion or other activities. We thank Sander Devisscher for technical assistance. We are grateful to Hisko de Vries for trialling incorporation of RINSE data in observado.org. The KORINA project is run by the Independent Institute for Environmental Issues (UfU e.V.). The *KORINA* app was funded by the European Agricultural Fund for Rural Development. The design of the app was developed by ö-konzept and arnolddesign (Halle). Quentin Groom acknowledges support of the EU BON project funded by the EU Framework Programme (FP7/2007-2013) under grant agreement № 308454. We are grateful to all volunteers who contributed data on invasive aliens using the *That's Invasive!* and *KORINA* apps. We thank three anonymous reviewers for providing helpful comments to improve this manuscript.

References

Adriaens T (2014) Waarnemingen.be as an early-detection tool, from centralised reporting to effective early warning. Aliens on the horizon Workshop. Brussels, 12 March, 2014. http://ias.biodiversity.be/outputs/201403_aliens_on_the_horizon

Bonney R, Cooper CB, Dickinson J, Kelling S, Phillips T, Rosenberg KV, Shirk J (2009) Citizen science: a developing tool for expanding science knowledge and scientific literacy. *BioScience* 59(11): 977–984, http://dx.doi.org/10.1525/bio.2009.59.11.9

Caffrey JM, Baars J-R, Barbour JH, Boets P, Boon P, Davenport K, Dick JTA, Early J, Edsman L, Gallagher C, Gross J, Heinimaa P, Horrill C, Hudin S, Hulme, P.E., Hynes S, MacIsaac HJ, McLoone P, Millane M, Moen TL, Moore N, Newman JR, O'Conchuir R, O'Farrell M, O'Flynn C, Oidtmann B, Renals T, Ricciardi A, Roy H, Shaw RH, van Valkenburg JLCH, Weyl O, Williams F, Frances LE (2014) Tackling invasive alien species in Europe: the top 20 issues. *Management of Biological Invasions* 5(1): 1–20, http://dx.doi.org/10.3391/mbi.2014.5.1.01

Chytry M, Pysek P, Wild J, Pino J, Maskell LC, Vila M (2009) European map of alien plant invasions based on the quantitative assessment across habitats. *Diversity and Distributions* 15(1): 98–107, http://dx.doi.org/10.1111/j.1472-4642.2008.00515.x

Copp C (2004) The NBN Data Model Part 1 Description of the Model. The NBN Trust, Newark, 92 pp

Crall AW, Newman GJ, Stohlgren TJ, Holfelder KA, Graham J, Waller DM (2011) Assessing citizen science data quality: an invasive species case study. *Conservation Letters* 4(6): 433–442, http://dx.doi.org/10.1111/j.1755-263X.2011.00196.x

EU BON (2014) EU Biodiversity Observation Network (EU BON). http://www.eubon.eu (Accessed 29 October 2014)

European Union (2014) Regulation (EU) no 1143/2014 of the European parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species. Official Journal of the European Union 4.11.2014, L317:35–55

Gallardo B, Zieritz A, Aldridge DC (2013) Targeting and prioritisation for INS in the RINSE project area. Report commissioned by the Interreg 2Seas RINSE project. Cambridge Environmental Consulting. University of Cambridge, Cambridge, UK, 98 pp

Gardiner MM, Allee LL, Brown PMJ, Losey JE, Roy HE, Smyth RR (2012) Lessons from lady beetles: accuracy of monitoring data from US and UK citizen-science programs. *Frontiers in Ecology and the Environment* 10: 471–476, http://dx.doi.org/10.1890/110185

GBIF (2011). GBIF Metadata Profile: How-To guide version 1.0. Global Biodiversity Information Facility, Copenhagen, 11 pp, http://links.gbif.org/gbif_metadata_profile_howto_en_v1/http://links.gbif.org/ gbif_metadata_profile_how-to_en_v1/

GBIF (2014) Global Biodiversity Information Facility (GBIF). http://www.gbif.org (Accessed 29 October 2014)

Genovesi P, Scalera R, Brunel S, Roy D, Solarz W (2010) Towards an early warning and information system for invasive alien species (IAS) threatening biodiversity in Europe. European Environment Agency (EEA). EEA Technical report No 5/2010, 47 pp

Genovesi P, Shine C (2004) European strategy on invasive alien species: Convention on the Conservation of European Wildlife and Habitats (Bern Convention). Council of Europe, t-pvs(2003)7, 67 pp

GEO BON (2014) Biodiversity Observation Network (GEO BON). http://www.earthobservations.org (Accessed 29 October 2014)

Graham EA, Henderson S, Schloss A (2011) Using mobile phones to engage citizen scientists in research. *Eos, Transactions American Geophysical Union* 92(38): 313–315, http://dx.doi.org/10.1029/2011EO380002

Groom QJ, Desmet P, Vanderhoeven S, Adriaens T (2015) The importance of open data for invasive alien species research, policy and management. *Management of Biological Invasions*, http://dx.doi.org/10.3391/mbi.2015.6.2.02

GSMA (2014) The Mobile Economy 2014. GSMA Intelligence, 82 pp, http://www.gsmamobileeconomy.com/GSMA_ME_Report_2014_R2_WEB.pdf

Jones KE, Russ JA, Bashta AT, Bilhari Z, Catto C, Csősz I, Gorbachev A, Győrfi P, Hughes A, Ivashkiv I, Koryagina N, Kurali A, Langton S, Collen A, Margiean G, Pandourski I, Parsons S, Prokofev I, Szodoray-Paradi A, Szodoray-Paradi F, Tilova E, Walters CL, Weatherill A, Zavarzin O (2013) Indicator Bats Program: a system for the global acoustic monitoring of bats. Biodiversity Monitoring and Conservation: Bridging the Gap between Global Commitment and Local Action, pp 211–247, http://dx.doi.org/10.1002/9781118490747.ch10

Kwok R (2009) Personal technology: Phoning in data. *Nature* 458: 959–961, http://dx.doi.org/10.1038/458959a

Newman G, Wiggins A, Crall A, Graham E, Newman S, Crowston K (2012) The future of citizen science: emerging technologies and shifting paradigms. *Frontiers in Ecology and the Environment* 10(6): 298–304, http://dx.doi.org/10.1890/110294

Nielsen (2013) The mobile consumer: a global snapshot. The Nielsen Company. http://www.nielsen.com

NOBANIS (2010) Recommendations from the workshop "Developing an early warning system for invasive alien species (IAS) based on the NOBANIS database". June 1–2, 2010, Waterford. http://www.nobanis.org/files/Workshop%20recommendations_FINAL.pdf

Roussos G, Sin G, Craft B (2012) The batphone. ACM SIGMOBILE *Mobile Computing and Communications Review* 16(1): 28–29, http://dx.doi.org/10.1145/2331675.2331683

Roy HE, Pocock MJO, Preston CD, Roy DB, Savage J, Tweddle JC, Robinson LD (2012) Understanding Citizen Science and Environmental Monitoring. NERC Centre for Ecology & Hydrology and Natural History Museum, 173 pp, http://www.ceh.ac.uk/news/news_archive/documents/understandingcitizenscienceenvironmentalmonitoring_report_final.pdf

Schneider K (2010) First steps for a management of invasive plants on a regional scale in Saxony-Anhalt, Germany. In: Kollmann J, van Mölken T, Ravn HP (eds), Biological Invasions in a Changing World - from Science to Management. 6th NEOBIOTA Conference, Denmark, September 14-17, 2010. Department of Agriculture & Ecology, University of Copenhagen, Faculty of Life Sciences, Copenhagen, pp 260, http://cis.danbif.dk/neobiota-2010-conference/Neobiota2010_abstractbook.pdf

Schneider K (2014) Communication: the fastest growing part of the management of plant invasions in Saxony-Anhalt, Germany. *EPPO Bulletin* 44(2): 251–256, http://dx.doi.org/10.1111/epp.12123

Schneider K, Hormann A (2012) Management of invasive plants on a regional scale in Saxony-Anhalt, Germany. In: Grupo Especialista en Invasiones Biologicas (eds), Neobiota 2012: 7th European Conference on Biological Invasions: Halting Biological Invasions in Europe: from Data to Decisions. Pontevedra, Spain, September 12–14, 2012. GEIB, Pontevedra, Spain, pp 121–122, http://neobiota2012.blogspot.be/p/book-of-abstracts.html

Science Communication Unit (2013) Science for Environment Policy In-depth Report: Environmental Citizen Science. University of the West of England (UWE), Bristol, 32 pp, http://ec.europa.eu/environment/integration/research/newsalert/pdf/IR9.pdf

Scyphers SB, Powers SP, Akins JL, Drymon JM, Martin CW, Schobernd ZB, Schofield PJ, Shipp RL, Switzer TS (2014) The role of citizens in detecting and responding to a rapid marine invasion. *Conservation Letters*, http://dx.doi.org/10.1111/conl.12127

Silvertown J (2009) A new dawn for citizen science. *Trends in Ecology & Evolution* 24(9): 467–471, http://dx.doi.org/10.1016/j.tree.2009.03.017

Stace C (2010) New flora of the British Isles 3rd ed. Cambridge University Press, Cambridge, 1266 pp

Sutherland WJ, Clout M, Côté IM, Daszak P, Depledge MH, Fellman L, Fleishman E, Garthwaite R, Gibbons DW, De Lurio J (2010) A horizon scan of global conservation issues for 2010. *Trends in Ecology & Evolution* 25(1): 1–7, http://dx.doi.org/10.1016/j.tree.2009.10.003

Teacher AG, Griffiths DJ, Hodgson DJ, Inger R (2013) Smartphones in ecology and evolution: a guide for the app-rehensive. *Ecology and Evolution* 3(16): 5268–5278, http://dx.doi.org/10.1002/ece3.888

TDWG (2014) Biodiversity Information Standards (TDWG). http://www.tdwg.org (Accessed 29 October 2014)

Tweddle JC, Robinson LD, Pocock MJO, Roy HE (2012) Guide to citizen science: developing, implementing and evaluating citizen science to study biodiversity and the environment in the UK. Natural History Museum and NERC Centre for Ecology and Hydrology for UK–EOF. http://www.ukeof.org.uk

Van Valkenburg JLCH, Odé B (2014) Exotenwaarnemingen van planten via apps. *De Levende Natuur* 115(5): 222–223

Wittenberg R, Cock MJ (2001) Invasive Alien Species: A Toolkit of Best Prevention and Management Practices. CABI Publishing, Wallingford, UK, http://dx.doi.org/10.1079/9780851995694.0000

Zieritz A, Gallardo B, Aldridge DC (2014) Registry of non-native species in the Two Seas region countries (Great Britain, France, Belgium and the Netherlands). *NeoBiota* 23: 65–80, http://dx.doi.org/10.3897/neobiota.23.5665

Supplementary material

The following supplementary material is available for this article:

Table S1. Overview of smartphone applications for reporting invasive species occurrences in Europe with the species they record, their country of origin, the project they are embedded in, the managing institution, the final database of the records and further references. Operating system was retrieved from the appropriate iTunes and GooglePlay stores.

Table S2. Summary of recorded information and functionalities in the in the RINSE *That's Invasive!* smartphone application, KORINA-website and smartphone application (O = obligatory, V = voluntary, C = categorized, A = automatically).

Table S3. Non-native species currently covered by the RINSE and KORINA smartphone applications with their scientific and English common names (plant common names derived from Stace (2010) or NBN gateway https://data.nbn.org.uk). The number of records received since the launch of the app is indicated between brackets.

Table S4. Non-native species data retrieved from the RINSE *That's Invasive!* smartphone application in the period June 2013 - January 2015.

Table S5. Non-native species data retrieved from the KORINA smartphone application in the period April - December 2014.

This material is available as part of online article from:
http://www.reabic.net/journals/mbi/2015/Supplements/MBI_2015_Adriaens_etal_Supplement.xls