Half a billion eyes on the ground: citizen science contributes to research, policy and management of biological invasions in Europe

Veronica Price-Jones, Peter Brown, Tim Adriaens, Elena Tricarico, Rachel A Farrow, Ana-Cristina Cardoso, Eugenio Gervasini, Quentin Groom, Lien Reyserhove, Sven Schade, Chrisa Tsinaraki, Elizabete Marchante

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Authors and Affiliations

Price-Jones V[1], Brown PMJ[1], Adriaens T[2], Tricarico E[3], Farrow RA[1], Cardoso AC[4], Gervasini E[4], Groom Q[5], Reyserhove L[2], Schade S[4], Tsinaraki C[4] & Marchante E.[6]

[1] School of Life Sciences, Anglia Ruskin University, Cambridge, United Kingdom.

[2] Research Institute for Nature and Forest (INBO), Brussels, Belgium.

[3] Department of Biology, University of Florence, Sesto Fiorentino (FI), Italy.

[4] European Commission – Joint Research Centre, European Alien Species Information Network (EASIN), Ispra, Italy.

[5] Botanic Garden Meise, Meise, Belgium.

[6] Centre for Functional Ecology, Department of Life Sciences; University of Coimbra, Coimbra, Portugal.

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Abstract

Invasive alien species (IAS) are a key driver of global biodiversity loss. Reducing their spread and impact is a target of the Sustainable Development Goals (SDG target 15.8) and of the EU IAS Regulation 1143/2014. The use of citizen science offers various benefits to alien species (AS) decision making and to society, since public participation in research and management boosts awareness, engagement and scientific literacy and can reduce conflict in IAS management. We report the results of a survey on AS citizen science initiatives within the framework of European Cooperation in Science and Technology (COST) Action Alien-CSI. We gathered metadata on 103 initiatives across 41 countries, excluding general biodiversity reporting portals, spanning from 2005 to 2020, offering the most comprehensive account of AS citizen science initiatives on the continent to date. We retrieved information on project scope, policy relevance, engagement methods, data capture, data quality and data management, methods and technologies applied and performance indicators such as the number of records coming from projects, the numbers of participants and publications. The 103 initiatives were unevenly

distributed geographically, with countries with a tradition of CS showing more active projects. The majority of projects were contributory and were run at a national scale, targeting the general public, alien plants and insects, and terrestrial ecosystems. Most projects focused on collecting species presence or abundance data, aiming to map presence and spread. As 75% of the initiatives specifically collected data on IAS of Union Concern, citizen science in Europe is of high policy relevance. Despite this, only half of the projects indicated sustainable funding. Nearly all projects had validation in place to verify species identifications. Strikingly, only about one third of the projects shared their data to open data repositories such as the Global Biodiversity Information facility or the European Alien Species Information Network. Moreover, many did not adhere to the principles of FAIR data management. Based on this dataset, we offer suggestions to strengthen the network of IAS citizen science projects and to foster knowledge exchange among citizens, scientists, managers, policy-makers, local authorities, and other stakeholders.

1. Introduction

The history of citizen science (CS), broadly defined as the practice of involving members of the public in scientific research (Wiggins and Crowston 2011), can be traced back centuries (Silvertown 2009), but over the course of recent decades, the field of CS has grown and transformed to reflect new attitudes and capabilities. Large and diverse audiences across the globe now contribute to initiatives carried out on scales ranging from short-term and local, to generational and international. The role of the citizen scientist is equally variable and as a result, the definition of CS has been subject to debate (Heigl et al. 2019; Haklay et al. 2021). In many environmental projects, citizen scientists merely collect and submit field observations to be analyzed by professional scientists (Bonney 1996); however, in this paper we also consider more in-depth involvement of citizen scientist, such as measuring impacts of IAS and collecting experimental data.

One area in which CS has clearly seen an increase in contributions is the domain of alien species (AS) science and policy (Adriaens et al. 2015; Roy et al. 2018; Schade et al. 2019; Johnson et al. 2020). Alien species are defined as species introduced into a new geographic range

by human intervention, either intentionally or by accident (Bellard et al. 2016). While AS may have a positive, neutral, or negative impact on their new environment (Goodenough 2010; Cox and Lima 2006), the term invasive alien species (IAS) refers to species whose introduction and spread has been found to threaten or adversely impact global biodiversity, ecosystem services, society and the economy (IPBES 2019; Seebens et al. 2017, 2020; EU Regulation 1143/2014). Concerns over the impacts of IAS have led to policy responses internationally, nationally, and locally. For example, the UN's Sustainable Development Goals (SDGs) include a specific target on IAS (target 15.8). Similarly, in 2014, the European Union published the EU Regulation 1143/2014 to control the spread of IAS in all member states through prevention, early detection, rapid eradication, and management. This Regulation identifies a list of IAS of Union concern which pose a threat to biodiversity and require concerted action at the European Union level. Accessible information on these IAS and implementation of associated policies is provided by the European Alien Species Information Network (EASIN; Katsanevakis et al. 2015; Schade et al. 2019). The core function of this system is to gather and integrate data on AS occurring in Europe from data partners and scientific literature (Katsanevakis et al. 2012). Data originate from official monitoring programmes and research projects, but also derive from several IAS-focussed CS projects active throughout Europe. These projects either deliver data to EASIN directly or publish to open data repositories like the Global Biodiversity Information Facility (GBIF), where they are harvested by the system.

The data gathered through IAS-focussed projects are very actionable, since they hold potential for use in early warning and rapid response, control programmes at various spatial scales, and policy implementation. Citizen science is especially valuable in an IAS context since tackling the spread of these species necessitates upscaled recording, improved understanding of the IAS problem and increased awareness at all levels of society, objectives for which CS is well suited. Ultimately, citizens who become involved in IAS CS projects gain a voice in promoting decision-making and policy implementation, thereby supporting the development of IAS policies (Groom et al. 2019). However, there is no updated and systematic analysis of IAS CS projects across Europe. This would allow a better understanding of the potential reach and gaps of such projects for European science and policy. Here, we present the first comprehensive overview of European IAS CS initiatives, comparing regional differences across Europe. Contrary to earlier work (Johnson et al. 2020), we focus on European AS-specific CS projects and journal

publication is not used as a criterion for inclusion. Since Europe adopted a common Regulation on IAS (the above mentioned EU Regulation 1143/2014) we wanted to assess the policy relevance of projects with a particular emphasis on the implementation of this Regulation. We further evaluated the performance of projects considering their numbers of participants, number of AS records they yield and the publications derived from them, in order to understand how various parameters contribute to engagement.

2. Materials and Methods

2.1 Data Collection

This survey was developed within the scope of COST Action CA17122 - "Increasing understanding of alien species through citizen science (Alien-CSI)", which includes participants from all EU member states and a few neighboring countries. This COST Action sets out six research coordination objectives, to be first approached through a European wide analysis of existing IAS CS initiatives (Roy et al., 2018).

The first version of the survey was tested, revised and validated in a workshop attended by representatives from 25 countries in the COST Action. The survey (Price-Jones et al. 2021) was shared as a Google Form with all COST Action participants, and disseminated online. Responses were collected from June 27, 2019 to April 6, 2020. For each country, existing CS projects involving AS were contacted and requested to complete the survey. All projects are/were active in EU member states and/or neighbouring countries. A list of projects was compiled, including from a web search and previously available lists of European CS projects (e.g., INNS, EASIN, Kus Veenvliet et al. 2019), and the missing projects in the survey database were contacted. Finally, to increase reach, the survey was also disseminated through the European Citizen Science Association (ECSA) newsletter and mailing list and respondents were asked to share it with colleagues and local networks via snowball sampling.

Survey questions and attribute values were developed using JRC metadata standards for CS projects (European Commission, Directorate-General for Environment 2018) and the project metadata model of PPSR Core, a set of global, transdisciplinary data and metadata standards for Public Participation in Scientific Research (PPSR Core). The survey included 62 questions (Price-Jones et al. 2021), in nine sections: 1) Contact information of the respondent; 2) General

characterization of the project, including a brief summary, geographical scope, time scale, hosting entities, funding, etc.; 3) Information on project scope, including target audience, taxonomic and environmental scope, project aims, type of data collected, etc.; 4) Policy-related information, i.e., policy relevance and inclusion of species listed in the EU IAS Regulation; 5) Information on engagement, such as type of involvement of the general public in the design of the project, engagement methods and social media used, skills needed to participate and frequency of contributions; 6) Information on feedback and support provided to participants by the project, e.g., if the project provides materials for species identification, guidelines, training activities, information on how data from the project are used, feedback mechanisms and support; 7) Data quality and data management, namely validation mechanism for records, registration type, methods of recording, whether data are open and accessible to the general public, data form used to store data, data standards and data licence used, whether a public data management plan was in place; 8) Performance indicators of projects, namely usage of apps, number of participants and number of records, whether learning is assessed, number and type of publications using data from the project; and 9) Notes and remarks.

2.2 Preprocessing

Only projects that simultaneously fulfilled the following criteria were included in the analyses: 1) a clearly CS-focussed project; 2) AS included in the main scope; and 3) project developed in Europe (even if not exclusively). As such, national biodiversity networks and portals collecting data on all species were only considered if they had a clear AS focus. Projects needed to have specific forms of public engagement related to AS, so projects solely devoted to improving IAS policies but without a typical CS component (e.g., data collection using target groups, interaction with volunteers) were not considered. However, projects where data gathering was less relevant, but which had clear educational and outreach goals on IAS, were included.

2.3 Statistical Analysis

2.3.1 Exploratory Analysis of Project Parameters

Of the nine survey sections, six asked for information about project parameters, or characteristics. These sections are: General characterization of the project, Information on project scope, Policy-related information, Information on engagement, Information on feedback and support, and Data quality and data management strategies. To explore the parameters of all surveyed projects, the frequency of each multiple choice or written answer was determined for each question within the above sections. Additionally, we were interested in determining if an association existed between target audience and target taxonomic group, or between target audience and target environment. Two-way chi square tests were conducted with a significance level of 0.05 to test for these associations.

2.3.2 Geographic Differences in Project Scope

In these series of analyses, we were interested in how the number of projects was affected by the scope of the project and whether the impact of project scope had a geographic component. For this, we identified five parameters related to project scope: common targeted taxa, audience, environment and aim. Europe was divided into five regions: Northern Europe, Eastern Europe, Southern Europe, Western Europe, and the UK and Ireland. The UK is considered as a separate region with Ireland, due to its extensive history with CS (Silvertown 2009). These divisions are commonly used in ecology, with minor variability in the countries in each region (e.g. Bilton et al. 1998). To normalise according to the different number of inhabitants per region, the number of projects was expressed per million inhabitants using population data from the United Nations (United Nations 2019). Maps were created using ESRI ArcGIS Pro 2.7. For each of three project scope parameters, a two-way chi square test was conducted to test for association with geographical region. The tests were carried out with a significance level of 0.05.

2.3.3 Impact of engagement, feedback and support on project performance

To test whether parameters related to engagement, feedback and support had an effect on project performance, we selected 11 explanatory variables (four related to engagement, six related to feedback / support, and project duration) and defined three project performance indicators: the number of participants taking part in the project, the number of species observations (records) gathered by the project and the number of publications related to the project (Table 1). Three cumulative link models (CLMs) were conducted in RStudio version 3.3.3 (2017) using the package "ordinal" (Christensen 2018) to determine if engagement, feedback / support and project duration had a significant effect on performance indicators (Table 1). Each of the three tests used a different performance indicator - number of participants, records and publications - as a response variable. All models were carried out with a significance level of 0.05. R code for these tests is published on Zenodo (Price-Jones et al. 2021).

Table 1: Variables used in the Cumulative Link Models.

Explanatory variables	Response variables
Project duration Project design (engagement factor) Use of social media (engagement factor) Level of skill/knowledge required (engagement factor) Expected contribution frequency (engagement factor) Provision of guidelines (feedback and support factor) Provision of training (feedback and support factor) Provision of sightings map (feedback and support factor) Provision of active informing (feedback and support factor) Provision of feedback (feedback and support factor) Provision of support (feedback and support factor)	Number of participants Number of records Number of publications

3. Results

3.1 Exploratory analysis of selected project parameters

Results are given as a percentage of answers that provided a definite response, as many questions did not have a 100% response rate, and respondents frequently answered "Unknown"

or "Not applicable." The exact number of respondents of a specific response and the total number of respondents that provided a definite response are also given for each question.

3.1.1 General characterization of the project

In total 129 projects/initiatives completed data for the survey and of these 103 fitted the criteria for inclusion and were considered for analysis. Of the 26 that were excluded, seventeen were not AS-focussed, seven had no specific forms of public engagement on AS and two were duplicate entries.

The number of new projects has increased over the past fifteen years with the oldest project recorded beginning in 2005 (Brown et al. 2008) while 21 began in 2019. A total of 42 countries were represented in the survey. A majority of projects (66%; 68/103) were run at the national level, and 85% (87/103) were active in a single country. However, one project, a survey of alien species of Union Concern on iNaturalist, was active in 38 countries. In four countries (Estonia, Malta, Montenegro, and North Macedonia) this represented the sole recorded project.

The type of organisation responsible for the projects varied between governmental (29%; 30/103) and non-governmental organizations (22%; 23/103), universities (28%; 29/103), public research organizations (22%; 23/103), and private companies, non-profit organizations and individual persons (12%; 12/103). Most projects are fully (54%; 56/103) or partially (19%; 20/103) funded, but 26% (27/103) reported having no funding. Governments were the largest source of funding, although only 36% of projects (28/78) report governments as being their sole source of funding. Otherwise, funding was provided by public entities, the EU LIFE program, NGOs or private sources, or a combination of the above.

3.1.2 Project scope

Plants were the most common target taxonomic group (30%; 31/103; Figure 1a), the general public was the most common target audience (89%; 92/103; Figure 1b), and terrestrial habitats the most common environment analysed in the projects (57%; 59/103). There was no association between target audience and taxon (χ^2 = 54.52, df = 48, p = 0.24), but an association was observed between target audience and environment (χ^2 = 51.97, df = 30, p = 0.0077). Two

trends in the data included the prevalence of terrestrial projects aimed at land managers, and freshwater and marine projects aimed at fishermen. The marine environment was also the environment type most frequently involving scientists and students.

84% of projects (87/103) focussed solely on AS and 9% (9/103) focussed partially on AS; 7% (7/103) responded that AS were not the main focus, yet AS data were collected and received some emphasis. Most projects had multiple aims, the most common being mapping of AS distribution (Figure 1c). Most projects also collected more than one type of data, with species presence and/or abundance being the most common.
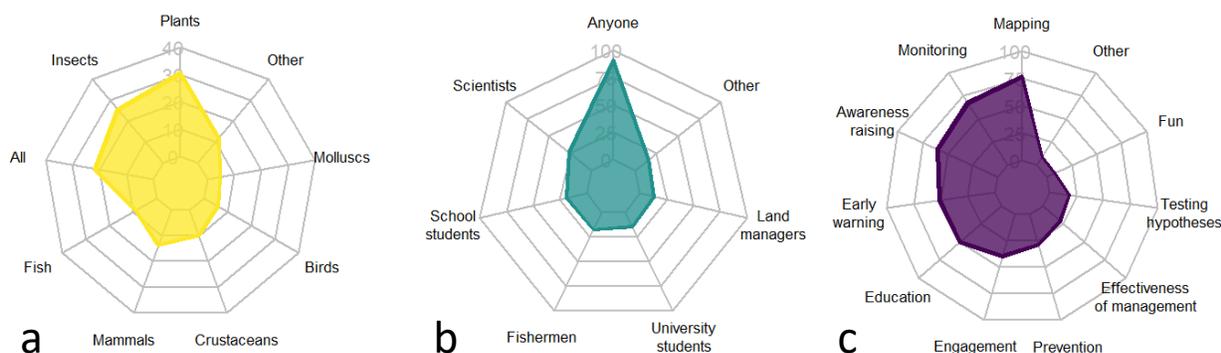
Figure 1. Percentage (indicated by numbers on radar plots) of projects that gave selected responses to project scope questions: **a** target taxon, **b** target audience, and **c** project aim.

3.1.3 Policy-related information

75% of projects (59/79) claimed to have policy relevance, with 79% (77/97) including species on the List of IAS of Union concern (EU Regulation 1143/2014), whether exclusively or partially.

3.1.4 Information on engagement

In terms of project design, 39% of projects (41/97) were categorized as collaborative and 53% (56/97) as contributory. The top three ways to engage citizens with the projects were through websites (83%; 83/99), social media (64%, 64/99) and live training (41%, 41/99). Of the

projects that used social media and stated the platform, Facebook was the most popular platform, used by 65% of projects (63/96), but Twitter, Instagram and YouTube were also used. Almost 95% of projects (94/99) responded that participants needed "None" or "Limited" skills nor prior knowledge to participate.

3.1.5 Information on feedback and support

The number of projects that provided species identification materials, guidelines, training, sighting maps, active informing, feedback and support is shown in Table 2. Of the 67% of projects (64/95) that offered training, 47% (45/95) offered group training, 31% (30/95) offered online training, and 7% (7/95) provided training through Bioblitzes.

Table 2: Responses to survey questions concerning various feedback and support factors.

	Percentage of projects		
Factor	Yes	No	Partial (if applicable)
Provision of species identification materials	76% (74/98)	7% (7/98)	17% (17/98)
Provision of guidelines	87% (85/98)	13% (13/98)	-
Provision of training	67% (64/95)	33% (31/95)	-
Provision of sightings map	86% (78/91)	14% (13/91)	-

Provision of active informing	69% (64/93)	7% (7/93)	24% (22/93)
Provision of feedback	89% (71/80)	11% (9/80)	-
Provision of support	93% (85/91)	7% (6/91)	-

3.1.6 Data quality and data management

Based on this survey, the large majority (86%, 89/103) of the projects had validation systems in place, and 6% (6/103) had partially implemented validation systems. An additional 6% of projects indicated that the validation system was unknown to them and only 2% (2/103) responded they did not have validation in place. Within the subset of projects implementing validation procedures, expert validation was most commonly used, as at least 93% (93/100) of the projects indicated to use experts for validation, either solely using experts (77%, 77/100), aided by automated systems (3%, 3/100) or in combination with peer validation (9%, 9/100) or all three together (3%, 3/100). Peer validation and automated validation without expert validation were only used by a minority of projects (2%, 2/100).

For data storage, projects used national repositories (38%, 34/89), hard drives (34%, 30/89), GBIF (30%, 27/89) and institutional repositories (23%, 21/89). 58 projects offered participants direct access to their own data. Excel (65%, 44/68) was the most common data form and Darwin Core (50%, 18/36) the most popular data standard. The license Creative Common Attribution (CC BY; 57%, 16/29) was the most common, followed by CC0 licence waiver (10%, 3/29) and Creative Commons Non-Commercial licence (7%, 2/29). Finally, most projects did not draft a data management plan (DMP; 73%, 40/55).
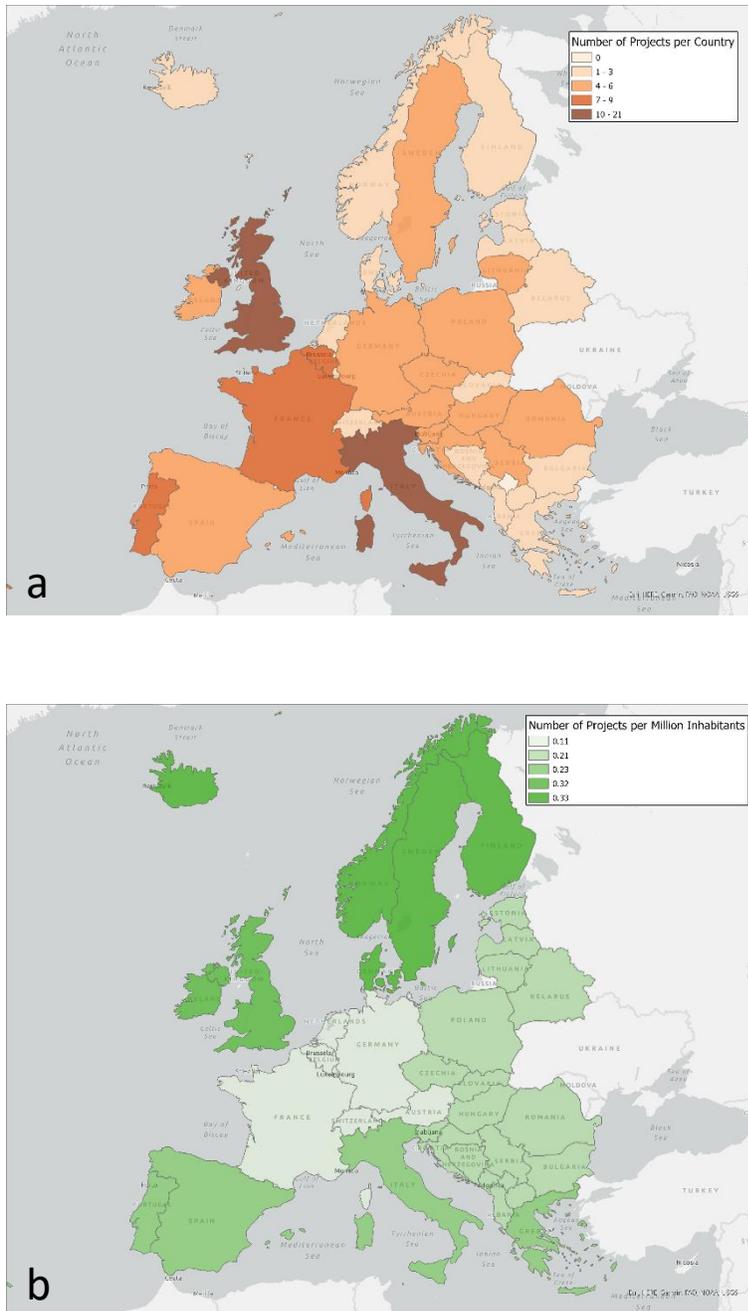
3.1.7. Project performance

The usage of applications developed or adopted by the project, number of participants, number of records and number of publications all show a distribution of responses that peaked in lower numbers and fell off quickly at higher numbers (Table 3). Only 33% of projects (21/63) assessed learning of the participants. A similar number of projects produced scientific peer-reviewed publications (94%, 33/37) and science communication publications aimed at the general public (85%, 30/37). Most of these publications directly presented data from the project (47%, 24/51) or were descriptive in nature (43%, 22/51).

Table 3: Responses to survey questions concerning project participation and publication.

	Number of respondents	Minimum response	Maximum response	Median response
Application usage	17	0% (5 projects)	100% (1 project)	11-25%
Number of participants	72	1 – 50 participants (16 projects)	> 10 001 participants (4 projects)	100-501 participants
Number of records	73	1 – 50 records (16 projects)	> 1 000 001 (1 project)	501 – 1000 records
Number of publications	62	0 publications (22 projects)	> 100 (1 project)	1 – 5 publications

3.2 Geographic differences in project scope

According to responses to our survey, the UK had more AS CS projects (21) than any other country, followed by Italy (13), Portugal (9) and France (9) (Figure 2a). However, when project counts per region are normalized by population, Northern Europe has the highest ratio, followed by the UK and Ireland, Southern Europe, Eastern Europe and Western Europe (Figure 2b). There was no association between geographic region and the target audience ($\chi^2 = 21.66$, df = 24, p = 0.60), taxon ($\chi^2 = 33.44$, df = 32, p = 0.40) or environment ($\chi^2 = 25.03$, df = 20, p = 0.20).

Figure 2: Geographic distribution of projects: **a** number of projects per country and **b** number of projects per region, per million inhabitants.

3.3 Engagement methods and performance

Project duration had a significant, positive impact on the three performance indicators tested, i.e., number of participants (z = 2.78, df = 1, p = 0.0054), publications (z = 3.38, df = 1, p

= 0.00073) and records (z = 3.01, df = 1, p = 0.0026). Projects that provided a map also outperformed projects that did not in number of participants (z = 2.13, df = 2, p = 0.033), publications (z = 2.77, df = 2, p = 0.0056) and records (z = 2.84, df = 2, p = 0.0045).

Provision of training positively impacted the number of publications (z = 2.85, df = 1, p = 0.044), as did use of social media (z = 2.35, df = 1, p = 0.019) and provision of guidelines (z = 2.01, df = 1, p = 0.045). Projects that required advanced prior knowledge performed better in number of publications than projects that required limited (z = -2.80, df = 2, p = 0.0052) or no (z = -2.74, df = 2, p = 0.0061) prior knowledge. The same result was seen in terms of number of records, with projects that required advanced prior knowledge performing better than projects which that required limited (z = -2.47, df = 2, p = 0.014) or no (z = -2.02, df = 2, p = 0.043) prior knowledge.

Provision of feedback positively impacted the number of publications (z = 2.01, df = 1, p = 0.044) but negatively impacted the number of records (z = -2.01, df = 1, p = 0.044). Provision of support negatively impacted the number of publications (z = -2.59, f = 1, p = 0.0096).

Large numbers of observations were discarded by R due to missing values, which will have detracted from the statistical power of the tests. 61 observations were omitted in the CLM that used participants as a response variable, 59 observations were omitted when publications were used as a response variable, and 64 observations were omitted when records were used as a response variable.

4. Discussion

4.1 Project Scope and Regional Variation

The dominance of national projects in our results is consistent with that observed for other research on management of biological invasions (Hulme et al. 2008). Several factors contribute to this tendency, including nationally-derived funding, differing degrees to which countries are exposed or aware of AS, species alien in one country being native to another, logistical convenience (Hulme et al. 2008) and uneven distribution of expertise (Hulme et al.

2009). However, international coordination is necessary to better protect native ecosystems from IAS (Perrings et al. 2010; Katsanevakis et al. 2013), as reflected by international agreements, from the Convention on Biological Diversity to EU Regulation 1143/2014.

Most projects target the general public, which is in line with informing (Genovesi et al. 2015) and engaging with and inspiring a passion for nature in as many participants as possible (Roy et al. 2015). Plants and insects are the most common target-taxa, possibly because both are broad and speciose groups that can be easily accessible, with many urban species. In addition, the prevalence of projects in the terrestrial environment reflects convenience for the public as reported for other CS projects (Aceves-Bueno et al. 2017), and is also highlighted by the association we found between target audience and target environment.

The most common aim is mapping of AS, and participants are often asked to submit species presence and/or abundance data; this type of data is useful for research and easy for citizen scientists to collect. Species presence in particular is easy to observe, report and validate (Hyder et al. 2015), and works well in conjunction with mapping (e.g. Malek et al. 2018; Kumar et al. 2019; Dissanayake et al. 2019).

The region with the most recorded projects is the UK and Ireland, reflecting a long history of CS in ecology (Silvertown 2009). After the UK, more projects in Western and Southern Europe may reflect a higher level of IAS awareness in these regions due to a relatively higher number of funded IAS projects (e.g., LIFE projects in Italy). On the other hand, a low number of projects, e.g., in the Netherlands, may be explained by a single dominant national biodiversity portal not being included in our survey. Additionally, there is a possible language bias, if projects from non-English speaking countries were not reached or not motivated to participate in the survey, which was only available in English.

4.2 Data Quality and Management

Studies evaluating data quality and management in CS projects sometimes have contradictory conclusions (Crall et al. 2011). Overall, volunteer contributions have been regarded favourably by scientists: e.g., 73% of papers positively described in analysis by Aceves-Bueno et al. (2017), but these authors concluded that differences between volunteer data and professional

data were significant in 38.4% of projects, necessitating agreement on what magnitude of difference is acceptable. Nevertheless, other studies showed that models trained with data from the public vastly increased the predicted spatial distribution of IAS (de Sá et al. 2019). Our analysis shows that the majority of CS projects focusing on the recording of AS in Europe have a verification step undertaken by experts, with some other projects using either peer validation, automated procedures, or a combination of the three. As some projects have indicated their data are used for removal or management of highly regulated species, correct species identification is of utmost importance. However, little information is available on the exact nature and quality of the data verification, including on the interaction between observers and validators. The most prominent approaches for validation of CS data are peer and expert validation, often aided by automatic filtering techniques (Balázs et al. 2021). Clearly, this is also the case for IAS CS in Europe (Adriaens et al. 2021).

Data generated by CS are often referred to as dark data: unreproducible, becoming more valuable over time, and at high risk of being lost (Costello and Wieczorek 2014). As such, implementation of a well-defined data management plan (DMP) can be used to prevent such loss of data. Nonetheless, few of the surveyed projects claimed to have a DMP. Many CS projects are relatively small scale and probably lack experience and/or access to tools for data management planning, which confirms earlier findings (Schade et al. 2017). Data management planning could improve the accessibility of data, an important component of FAIR (Findability, Accessibility, Interoperability, and Reusability) data management (Wilkinson et al. 2016; Reyserhove et al. 2020).

Specifically with regards to AS, openness of data is important to unlock their full potential for science, policy and management (Groom et al. 2015, 2017a,b). However, although some projects deposit their data on national or institutional repositories, less than one third open up their data by making them freely available on an open data repository, e.g., through GBIF publication. We also found that most AS CS projects produced peer-reviewed papers, but these were not necessarily Open Access; however, most produced scientific communications aimed at the public. Reasons for avoiding open data may be multiple, e.g., projects that choose not to share data might do so due to licensing issues, funding limitations, technical barriers or out of concerns for the vulnerability of rare species or the privacy of the participants (Ganzevoort et al.

2017). Ganzevoort et al. (2017) found that half of the citizen scientists they surveyed believed that data collected by the CS organisation was a public good, but only 12.3% supported unconditional use. The question of data ownership is complex and can be addressed in legal terms by choice of license. We found that 92.3% of projects that provided license information had a license allowing public use. Overall, these parameters around data accessibility are consistent with findings of Wiggins and Crowston (2011) and Schade and Tsinaraki (2016), indicating a willingness to provide access to data.

4.3 Optimisation of Engagement

We anticipated that higher levels of feedback, support and engagement would improve performance, e.g., the number of participants, records and publications, through the generation of commitment and empowerment. However, results were somewhat inconsistent: as expected, provision of maps, training and guidelines positively impacted one or more of the performance indicators. Unexpectedly, while provision of feedback positively impacted the number of publications, it negatively impacted the number of records, and provision of support also negatively impacted the number of publications. These negative impacts are in contradiction to previous studies. For example, Geoghegan et al. (2016) found that 77% of citizen scientists surveyed claimed that receiving feedback was "very important" to their continued participation. A reduced sample size (n=80 for feedback and n=91 for support) may skew our result. In addition, many projects were relatively new (17 started in 2017 and 21 in 2019, the year the survey was distributed) and as such this may also have influenced this result. Lastly, it might have been unclear to survey respondents what specific activities were comprised under feedback and support.

Only 39% of the projects were designed collaboratively, thus in most cases citizens were contributing in a predetermined way (usually data collection: Wiggins and Crowston 2011). Even so, *a priori* fewer projects were expected to be collaborative (e.g., Pocock et al. 2017 analysed more than 500 ecological and environmental CS projects and only 4% were collaborative) and so we suspect that this question may have been misunderstood. We define a collaboratively-designed project as a project with citizen scientist participation in the initial conception of the project and all subsequent steps. In contrast, the 39% of respondents who

claimed collaborative project design may have considered lesser roles, such as feedback from participants on project design, as collaboration.

Surveyed projects mostly required low levels of time commitment for learning and participation, possibly recognizing that most participants in CS projects are amateur observers (Bonney et al. 2009). From the authors' own experience, even though many projects target the general public, in reality many of the participants do have some level of expertise in the taxonomic group they report. Wandersee and Schüssler (1998) note that the general public generally do not notice plants ("plant blindness"), suggesting that contributors to plant-focussed CS projects already have some knowledge about the taxon. Nonetheless, few projects assumed that citizens possessed a deeper understanding, such as the ability to distinguish between similar species (Rowley et al. 2019). Like the requirement of prior expertise, a demanding contribution schedule may impede participation, explaining the prevalence of projects requiring one-off or irregular contribution. The pattern in these parameters appears consistent with the result that few projects we assessed offer learning assessment.

Another unexpected result was that projects with limited or no skill requirements yielded a significantly lower number of records and publications. Possibly, participants with advanced skill levels, having already invested the time in learning, had a stronger commitment to contributing. This should not be taken as an argument towards raising thresholds, without serious consideration of whether it is warranted. Encouraging anyone to participate is highly relevant to the goal of reconnecting people with nature (Devictor et al. 2010) and increasing the chances of prevention and early-detection of IAS. Following engagement, projects must encourage continued participation (Penner 2002). To this end, the provision of different kinds of feedback and support presented a mix of positive and negative impacts. First, provision of a map positively impacted participation, records and publications, and provision of training positively impacted the number of publications. These both provide support for social exchange theory, which dictates that a demonstration of investment in participants by the project's organisers will encourage participants to reciprocate (Meek et al. 2011). Additionally, publicly displayed maps allow recognition of citizen scientists' efforts (Williams and DeSteno 2008; Crowston and Prestopnik 2013). The number of publications using data from the project might be an underestimation and could be highly biased by the level of knowledge of the respondents. To

overcome this, future work could use the contingence of openly published datasets and link their identifiers to published scientific work. Data aggregators like GBIF consistently check for use of published and downloaded data in scientific publications and link those through data citation using digital object identifiers.

Finally, the majority of projects used an internet-based engagement method, such as a website or social media, reflecting the ubiquity of these technologies in Europe (Kemp 2021). Social media was also shown to have a positive impact on the number of publications. Organisations exploiting the internet and the most-used social media platform, Facebook (Kemp 2021), can clearly reach larger audiences than ones relying on print or radio. Alongside mobile applications, these strategies may help to recruit youth, as younger age groups are less well-represented in CS projects (Geoghegan et al. 2016). There is a recognized need to encourage children to go out and explore the natural world, not only to inspire a new generation of citizen scientists, but also so they can get to know and care for it (MacPhail and Colla 2020). However, if digital communication methods are not complemented by alternative strategies, participants who are not technologically able may become excluded (Encarnação et al. 2021).

4.4 Applications and Recommendations

Several lessons can be drawn from the results of our survey. First, a large number of CS projects apparently have not yet opened up their data. Open data publication maximizes the use of the data in policy processes, such as their use by EASIN in the implementation of the EU IAS Regulation (Schade et al. 2019) and provides better return to CS participants on their contribution and value of their data. A clear recommendation from our work is therefore to actively support the flow of data from European citizen science projects to EASIN through open data publication. To this end, mechanisms should be installed to promote data sharing and interoperability. The adoption of data standards, including agreed invasion frameworks and terminology (Groom et al. 2019), is a part of this process. Major research networks or institutions could play an important role in facilitating this process, and the application of FAIR data principles could be made a prerequisite for funding CS projects. At a more practical level, active outreach to those projects, exploring their barriers to data sharing and providing technical support to implement open data flows can improve the use of IAS data in European policy.

One partial solution to openness and data management issues might be the drafting of DMPs. Strikingly, many projects are missing a DMP, but this is clearly needed to facilitate better storage, maintenance and use of data. As part of the DMP, strategies can be designed to make data openly accessible, for example on the platform GBIF. Relatively few respondents provided information about their scientific outputs, and further inspection revealed that there is often no information on project web pages about whether they publish their datasets on GBIF. Furthermore, GBIF does often not reliably allow data to be tracked back to the project where it originated. Such practices may arise from privacy concerns, which may be circumvented by informing participants how and by whom their contributions are used prior to open data publication (Ganzevoort et al. 2017).

To further improve outreach and onboarding of new citizen scientists, and sustained participation, our results suggest that the provision of maps with sightings and the provision of training are important. Additionally, although our results were confusing concerning benefits from collaborative project design, other studies show that this type of design may be motivational (Geoghegan et al. 2016), and as such we recommend that, when possible, the public should be involved from the conception of the project and not only as data collectors. Future work could also be undertaken to compare the performance of different validation procedures and provide recommendations to new projects to improve data quality.

Our results show an increasing number of new AS CS projects in the last few years that contribute to IAS mapping and policy implementation. Clearly, some regions still hold untapped potential for new CS initiatives related to AS. In light of their common goal, we recommend that careful consideration should be made when considering new projects to avoid overlap and duplication of investments. Given that many CS projects are confronted with the issue of financial sustainability, we should instead promote better use and harmonization of projects and technologies already publicly available and customizable, such as iNaturalist, PlantNet or the "Invasive Alien Species Europe" app from EASIN. Building new initiatives onto an existing user base is also more efficient (Adriaens et al. 2015). Existing projects may also be improved and made accessible to new audiences through language translation or simplification, and through tailoring of aims and species lists to geographic regions (e.g., Invasive Alien Species in Europe application; Trichkova et al. 2021).

Finally, the similarity of goals across borders also signals that international cooperation is feasible, arguably becoming essential, given the global nature of biodiversity goals. The UN's SDGs provide an excellent model for how CS can be relevant to setting and achieving goals at a global level. Although SDGs were not initially developed with CS in mind, data gathered through CS can be used directly for feeding SDG indicators (Fritz et al. 2019), can increase the temporal and spatial scale of data collection (Schade et al. 2019) and can engage people with science and the environment (Pocock et al. 2014). Nonetheless, Fraisl et al. (2020) noted poor alignment of CS initiatives with target 15.8 on IAS.

4.5 Conclusions

The many CS projects contributing to IAS mapping and policy implementation described in our paper clearly demonstrate that CS for IAS is currently booming and that the information on the presence, abundance and spread of IAS gathered through CS is highly relevant for (inter)national legislation. The EU IAS Regulation can likewise benefit from international cooperation in IAS research and in fact a majority of IAS CS projects have a focus on IAS of Union Concern. Nonetheless, our results show that less than half of projects receive government funding. Considering the massive contribution and untapped potential of the "billion eyes on the ground" to the implementation of IAS policies, and also IAS research and management, strategies should be developed to support regions where AS CS is only emerging, to strengthen the links between CS projects and networks around the EU Regulation and to provide networking opportunities where CS projects can exchange experiences to further foster an active AS CS landscape across the continent.

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Competing Interests

The authors have declared that no competing interests exist.

References

Aceves-Bueno E, Adeleye AS, Feraud M, Huang Y, Tao M, Yang Y, Anderson SE (2017) The Accuracy of Citizen Science Data: A Quantitative Review. The Bulletin of the Ecological Society of America 98: 278-290. https://doi.org/10.1002/bes2.1336

Adriaens T, Sutton-Croft M, Owen K, Brosens D, Valkenburg J van, Kilbey D, Groom Q, Ehmig C, Thürkow F, Hende PV, Schneider K (2015) Trying to engage the crowd in recording invasive alien species in Europe: experiences from two smartphone applications in northwest Europe. Management of Biological Invasions 6: 215-225. https://doi.org/10.3391/mbi.2015.6.2.12

Adriaens T, Tricarico E, Reyserhove L, Cardoso AC, Lopez Canizares C, Mitton I, Schade S, Spinelli F, Tsiamis K (2021) Data-validation solutions for citizen science data on invasive alien species: Tailoring validation tools for the JRC app "Invasive Alien Species in Europe", EUR 30857 EN. Publications Office of the European, Luxembourg. ISBN 978-92-76-42055-2, doi:10.2760/694386, JRC126140.

Balázs, B, Mooney, P, Nováková, E, Bastin, L, Arsanjani, JJ (2021). Chapter 8: Data Quality in Citizen Science. In: K. Vohland et al. (eds.), The Science of Citizen Science: 139-158. https://doi.org/10.1007/978-3-030-58278-4.

Bellard C, Cassey P, Blackburn TM (2016) Alien species as a driver of recent extinctions. Biology Letters 12:20150623 . https://doi.org/10.1098/rsbl.2015.0623

Bilton DT, Mirol PM, Mascheretti S, Fredga K, Zima J, Searle JB (1998) Mediterranean Europe as an area of endemism for small mammals rather than a source for northwards postglacial

colonization. Proceedings of the Royal Society of London. Series B: Biological Sciences 265: 1219-1226. https://doi.org/10.1098/rspb.1998.0423

Bonney R (1996) Citizen science: a lab tradition. Living Bird 15: 7-15.

Bonney R, Phillips TB, Ballard HL, Enck JW (2016) Can citizen science enhance public understanding of science? Public Understanding of Science 25: 2-16. https://doi.org/10.1177/0963662515607406

Brown PMJ, Roy HE, Rothery P, Roy DB, Ware RL, Majerus MEN (2008) *Harmonia axyridis* in Great Britain: analysis of the spread and distribution of a non-native coccinellid. BioControl volume 53(1): 55–67. https://doi.org/10.1007/s10526-007-9124-y

Christensen R (2018) Cumulative link models for ordinal regression with the R package ordinal. Submitted in Journal of Statistical Software.

Council 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 L317: 37-38.

Costello MJ, Wieczorek J (2014) Best practice for biodiversity data management and publication. Biological Conservation 173: 68-73. https://doi.org/10.1016/j.biocon.2013.10.018

Cox JG, Lima SL (2006) Naiveté and an aquatic–terrestrial dichotomy in the effects of introduced predators. Trends in Ecology & Evolution 21: 674-680. https://doi.org/10.1016/j.tree.2006.07.011

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: 433-442. https://doi.org/10.1111/j.1755-263X.2011.00196.x

Crowston K, Prestopnik NR (2013) Motivation and Data Quality in a Citizen Science Game: A Design Science Evaluation. In: 2013 46th Hawaii International Conference on System Sciences. IEEE: 450-459. https://doi.org/10.1109/HICSS.2013.413

de Sá NC de, Marchante H, Marchante E, Cabral JA, Honrado JP, Vicente JR (2019) Can citizen science data guide the surveillance of invasive plants? A model-based test with Acacia trees in Portugal. Biological Invasions 21: 2127-2141. https://doi.org/10.1007/s10530-019-01962-6

Devictor V, Whittaker RJ, Beltrame C (2010) Beyond scarcity: citizen science programmes as useful tools for conservation biogeography. Diversity and Distributions 16: 354-362. https://doi.org/10.1111/j.1472-4642.2009.00615.x

Dissanayake RB, Stevenson M, Allavena R, Henning J (2019) The value of long-term citizen science data for monitoring koala populations. Scientific Reports 9: 1-12. https://doi.org/10.1038/s41598-019-46376-5

Encarnação J, Teodósio MA, Morais, P (2021) Citizen science and biological invasions: A review. Frontiers in Environmental Science 8: 303.

European Commission, Directorate-General for Environment (2018) Citizen science for environmental policy: development of an EU-wide inventory and analysis of selected practices, Publications Office. https://data.europa.eu/doi/10.2779/961304

Fraisl D, Campbell J, See L, Wehn U, Wardlaw J, Gold M, Moorthy I, Arias R, Piera J, Oliver JL, Masó J, Penker M, Fritz S (2020a) Mapping citizen science contributions to the UN sustainable development goals. Sustainability Science 15: 1735-1751. https://doi.org/10.1007/s11625-020-00833-7

Fritz S, See L, Carlson T, Haklay M, Oliver JL, Fraisl D, Mondardini R, Brocklehurst M, Shanley LA, Schade S, Wehn U, Abrate T, Anstee J, Arnold S, Billot M, Campbell J, Espey J, Gold M, Hager G, He S, Hepburn L, Hsu A, Long D, Masó J, McCallum I, Muniafu M, Moorthy I, Obersteiner M, Parker AJ, Weisspflug M, West S (2019) Citizen science and the United Nations Sustainable Development Goals. Nature Sustainability 2: 922-930. https://doi.org/10.1038/s41893-019-0390-3

Ganzevoort W, Born RJG van den, Halffman W, Turnhout S (2017) Sharing biodiversity data: citizen scientists' concerns and motivations. Biodiversity and Conservation 26: 2821-2837. https://doi.org/10.1007/s10531-017-1391-z

Genovesi P, Carboneras C, Vilà M, Walton P (2015) EU adopts innovative legislation on invasive species: a step towards a global response to biological invasions? Biological Invasions 17: 1307-1311. https://doi.org/10.1007/s10530-014-0817-8

Geoghegan H, Dyke A, Pateman R, West S, Everett G (2016) Understanding motivations for citizen science. Final report on behalf of UKEOF, University of Reading, Stockholm Environment Institute (University of York) and University of the West of England

Goodenough AE (2010) Are the ecological impacts of alien species misrepresented? A review of the "native good, alien bad" philosophy. Community Ecology 11: 13-21. https://doi.org/10.1556/ComEc.11.2010.1.3

Groom Q, Weatherdon L, Geijzendorffer IR (2017a) Is citizen science an open science in the case of biodiversity observations? Journal of Applied Ecology 54: 612-617. https://doi.org/10.1111/1365-2664.12767

Groom Q, Desmet P, Vanderhoeven S, Adriaens T (2015) The importance of open data for invasive alien species research, policy and management. Management of Biological Invasions 6: 119-125. https://doi.org/10.3391/mbi.2015.6.2.02

Groom Q, Strubbe D, Adriaens T, Davis AJS, Desmet P, Oldoni D, Reyserhove L, Roy HE, Vanderhoeven S (2019a) Empowering Citizens to Inform Decision-Making as a Way Forward to Support Invasive Alien Species Policy. Citizen Science: Theory and Practice 4: 1-11. https://doi.org/10.5334/cstp.238

Groom Q, Desmet P, Reyserhove L, Adriaens T, Oldoni D, Vanderhoeven S, Baskauf SJ, Chapman A, McGeoch M, Walls R, Wieczorek J, Wilson J, Zermoglio PF, Simpson A (2019b) Improving Darwin Core for research and management of alien species. Biodiversity Information Science and Standards 3: e38084. https://doi.org/10.3897/biss.3.38084

Groom Q, Adriaens T, Desmet P, Simpson A, Wever AD, Bazos I, Cardoso AC, Charles L, Christopoulou A, Gazda A, Helmisaari H, Hobern D, Josefsson M, Lucy F, Marisavljevic D, Oszako T, Pergl J, Petrovic-Obradovic O, Prévot C, Ravn HP, Richards G, Roques A, Roy HE, Rozenberg M-AA, Scalera R, Tricarico E, Trichkova T, Vercayie D, Zenetos A, Vanderhoeven S (2017b) Seven Recommendations to Make Your Invasive Alien Species Data More Useful. Frontiers in Applied Mathematics and Statistics 3: 13. https://doi.org/10.3389/fams.2017.00013

Haklay M, Fraisl D, Tzovaras BG, Hecker S, Gold M, Hager G, Ceccaroni L, Kieslinger B, Wehn U, Woods S, Nold C, Balázs B, Mazzonetto M, Ruefenacht S, Shanley LA, Wagenknecht K, Motion A, Sforzi A, Riemenschneider D, Dorler D, Heigl F, Schaefer T, Lindner A, Weißpflug M, Mačiulienė M, Vohland K (2021) Contours of citizen science: a vignette study. Royal Society Open Science 8: 202108. https://doi.org/10.1098/rsos.202108

Heigl F, Kieslinger B, Paul KT, Uhlik J, Dörler D (2019) Opinion: Toward an international definition of citizen science. Proceedings of the National Academy of Sciences 116: 8089-8092. https://doi.org/10.1073/pnas.1903393116

Hulme P, Roy D, Cunha T, Larsson T (2008) A pan-European inventory of alien species: rationale, implementation and implications for managing biological invasions. In: Handbook of Alien Species in Europe. Springer (Dordrecht, Netherlands): 1–14.

Hulme PE, Nentwig W, Pyšek P, Vilà M (2009) Common market, shared problems: time for a coordinated response to biological invasions in Europe? Neobiota 8: 3–19.

Hyder K, Townhill B, Anderson LG, Delany J, Pinnegar JK (2015) Can citizen science contribute to the evidence-base that underpins marine policy? Marine Policy 59: 112-120. https://doi.org/10.1016/j.marpol.2015.04.022

IPBES (2019). Global assessment report on biodiversity and ecosystem services, summary for policy-makers. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

Johnson BA, Mader AD, Dasgupta R, Kumar P (2020) Citizen science and invasive alien species: An analysis of citizen science initiatives using information and communications technology (ICT) to collect invasive alien species observations. Global Ecology and Conservation 21: e00812. https://doi.org/10.1016/j.gecco.2019.e00812

Katsanevakis S, Bogucarskis K, Gatto F, Vandekerkhove J, Deriu I, Cardoso AC (2012) Building the European Alien Species Information Network (EASIN): a novel approach for the exploration of distributed alien species data. BioInvasions Records 1: 235-245. https://doi.org/10.3391/bir.2012.1.4.01

Katsanevakis S, Genovesi P, Gaiji S, Hvid HN, Roy H, Nunes AL, Aguado FS, Bogucarskis K, Debusscher B, Deriu I, Harrower C, Josefsson M, Lucy F, Marchini A, Richards G, Trichkova T, Vanderhoeven S, Zenetos A, Cardoso AC (2013) Implementing the European policies for alien species – networking, science, and partnership in a complex environment. Management of Biological Invasions 4: 3-6. https://doi.org/10.3391/mbi.2013.4.1.02

Katsanevakis S, Deriu I, D'Amico F, Nunes AL, Sanchez SP, Crocetta F, Arianoutsou M, Bazos I, Christopoulou A, Curto G, Delipetrou P, Kokkoris Y, Panov VE, Rabitsch W, Roques A, Scalera R, Shirley SM, Tricarico E, Vannini A, Zenetos A, Zervou S, Zikos A, Cardoso AC (2015) European Alien Species Information Network (EASIN): supporting European policies and scientific research. Management of Biological Invasions 6: 147-157. https://doi.org/10.3391/mbi.2015.6.2.05

Kemp S (2021): Digital 2021: Global Digital Overview. https://datareportal.com/reports/digital-2021-global-digital-overview

Kumar A, Sinha A, Kanaujia A (2019) Using citizen science in assessing the distribution of Sarus Crane (Grus antigone antigone) in Uttar Pradesh, India. International Journal of Biodiversity and Conservation 11: 58-68. https://doi.org/10.5897/IJBC2018.1245

Kus Veenvliet, J., P. Veenvliet, M. de Groot & L. Kutnar (eds.). 2019. A Field Guide to Invasive Alien Species in European Forests. Nova vas: Institute Symbioisis, so. e.; Ljubljana: The Silva Slovenica Publishing Centre, Slovenian Forestry Institute.

MacPhail VJ, Colla SR (2020). Power of the people: A review of citizen science programs for conservation. Biological Conservation 249: 108739. https://doi.org/10.1016/j.biocon.2020.108739

Malek R, Tattoni C, Ciolli M, Corradini S, Andreis D, Ibrahim A, Mazzoni V, Eriksson A, Anfora G (2018) Coupling Traditional Monitoring and Citizen Science to Disentangle the Invasion of Halyomorpha halys. ISPRS International Journal of Geo-Information 7: 171. https://doi.org/10.3390/ijgi7050171

Meek WR, Davis–Sramek B, Baucus MS, Germain RN (2011) Commitment in Franchising: The Role of Collaborative Communication and a Franchisee's Propensity to Leave. Entrepreneurship Theory and Practice 35: 559-581. https://doi.org/10.1111/j.1540-6520.2011.00445.x

Penner LA (2002) Dispositional and Organizational Influences on Sustained Volunteerism: An Interactionist Perspective. Journal of Social Issues 58: 447–467.

Perrings C, Burgiel S, Lonsdale M, Mooney H, Williamson M (2010) International cooperation in the solution to trade-related invasive species risksa. Annals of the New York Academy of Sciences 1195: 198-212. https://doi.org/10.1111/j.1749-6632.2010.05453.x

PPSR Core: PPSR Core. https://core.citizenscience.org/

Pocock MJ, Chapman D, Sheppard L, Roy H (2014) Choosing and Using citizen science: a guide to when and how to use citizen science to monitor biodiversity and the environment. NERC/Centre for Ecology & Hydrology (Wallingford): 1–24.

Pocock MJO, Tweddle JC, Savage J, Robinson LD, Roy HE (2017) The diversity and evolution of ecological and environmental citizen science. PLOS ONE 12: e0172579. https://doi.org/10.1371/journal.pone.0172579

Price-Jones V, Brown PMJ, Adriaens T., Tricarico E, Farrow RA, Cardosa AC, Gervasini E, Groom Q, Reyserhove L, Schade S, Tsinaraki C, Marchante E (2021) Citizen Science projects on Alien Species in Europe [dataset]. https://doi.org/10.5281/zenodo.4719259

Reyserhove L, Desmet P, Oldoni D, Adriaens T, Strubbe D, Davis AJS, Vanderhoeven S, Verloove F, Groom Q (2020) A checklist recipe: making species data open and FAIR. Database 2020: 1-12. https://doi.org/10.1093/database/baaa084

Rowley JJL, Callaghan CT, Cutajar T, Portway C, Potter K, Mahony S, Trembath DF, Flemons P, Woods A (2019) FrogID: Citizen scientists provide validated biodiversity data on frogs of Australia. Herpetological Conservation and Biology 14: 155–170.

Roy D, Alderman D, Anastasiu P, Arianoutsou M, Augustin S, Bacher S, Başnou C, Beisel J, Bertolino S, Bonesi L, Bretagnolle F, Chapuis JL, Chauvel B, Chiron F, Clergeau P, Cooper J, Cunha T, Delipetrou P, Desprez-Loustau M, Détaint M, Devin S, Didžiulis V, Essl F, Galil BS, Genovesi P, Gherardi F, Gollasch S, Hejda M, Hulme PE, Josefsson M, Kark S, Kauhala K, Kenis M, Klotz S, Kobelt M, Kühn I, Lambdon PW, Larsson T, Lopez-Vaamonde C, Lorvelec O, Marchante H, Minchin D, Nentwig W, Occhipinti-Ambrogi A, Olenin S, Olenina I, Ovcharenko I, Panov VE, Pascal M, Pergl J, Perglová I, Pino J, Pyšek P, Rabitsch W, Rasplus J, Rathod B, Roques A, Roy H, Sauvard D, Scalera R, Shiganova TA, Shirley S, Shwartz A, Solarz W, Vilà M, Winter M, Yésou P, Zaiko A, Adriaens T, Desmet P and Reyserhove L (2020) DAISIE - Inventory of alien invasive species in Europe. Version 1.7. Research Institute for Nature and Forest (INBO). https://doi.org/10.15468/ybwd3x

Roy H, Groom Q, Adriaens T, Agnello G, Antic M, Archambeau A-S, Bacher S, Bonn A, Brown P, Brundu G, López B, Cleary M, Cogălniceanu D, Groot M de, Sousa TD, Deidun A, Essl F, Pečnikar ŽF, Gazda A, Gervasini E, Glavendekic M, Gigot G, Jelaska S, Jeschke J, Kaminski D, Karachle P, Komives T, Lapin K, Lucy F, Marchante E, Marisavljevic D, Marja R, Torrijos LM, Martinou A, Matosevic D, Mifsud C, Motiejūnaitė J, Ojaveer H, Pasalic N, Pekárik L, Per E, Pergl J, Pesic V, Pocock M, Reino L, Ries C, Rozylowicz L, Schade S, Sigurdsson S, Steinitz O, Stern N, Teofilovski A, Thorsson J, Tomov R, Tricarico E, Trichkova T, Tsiamis K, Valkenburg J van, Vella N, Verbrugge L, Vétek G, Villaverde C, Witzell J, Zenetos A, Cardoso AC (2018) Increasing understanding of alien species through citizen science (Alien-CSI). Research Ideas and Outcomes 4: e31412. https://doi.org/10.3897/rio.4.e31412

Roy HE, Rorke SL, Beckmann B, Booy O, Botham MS, Brown PMJ, Harrower C, Noble D, Sewell J, Walker K (2015) The contribution of volunteer recorders to our understanding of biological invasions. Biological Journal of the Linnean Society 115: 678-689. https://doi.org/10.1111/bij.12518

Schade S, Tsinaraki C, Roglia E (2017) Scientific data from and for the citizen. First Monday 22. https://doi.org/10.5210/fm.v22i8.7842

Schade S, Kotsev A, Cardoso AC, Tsiamis K, Gervasini E, Spinelli F, Mitton I, Sgnaolin R (2019) Aliens in Europe. An open approach to involve more people in invasive species detection. Computers, Environment and Urban Systems 78: 101384. https://doi.org/10.1016/j.compenvurbsys.2019.101384

Schade S, Tsinaraki C (2016) Survey report: data management in Citizen Science projects. Publication Office of the European Union: Luxembourg. Technical report: 1–56.

Seebens H, Bacher S, Blackburn TM, Capinha C, Dawson W, Dullinger S, Genovesi P, Hulme PE, Kleunen M, Kühn I, Jeschke JM, Lenzner B, Liebhold AM, Pattison Z, Pergl J, Pyšek P, Winter M, Essl F (2020) Projecting the continental accumulation of alien species through to 2050. Global Change Biology 27: 97-982. https://doi.org/10.1111/gcb.15333

Seebens H, Blackburn TM, Dyer EE, Genovesi P, Hulme PE, Jeschke JM, Pagad S, Pyšek P, Winter M, Arianoutsou M, Bacher S, Blasius B, Brundu G, Capinha C, Celesti-Grapow L, Dawson W, Dullinger S, Fuentes N, Jäger H, Kartesz J, Kenis M, Kreft H, Kühn I, Lenzner B, Liebhold A, Mosena A, Moser D, Nishino M, Pearman D, Pergl J, Rabitsch W, Rojas-Sandoval J, Roques A, Rorke S, Rossinelli S, Roy HE, Scalera R, Schindler S, Štajerová K, Tokarska-Guzik B, Kleunen M van, Walker K, Weigelt P, Yamanaka T, Essl F (2017) No saturation in the accumulation of alien species worldwide. Nature Communications 8: 1-9. https://doi.org/10.1038/ncomms14435

Silvertown J (2009) A new dawn for citizen science. Trends in Ecology & Evolution 24: 467-471. https://doi.org/10.1016/j.tree.2009.03.017

Trichkova T, Paunović M, Cogălniceanu D, Schade S, Todorov M, Tomov R, Stănescu F, Botev I, López-Cañizares C, Gervasini E, Hubenov Z, Ignatov K, Kenderov M, Marinković N, Mitton I, Preda C, Spinelli FA, Tsiamis K, Cardoso AC (2021) Pilot Application of 'Invasive Alien Species in Europe' Smartphone App in the Danube Region. Water 13: 2952. https://doi.org/10.3390/w13212952

United Nations (1992) Convention on Biological Diversity: 28.

United Nations, Department of Economic and Social Affairs, Population Division (2019): World Population Prospects 2019, Online Edition. Rev. 1. https://population.un.org/wpp/Download/Standard/Population/

Wandersee JE, Schüssler EE (1998). A Model of Plant Blindness. Poster-paper presented at the 3rd Annual Associates Meeting of the 15 Degree Laboratory, Louisiana State University, Baton Rouge, LA.

Wiggins A, Crowston K (2011) From Conservation to Crowdsourcing: A Typology of Citizen Science. In: 2011 44th Hawaii International Conference on System Sciences. IEEE: 1-10. https://doi.org/10.1109/HICSS.2011.207

Wilkinson MD, Dumontier M, Aalbersberg IjJ, Appleton G, Axton M, Baak A, Blomberg N, Boiten J-W, Santos LB da S, Bourne PE, Bouwman J, Brookes AJ, Clark T, Crosas M, Dillo I, Dumon O, Edmunds S, Evelo CT, Finkers R, Gonzalez-Beltran A, Gray AJG, Groth P, Goble C, Grethe JS, Heringa J, Hoen PAC 't, Hooft R, Kuhn T, Kok R, Kok J, Lusher SJ, Martone ME, Mons A, Packer AL, Persson B, Rocca-Serra P, Roos M, Schaik R van, Sansone S-A, Schultes E, Sengstag T, Slater T, Strawn G, Swertz MA, Thompson M, Lei J van der, Mulligen E van, Velterop J, Waagmeester A, Wittenburg P, Wolstencroft K, Zhao J, Mons B (2016) The FAIR Guiding Principles for scientific data management and stewardship. Scientific Data 3: 1-9. https://doi.org/10.1038/sdata.2016.18

Williams LA, DeSteno D (2008) Pride and perseverance: The motivational role of pride. Journal of Personality and Social Psychology 94: 1007. https://doi.org/10.1037/0022-3514.94.6.1007