

This is a repository copy of *Ethical dilemmas when using citizen science for early detection of invasive tree pests and diseases*.

White Rose Research Online URL for this paper:

<https://eprints.whiterose.ac.uk/168136/>

Version: Published Version

Article:

Pocock, Michael J.O., Marzano, Mariella, Bullas-Appleton, Erin et al. (4 more authors) (2020) Ethical dilemmas when using citizen science for early detection of invasive tree pests and diseases. *Management of Biological Invasions*. pp. 720-732. ISSN 1989-8649

<https://doi.org/10.3391/mbi.2020.11.4.07>

Reuse

This article is distributed under the terms of the Creative Commons Attribution (CC BY) licence. This licence allows you to distribute, remix, tweak, and build upon the work, even commercially, as long as you credit the authors for the original work. More information and the full terms of the licence here:

<https://creativecommons.org/licenses/>

Takedown

If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing eprints@whiterose.ac.uk including the URL of the record and the reason for the withdrawal request.

Viewpoint**Ethical dilemmas when using citizen science for early detection of invasive tree pests and diseases**Michael J.O. Pocock^{1*}, Mariella Marzano², Erin Bullas-Appleton³, Alison Dyke⁴, Maarten de Groot⁵, Craig M. Shuttleworth⁶ and Rehema White⁷¹UK Centre for Ecology & Hydrology, Wallingford, Oxfordshire OX10 8BB, United Kingdom²Forest Research, Northern Research Station, Roslin, Scotland EH25 9SY, United Kingdom³Canadian Food Inspection Agency, 174 Stone Road West, Guelph, Ontario, Canada N1G 4S9⁴Stockholm Environment Institute, Department of Environment and Geography, University of York, YO10 5NG, United Kingdom⁵Slovenian Forestry Institute, Večna pot 2, 1000 Ljubljana, Slovenia⁶School of Natural Sciences, Bangor University, Bangor, Gwynedd LL57 2UW, United Kingdom⁷School of Geography and Sustainable Development, University of St Andrews, St Andrews, Scotland KY16 9AL, United KingdomAuthor e-mails: Michael.pocock@ceh.ac.uk (MP), Mariella.marzano@forestresearch.gov.uk (MM), erin.bullas-appleton@canada.ca (EBA), alison.dyke@york.ac.uk (AD), maarten.degroot@gozdis.si (MDG), craig.shuttleworth@rsst.org.uk (CMS), rmw11@st-andrews.ac.uk (RW)

*Corresponding author

Co-Editors' Note: This study was contributed in relation to the international conference "Detection and control of forest invasive alien species in a dynamic world" held in Ljubljana, Slovenia, September 25th–29th, 2019 organized by the project LIFE ARTEMIS (LIFE15 GIE/SI/000770) (<https://www.tuje-rodne-vrste.info/en/project-life-artemis/project-activities/international-conference-2019/>). This conference has provided a venue for the exchange of information on various aspects of early detection and rapid response of forest invasive alien species. The conference provided an opportunity for dialog between academia, policymakers, and forestry practitioners.**Citation:** Pocock MJO, Marzano M, Bullas-Appleton E, Dyke A, de Groot M, Shuttleworth CM, White R (2020) Ethical dilemmas when using citizen science for early detection of invasive tree pests and diseases. *Management of Biological Invasions* 11(4): 720–732, <https://doi.org/10.3391/mbi.2020.11.4.07>**Received:** 19 December 2019**Accepted:** 9 June 2020**Published:** 21 October 2020**Handling editor:** Jana Kus Veenvliet**Thematic editor:** Maarten de Groot**Copyright:** © Pocock et al.

This is an open access article distributed under terms of the Creative Commons Attribution License (Attribution 4.0 International - CC BY 4.0).

OPEN ACCESS**Abstract**

The early detection of tree health pests and disease is an important component of biosecurity to protect the aesthetic, recreational and economic importance of trees, woodlands and forestry. Citizen science is valuable in supporting the early detection of tree pests and diseases. Different stakeholders (government, business, society and individual) will vary in their opinion of the balance between costs and benefits of early detection and consequent management, partly because many costs are local whereas benefits are felt at larger scales. This can create clashes in motivations of those involved in citizen science, thus leading to ethical dilemmas about what is good and responsible conduct for the use of citizen science. We draw on our experience of tree health citizen science to exemplify five dilemmas. These dilemmas arise because: the consequences of detection may locally be severe (e.g. the destruction of trees); knowledge of these impacts could lead to refusal to make citizen science reports; citizen science reports can be made freely, but can be costly to respond to; participants may expect solutions even if these are not possible; and early detection is (by definition) a rare event. Effective engagement and dialogue across stakeholders, including public stakeholders, is important to properly address these issues. This is vital to ensure the public's long-term support for and trust in the use of citizen science for the early detection of tree pests and diseases.

Key words: alien species; volunteer; eradication; participatory research**Introduction**

Recently there has been increased focus of tree health in policy because of significant and high profile tree pests and pathogens and the impact of future threats on the aesthetic, recreational, ecosystem service and economic importance of trees and woodlands (Boyd et al. 2013). The early detection of tree health pests and disease is an important component of biosecurity (Aukema et al. 2011). The widespread appeal of trees, the need to engage

the public about tree health and the search for more “cost effective” solutions to natural resource management (White et al. 2019) has led to citizen science being given importance in tree health and invasive species policy, as exemplified in the UK (House of Commons Environmental Audit Committee 2019; Tree Health and Plant Biosecurity Expert Taskforce 2012).

Citizen science is the intentional involvement of the public in scientific research and monitoring, and has great potential for invasive species, including tree pests and diseases (Groom et al. 2019). Broadly, citizen science ranges from *mass participation* in which records can be made by any individual typically using smartphone apps and websites (Adriaens et al. 2015), through to *structured monitoring* in which volunteers will follow protocols (Pocock et al. 2017b). Mass participation can be especially effective for the detection of rare events, at large spatial extents and over long time periods (Pocock et al. 2014), although recording effort will be uneven across space, thus requiring careful analysis to take account of this bias (Bird et al. 2014). Citizen science can also include participation of people in the creation of research questions, design of monitoring programmes and planning action on the basis of results (Haklay 2013). It can complement traditional awareness-raising campaigns by enhancing public awareness and engagement leading to more pro-environmental attitudes and behaviours (Japelj et al. 2019; Klapwijk et al. 2016).

Ethics are the principles defining good conduct and the ways of acting responsibly. Ethics are important in science, and are especially pertinent in participatory forms of science (including citizen science) due to the need to consider issues such as data ownership, power relations and responsibility (Lawrence 2006; Rasmussen and Cooper 2019; Resnik et al. 2015). Ethical dilemmas can occur when what is perceived as “good conduct” differs between stakeholders, due to differences in their motivations, opinion about management impacts, or the value that they place on nature (Heink et al. 2018).

Here we identified ethical dilemmas that are pertinent to citizen science for the early detection of invasive tree pests and diseases. Firstly, we discuss the motivations for citizen science and when motivations between stakeholders might clash. Secondly, we draw on existing knowledge from a range of projects to illustrate how clashing motivations lead to ethical dilemmas. We used evidence from semi-structured interviews conducted for the New Technologies for the Early Detection of tree pests and pathogens (NTED) project in the UK (Marzano et al. 2018; White et al. 2018, 2019). Interviews were conducted with a broad range of actors, including six participants in a citizen science project using pheromone traps to detect longhorn beetles. Interviews (30–90 min) were professionally transcribed and coded using both inductive and deductive coding (Bryman 2012) against themes (including personal experience, motivation, implications of results, perceived efficacy of citizen science) and actor roles (including

forest manager, government agency, expert volunteers). In addition we draw on experience from the LIFE ARTEMIS project in Slovenia and the Box Tree Moth Citizen Science Campaign in Canada plus other published work. Finally, we discuss the role of dialogue in mitigating ethical dilemmas in tree health citizen science.

Clashing motivations leads to ethical dilemmas

Understanding the motivations of those involved in citizen science, both as participants and as organisers is important. The motivations of organisers tend to be primarily functional, e.g. collection of biodiversity data to contribute evidence to policy, inform land management, and raise awareness (Geoghegan et al. 2016). Recent interviews with science, management and policy practitioners showed that citizen science was valuable for tree health monitoring and policy (Gupta and Slawson 2019). One science interviewee said: “The UK maybe has two hundred plant tree health inspectors... can you increase that number to two thousand by bringing in... a volunteer army of trained, but amateurs, to help you with that surveillance?”. This leads to recommendations, such as made recently by the UK parliament, to develop “a ‘biosecurity citizens’ army’ of 1.3 million volunteers to identify and respond to outbreaks of invasive species” (House of Commons Environmental Audit Committee 2019).

The motivations of volunteers in citizen science may differ substantially from those of organisers. Volunteer motivations are often framed as intrinsic (offering internal rewards stemming directly from involvement), or extrinsic (offering external rewards) (Finkelstien 2009; see also Rotman et al. 2012). In a survey of environmental citizen science volunteers, West et al. (2016) found that intrinsic motivations were most common among volunteers, e.g. wanting to benefit science or protect trees, enjoying the process of participating, or appreciating learning. The most frequently mentioned extrinsic motivation was that “someone else wanted me to take part”. One of the NTED interviewees was typical: “now in retirement I’ve got time to sort of get involved, and contribute a bit more, both sort of contribute to knowledge and also because I love being out in the countryside”; while another emphasised the importance of friendship and learning: “I suddenly found this community of people... a couple of them have really nurtured me... you start picking things up and learning for yourself”.

In many types of environmental citizen science the motivations of organisers and participants align, e.g. wildlife monitoring is often conducted by volunteers who are interested in nature, and the data are used by organisations to support nature conservation. This is not necessarily the case for tree health biosecurity citizen science because the activity has the outcome to detect or study problematic species, for social and ecological benefit. This means that participants align with a set of values that privilege some species over others and show altruism for these, as

expressed in management for eradication. However the concepts of species' status, such as native, alien or pest, are contested, likely to shift over time (Head 2017) and likely to vary between stakeholders, e.g. individuals, government and business. For example, "protected zone" status, defined under the European Union Regulation (EU) 2016/2031, means that a country must ensure that specific harmful organisms remain absent by following EU measures and carrying out surveys. Protected zone status provides economic benefits to businesses through trade but maintaining this status requires authorities to undertake monitoring and to eradicate outbreaks, even if this comes at societal cost. Stakeholders will vary in their opinion of the balance between costs and benefits of maintaining protected zone status, partly due to their different expectations and the spatial scale at which costs and benefits are experienced. This can create clashes in motivations, thus leading to dilemmas about the ethics, i.e. what is good and responsible conduct for all those involved? Below we consider case studies where ethical dilemmas may occur in tree health citizen science projects.

Case studies of potential ethical dilemmas in citizen science for the early detection of tree pests and diseases

The consequences of detection may be locally severe

The early detection of a "problematic" species, such as some tree pests or diseases, is important because it allows a rapid response that can limit or eliminate any negative impacts. However management can be locally severe because it will often impact upon the trees themselves (Vicent and Blasco 2017), their associated biodiversity, and the benefits that people gain from the trees, even if the health of the trees themselves is not imminently at risk. This can create a clash of motivations between individuals and authorities (Marzano et al. 2015). This is particularly pertinent for citizen science if the person making a report is unaware of the potential consequences of management, unwilling to accept these consequences, or disagrees about the value of management.

Control efforts for pests such as Asian longhorn beetle (in the UK: ALB; *Anoplophora glabripennis* (Motschulsky, 1853)) and emerald ash borer (*Agrilus planipennis* Fairmaire, 1888) (in the USA and Canada) can lead to large-scale tree loss. This is likely to cause a serious negative impact in communities and underlines the importance of community engagement, being sensitive to the range of feelings people will have about this impact (Mackenzie and Larson 2010; Porth et al. 2015). At the time of the NTED project, positive identification of Asian longhorn beetle in the citizen science traps would have resulted in many trees in the vicinity being felled. One NTED individual stated that "I was dreading that happening [finding ALB].... Absolutely dreading that!" Many of the interviewees in the NTED project understood the benefits of early detection and eradication: "you

have a chance of keeping them [tree pests or diseases] at bay or eradicating them...”. Some individuals expressed altruism based on their understanding that suffering local impacts is worthwhile for the greater good (see also Andow et al. 2016); one individual was worried about ALB being found in an ecologically and culturally important woodland, but would report an ALB finding since “as sad as it would be to see, it’s for the greater good that it wouldn’t spread”. In the NTED study, we ensured that participants and landowners were fully aware of the consequences of ALB detection. One interviewee said that “what was really interesting is that I was really worried that I might find an Asian longhorn and nobody else seemed particularly bothered by it”, nevertheless he talked of the responsibility he felt in relation to the consequences of a detection. However, since more people are being encouraged to become engaged with tree health citizen science, there is greater likelihood that the people contributing records are not aware of the consequences of their records, and may be shocked by the severity of local management in response to a confirmed citizen science report. The local communities can be disproportionately affected because negative impacts are experienced at a local scale, while the benefits of extirpation (lack of species’ establishment) are gained at the larger national scale. This poses problems in the perception of justice, and citizen science organisers need to engage with public stakeholders to understand the upset that action may cause (Lecuyer et al. 2018).

One NTED interviewee took this further in stating that the risks are also experienced locally. He indicated that eradication may not be effective: “it’s one of these things if you say well, have they got a good chance of actually controlling or eliminating the beetle, or is it just something which they feel they should do, but they’ve actually got no chance of getting rid of it?” He went on to express the fear that some of the actions were not proportionate. Also, regulations will change as a species becomes established, so that after some time it is “no longer a notifiable pest” and no action is required. When this happens, sites with early detections will have disproportionately suffered the cost of management. Indeed, one person withdrew from the NTED research study over concerns such as these.

The impact of the changing status of a species is exemplified in the Observatree project. This has trained over two hundred people in the UK to support the early detection of priority tree pests and diseases (Observatree 2019). In 2015, Observatree volunteers were alerted to the first UK occurrence of Oriental chestnut gall wasp (*Dryocosmus kuriphilus* Yasumatsu, 1951) and asked to check local sweet chestnut (*Castanea sativa* Mill.) trees. The story of one volunteer is reported in a promotional video (Youtube: <https://www.youtube.com/watch?v=xKaw3LkX9g8>). She found the species, its second sighting in the UK, and immediately reported this to the Forestry Commission in England, “so that they can pick it up and act on it... The next thing I knew was... I saw the remains of the trees being

swept up and taken away in a van. So, very quickly what I said and what I found had had really quite a big impact.” Government agency staff acted in accordance with best practice based on the information available to them. They also carried out wider surveillance but there were no further detections (Morath et al. 2015). Unfortunately, the story did not stop there: in 2016 *Dryocosmus kuriphilus* was found to be relatively widespread in London and no further management of sweet chestnut trees was undertaken within the infestation zone (Forest Research 2019). So, in 2015 felling the sweet chestnut trees in response to the report was a justifiable action, but by 2016 felling was deemed unnecessary. This exemplifies the ethical dilemma of rapidly responding to citizen science reports, while recognising that early detection information from citizen science will always be incomplete.

Knowledge of the management impacts could lead to refusal to report

Responsibility and trust are issues both for citizen science participants and for those organising or responding to citizen science contributions. Participants need to ensure due diligence and care in reporting, whilst organisers need to respond appropriately and to robustly address the impacts of detection. Good communication is required because people who could be effective early detectors may be dissuaded from reporting due to their concerns about the impacts of eradication measures, both to methods used (e.g. insecticides or culling mammals) or their outcome (felling trees or restricting recreational access). For instance, one UK outbreak of oak processionary moth (*Thaumetopoea processionea* Linnaeus, 1758) was from a small town bordered by native woodland 60 km west of London. The introduction site was located and destroyed, but monitoring continued to detect oak processionary moth individuals and the government agency decided to use an insecticide spray in nearby woodland nature reserves – a highly controversial decision (Butterfly Conservation 2013). The network of volunteer moth recorders is potentially valuable in early detection of oak processionary moth (Pocock et al. 2017a), but moth recorders have alleged, in conversations with the authors, that fellow volunteer recorders would (or have) withheld records of oak processionary moth due to the controversy of its management. This reveals the clash of values: government agencies undertake eradication for the benefit of tree health (the caterpillars possibly can cause defoliation), human health (the caterpillar hairs can cause skin and lung irritation) and economics (Protected Zone status under EU regulations); in contrast some local naturalists may disagree that the perceived costs to local woodland biodiversity outweigh the perceived national benefits, yet they may be holding records of value to government agencies.

Citizen science is also valuable in situations where invasive species are becoming established and management of populations is required to

reduce impacts of the invasive species. For example, citizen science is considered vital in involving people in the detection of invasive grey squirrels (*Sciurus carolinensis* Gmelin, 1788), especially in forests occupied by native red squirrels (*Sciurus vulgaris* Linnaeus, 1758) (Shuttleworth et al. 2020). Yet established invasive species can offer economic and societal well-being benefits (e.g. fuel wood or hunting opportunities) that would be lost as a result of management of populations (Hanley and Roberts 2019; Shackleton et al. 2019a). While the culling of grey squirrels is argued as important for the greater good (because they cause red squirrel extirpation and damage commercial timber crops), in many areas grey squirrel may be the only squirrel species people see and their removal may be difficult for the public to accept (Crowley et al. 2018; Dunn et al. 2018; Japelj et al. 2019).

Increasing public awareness through the provision of information can support the acceptance of management, but this varies by species and context (Novoa et al. 2017). In the examples above increased public awareness may be sufficient to persuade non-reporters to change their mind, although dialogue would also be valuable (see also Novoa et al. 2016). Of course, even if some people do withhold records, there may still be sufficient citizen science records from other people to support adequate monitoring of an invasive species.

There is little cost to participants in reporting, but high costs may be borne by stakeholders

The costs borne by different stakeholders in projects will vary, e.g. there may be little cost to making a report, but a high cost of responding to the report. This can become an ethical issue because it raises the question of “acting responsibly”, both for project organisers and participants. The confirmation of ash dieback (*Hymenoscyphus fraxineus* (T. Kowalski) Baral, Queloz & Hosoya) in the UK in 2012 created a challenge for citizen science. There was public concern about the disease, which was amplified through the media (Urquhart et al. 2018). A smartphone app for reporting suspected ash dieback cases was developed, downloaded 12,000 times in two months and 1,000 geo-located photos were received (University of East Anglia 2014). Only 70 reports were classed as likely to be correct so there was little gain in information compared to the cost to the government agency in checking all the records. However, since then the Observatree project in the UK was developed to build an expert citizen science network to verify records of tree pests and diseases and reduce the burden on the agency (<https://www.observatree.org.uk/>).

Spurious records could also be costly. In the LIFE ARTEMIS project in Slovenia, a photographic record of Asian longhorn beetle *A. glabripennis* was submitted via the information system “Invazivke” (<https://www.invazivke.si/>). The information came from a student who participated during one of the

Invasive Species survey weeks organised for schools. Further investigation revealed that the image was from the internet and submitted as part of a school assignment and the student did not understand the potential cost to the authorities in assessing and acting upon this record.

Another type of cost is the cost of management to the landowner after making a report (Andow et al. 2016). For example, reports of oak processionary moth in “control zones” in the UK can carry a cost to the government agency (verifying the record and issuing a Statutory Plant Health Notice) and to the landowner (paying for a contractor to undertake the legally-required management). But what about when other people make a report from someone else’s land of an invasive or protected species, which leads to costs or restrictions on landowners? These dilemmas are important but thus far there is no clear guidance for citizen science practitioners.

Participants may expect solutions to tree health concerns even when these are not possible

It may be appealing for citizen science organisers to appeal to extrinsic motivators, such as fear and threat, because these support recruitment to projects and garner media attention (Blackmore et al. 2013). However, the use of language must be carefully moderated to ensure the citizen science is not misconstrued and trust is maintained. For example, the Conker Tree Science project enabled people to report on the spread of the horse-chestnut leaf-miner *Cameraria ohridella* Deschka & Dimic, 1986 in the UK (Pocock and Evans 2014). In a press release issued in 2011, the wording was emotive: “Conker fans from across the country are being called upon to help save the beloved trees from a perilous moth which is threatening their beauty.” (<http://www.bris.ac.uk/news/2011/7744.html>). Correspondence with some participants showed that they expected that their records would lead to direct action to “save” individual trees, yet previous work suggested that this was not possible (Gilbert et al. 2005). Therefore, to reduce potential misunderstanding, the wording on the website was updated: “...we have been inviting people to take part in real science to discover more about conker tree health by taking part in our missions.” (<http://www.conkertreescience.org.uk/home>, accessed 9 November 2019).

Early detection is (by definition) a rare event

One of the paradoxes of citizen science for early detection is that very few people, or none at all, will record the species they are being asked to look for. The emerald ash borer (*Agrilus planipennis*) is a priority species that is not (yet) known to be present in the European Union, but it is likely to arrive (Gallardo et al. 2016). There is great benefit to authorities in receiving records of the species in Europe, because of the potential to undertake eradication and avoid the potentially vast social, economic and biodiversity

cost of the species' establishment (Herms and McCullough 2014), but the chance of any individual person finding the species is vanishingly small. Some people who were running traps in the NTED project for Asian longhorn beetle were philosophical, saying “you have to accept in nature that you don't always find things... a negative result is what it is, isn't it?” They were relieved not to find the invasive species, but found it difficult to maintain momentum to check traps. Another interviewee said that “it got less and less exciting... you think your motivation is helping science... but actually the longer time went on, and the less there was in the trap... the less motivation there was there to kind of leap out of bed in the morning and go ‘aah, I must check the trap on the way into work’.” However, for the occasion when a target species is detected, the emphasis needs to be on developing efficient data flows (Pocock et al. 2017a), while seeking to minimise the costs associated with dealing with incorrect reports.

Solutions to address ethical issues in citizen science for early detection of tree pests and diseases

For every project, it is critical to consider the data requirements, interests and concerns of all participants through the project design and implementation (Ryan et al. 2018). Emphasis should be placed on identifying potential clashes in motivations and addressing potential ethical dilemmas through engagement and dialogue.

Recruitment of citizen scientists from target interest groups can be beneficial to ensure that the expectations of organisers and participants align. For example, “Master Gardeners” were recruited to support the 2019 Box Tree Moth Citizen Science Campaign in Ontario, Canada (Canadian Food Inspection Agency 2019a; <https://twitter.com/InvSp/status/1116064574439133186>) to look for *Cryptographis perspectalis* Walker, 1859. They were substantially more active with respect to reports, sample submissions and inquiries than citizen participants recruited more passively through social media and email. The shared interest in protecting the host plant helped support a control program in industry and provided data to help inform regulatory decisions.

Developing greater connection among stakeholders creates a shared responsibility towards biosecurity. In Canada, this has been addressed by establishing pest-specific technical advisory committees to support ongoing communication and action to mitigate risks associated with priority plant pests. Utilising such committees to design and implement citizen-based monitoring programs has fostered a greater connection among citizens, stakeholders, industry and all levels of government. The shared responsibility can be formalised through the development of collaborative preparedness and response plans. These enable a thorough understanding of pest problems, management options, risks and consequences as well as associated economic and social costs that may be incurred at various levels.

It can be particularly difficult to engage with potential participants in mass participation citizen science, because their identity is not known in advance. However, the Oak Wilt Response Framework for Canada demonstrates how multiple levels of government and partnering organizations can work collaboratively, including representation from publics, to define comprehensive measures that may be implemented in the event of a new pest incursion (Canadian Food Inspection Agency 2019b). This demonstrates the role of citizen science by motivated participants being involved in monitoring and stakeholder engagement (Aceves-Bueno et al. 2015).

The management of alien species is often surrounded by conflicts of interest (Shackleton et al. 2019b). Empowering people through citizen science co-design can help to reduce conflicts of interest that otherwise may emerge in conventional policy development (Kythreotis et al. 2019). We have illustrated ethical dilemmas in citizen science with examples of tree health from a few countries (UK, Slovenia and Canada), but effective engagement and dialogue will ensure that policy development and management solutions are sensitive to the differences in culture and motivation of people within and between countries (Loos et al. 2015; Pocock et al. 2019).

Conclusions

Citizen science is a valuable tool for engagement and data collection, especially in issues of public concern such as tree health, but ethical dilemmas about the use of citizen science can arise due to clashes between the motivations of different stakeholders and participants. This creates potential for unintended consequences and unexpected impacts of management (e.g. the local destruction of trees). Addressing these ethical dilemmas in using citizen science is vital to maintain society's continuing support for, and trust in, citizen science. We have provided an overview of some ethical issues pertinent to tree health citizen science based on our experience, but we recommend that ethical issues are considered thoroughly and addressed directly in the development of citizen science projects on tree health and invasive species more generally in the future.

Acknowledgements

This article is a part of the conference Detection and control of alien forest species in a changing world organized by the project LIFE ARTEMIS (LIFE15 GIE/SI/000770), co-funded by the LIFE programme, Ministry of Environment and Spatial planning of the Republic of Slovenia, the Municipality of Ljubljana and the Slovenian Research Agency. The article processing charges were covered by the project LIFE ARTEMIS. We thank Peter Crow and anonymous reviewers for helpful comments, and the COST Action Alien CSI (CA17122) for providing opportunities for discussion.

Funding declaration

MP, MM and RMW all received funding from the project "New approaches for the early detection of tree health pests and pathogens" (<http://protectingtreetreehealth.org.uk/>) that was supported by a grant funded jointly by the Biotechnology and Biological Sciences Research Council, the Department for Environment, Food and Rural Affairs, the Economic and Social

Research Council, the Forestry Commission, the Natural Environment Research Council and the Scottish Government, under the Tree Health and Plant Biosecurity Initiative [grant number BB/L012251/1]. MG received funding via the project LIFE ARTEMIS and ARRS research programme “Forest Ecology, biology and technology” (P4-0107) that was supported by the Slovenian Research Agency.

Ethics and Permits

Ethical approval for the NTED interviews was received from University of St Andrews ethics committee.

References

- Aceves-Bueno E, Adeleye AS, Bradley D, Brandt WT, Callery P, Feraud M, Garner KL, Gentry R, Huang Y, McCullough I, Pearlman I, Sutherland SA, Wilkinson W, Yang Y, Zink T, Anderson SE, Tague C (2015) Citizen science as an approach for overcoming insufficient monitoring and inadequate stakeholder buy-in in adaptive management: criteria and evidence. *Ecosystems* 18: 493–506, <https://doi.org/10.1007/s10021-015-9842-4>
- Adriaens T, Sutton-Croft M, Owen K, Brosens D, van Valkenburg J, Kilbey D, Groom Q, Ehmig C, Thürkow F, Van Hende P, 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>
- Andow DA, Borgida E, Hurley TM, Williams AL (2016) Recruitment and retention of volunteers in a citizen science network to detect invasive species on private lands. *Environmental Management* 58: 606–618, <https://doi.org/10.1007/s00267-016-0746-7>
- Aukema J E, Leung B, Kovacs K, Chivers C, Britton KO, Englin J, Frankel SJ, Haight SG, Holmes TP, Liebhold AM, McCullough DG, Von Holle B (2011) Economic impacts of non-native forest insects in the continental United States. *PLoS ONE* 6: e24587, <https://doi.org/10.1371/journal.pone.0024587>
- Bird TJ, Bates AE, Lefcheck JS, Hill NA, Thomson RJ, Edgar GJ, Stuart-Smith RD, Wotherspoon S, Krkosek M, Stuart-Smith JF, Pecl GT, Barrett N, Frusher S (2014) Statistical solutions for error and bias in global citizen science datasets. *Biological Conservation* 173: 144–154, <https://doi.org/10.1016/j.biocon.2013.07.037>
- Blackmore E, Underhill R, McQuilkin J, Leach R (2013) Common Cause for Nature: Finding values and frames in the conservation sector. Machynlleth, Wales: Public Interest Research Centre, 176 pp
- Boyd IL, Freer-Smith PH, Gilligan CA, Godfray HCJ (2013) The consequence of tree pests and diseases for ecosystem services. *Science* 342: 1235773–1235773, <https://doi.org/10.1126/science.1235773>
- Bryman A (2012) *Social Research Methods*. 4th ed. Oxford Univ. Press, Oxford, UK, 766 pp
- Butterfly Conservation (2013) Aerial spraying of woodland to control oak processionary moth (statement). <https://butterfly-conservation.org/sites/default/files/bc-opm-statement-may-2013-fin.pdf>
- Canadian Food Inspection Agency (2019a) Box Tree Moth. <https://inspection.gc.ca/plant-health/plant-pests-invasive-species/insects/box-tree-moth/eng/1554215562798/1554215563084> (accessed 9 November 2019)
- Canadian Food Inspection Agency (2019b) Oak wilt response framework for Canada. <https://www.inspection.gc.ca/plant-health/plant-pests-invasive-species/diseases/oak-wilt/response-framework/eng/1563898431188/1563898479048> (accessed 9 November 2019)
- Crowley SL, Hinchliffe S, McDonald RA (2018) Killing squirrels: Exploring motivations and practices of lethal wildlife management. *Environment and Planning E: Nature and Space* 1: 120–143, <https://doi.org/10.1177/2514848617747831>
- Dunn M, Marzano M, Forster J, Gill RMA (2018) Public attitudes towards “pest” management: Perceptions on squirrel management strategies in the UK. *Biological Conservation* 222: 52–63, <https://doi.org/10.1016/j.biocon.2018.03.020>
- Finkelstien MA (2009) Intrinsic vs. extrinsic motivational orientations and the volunteer process. *Personality and Individual Differences* 46: 653–658, <https://doi.org/10.1016/j.paid.2009.01.010>
- Forest Research (2019) Oriental chestnut gall wasp (*Dryocosmus kuriphilus*). <https://www.forestresearch.gov.uk/tools-and-resources/pest-and-disease-resources/oriental-chestnut-gall-wasp-dryocosmus-kuriphilus/> (accessed 10 December 2019)
- Gallardo B, Zieritz A, Adriaens T, Bellard C, Boets P, Britton JR, Newman JR, van Valkenburg JLCH, Aldridge DC (2016) Trans-national horizon scanning for invasive non-native species: a case study in western Europe. *Biological Invasions* 18: 17–30, <https://doi.org/10.1007/s10530-015-0986-0>
- 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, 120 pp

- Gilbert M, Guichard S, Freise J, Grégoire J-C, Heitland W, Straw N, Tilbury C, Augustin S (2005) Forecasting *Cameraria ohridella* invasion dynamics in recently invaded countries: from validation to prediction. *Journal of Applied Ecology* 42: 805–813, <https://doi.org/10.1111/j.1365-2664.2005.01074.x>
- Groom Q, Strubbe D, Adriaens T, Davis AJS, Desmet P, Oldoni D, Reysers L, Roy HE, Vanderhoeven S (2019) Empowering citizens to inform decision-making as a way forward to support invasive alien species policy. *Citizen Science: Theory and Practice* 4: 33, <https://doi.org/10.5334/cstp.238>
- Gupta N, Slawson D (2019) Tree Health Citizen Science in UK: Opportunities, Challenges and Future Roadmap. <https://www.imperial.ac.uk/media/imperial-college/faculty-of-natural-sciences/centre-for-environmental-policy/public/THCS-in-the-UK---Opportunities--Challenges-and-Future-Roadmap--Defra-Report-September-2019.pdf>
- Haklay M (2013) Citizen Science and Volunteered Geographic Information: overview and typology of participation. In: Sui DZ, Elwood S, Goodchild MF (eds), *Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in Theory and Practice*. Springer, Dordrecht, Netherlands, pp 105–122, https://doi.org/10.1007/978-94-007-4587-2_7
- Hanley N, Roberts M (2019) The economic benefits of invasive species management. *People and Nature* 1: 124–137, <https://doi.org/10.1002/pan3.31>
- Head L (2017) The social dimensions of invasive plants. *Nature Plants* 3: 17075, <https://doi.org/10.1038/nplants.2017.75>
- Heink U, Van Herzele A, Bela G, Kalóczkai Á, Jax K (2018) Different arguments, same conclusions: how is action against invasive alien species justified in the context of European policy? *Biodiversity & Conservation* 27: 1659–1677, <https://doi.org/10.1007/s10531-016-1170-2>
- Herms DA, McCullough DG (2014). Emerald ash borer invasion of North America: history, biology, ecology, impacts, and management. *Annual Review of Entomology* 59: 13–30, <https://doi.org/10.1146/annurev-ento-011613-162051>
- House of Commons Environmental Audit Committee (2019) Invasive species. House of Commons, London, UK, 69 pp
- Japelj A, Kus Veenliet J, Malovrh J, Verlič A, de Groot M (2019) Public preferences for the management of different invasive alien forest taxa. *Biological Invasions* 21: 3349–3382, <https://doi.org/10.1007/s10530-019-02052-3>
- Klapwijk MJ, Hopkins AJM, Eriksson L, Pettersson M, Schroeder M, Lindelöw Å, Rönnberg J, Kesitalo ECH, Kenis M (2016) Reducing the risk of invasive forest pests and pathogens: Combining legislation, targeted management and public awareness. *Ambio* 45: 223–234, <https://doi.org/10.1007/s13280-015-0748-3>
- Kythreotis AP, Mantyka-Pringle C, Mercer TG, Whitmarsh LE, Corner A, Paavola J, Chambers C, Miller BA, Castree N, (2019) Citizen social science for more integrative and effective climate action: a science-policy perspective. *Frontiers in Environmental Science* 7: 10, <https://doi.org/10.3389/fenvs.2019.00010>
- Lawrence A (2006) ‘No personal motive?’ Volunteers, biodiversity, and the false dichotomies of participation. *Ethics, Place & Environment* 9: 279–298, <https://doi.org/10.1080/13668790600893319>
- Lecuyer L, White RM, Schmook B, Lemay V, Calmé S (2018) The construction of feelings of justice in environmental management: An empirical study of multiple biodiversity conflicts in Calakmul, Mexico. *Journal of Environmental Management* 213: 363–373, <https://doi.org/10.1016/j.jenvman.2018.02.050>
- Loos J, Horcea-Milcu AI, Kirkland P, Hartel T, Osváth-Ferencz M, Fischer J (2015) Challenges for biodiversity monitoring using citizen science in transitioning social-ecological systems. *Journal for Nature Conservation* 26: 45–48, <https://doi.org/10.1016/j.jnc.2015.05.001>
- Mackenzie BF, Larson BMH (2010) Participation under time constraints: landowner perceptions of rapid response to the emerald ash borer. *Society & Natural Resources* 23: 1013–1022, <https://doi.org/10.1080/08941920903339707>
- Marzano M, Dandy N, Bayliss HR, Porth E, Potter C (2015) Part of the solution? Stakeholder awareness, information and engagement in tree health issues. *Biological Invasions* 17: 1961–1977, <https://doi.org/10.1007/s10530-015-0850-2>
- Marzano M, White RM, Jones G (2018) Enhancing socio-technological innovation for tree health through stakeholder participation in biosecurity science. In: Urquhart J, Marzano M, Potter C (eds), *The Human Dimensions of Forest and Tree Health: Global Perspectives*. Springer, Dordrecht, Netherlands, pp 299–329, https://doi.org/10.1007/978-3-319-76956-1_12
- Morath S, Fielding N, Tilbury C, Jones B (2015) Features: Oriental Chestnut Gall Wasp. *Quarterly Journal of Forestry* 109(4): 253–258.
- Novoa A, Kaplan H, Wilson JRU, Richardson DM (2016) Resolving a prickly situation: involving stakeholders in invasive cactus management in South Africa. *Environmental Management* 57: 998–1008, <https://doi.org/10.1007/s00267-015-0645-3>
- Novoa A, Dehnen-Schmutz K, Fried J, Vimercati G (2017) Does public awareness increase support for invasive species management? Promising evidence across taxa and landscape types. *Biological Invasions* 19: 3691–3705, <https://doi.org/10.1007/s10530-017-1592-0>
- Observatree (2019) Observatree. <https://www.observatree.org.uk/about/> (accessed 10 December 2019)

- Pocock MJO, Evans DM (2014) The success of the horse-chestnut leaf-miner, *Cameraria ohridella*, in the UK revealed with hypothesis-led citizen science. *PLoS ONE* 9: e86226, <https://doi.org/10.1371/journal.pone.0086226>
- Pocock MJO, Chapman DS, Sheppard LJ, Roy HE (2014) Choosing and Using Citizen Science: a guide to when and how to use citizen science to monitor biodiversity and the environment. Centre for Ecology & Hydrology, Wallingford, Oxfordshire, 24 pp
- Pocock MJO, Roy HE, Fox R, Ellis WN, Botham M (2017a) Citizen science and invasive alien species: Predicting the detection of the oak processionary moth *Thaumetopoea processionea* by moth recorders. *Biological Conservation* 208: 146–154, <https://doi.org/10.1016/j.biocon.2016.04.010>
- Pocock MJO, Tweddle JC, Savage J, Robinson LD, Roy HE (2017b) The diversity and evolution of ecological and environmental citizen science. *PLoS ONE* 12: e0172579, <https://doi.org/10.1371/journal.pone.0172579>
- Pocock MJO, Roy HE, August T, Kuria A, Barasa F, Bett J, Githiru M, Kairo J, Kimani J, Kinuthia W, Kissui B, Madindou I, Mbogo K, Mirembe J, Mugo P, Muniala FM, Njoroge P, Njuguna EG, Olendo MI, Opige M, Otieno TO, Ng'weno CC, Pallangyo E, Thenya T, Wanjiru A, Trevelyan R (2019) Developing the global potential of citizen science: Assessing opportunities that benefit people, society and the environment in East Africa. *Journal of Applied Ecology* 56: 274–281, <https://doi.org/10.1111/1365-2664.13279>
- Porth EF, Dandy N, Marzano M (2015) “My garden is the one with no trees:” Residential lived experiences of the 2012 Asian longhorn beetle eradication Programme in Kent, England. *Human Ecology* 43: 669–679, <https://doi.org/10.1007/s10745-015-9788-3>
- Rasmussen LM, Cooper C (2019) Citizen Science Ethics. *Citizen Science: Theory and Practice* 4: 5, <https://doi.org/10.5334/cstp.235>
- Resnik DB, Elliott KC, Miller AK (2015) A framework for addressing ethical issues in citizen science. *Environmental Science & Policy* 54: 475–481, <https://doi.org/10.1016/j.envsci.2015.05.008>
- Rotman D, Preece JJ, Hammock J, Procita K, Hansen DL, Parr CS, Lewis D, Jacobs D (2012) Dynamic changes in motivation in collaborative citizen-science projects. CSCW '12: Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work, pp 217–226, <https://doi.org/10.1145/2145204.2145238>
- Ryan SF, Adamson NL, Aktipis A, Andersen LK, Austin R, Barnes L, Beasley MR, Bedell KD, Briggs S, Chapman B, Cooper CB, Corn JO, Creamer NG, Delborne JA, Domenico P, Driscoll E, Goodwin J, Hjarding A, Hulbert JM, Isard S, Just MG, Kar Gupta K, López-Urbe MM, O'Sullivan J, Landis EA, Madden AA, McKenney EA, Nichols LM, Reading BJ, Russell S, Sengupta N, Shapiro LR, Shell LK, Sheard JK, Shoemaker DD, Sorger DM, Starling C, Thakur S, Vatsavai RR, Weinstein M, Winfrey P, Dunn RR (2018) The role of citizen science in addressing grand challenges in food and agriculture research. *Proceedings of the Royal Society B: Biological Sciences* 285: 20181977, <https://doi.org/10.1098/rspb.2018.1977>
- Shackleton RT, Adriaens T, Brundu G, Dehnen-Schmutz K, Estévez RA, Fried J, Larson BMH, Liuh S, Marchante E, Marchante H, Moshobane MC, Novoa A, Reed M, Richardson DM (2019a) Stakeholder engagement in the study and management of invasive alien species. *Journal of Environmental Management* 229: 88–101, <https://doi.org/10.1016/j.jenvman.2018.04.044>
- Shackleton RT, Shackleton CM, Kull CA (2019b) The role of invasive alien species in shaping local livelihoods and human well-being: A review. *Journal of Environmental Management* 229: 145–157, <https://doi.org/10.1016/j.jenvman.2018.05.007>
- Shuttleworth CM, Robinson N, Halliwell EC, Clews-Roberts R, Podgornik G, Stinson M, Rice S, Finlay C, McKinney C, Peek H, Everest DJ, Larsen KW (2020) Evolving grey squirrel management techniques in Europe. *Management of Biological Invasions* 4: 747–761, <https://doi.org/10.3391/mbi.2020.11.4.09>
- Tree Health and Plant Biosecurity Expert Taskforce (2012) Interim Report. <https://www.gov.uk/government/publications/tree-health-and-plant-biosecurity-expert-taskforce-interim-report> (accessed 9 November 2019)
- University of East Anglia (2014) 2014 Environmental Report. <https://www.uea.ac.uk/about/university-information/sustainability/strategy-policy-and-compliance> (accessed 9 November 2019)
- Urquhart J, Barnett J, Fellenor J, Mumford J, Potter C, Quine CP (2018) The social amplification of tree health risks: the case of ash dieback disease in the UK. In: Urquhart J, Marzano M, Potter C (eds), *The Human Dimensions of Forest and Tree Health*. Springer, Dordrecht, Netherlands, pp 165–192, https://doi.org/10.1007/978-3-319-76956-1_7
- Vicent A, Blasco J (2017) When prevention fails. Towards more efficient strategies for plant disease eradication. *New Phytologist* 214: 905–908, <https://doi.org/10.1111/nph.14555>
- West S, Pateman R, Dyke A (2016) Data Submission in Citizen Science Projects. Report for Defra (Project Number PH0475).
- White RM, Young J, Marzano M, Leahy S (2018) Prioritising stakeholder engagement for forest health, across spatial, temporal and governance scales, in an era of austerity. *Forest Ecology and Management* 417: 313–322, <https://doi.org/10.1016/j.foreco.2018.01.050>
- White RM, Marzano M, Leahy S, Jones G (2019) Are we defending the indefensible? Reflecting on policy and practice around ‘the border’ in plant biosecurity for tree health. *Forests* 10: 716, <https://doi.org/10.3390/f10090716>