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Management in Practice

Using Citizen Science to monitor the spread of tree pests and diseases: outcomes of two projects in Slovenia and the UK

Peter Crow[1,*], Ana Perez-Sierra[1], Andreja Kavčič[2], Kate Lewthwaite[3], Marija Kolšek[4], Nikica Ogris[2], Barbara Piškur[2], Jana Kus Veenvliet[5], Simon Zidar[2], Suzanne Sancisi-Frey[1] and Maarten de Groot[2]

[1]*Forest Research, Alice Holt Lodge, Farnham, Surrey GU10 4LH, UK*
[2]*Department of Forest Protection, Slovenian Forestry Institute, 1000 Ljubljana, Slovenia*
[3]*Woodland Trust, Kempton Way, Grantham, Lincolnshire, NG31 6LL, UK*
[4]*Slovenia Forest Service, 1000 Ljubljana, Slovenia*
[5]*Institute Symbiosis, so.e., 1385 Nova Vas, Slovenia*

Author e-mails: *peter.crow@forestresearch.gov.uk (PC), maarten.degroot@gozdis.si (MG)*

**Corresponding author*

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Abstract

The trees and forests of Europe are increasingly under threat from new pests and diseases that have originated in other parts of the world. Early detection of alien species when they first appear in European countries allows rapid response and offers the best chance to mitigate against their establishment and spread. Citizen science initiatives such as LIFE ARTEMIS in Slovenia, and Observatree in the UK, provide members of the public with the necessary training and educational resource to identify these tree pests and diseases and report them to the appropriate authorities, thereby increasing the level of surveillance and the capacity of the early warning system. This paper summarises some of the outcomes of these two projects and how they have both become integral parts of the official forest and tree health monitoring systems within their respective countries of Slovenia and the United Kingdom.

Key words: invasive alien species, plant health, tree health, forest health, early warning, rapid response

Introduction

In recent decades, the number of alien (non-native) forest pests and diseases that have entered Europe has dramatically increased (Crowl et al. 2008; Mumford et al. 2017). Many have been inadvertently introduced to new parts of the world due to global trade and the movement of goods. The movement of timber or wood products can allow pests and diseases within them, to be carried far beyond their natural range. Transported trees for landscape planting, ornamental plants or contaminated soils all have the potential to increase the spread of pests and diseases. And tourists buying wooden products to take home or hiking in different countries without cleaning their walking boots and clothing in between, can all accidently be a pathway for the introduction of alien species into a new country. In Europe invasive alien species are affecting strong impacts on biodiversity, health and economics. The costs of invasive alien species on the economic and ecosystem services depends on species and area impacted. One study in Britain estimated the total economic cost of chalara dieback of ash (*Hymenoscyphus fraxineus* Baral et al., 2014) to be £14.8 billion (Hill et al. 2019), whilst in Italy, Greece and Spain, the impacts of the bacterium *Xylella fastidiosa* (Wells et al., 1987) on olive oil production may be of a similar magnitude (Schneider et al. 2020).

To become invasive, alien organisms need to be able to survive, reproduce and establish within a new location and a food source, a conducive environment and a low level of predation or other biological resistance are the prerequisites for their success (Herms and McCullough 2014; Liu and Stiling 2006). Many of the pests and diseases entering Europe originate from warmer climates such as southeast Asia (Santini et al. 2013) and the milder winters experienced in many European countries in recent decades are increasing the chance of survival in areas that may once have been too cold. Where a new alien pest or disease can find a suitable host, that tree may have low levels of natural resistance because it has not evolved alongside the invasive species (Herms and McCullough 2014). The susceptibility of a European tree species to an Invasive Alien Species (IAS) may therefore be high and, when combined with favourable climatic conditions, can facilitate rapid establishment and dissemination, often causing significant environmental and economic damage (Herms and McCullough 2014).

To help prevent the establishment of alien species, early detection of their presence is essential. If identified early enough, it may be possible to introduce control measures to reduce the likelihood of spread, establishment or eradicate completely (Defra 2019). To facilitate early detection, citizen scientists can be mobilised as additional observers and reporters (Brown et al. 2017; Pocock and Evans 2014; Roy et al. 2012). Providing a greater number of individuals on the lookout for IAS creates a wider network of reporters and increases the likelihood of a more rapid response to new findings. This article introduces two similar citizen science projects from different European countries that are both designed to increase the capacity for IAS detection. The purpose of this study is to show the similarities and differences between these two projects and the successful ways in which they have become part of their national approaches to IAS management.

Why Citizen Science?

European forests cover large areas, often sparsely populated by people. Professional tree health inspectors surveying for forest pests or diseases typically have extensive areas to monitor (Ingwell and Preisser 2011). Remote sensing methods such as aerial photography can assist with such wide-scale surveillance (Chen and Meentemeyer 2016), but depending upon the methods applied and the frequency of use, detection of a new pest or disease may not occur until a sufficiently large area is affected and visible from a distance (Hernández-Clemente et al. 2019). By engaging with residents, land managers, or those working in the forest and getting their assistance with tree health monitoring, the likelihood of early detection can be increased.

Where IAS enter a country via commodities or tourism, they may first be detected close to ports, road or rail networks, ferry terminals or airports and imported plants may introduce them to plant/tree nurseries, historic gardens or other in public areas through amenity plantings. Trees in or surrounding urban or industrial areas may therefore be the first to show signs of IAS damage. Educating people who work or live in these areas about the threats of IAS to tree health and how to identify and report pests or diseases can contribute to early interception and an increased chance of eradication (Tomlinson et al. 2015). To help increase the number of individuals looking for IAS, projects such as LIFE ARTEMIS in Slovenia and Observatree in the UK recruit landowners, members of the public and other volunteers to report new sightings to the relevant authorities, thereby helping to support their work.

Citizen science is not a new concept, and in countries such as the UK, members of the public have, for many years, volunteered their time and submitted data on the distribution of plants and animals or the dates on which phenological changes are first observed (Roy et al. 2012). Trees, woods and forests are valued by many people and cultures and there is interest in their protection and health (Hall et al. 2019; International Tree Federation 2018; Woodland Trust 2017). It was therefore perhaps inevitable that citizen science projects associated with tree health in the UK increased in number, especially following the discovery of chalara dieback of ash (*H. fraxineus*) in 2012 (Defra 2013) that highlighted the threats to the UK's trees from IAS. Conversely, in some European countries, activities such as tree health monitoring would historically be regarded as an activity for the national authorities and the use of citizen scientists to collect data for scientific purposes is a new concept, the importance of which may need to be communicated to the public. The willingness of citizens to volunteer (used henceforth to refer to someone who donates their time to engage with a project) can initially be lower in countries where it has not been a common practice in the past. The application of citizen science to monitor tree health across Europe can therefore have varying challenges and country-specific communication and promotion may be necessary. In Slovenia, citizen science is a relatively new concept. Although several species distribution atlases (for birds, dragonflies, bats, butterflies and other animals) have been produced using citizen science data, it was mainly informed volunteers (e.g. members of interest groups) who contributed the data. Involving the general public to collect data on alien species was only done in the project Thuja 2 (Kus Veenvliet and Jogan 2014), where data were collected for several alien species in Slovenia, but without any data quality assessment. Another project activity within Thuja 2 set up a monitoring network of volunteer botanists. However, from a forest health and early warning perspective, LIFE ARTEMIS was the first project of its kind in Slovenia.

One of the biggest challenges in citizen science projects is maintaining the engagement of volunteers. For short-term projects, this may not be a problem. A mass-engagement campaign, for example, via mainstream media, can generate high levels of interest and larger numbers of participants in survey activities such as those within the OPAL project (Gupta and Slawson 2019). But within a short timeframe, the quantity of submitted information can fall rapidly (Crall et al. 2017). This may not be a problem where regular media activity can be used and a high turnover of volunteers is acceptable. Where projects desire a longer-term commitment from volunteers, it is best to identify those with a higher level of interest in the outcome of the project. For tree health surveys, this could include landowners, where the sites are open to the public and safety is a primary concern or where the loss of ecosystem services resulting from IAS would be sufficiently high that early detection and possible eradication would be beneficial (Larson et al. 2020). Professionals, such as arborists, work with trees daily; they may not be professional tree health inspectors, but they understand the implications of tree health and, if given the right information, are often willing to learn, add to their professional development and submit reports to the appropriate authorities. There will also be certain members of the public who have a higher level of affinity towards trees, woods and forests and they are more likely to proactively engage with a project for a longer period. These individuals can be given more extensive training and resources to help them identify a range of pests and diseases. But a greater level of investment in these volunteers will be required. In the UK, significant processes were put in place to select the right individuals as volunteers for the Observatree project (often people with previous volunteering experience and some tree identification skills) and levels of expectation around engagement from both the volunteers and the project were highlighted. In Slovenia, where volunteering as citizen scientists that monitor and report plant pests and diseases is a newer concept, a more general approach was taken to educate the wider population in the threats to the nation's forests and encourage anyone and everyone to engage with the project.

The Slovenian LIFE ARTEMIS project and the UK's Observatree project have used varying combinations of the engagement strategies, often targeting different audiences, but both with the aim of encouraging people to look for and report tree health-related invasive alien species. The LIFE ARTEMIS project examines a wider range of forest IAS (including pests, diseases, invasive plants and mammals) than Observatree, which focuses on tree pests and diseases. For comparative purposes, only the tree health aspect of LIFE ARTEMIS, including pests and diseases, is considered within this paper.

Materials and methods

LIFE ARTEMIS

The LIFE ARTEMIS project started in July 2016. The partners are the Slovenian Forestry Institute, the Slovenia Forest Service, Institute of Nature Conservation of Republic Slovenia and Institute Symbiosis. The main aim of LIFE ARTEMIS is to contribute to the reduction of the harmful impacts of IAS on forest biodiversity by increasing public awareness and by setting up an effective Early Warning and Rapid Response (EWRR) framework.

LIFE ARTEMIS is one of the first larger-scale projects dealing with an intensive citizen science programme in Slovenia and Central Europe where volunteers are educated to recognise the different alien species in Slovenian forests. The project methods included an awareness-raising campaign (using media such as television and radio) on IAS in forests that was targeted at the general public. And methods for reporting IAS via the EWRR system were developed, along with several identification guides for IAS and other supporting literature. Furthermore, an **Alert List** of IAS **believed not to occur, or that were newly arrived in Slovenia,** was produced. The alert list included 13 insect species and 13 fungi species capable of attacking trees. Among them are the Asian long-horn beetle (*Anoplophora glabripennis* Motschulsky, 1853) and the citrus long-horn beetle (*Anoplophora chinensis* Forster, 1771) which are known to kill many deciduous tree species. An **Observation List** was compiled that contained species that are **known to be widespread** in some Slovenian forests. This list contained 10 insect species and 8 fungi species. The observation list was created to collect information about the more common IAS and to promote engagement by providing something widespread for all volunteers to report and practice on. The alert list and the observation list are reviewed every two years by experts. The species to be monitored by the volunteers needed to be relatively easy to recognise, although a few species were also included that needed morphological or molecular identification in the laboratory and it was necessary for the volunteers to submit samples. A user-friendly mobile and web app called "Invazivke" was developed where data are submitted by the general public. The received data and associated photographs are checked by experts and forwarded to the competent institution for information and any follow-up action. Confirmed data are added to the project database, whilst any incorrect data is sent back to the volunteer, with feedback regarding their observed species and guidance for improved future reporting. At the beginning of the project, face-to-face workshops on IAS and the EWRR system were given for forest professionals, citizen scientists, and forest related businesses. The EWRR system developed under LIFE ARTEMIS was tested for a single species (Eutypella canker of maple) and for a specific area (the urban forest in Ljubljana: landscape park Tivoli, Rožnik and Šiški hill).

The LIFE ARTEMIS project encourages the reporting of more than 100 IAS in Slovenian forests (incorporating both the Alert and Observation lists). These include several forest pests and diseases. The forest pests covered by the project also include invasive mammal species, but only the 20 insect pests are considered within this paper. Diseases examined by the LIFE ARTEMIS project include 19 fungal and 1 bacterial infections. The tree pests and diseases therefore shown in Table 1 are only a small part of the IAS monitored by the LIFE ARTEMIS project.

During the first part of the project, emphasis was given to the education of the forest professionals and landowners. In later years, the focus shifted to the use of educational resources and user-friendly systems that are accessible to wider audiences without the need for face-to-face training or practical workshops. It was noted that those members of the public who chose to engage with the project already had an interest in nature and forests. The project does not actively manage a network of selected volunteers but focuses on wider dissemination via a combination of broadcast, printed, social and other digital media.

Observatree

Established in 2013 and led by Forest Research, this multi-partner project was originally a four-year project receiving 50% funding from the EU's LIFE Programme. Thanks to additional funding from within the partnership and Defra, Observatree is now in its seventh year and continuing for the foreseeable future. The project is designed to give people with an existing interest in trees or biological recording, the skills and resources to identify a priority list of tree pests and diseases and to report them to the correct authorities. It does this by:

- Providing a range of educational resources (identification guides, posters, videos, webinars) which are freely accessible on the Observatree website
- Intensively supporting a network of around 150 volunteers who receive extensive training in the identification of pests and diseases; these volunteers survey their local trees and report on their health
- Active volunteer management and engagement via an online forum, regular project communications, training and mentoring events

Unlike many mass engagement citizen science projects, Observatree invests heavily in the provision of detailed training to a small group of volunteers who are interviewed and selected for their existing knowledge of trees. This selection process is also intended to make the volunteer aware of their expected level of activity (a minimum of 12 reports a year and participating in local training events). This helps to ensure that the right people are engaged with the project and are prepared to take a proactive role for a longer duration (some volunteers have remained with the project since its launch). The Observatree project offers a variety of face-to-face training, literature and distance-based learning to provide the skills that the volunteers need to survey for tree pests and diseases, to report them, to collect samples for analysis when needed and how to follow appropriate biosecurity procedures to ensure that their activities do not promote the spread of IAS. The training materials are produced by scientists from organisations within the project partnership and contain the latest information on how to identify tree pests and diseases. The high quality of these materials has led to many of them being used by foresters, other professionals and stakeholders world-wide; and has helped to give the project a high reputation.

Tree health data collected by the Observatree volunteers are submitted via online systems. All submitted reports of suspected pests or diseases are examined by government tree health pathologists and entomologists for a diagnosis and confirmation. Data on regulated IAS are shared with the relevant authorities to allow follow-up management where necessary. Other data are used to monitor and map findings and changing distribution across the UK. Any wrongly diagnosed reports (typically few) are still used and feedback is provided to the volunteer with a correct identification and guidance on how to improve their techniques. The work and reporting quality of many of the Observatree volunteers has impressed tree health officials and this has led to increased collaboration between volunteers and professionals at a local level. Some individuals who have been with the project for several years have obtained high levels of competence. Similarly, the good reputation of the project helps to attract new volunteers with existing relevant expertise or experience. Observatree is now an accepted part of the UK's approach to tree health. In the event of a new detection of an IAS, the Observatree volunteers, although not replacing official inspectors, may be called upon to support them by surveying areas outside of those which need to be examined by officials. The high regard of the project helps to retain many volunteers who feel some degree of pride to be part of this elite network and has led to a waiting list of people wishing to join.

Asking volunteers to routinely look for a pest or disease that may not be present in their home country can be an unrewarding task. Whilst the Observatree team have provided training on many important pests or diseases that are not thought to be in the UK, other pests and diseases that have become established are included. These provide the volunteers with an opportunity to practice their skills and generates important data on the distribution and rates of spread of IAS across the UK.

It is impractical and unrealistic to attempt to train our volunteers to identify all the potential IAS threatening trees in the UK. Additionally, not all pests or diseases are appropriate for citizen science. For example, some may require specialist techniques or equipment to enable correct identification. Others may only produce subtle symptoms that are easily missed by inexperienced eyes or regarded as a very low risk to the overall vitality of the host tree species. The project has therefore selected 22 priority pests and diseases (12 of which are shared with the LIFE ARTEMIS project) that are of interest in the UK. This short-list is reviewed annually by tree health experts from across the project partnership and pests or diseases can be added or removed as necessary. However, there is no intention to significantly increase the total number to ensure the volunteers can maintain their focus on those pests or diseases believed to be of current priority within the UK.

The priority pest and disease list includes species that are not thought to be present but have caused serious problems in other countries, and where there is concern about the impacts they could potentially have in the UK. These include insects such as the emerald ash borer (*Agrilus planipennis* Fairmaire, 1888), which has killed many ash trees in North America and Canada (Anulewicz et al. 2007). In addition to the project's priority list of IAS, volunteers can report sightings of other (non-priority) pests or diseases or unusual signs or symptoms of concern. These reports of other or unknown pests or diseases are checked by diagnosticians working within the project.

Observatree volunteers have always been encouraged to provide reports on areas that they visit where no pests or diseases are found. This provides the project with important background data that allows the spread of IAS to be assessed. Many volunteers found that providing reports on a large area of mixed forest where no pests or diseases was a challenging task, especially when the focus of reporting systems was on capturing the symptoms of a single tree when a pest of disease was found. To help facilitate the negative reporting and help volunteer activity, the concept of Sentinel Trees was introduced. Under this initiative, the volunteers selected individual or small groups of trees of varying species to monitor. Several times a year, the volunteers would submit reports on the health of those trees and any change in condition. This was an additional activity and did not replace the general tree health survey activity where volunteers were also monitoring trees in the wider environment.

Results

Outcomes of the projects

Comparative data from the two projects is shown in Table 1. Whilst both have applied different approaches to target and educate different audiences, there is a common message on the potential threat of IAS to tree

Table 1. Comparative tree health related data from the LIFE ARTEMIS and Observatree projects

Metric	LIFE ARTEMIS	Observatree
Engagement focus	Professionals, land managers, owners, special interest groups, wider public	Professionals, land managers, owners, special interest groups
Duration of project so far (in months to end of 2019)	42	75
Total number of volunteers trained by the project (to end of 2019)	Unknown total media audience	452
Total number of tree health reports submitted by volunteers (to end of 2019)	1183	9456
Total number of volunteers submitting reports during 2019	49	122
Total number of reports submitted during 2019	409	4381
Average (mean) number of reports per person during 2019	8.3	35.9
Average (median) number of reports per person during 2019	3	11.5
Maximum number of reports per person during 2019	73	334
Number of volunteers submitting 20 or more reports during 2019	5	48
Species examined by project	74 pests and diseases (155 incl. plants)	22
Tree Pests (insects) included within the project	42	13
Tree Pests known to be present with project country (geographically)	21	5
Project Tree Pests reported by volunteers	18	5*
Number of Tree Pests reports received	753	278
Tree Diseases included within the project	32	9
Tree Diseases known to be present with project country (geographically)	19	8
Project Tree Diseases reported by volunteers	16	8 *
Number of Tree Diseases reports received	426	1137
Have reports led to action by officials?	Yes	Yes
Is project part of the national approach to IAS (tree health)?	Yes	Yes

*Value relates to the species examined by the project. Other (non-project focused) pests or diseases were also reported by volunteers.

health and the importance of citizen science in early warning and rapid response to new findings. LIFE ARTEMIS has monitored a greater number of IAS than Observatree, engaging a wider audience and generating a higher total number of submitted reports. It is important to emphasise that Table 1 only shows insect pests and diseases for the LIFE ARTEMIS project to facilitate some comparative analysis between the two projects. The table therefore only shows a partial representation of the total figures captured by the LIFE ARTEMIS project.

Both projects focussed on the quality of submitted reports, rather than quantity and have incorporated the monitoring of pests and diseases known to be present in each country to support volunteer engagement and provide additional data. Some of the longer-serving volunteers with both projects have developed more confidence in what they are observing and reporting and submit very high quality and accurate information. In LIFE ARTEMIS, all data received from volunteers were examined by project staff and 95% were considered to be correctly identified. Similar levels of correct reporting have been found by others, especially when volunteers with an interest in the subject are trained and given realistic tasks that do not require specialist equipment (Gallo and Waitt 2011; Meentemeyer et al. 2015; Roman et al. 2017). For both the LIFE ARTEMIS and Observatree projects, when volunteers found possible quarantine species, experts are sent to check the observation.

LIFE ARTEMIS had many volunteers (93) in the period from 2017–2019 who reported data on tree pests or diseases, but the distribution of records among the volunteers was not equal. Some volunteers were collecting many records while most of the volunteers were only submitting less than five records. A similar pattern was found within the Observatree project, with some individuals submitting more than 100 reports during 2019, but with the majority submitting fewer than 20.

Observatree priority pests and diseases include 13 species that are known to be in the UK. Confirmed cases of 12 of these have been reported by Observatree volunteers during the time of the project. Whilst Observatree volunteers receive training on the selected priority pests or diseases, they are also encouraged to report other unusual findings of concern or suspected cases of non-priority pests or diseases, allowing for the potential finding of an unknown or unexpected disorder. The number of different reported types of tree pest, disease or unknown symptom of concern has increased each year within the Observatree project. This could be interpreted as increasing confidence shown by volunteers in their abilities; especially as they are attempting to identify a suspected pest or disease that is not a priority for the project and therefore not a species that they have been trained on or asked to report.

The volunteers in the project LIFE ARTEMIS greatly improved the knowledge on the distribution of different invasive forest pests and diseases. Two insect species and one fungi species from the Alert List were found in the period of the 2017–2019. The insect species included the brown marmorated stink bug (*Halyomorpha halys* Stål, 1855) and the oak lace bug (*Corythucha arcuate* Say, 1832). The former was found in the west of the country, while the oak lace bug was first observed close to Brežice in 2016 (Jurc and Jurc 2017). During the project, more records submitted through the "Invazivke" system showed that the oak lace bug was more common in the east around Maribor and Celje, but slowly spread to the west, including a record received close to the Italian border in 2019. A focus of the LIFE ARTEMIS was also to mitigate the population of the eutypella canker of maple (*Eutypella parasitica* Davidson & Lorenz, 1938). A significant media campaign was implemented via the volunteer network, popular articles and social media regarding the recognition of eutypella canker. In total 81 trees with eutypella canker were found (to the end of 2019). The infected trees will be removed in the coming year to help mitigate the spread of eutypella canker.

The focus of Observatree on a small number of dedicated volunteers reduces the potential number of individuals looking for IAS. But like the LIFE ARTEMIS project, Observatree also has a significant outreach aspect and promotes an awareness-raising media campaign every year and attends selected stakeholder events and exhibitions that are targeted at foresters and arboriculturalists. Over the duration of the project, attendees at such events have increasingly stated their awareness of the project and that they already download and use many of the resources from the website (activity that is supported by website statistics). Observatree is now in its seventh year and whilst knowledge of the project within these key stakeholder groups is good, there continues to be a need to reach a new audience, and this remains an important part of the project. For the project LIFE ARTEMIS, a baseline survey of 900 people in 2016 and a repeat survey of approximately 500 people two years later showed that the awareness of the project had risen to 18%. An increase in the recognition of lesser known IAS was also observed after this two-year period (Japelj et al. 2017). During the workshops for volunteers and forestry experts, special emphasis was given to the EWRR system and the recognition of the Alert List species. A dedicated field guide for alien species in Slovenian forests was prepared (Kutnar et al. 2019) for the project and subsequently adjusted to European level distributions and translated into English (Flajšman et al. 2019) with the help of the COST action "Alien CSI" (COST action CA17122).

The Observatree volunteers have reported many important findings. Examples include the identification of oriental chestnut gall wasp (*Dryocosmus kuriphilus* Yasumatsu, 1951) that was found in a new area, away from the only previously known UK occurrence. This led to follow-up survey work by official inspectors in the wider environment and changed the understanding of the disribution of the pest. Reports by volunteers on oak processionary moth (*Thaumetopoea processionea* Linnaeus, 1758) and sweet chestnut blight (*Cryphonectria parasitica* Barr, 1978) have also led to action by officials. Other volunteers have focused on submitting data on widespread diseases such as chalara dieback of ash (*Hymenoscyphus fraxineus*), but focusing on parts of the UK where it had not previously been reported, thereby filling in gaps on the map and contributing to the understanding of the distribution of the pathogen. The introduction of the Sentinel Tree concept and the changes in volunteer recruitment and management have led to a sharp rise in reporting in recent years (Figure 1).

The Observatree volunteers have access to an online discussion forum, where they can post questions or organise local meetings. Scientists working on the project can answer questions relating to any interesting or unusual observed symptoms, and this may include guidance on how to sample or report them. But increasingly, the more experienced volunteers are answering the questions of less-experienced individuals, thereby providing supplementary support to the project scientists.

Discussion

Volunteer management and engagement

Towards the end of the LIFE-funded part of Observatree, the numbers of volunteers within the network that were actively submitting data had dropped

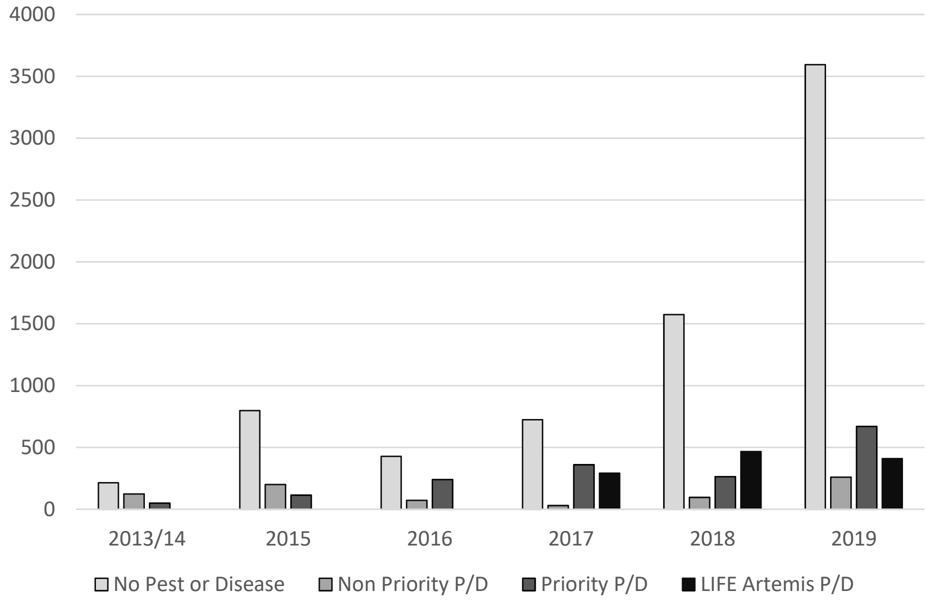

Figure 1. Tree health reports submitted by volunteers to the Observatree (grey columns) and LIFE Artemis (black column) projects.

dramatically. At the lowest point only 15% of the volunteers listed on the project were submitting data. There were several possible reasons for this, including the anticipated end of the project, or volunteers being no-longer able or willing to participate. With training offered to the volunteers and the building of the online resource library, there are significant costs associated with running the Observatree network. The revised management systems put in place at the start of post-LIFE phase have provided the tools to manage inactive volunteers from the project, freeing up space for further recruitment. Because the new volunteers are made aware of the levels of expectation when they join the project, the proportion of them actively engaged with the project in recent years has risen. It is inevitable that some will leave the project, but the current system of removing those who become inactive is proving to be effective. LIFE ARTEMIS shows a similar trend as Observatree in the last years of the LIFE funded part and a new funding mechanism needs to be found for the project to continue.

The introduction of the sentinel trees greatly increased the reporting activity of the Observatree volunteers, many of whom found the task to be more directed and easier to participate in. This is seen in Figure 1, where many of the increased reports are derived from sentinel trees, of which there are over 400 monitored across the UK.

Some Observatree volunteers now give talks to other local volunteer groups about their role and provide mentoring support to some of the new recruits on the project. These individuals have become unofficial ambassadors of the project and are keen to pass on their tree health knowledge and share the importance of their role. The increased level of confidence is seen in what the volunteers are reporting, especially in combination with their discussions on the forum, and it is a testament to their hard work and determination. It is possible that the next unexpected or unknown tree pest or disease to be identified in the UK will be found via these volunteer-led activities.

Inevitably, there is variability in the levels of engagement with these projects by the respective volunteers, but both projects show that some individuals are willing to submit high numbers of reports, are very active and effective. These volunteers are usually passionate about their tasks, believe their contribution to tree health is important are self-motivated and do not require high levels of engagement from the project staff. For others, finding new activities which they find engaging can be challenging, but as shown by the sentinel tree concept in Observatree, they can be very effective. Some volunteers will stop submitting data, and the ability to find new pools of volunteers for future recruitment is important and on-going recruitment will be required.

Providing and receiving feedback

Throughout the duration of both projects, surveys of the volunteers, their views on the project, motivation and suggestions for improvement have been sought. Additionally, attendees at training events provide feedback on the day. Such information, combined with correspondences with individual volunteers over the years, has allowed the Observatree team to improve their understanding of volunteer requirements and aspirations. Citizen scientists are giving their time to support projects such as LIFE ARTEMIS and Observatree. Whilst they are not expecting any reward for their efforts, recognition of their contribution is well received. The ability to see submitted reports on maps can help to provide motivation and show where others within the wider network have or have not been active. Capturing quotes from plant health or forestry officials that praise the work of the volunteers should always be shared with the latter, along with regular project updates and news. Where possible, encouraging the volunteers to submit their own news, or views on future developments facilitates a sense of ownership and can help to obtain longer continued engagement with the project.

Other supporting research activities

Many of the Observatree volunteers show a preference for more directed activities. This is shown by the high uptake of the sentinel tree concept, but similarly project volunteers have been keen to support IAS research and have deployed simple insect traps in their local area and returned them after a defined sampling period. These activities are popular, often have a more clearly defined duration and results can be shared with the whole network.

Data Quantity and Quality

Citizen scientists, by definition, are not paid professionals and volunteer to undertake surveys and submit data in their own time. Their levels of background knowledge in IAS, forestry and tree health will vary widely. Different citizen science projects will require differing levels of data quality and volunteer training depending upon the tasks to be completed (Brown et al. 2017; Gallo and Waitt 2011; Roy et al. 2012). To obtain the best use of any data they provide, it is important to select tasks that are achievable by non-specialists and provide the necessary tools and level of training to enable completion. Providing this training will not always guarantee a minimum level of quality, but when combined with practical experience and time can deliver significant results (Roman et al. 2017). Of the pests and diseases known to be present in each country and studied by these projects, volunteers from both have submitted reports on, and successfully identified, many of them. In LIFE ARTEMIS, 95% of the records of the species were correctly identified. One prerequisite of the selected species in “Invazivke” (especially for the species on the Observation List) was that they should be identifiable from photos that were submitted to the information system. This helped to obtain a high success rate. Such high levels of success have been previously reported by others (Gallo and Waitt 2011; Roman et al. 2017) and show what can be done by informed and engaged volunteers. Only a few species, such as ambrosia beetles (*Xylosandrus* spp.), were not easily recognised from submitted reports and these were checked in the field or samples were sent to the experts. However, this did not happen very often during the project period, as most reported species were of easily distinguished species.

The importance of Time

Any new initiative takes time to become established and embedded as standard practice. The same is true for citizen science-based EWRR systems. Both projects have shown that volunteer engagement and report submission can increase as the projects continue, but on-going communication and project promotion is required to sustain or increase these levels. Social media was used as a platform for promoting both projects, and by monitoring links to project websites from social media sites, it was possible to see how much traffic originated from them. Increased website activity was often seen following a social media publicity campaign. Both projects found that social media has an important and effective role to play in promoting tree health and IAS.

The increased number of symptoms reported by Observatree volunteers beyond the IAS in which they were formally trained shows their increasing confidence and abilities that the on-going time with the project and continued interaction with experts has allowed to develop. The investment in training such volunteers and creating these networks of citizen scientists allows them to be called upon to assist in official surveys in the event of an outbreak or interception of a new IAS into an area. Interestingly, LIFE ARTEMIS produced a media campaign every year, focusing on one species.

Although this resulted in a higher number of related records being submitted in the same year, also many data on those species were reported in the subsequent year. It takes time to communicate tree health concerns to the general public and even longer for those messages to become embedded.

Conclusions

Biosecurity threats by IAS are current and ongoing concern across Europe. Citizen scientists have an important role to play in contributing to the early detection of forest pests and diseases and facilitate rapid response to prevent potential damage. The increased ability to access information via computers and smart mobile devices allow citizen scientists to compare field-based observations with identification resources and allow interactive reporting and the provision of feedback via tools such as online mapping of submitted data. Many mobile devices allow for geolocated photographs to be taken and uploaded during a survey, helping rapid reporting, thereby supporting an EWRR system. Technological developments are, and will continue to support the role of volunteers in environmental and biological monitoring and the reporting of IAS.

There may be different challenges associated with recruiting volunteers in different countries across Europe, but where that can be addressed, projects such as these show that citizen science can make a difference. In many cultures, trees, woods and forests are highly valued (Hall et al. 2019; International Tree Federation 2018; Woodland Trust 2017), and with the ongoing predictions of further carbon dioxide emissions and climate change scenarios, protecting Europe's green landscapes has never been more important. These projects have shown that citizen scientists can make a positive contribution to EWRR systems and are capable of correctly identifying a wide variety of tree pests and diseases. Both projects have become part of the national responses to providing EWRR systems and monitoring IAS within Slovenia and the UK, emphasising the importance of the contributions these projects can make to national biosecurity and the success of the tree health citizen science model. Successful projects such as these should be used to raise awareness of the threats from IAS, stress the importance of the involvement of volunteers and show that they can make a difference. These are proven models that can, and are being replicated elsewhere.

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