A Strategic Framework to Support the Implementation of Citizen Science for Environmental Monitoring

FINAL REPORT

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Executive summary

Citizen science is the involvement of volunteers in the collection and/or analysis of data. It has become an increasingly popular approach to undertake science and conduct monitoring. This is for many reasons, but particularly because it provides an excellent way to engage with the public whose participation allows for cost-efficient collection of data over large spatio-temporal scales. The development of citizen science approaches have been aided by recent advances in communication technologies. However, there are also disadvantages to a citizen science approach. Importantly, citizen science it is not free; it requires resources to make it successful, and investment in recruiting, retaining and motivating volunteers.

In this report we provide a decision framework that can be used to guide whether and when to use a citizen science approach for environmental monitoring. Before using the decision framework we recommend that five precursors to a citizen science approach are considered. This is because citizen science is most successful when:

- the aim/questions are clear;
- engagement with people is given a high priority;
- sufficient resources are available to begin and continue the project until its completion;
- scale of sampling is relatively large (because it is often not cost-efficient to use a citizen science approach at small spatio-temporal scales);
- the protocol required for data collection is not too complex.

Citizen science covers a wide variety of different approaches, and it can be difficult to assess which approach is most appropriate for particular monitoring activities. We have developed a decision framework to assist in answering this question. The decision framework is presented in the format of an annotated dichotomous key. We anticipate that this decision framework will be used interactively by people in order to help shape their ideas about potential citizen science projects.

Even if citizen science appears suitable for environmental monitoring, it may not be the optimum approach; instead of citizen science it may be better to have professional monitoring (if funding can be obtained) and use remaining resources for public engagement. If a citizen science approach is embarked upon, then we recommend careful consideration of five further aspects: time required by the organisers, development of infrastructure and data protection, the importance of quality assurance of the data, communication with potential participants, and legislative implications of the project. We also recommend using the Guide to Citizen Science (Tweddle et al., 2012) to help develop the project.

We also provide an overview of the usefulness of a citizen science approach for the environmental pressures that are relevant to SEPA. We have considered each relevant pressure, its impacts and have provided a commentary on the potential usefulness of a citizen science approach in monitoring impacts of the pressure. In many cases, we thought that citizen science was worth considering further, and for some pressures a citizen science approach was likely to be extremely useful. We provide recommendations about how citizen science could be implemented for each pressure.

Finally, we developed two cases studies to show how a citizen science approach could be implemented for:

1. Identifying and locating barriers to fish migration in rivers;
2. Monitoring the effect of the Seven Lochs Wetland Park on water quality.

We have provided these case studies as worked examples of the use of the decision framework to inform the delivery of a citizen science project. We have undertaken this to the best of our knowledge of SEPA's priorities and resources available in order to help develop SEPA's approach to implementing citizen science.

Contents

Part 1. Introduction to citizen science

1.1 What is citizen science?

Citizen science is the involvement of volunteers in the collection and/or analysis of data. Various definitions have been applied to citizen science, including:

> "Volunteers collect and share data that can be analyzed by scientists, project participants, or both" (Cornell Lab of Ornithology 2013a)

As this definition suggests, there are many different types of citizen science, and projects can be contributory (i.e. led by professionals and to which members of the public contribute), or can be much more strongly shaped by the participants themselves (collaborative and co-created projects) (Bonney *et al.* 2009). For many projects involving environmental monitoring, the contributory model of citizen science is most relevant, leading to a specific definition of citizen science useful for this report, and which was used in a recent review of citizen science in environmental monitoring (Roy *et al.* 2012):

> Citizen science in environmental sciences is the "volunteer collection of biodiversity and environmental information which contributes to expanding our knowledge of the natural environment, including biological monitoring and the collection or interpretation of environmental observations" (UK-EOF 2011).

We note, however, that these definitions are working terms rather than fixed entities. Recent discussion has resulted in a preference for the descriptive, but lengthy, term: public participation in scientific research (PPSR). According to the Cornell Lab of Ornithology (2013) PPSR "includes citizen science, volunteer monitoring, and other forms of organized research in which members of the public engage in the process of scientific investigations: asking questions, collecting data, and/or interpreting results". This diversity within 'citizen science' is confirmed by a recent systematic review of environmental citizen science showing the range of citizen science projects (Roy *et al.* 2012). Also, participants can be involved to different extents in shaping and guiding the questions addressed, the data collected and its interpretation and application (Bonney *et al.* 2009).

An additional source of potential confusion concerns the definition of participants as 'volunteers' or 'members of the public'. It raises the question of the limits of citizen science; how 'expert' do 'expert volunteers' need to become before the definition of citizen science does not apply to their project? Although we are aware of these issues, we do not consider them in detail and take a broad approach to considering contributory citizen science for environmental monitoring in this report.

1.2 Why is citizen science so popular?

Citizen science "offers a means of doing substantial, thoughtful public outreach and of tackling otherwise intractable, laborious or costly research problems" (Gura 2013). It is an increasingly popular approach to undertaking research; many new projects are being promoted each year and there are an increasing number of publications based on the data collected by citizen scientists (Gura, 2013). We believe that there are several important reasons why citizen science has become so popular in recent years:

1. **Excellent engagement.** Citizen science provides a means for people to engage with science and their environment. Although people's motivation for taking part in citizen science varies considerably, participants often describe it as fun. Citizen science can provide a way for people to feel they are contributing to something important. The engagement people have with nature through citizen science is a potentially powerful communication tool that enhances people's appreciation of nature (for more detail see Common Cause for Nature: http://valuesandframes.org/initiative/nature/)
2. **Resource-efficient data collection.** Citizen science provides the potential to collect data at much larger spatio-temporal extents and much finer resolutions than would otherwise be possible. Even if the data could be collected via other means, citizen science can be a very cost-efficient way of collecting the data. This is particularly so if the value of the public engagement aspect of citizen science is taken into account.
3. **Technological advances make promotion and data collection increasingly straightforward.** Over the past decade, advances in technology, especially in communications technology, have made it easy to set-up and promote citizen science projects. Data collection, via websites or smartphones, is now a standard approach and relatively cheap to set up. Feedback to participants can be provided quickly and easily.
4. **The data can be trusted.** Increasingly, citizen science projects are incorporating data validation and verification steps ensuring the data are of known quality. Sometimes, only verified data is accepted, so the data are known to be correct. In other projects a sample of the data is verified in order to assess the quality of the data so that error or bias can be taken into account in the analyses. Both approaches provide trustworthy data. The results of many such projects have been published in the scientific literature, and citizen science data is also used in national indicators.
5. **Volunteer involvement in science has a long history, but can now be included under the umbrella term of citizen science.** Therefore, many types of volunteer-led monitoring that have been undertaken over the past decades, can now be 're-branded' as citizen science, and

considered as this single entity. The term 'citizen science' can thus be applied to activities that pre-date the term, such as systematic surveys by expert volunteers (e.g. the UK's Breeding Bird Survey, whose pre-cursor started in 1962) or unstructured recording of the presence of species (e.g. the long-term datasets on species' occurrence collated by the Biological Records Centre (Preston, Roy, & Roy 2012)).

Citizen science can appeal to many diverse audiences, and different types of citizen science can appeal to different types of audience, e.g. expert volunteers, interested community stakeholders or members of the general public. Often the focus for citizen science is caricatured as engaging any member of the public via mass media, i.e. the sort of 'mass participation' project that anyone can take part in anywhere. However, this is not the only type of citizen science (Roy *et al.* 2012) and different types of projects can be extremely successful in engaging with more targeted audiences, e.g. working with volunteer experts (Grove-White *et al.* 2007).

1.3 Citizen science and its role in long-term monitoring

One of the distinctive scientific roles for citizen science is its use in long-term monitoring. The reason for this is that motivated volunteers can be very committed, permitting the long-term collection of data in widely distributed locations. If resources are available to support the volunteers then large-scale monitoring projects can run for decades (e.g. the UK's Breeding Bird Survey and the UK Butterfly Monitoring Scheme).

1.3.1 Citizen science can provide high quality data

Although the data from citizen science projects can vary in quality, if it is collected appropriately and subject to quality assurance, then the data can be eminently suitable for regulatory purposes. For example, 7 of the 26 UK headline biodiversity indicators are reliant on volunteer-collected data (Defra 2012), and monitoring of water courses in the USA is undertaken by volunteers according to the United States Environmental Protection Agency (EPA) protocols to meet regulatory requirements (Nerbonne & Nelson 2004), although as yet these data are not combined across different projects to provide national indicators of water quality.

1.3.2 Citizen science requires investment and resources

It can be tempting to think that citizen science is a cheap way of fulfilling all large-scale monitoring needs. This is certainly not the case. Many subjects are not suitable for citizen science: for example, data may not be able to be collected safely or accurately, or the subject is not appealing to volunteers. Additionally, although citizen science data may be free at the point-of-collection the annual support for citizen science projects providing data for UK headline biodiversity indicators still amounts to approximately £100K per project per year (Roy et al. 2012). However, citizen science may be very cost-effective. Citizen science need not replace professional monitoring, where this currently occurs. We consider that professional and citizen science monitoring are not mutually exclusive. Citizen science could be most effective when augmenting and complementing professionally-collected data. For example, the value of systematic monitoring of a wide range of receptors at one site could be greatly enhanced by unstructured recording of a few receptors at a much larger number of sites. Alternatively citizen science data could provide point sampled ground-truthing of remote sensed data. It is important to note that modern analytical techniques (e.g. hierarchical modelling) mean that data from different sources can potentially be combined within single analyses.

1.3.3 Motivations of volunteers need to be understood

Especially when considering long-term monitoring, the role of volunteers needs to be understood. There can be tensions between the motivations of volunteers and the goals of the organisers (Nerbonne & Nelson 2004) which need to be understood for the project to be successful. The participants may have the expectation that local action will result from their data, but for many reasons this may not occur, or even be intended, so communication needs to be clear. Much work has been done on the motivations of volunteers, e.g. citations in Roy et al. (2012).

1.3.4 Advantages and disadvantages of a citizen science approach

Often citizen science data are not collected in a systematic, structured way and so the analysis of the data and interpretation of the results can provide a challenge. Therefore, citizen science projects should not be entered into lightly. However, there are many benefits in undertaking citizen science. Advantages and disadvantages of a citizen science approach are summarised below:

Advantages of a citizen science approach

- By getting people to be hands-on with data, it engages them with important issues, including the complexity of the issues of concern and the challenge of monitoring impacts.
- It can help to build trust in organisations.
- It can be a cost-efficient way of gathering data, especially at large spatio-temporal extent and fine spatio-temporal resolution. That is, the cost of acquiring suitable data ‘professionally’ is more than the cost of supporting volunteers to acquire these data.
- For long-term monitoring, committed volunteers could provide a more reliable way of gathering data, less subject to the vagaries of agency funding than professional monitoring.
- It can permit many more simultaneous observations than would otherwise be possible.
- Where rare but significant events are noteworthy to members of the public (e.g. diseased wild animals, otters killed on roads, landslides etc.) it can permit the reporting of these

events across large spatial-temporal extents, whereas using paid surveyors to report such events would not be practical.

- It need not be restricted to what people can see; people can use sensors, or they can collect samples for analysis by volunteers or by professionals.
- Many potentially interested people are willing to be directed and to be 'useful'. Collecting data gives them purpose and helps them feel involved – thus encouraging commitment.
- By allowing lots of people to each undertake small or simple tasks (i.e. 'crowd sourcing', often of tasks that are simple for humans to undertake but difficult for computers, such as image recognition), it can provide a means of analysing large datasets for properties that cannot be picked up by an automated process and have so much data that it cannot realistically be achieved by a smaller number of people.
- Even the most unlikely subjects can be made engaging by applying the creativity and imagination of communicators – therefore almost any subject is potentially suitable for a citizen science approach.
- In some cases the expert amateur could have superior skills to the professional – this is particularly the case when surveying for and identifying plants and animals.

Disadvantages of a citizen science approach

- It may be more efficient (and cost-effective) to undertake systematic sampling with paid professional surveyors.
- Data acquisition becomes reliant on a resource that is outside of your control. That is, citizen science is most suitable where data cannot be collected any other way (i.e. you are not diverting resources from currently adequate monitoring), or where the data will be useful but not essential.
- Providing feedback to volunteers can be costly, in terms of time, but has to be maintained for the life of the project in order to motivate participants.
- The expense in providing secure infrastructure for data acquisition (e.g. online databases and web interfaces, or smartphone apps) can be relatively high.
- There can be tensions between the motivations of volunteers and the needs of the organisers. People take part because they are motivated through interest, curiosity, fun or concern. In the authors' experience, people appear not to be motivated to take part because they are told they ought to, or because it is for someone else's good.

- Often citizen science data (especially mass participation) is *ad hoc* in its collection (i.e. the times and locations of samples are not subject to statistical design), so can require complex analytical approaches or may not be suitable for purpose for which it was intended.
- Data quality may be variable, so its suitability for scientific research or regulatory purposes needs to be carefully evaluated. The risk of not having adequate data to meet regulatory requirements (e.g. data is not collected over suitable time periods, or patterns of data collection change over time).
- For long-term surveillance, either considerable commitment by individual volunteers, and/or a long-term commitment to recruiting volunteers, is required.
- For long-term surveillance, organisers of citizen science need to have a long-term commitment to supporting and retaining volunteers (e.g. through training, mentoring, providing feedback, refreshing materials etc.)
- Volunteers need to be recruited. Therefore knowledge of your audience and what may interest them is essential, but it can still be challenging to 'pitch' the project to people, especially the media.
- The success of recruiting participants may depend on the reputation of the recruiting organisation. Government agencies may find recruiting harder, either because people trust them less than charities or universities, or because people believe that the activity should be supported with public funds, but working with partner organisations may lead to greater success in recruiting volunteers.

1.4 The aim of this report

In this report we aim to provide a decision framework to help guide people who are considering whether a citizen science approach is suitable for their science or regulatory needs (e.g. a question that needs to be answered, or a feature of the environment whose condition needs to be monitored and/or reported upon). In this report, our primary focus is environmental/biological monitoring in freshwater and terrestrial environments, but we have created the decision framework in such a way that it will be applicable to citizen science in general. In so doing we aim to guide people:

(1) to discover whether citizen science is suitable for their proposed project, and;
(2) to discover what type of citizen science is most appropriate for them to adopt.

We believe that the decision framework will help people to more clearly understand the potential opportunities and limitations of citizen science. This is necessary because there are so many different types of citizen science projects (Roy *et al.* 2012) and not every type is suitable for all situations. Therefore, for someone with a question which needs to be answered, or with a monitoring need to be addressed, it can be daunting to consider whether citizen science can be used and, if so, what sort of citizen science project should be adopted. In this report we do not repeat the “Guide to Citizen Science” (Tweddle *et al.* 2012) which was written specifically to consider environmental and biodiversity science, or the Citizen Science Toolkit (Cornell Lab of Ornithology 2013b). We recommend that interested people consider the decision framework in this report and then, if they conclude that a citizen science approach is worthwhile, consult the Guide to Citizen Science (Tweddle et al. 2012) and follow the advice given.

Part 2. The decision framework

In this part of the report we present the decision framework, to assist in the selection of a citizen science approach. We also include some preliminary questions and subsequent thoughts to advise on the suitability of citizen science.

2.1 Precursor to the decision framework: before you even consider citizen science

We recommend that before seriously considering citizen science, it is important to consider five aspects:

1. the clarity of your question/aim
2. the importance of engagement
3. the resources available
4. the spatio-temporal scale of sampling and
5. the complexity of the protocol.

The suitability of a citizen science approach is summarised in Fig. 1, and expanded in the remainder of this section.

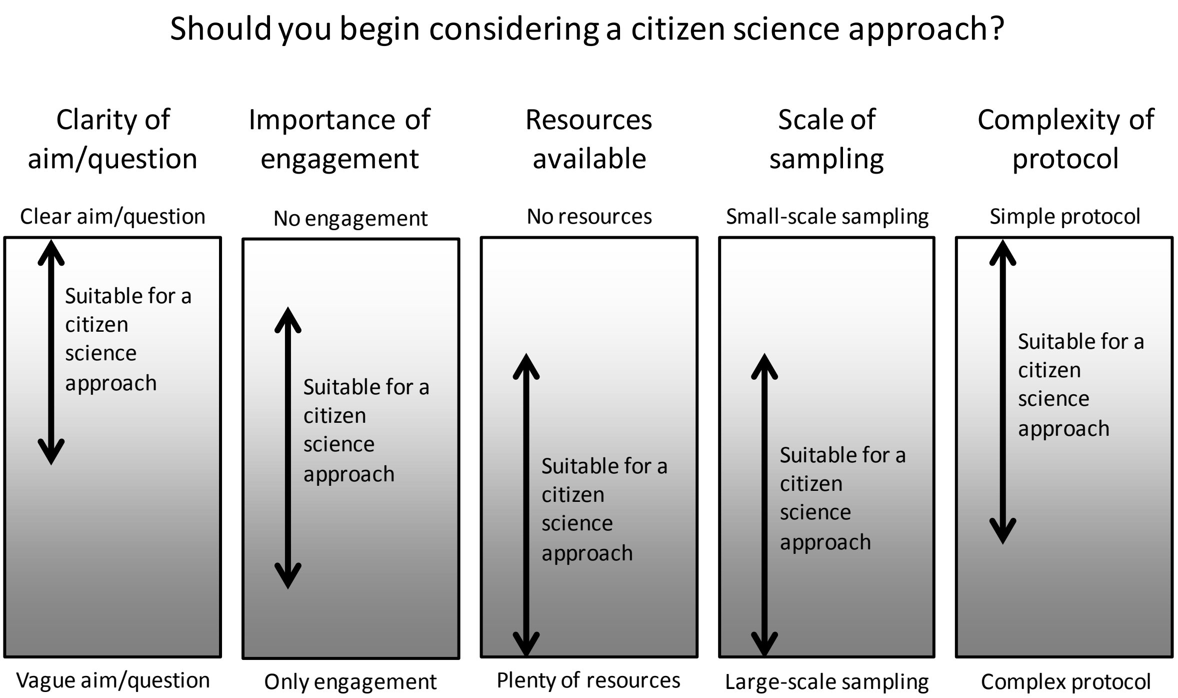


Fig. 1. Five broad areas to consider prior to using the decision framework to assess the suitability of citizen science to your circumstances.

2.1.1. The clarity of the aim/question

Citizen science is at its best when it is specific, i.e. when the question being addressed is precise. For citizen science to be effective the data need to be fit-for-purpose, therefore the purpose needs to be clearly defined.

For many projects, e.g. where citizen science contributes to primary scientific research, the aim is well-defined. It can be phrased as a testable hypothesis, leading to very effective citizen science (Silvertown 2009). However, citizen science can also contribute to environmental surveillance and monitoring. It can do this either by providing a spatial snapshot of the current state of a pressure or an assessment of change over time. In such cases, citizen science can contribute to an indicator of environmental change. In such cases, and as with the development of any indicator, it is important that there is an empirically-tested and unique cause-and-effect pathway from the pressure to the indicator (Fig. 2).

Key question: do you have a precise and clearly-defined aim for your citizen science?

Example: The Conker Tree Science project (www.conkertreescience.org.uk) sought to address two hypotheses relating to the invasive horse-chestnut leaf-miner, *Cameraria ohridella*, namely: does the (1) level of damage caused by the moth caterpillar and (2) the parasitism of the moth caterpillar increase with the length of time that the moth has been present. Both hypotheses were communicated clearly to participants at the start of the project. These hypotheses were tested with the data that were submitted via the project website and smartphone app.

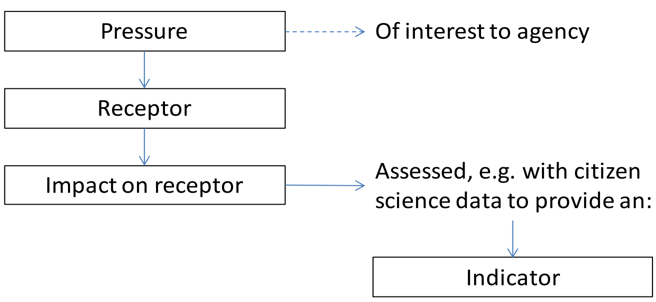


Fig. 2. Idealised role of citizen science in contributing to an official indicator of an environmental pressure. For any indicator each of the steps should be empirically quantified and there should be a unique link between the pressure and the indicator (or such a link should be determinable once confounded factors have been taken into account statistically).

2.1.2 The importance of engagement

Engagement is an important component of citizen science but engagement alone is not citizen science. Perhaps you have an important message to convey but with no need to gather data. There are many examples of engagement working really well to raise awareness of a particular issue by communicating with many people without it being citizen science. However, perhaps you have an idea for engagement which could be quite simply extended to actively involve people in gathering relevant data either for your end-use or for the benefit of the citizen science community. You could collaborate with others to successfully combine engagement and data gathering to answer a question of shared interest. Citizen science can provide an effective way of engaging people in complex scientific concepts while gathering valuable, high quality data. Indeed as people commit to the citizen science project, it is possible that the engagement aspect will be more successful – the citizen science acts as a highly participatory way for people to engage (Common Cause 2013). So if you are considering engagement think whether you can get more from the initiative by encouraging people to contribute through citizen science (i.e. asking a genuinely interesting scientific question, or gathering data for a genuinely useful scientific need). Increasing the awareness around a particular issue is extremely important and there may be no need for people to gather data. In which case keep it simple and invest in excellent engagement alone.

Key question: Can you extend your engagement activity into meaningful and relevant citizen science?

Example: The killer shrimp, *Dikerogammarus villosus*, arrived in England in 2010. Recognising the threat of this invasive non-native species the Non-Native Species Secretariat, in collaboration with a number of partners, developed an attractive biosecurity campaign (Check, Clean, Dry) targeted at people using high risk sites for watersports. The priority was to inform people of the potential for inadvertently spreading this species through movement of contaminated watersports equipment and how simple biosecurity methods could reduce the risk. Engagement and raising awareness of key users of high risk sites was critical to the biosecurity approach. However, the Check, Clean, Dry campaign also included a link to a website and associated e-mail address for reporting sightings of the killer shrimp; many people have used these systems for reporting not only killer shrimps but other species potentially of concern.

2.1.3 The resources available

Citizen science can seem an attractive approach because it is considered to be low cost. However, citizen science can require extensive resources. Indeed policy-relevant citizen science projects in the UK typically cost more than £100k per annum for coordination and supporting volunteers (Roy et al. 2012). It is important to consider what resources will be required to run your initiative effectively.

Will you need a website? Will you need an online database? And, if so, can you use existing technology, such as Indicia (a database toolkit for biological observations developed by the Centre for Ecology & Hydrology; http://www.indicia.org.uk/), to meet this need? Will you need to provide supporting resources such as guidance notes or specialist equipment? If many resources are needed to adequately support a project and the cost of this is seemingly prohibitive then you could consider collaborating with other providers or consider using open-source software, which may bring the costs down. The 'Guide to Citizen Science' (Tweddle *et al.* 2012) includes more detail about the sort of resources required for setting up and running a citizen science project.

Key questions: Do you have sufficient resources available to ensure you can support your volunteers for the entirety of the project? If not, can you collaborate and share resources, which might also reduce duplication of effort?

Example: The Open Air Laboratories (Opal project) http://www.opalexplorenature.org/ developed a wide range of resources to support citizen science activities on air, water, soil and biodiversity. A network of partners with a range of expertise worked together to develop attractive and accessible resources.

2.1.4 The scale of sampling

Citizen science is particularly effective at addressing questions that require a large-scale approach, especially across large spatial scales (by engaging many volunteers simultaneously). It is also useful when considering a very long-term approach, in which volunteer-led monitoring can remain consistent through peaks and troughs of funding cycles (although long-term citizen science does require a long-term commitment from the organiser), or when data is required at fine resolution (especially temporally). Citizen science could potentially work extremely well for both extensive large-scale and intensive small-scale studies. However, where there is a need for data across a large spatial scale it is important to consider whether information is needed from particular sites or whether an ad hoc approach will suffice. Site remoteness is also a consideration, as it may be difficult to persuade people to travel to these sites of interest.

Key question: Do you need lots of people (or volunteer time) to achieve your aims?

Example: Biological recording has a long history in Britain and the enthusiasm of people to contribute wildlife observations for many taxonomic groups is inspirational. The UK Butterfly Monitoring Scheme (UK BMS) http://www.ukbms.org/ involves a network of volunteers walking transects and recording butterfly abundance. The data contributes to one of the Defra biodiversity indicator assessments and enables trends to be reported on a regular basis. In recent years the UK BMS has been extended to include the Wider Countryside Butterfly Survey which includes random 1 km squares across the country, recognising the importance of recording in a wide variety of habitats. In 2012, the butterfly species present and their respective abundances were recorded by volunteers in more than 700 squares.

2.1.5 The complexity of the protocol

Perception of citizen science is skewed by citizen science projects promoted through the mass media, which are typically those involving many people in gathering simple data (e.g. an observation or a single measurement) through so called "mass participation" projects. Simplicity is often key to the success of mass participation citizen science projects. Typically, a relatively large number of people will be prepared to get involved with an initiative that does not demand much time or expertise but as the complexity of the protocol increases then the number of participants is likely to decrease, even though the value of the data may increase. If you require the use of a complex protocol then ensure you provide sufficient support for participants and the protocol must be thoroughly tested (Tweddle *et al.* 2012). A complex protocol is likely to result in fewer people participating, but there may still be sufficient to provide enough data. Never presume too much of a volunteer; their time is given freely and they are not obliged to provide data. Ensure that you consider the motivation of your participants and maximise their enjoyment and satisfaction in taking part. This includes supporting their understanding of the importance of their record, and so requires you to provide feedback to participants. Feedback should ideally include an immediate response (e.g. a 'thank you' for the record which could be automated or personal) and more considered feedback (e.g. an end-of-year report for volunteers).

Key question: Is your protocol practical for volunteer involvement? Are you expecting too much from the volunteer community?

Example: More than 40 000 people have submitted records of the harlequin ladybird, *Harmonia axyridis*, to the UK Ladybird Survey www.ladybird-survey.org. It probably takes people less than 5 minutes to observe and record this species. By contrast, very few people got involved with the Ladybird Parasite Survey which involved a much more complex protocol than submission of a harlequin ladybird record. The data from both surveys has proved invaluable and, despite the mismatch in volume of data, both have provided insights into the ecology of this invader.

2.1.6 The motivations of participants

People will get involved and continue to stay involved in a project for many different reasons, and these reasons will vary between people and can change over time (Rotman *et al.* 2012). It is important to consider people's motivations. Progression in a project can be important for them to remain motivated.

In terms of initial involvement, different projects will resonate with people in many different ways. Successful projects may resonate because of a sense of place ("it is my river"), a sense of community ("I can take part with my children"), a pre-existing interest ("I've always liked butterflies"), a sense of discovery ("I had no idea that…"), being part of a narrative ("I'm taking part with others …") or a sense of jeopardy ("my trees are under threat"). This does not mean that the focus of your proposed study has to already have popular appeal, because even unlikely subjects can be communicated in such a way that they resonate with people.

People also need a 'trigger' or prompt to make a record. Ideally triggers that will prompt involvement should not be too common (otherwise people feel overwhelmed and disengaged) or too rare (otherwise people will forget to participate), unless the event is rare and spectacular (e.g. a dead swan or a landslide). Often subtle changes to a question can make the trigger clearer and the data more useful. For example, asking people to report the health of garden birds is too general, while asking people to report sick birds in their garden or to report the health of garden birds on a particular day may be more successful.

Remember that it is irrelevant how important you think an issue is – it is how it resonates with potential volunteers which will determine how motivated they are.

Key question: Does your project resonate with potential volunteers, and are there clear and appropriate triggers for people to make records?

Example: The Riverfly Partnership was a project created by anglers concerned about the quality of rivers and supported by organisations for which this information was important. This project resonated with new participants because it concerned places that were important to them, and empowered them to seek improvements in water quality (because their data could have impacts on management of the river). This feeling was enhanced through jeopardy, because the rivers were potentially vulnerable to pollution events which, without the data, would go undetected. The partnership successfully worked to create a larger sense of community among participants across the country, so supporting the efforts of individuals. There is a structured calendar for monitoring (e.g. monthly) so there is no specific trigger that people respond to prompt observations.

2.1.7 Types of data

Two current stereotypes of citizen science are (1) 'mass participation' citizen science, in which the media promote a project for anyone to take part anywhere, and (2) expert volunteers committed to making observations that provide long-term surveillance. However, there are many other types of citizen science that could be considered: Observations are not the only contribution citizen scientists can make, they could take samples instead. In some cases people have a vested interest in the results and are even willing to pay for analysis of the samples. You need not be restricted to considering observations that people can make directly; many sensors exist for people to record things that they otherwise cannot directly observe (e.g. radiation) or cannot otherwise quantify (e.g. temperature or noise). These sensors can use the capabilities of smartphones directly, or be developed as sensors that plug in to the internet, especially via mobile phones. This is likely to be an increasing field of activity, though if people begin passively dispersing sensors (e.g. air pollution sensors in cars) then it will raise debate as to whether it has enough engagement to be classed as 'citizen science'! Similarly, it is possible to harvest social media, such as Twitter, for information which is contributed (albeit inadvertently) by a member of the public. This uses the information in the public domain, but does not engage with people to collect it.

One of the strengths of citizen science is having a widely dispersed pool of volunteers. However, you do not need to restrict your thinking to tasks that require people to go out and make observations; for some projects people can get involved via the computer. There are many tasks that are difficult to automate, but easy for humans, e.g. pattern recognition, and if these can be divided into small tasks then the problem can be 'crowd sourced'.

Key question: Have you considered different types of citizen science, including crowd-sourcing, collecting physical samples, citizen sensor networks, harvesting social media etc.

Examples: In the State of the Oyster project participants collect shellfish samples and pay for laboratory sampling for harmful bacteria in order to receive information on their shellfish, while the results contribute to an overall understanding of faecal contamination of the sea water: http://wsg.washington.edu/mas/ecohealth/state_of_oyster.html. In Radiation-Watch, members of the public funded the development of a sensor which is now available commercially to plug into a smartphone and provide real-time data on radiation levels (e.g. in Japan after radiation leaks): www.radiation-watch.org. Zooniverse and Crowd Crafting (PyBossa) are both platforms for the development of crowd sourced projects: www.zooniverse.org, http://crowdcrafting.org/. Forest Watchers invites people to contribute their intelligence to interpret satellite imagery and so quantify deforestation: www.forestwatchers.net. Geocloud in Oak Mapper harvests Flickr and Twitter to map potential records of sudden oak death in California: http://www.oakmapper.org.

2.2 The decision framework

We have created the decision framework to provide guidance whether citizen science is suitable for you and, if suitable, which type of citizen science you should consider.

2.2.1 How to use the decision framework

Using the decision framework with an extremely clearly defined question

The decision framework is presented as a dichotomous key. You can use the decision framework with a specific aim/question that was been extremely clearly defined in advance. This was our initial expectation when developing the decision framework. You can then simply work through the questions in the decision framework to discover the suitability of citizen science for your proposed project. In this case the decision framework is used as a formulaic decision-making tool. As we developed the decision framework, we became increasingly aware that it was unlikely that a person would have such perfect clarity in their aims. It is therefore unlikely that the decision framework will be used so inflexibly.

Using the decision framework interactively

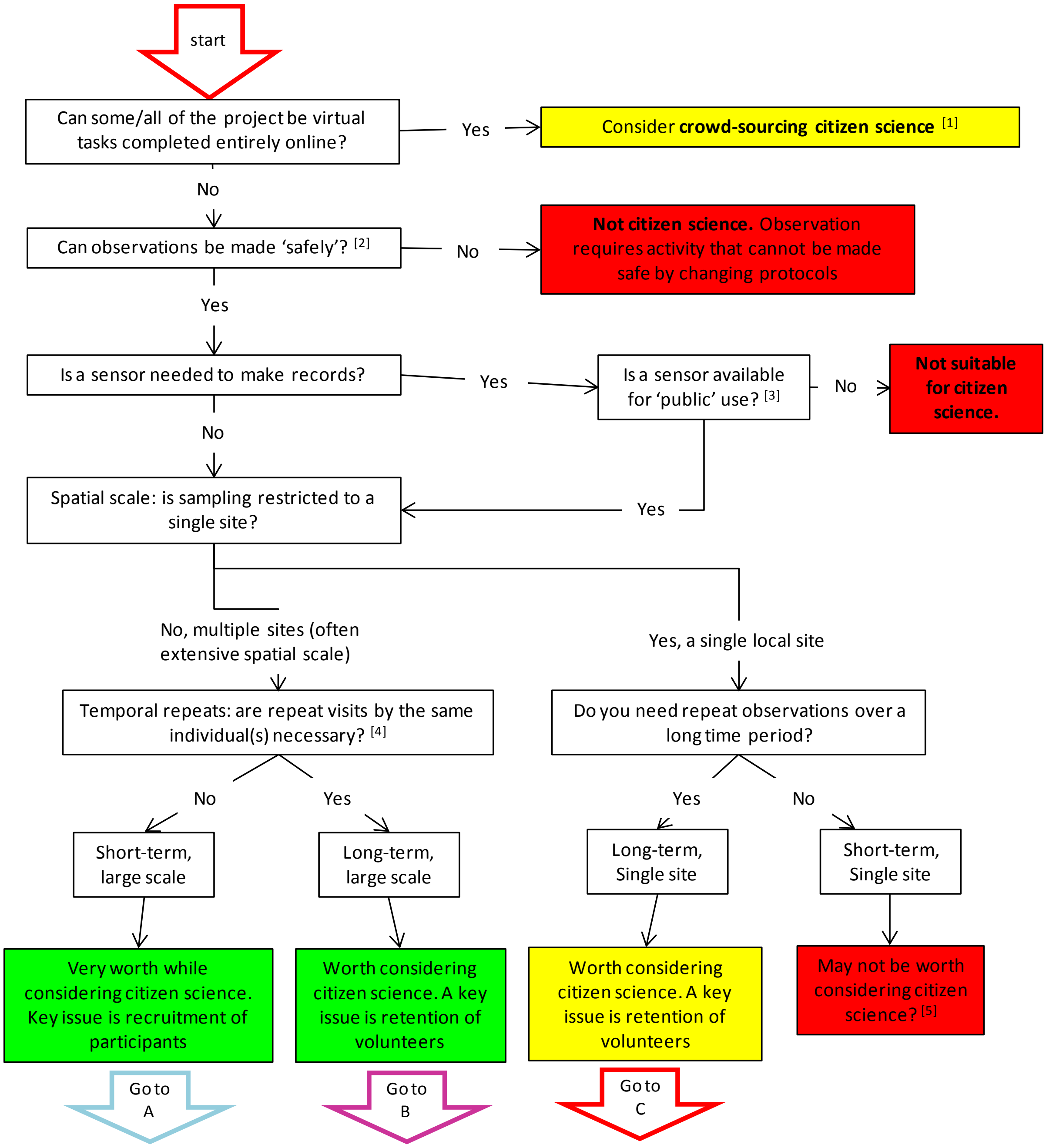
In constructing the decision framework, we discovered a second, more practical and more productive use of the decision framework. In this case, you have a fairly well-defined question/aim (see section 2.1.1) and you can develop, refine and clarify your aim by using the decision framework as an interactive tool. We anticipate that by working through the decision framework, you will face questions that you have not previously considered. The decision framework allows you to see the outcome of your decisions at each point in the decision framework. Using the decision framework could:

- Raise questions that you have not previously envisaged, thus broadening what you considered possible and so revealing the potential of a citizen science approach;
- Ask questions that you have not previously clarified, thus helping you refine your overall question, so making it more precise;
- Allow you to see the likely impact of each decision on the suitability of citizen science for your proposed project.

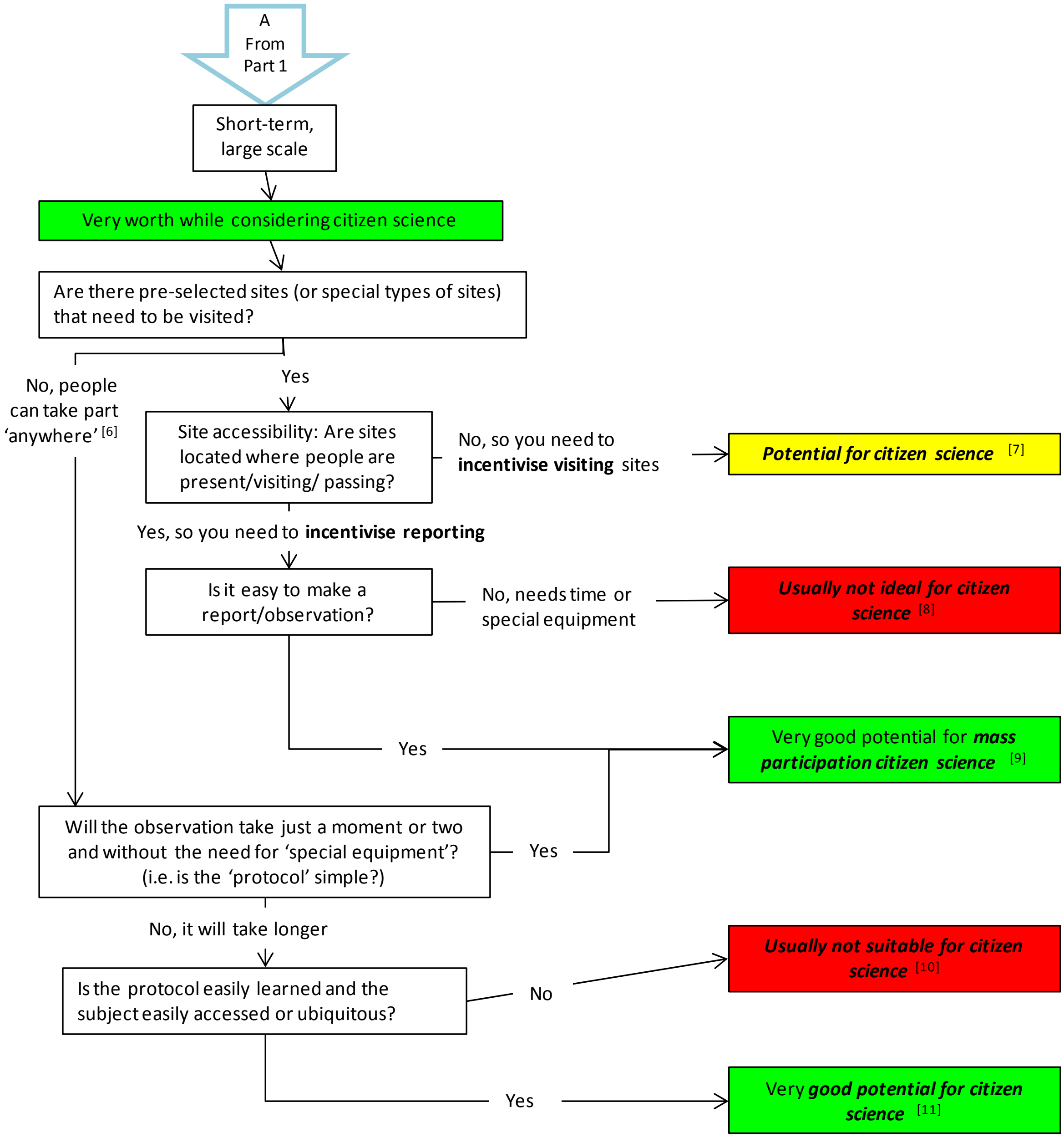
We believe that the decision framework will be most-productively used in an interactive way, rather than a formulaic way.

2.2.2 The decision framework for citizen science

Part 1 of the decision framework.



Part 2 of the decision framework.



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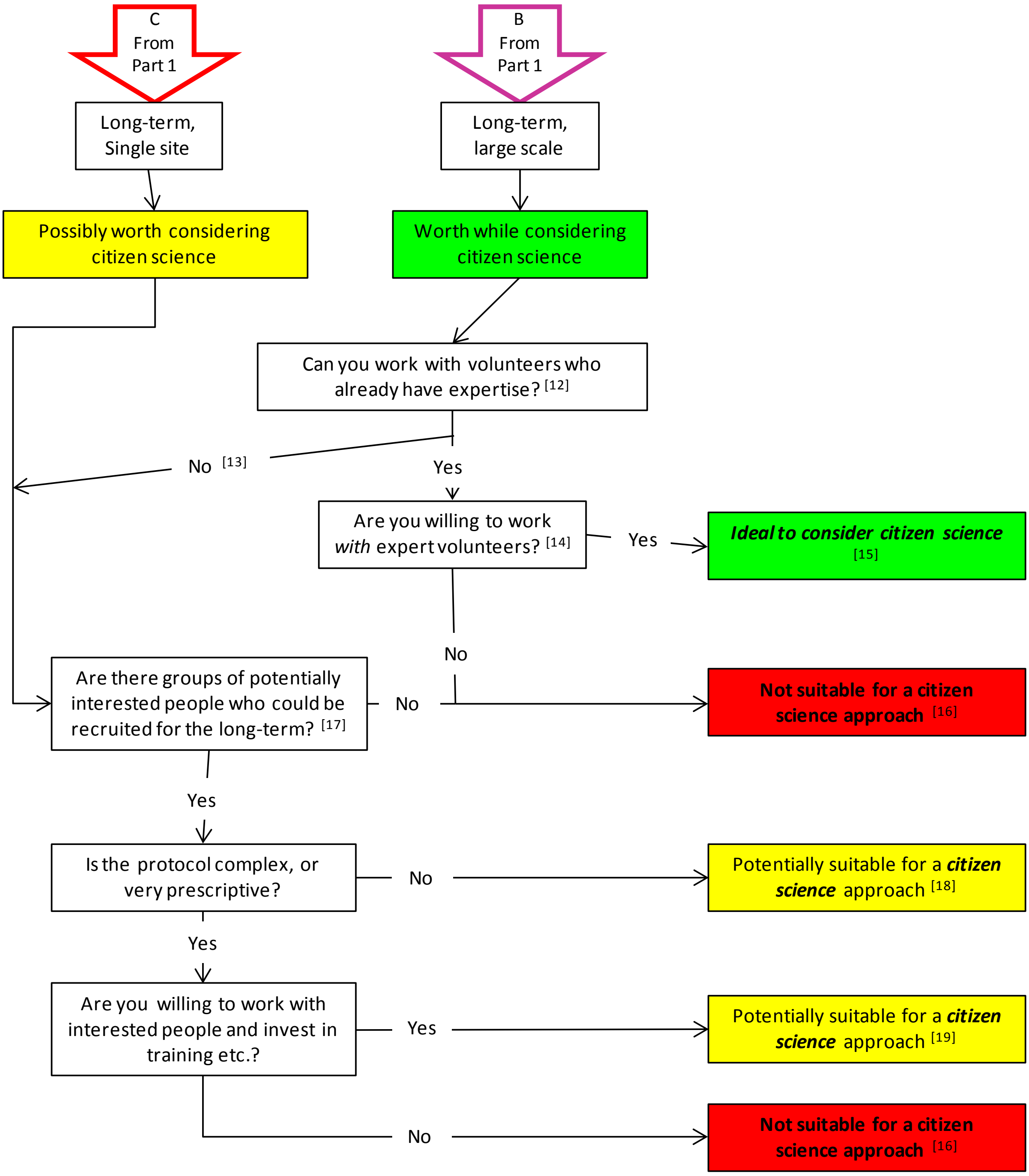
Part 2 of the decision framework (continued)



Notes on the decision framework

[1] Here we use the term ‘crowd-sourcing’ to describe the sort of tasks that can easily be distributed for people to do on their own terms, especially at the computer. They are ideal for tasks that require human intelligence for problem solving or pattern recognition. Sometimes projects can be broken down to separate making out-of-doors observations from a crowd-sourced (computer-based) component, thus permitting people to be engaged with the crowd-sourced components even when they are unable to make observations outside.

[2] Safely does not mean risk free, risk can be reduced with appropriate training but risk assessment is *always* needed for citizen science projects.

[3] Limitations to a sensor being ‘available’ for public use include it being too complex or too expensive. However technological advances may quickly make sensor approaches affordable and tractable. Making sensors available could be providing them free, or making them available to purchase (a form of ‘crowd funding’ of the project), hire or borrow.

[4] We ask whether the project requires repeat visits rather than whether the project is ‘long-term’, because monitoring can be long term but collected by multiple people (from the same site or from multiple sites). Our distinction here makes clear an emphasis on volunteer *retention*, not just *recruitment*.

[5] Short-term, single-site projects can be ideal to engage with people and provide education, but are less suitable for citizen science. ‘Bioblitzes’ (recording as many species as possible on a site in one day) are short-term, single-site projects; their scientific value is due to the presence of experts, but they have an important role in public engagement with nature.

[6] ‘Anywhere’ means people do not have to travel to somewhere specific to take part, though they may need to be in a suitable habitat. Clearly, there is a judgement to be made for each circumstance and intended audience whether locations could be viewed as ‘anywhere’. For example, depending on the audience, ‘large rivers’ or ‘arable fields’ could be argued either way (most people are not near large rivers or spent time in arable farmland, but equally, a lot of people will visit large rivers or walk near arable farmland). Equally a project requiring a visit to ‘woodland’ might require a special trip, but many people could choose to make that trip.

[7] There are relatively few citizen science examples of trying to incentivise the visiting of sites (as is done with geo-caching), but there is potential for this.

[8] Usually not suitable for citizen science due to a mismatch between the intended audience and the ease of reporting.

[9] Mass participation projects can be ideal in gaining a ‘snap-shot’ overview of the state of something. Its success can rely on being featured in the mass media; alternatively it can take advantage of breaking stories in the news, in which case rapid response is necessary. You need to think clearly about the trigger for involvement (why would someone take part? Is it recording something ‘special’?). Also, how many records will be sufficient for your needs? Asking people to record something that occurs or is seen too infrequently is not ideal because they may forget the prompt to report it (unless it is very memorable). Asking people to record

something that occurs or is seen too frequently (e.g. all sightings of a common animal, or reports of river quality) is not ideal because there are too many triggers to record, hence it becomes too overwhelming and reduces motivation to submit reports. Making these observations more structured is an alternative (e.g. report your local river quality each month), but this comes under the sections regarding 'long-term' surveillance.

[10] Usually not suitable for citizen science due to a mismatch between the intended audience (anyone) and the accessibility of the project (limited opportunities).

[11] Engaging with a general audience to undertake a reasonably detailed task is a typical example of citizen science (e.g. OPAL http://www.opalexplorenature.org/). One of the key aspects to this is to ask why people would get involved – what is the trigger to get involved now rather than wait (and potentially forget to take part), and to ask why people would take part a second time – what are the incentives for continued engagement? Such a project definitely needs sufficient (i.e. substantial) investment in supporting resources and in recruitment.

[12] It can be more successful to work with people who already have expertise (and interest) in the subject, e.g. working with birdwatchers to undertake surveys, rather than trying to recruit people who do not already have an interest in birds. Generally this question is only relevant when considering extensive/multiple site surveys.

[13] If you desire long-term large-scale monitoring by volunteers but do not have a ready pool of willing expert volunteers then you need to think carefully about what is their incentive to be involved.

[14] This question is important because although there may be regulatory desire to collect data in a certain way, if the intended volunteer participants are not amenable to that approach then developing the project may not be sensible, as the project will have a high chance of failure. However, by working with the intended participants you could collaborate in the design of the project to develop an approach that is acceptable for the intended participants and gain greater support for your project.

[15] For this long-term surveillance, you need to demonstrate a long-term commitment to the project to fully engage with volunteers.

[16] For this long-term surveillance, it is not suitable for citizen science because of a lack of potential participants or an unwillingness to be flexible in project design.

[17] This is a question about the audience that you have identified. Groups of potentially interested people are often people who have a vested interest in the outcome of the surveillance, e.g. local action groups, or anglers concerned about river quality, mountain walkers concerned about invasive plants etc.

[18] A key question that you need to consider is why someone would start to get involved and why they would continue to be involved. Training participants requires time and investment. You could have quite high drop-out rates, but this approach has the potential to produce some really committed volunteers.

[19] It may not be suitable because you are unable to commit sufficient resources for a long enough time period.

2.3 Final thoughts on the use of the decision framework for citizen science

If you have decided that citizen science may be useful, we strongly recommend that you refer to the 'Guide to Citizen Science' (Tweddle *et al.* 2012) to help you consider the steps in actually setting up a citizen science project. Below we summarise a few important aspects that you should consider, which are largely based on the Guide.

2.3.1 Stop and check: is citizen science appropriate or would it be better to use an alternative approach?

Citizen science can be effective and excellent, but it is not always optimum for data collection: the advantages of a citizen science approach do not outweigh the disadvantages in some circumstances. If you have decided that citizen science may be useful to you, we would encourage you to stop and consider once again whether citizen science is the best way to proceed. Undertaking systematic surveying with contracted professionals may be more effective because it allows you to stipulate the sampling requirements. You will gain data sufficient for your needs and can specify the spatio-temporal extent of sampling in response to formal investigation (e.g. knowledge of rates of change or seasonal variation, or a formal analysis of statistical power). With citizen science, a great risk is that you have insufficient public participation to gain adequate data for your needs. See Pocock & Evans (in press) for discussion considering the competing aspects of citizen science versus professional monitoring.

While citizen science will have the added benefit of allowing people to engage with their environment, this could also be undertaken with a separate programme of public engagement. By separating the data collection and the public engagement with the environment, these two activities could each excel and proceed in parallel.

2.3.2 Resources: the organisers' time

Resources are needed at all stages of projects: in the set up and design, in the running of the project, and in the reporting phase of the project. Although citizen science can be very cost-effective, it is not free, and has to be resourced properly. The most important resource is people's time, especially for communicating with participants (via email, via the media, through blogs etc.). Time is also required when setting up projects, and there has to be sufficient lead time to perfect protocols, set up databases and websites etc.

During the running of the project it is important to ensure websites continue to operate well (website links work, databases work, blogs are updated etc.). Project organisers (or other staff) need to be able to commit time for the life-time of the project, and in larger organisations it is essential to recognise this, including the value of maintaining the same staff where they have public-facing roles in order to build rapport and trust with participants. The enthusiasm of people involved in organising citizen science projects is vital, and within a larger organisation this should be highly valued; there are many examples of citizen science project blogs that have been launched with great excitement but have rapidly ceased to be active or updated.

Resources also need to be provided for the analysis, interpretation and communication of results. Often the analysis of citizen science data is complex and while the analytical approach should be planned before the project is started, undertaking the analysis and communicating the results to participants, and the general public (if appropriate), still requires resources.

2.3.3 Resources: infrastructure and data protection

Infrastructure is an important aspect of citizen science, particularly the use of online databases, visualisation and feedback. Although web developers can set up bespoke databases, there are many examples of mature technologies for databases and for visualisation (Roy *et al.* 2012). Broadly these can be divided into: 1) bespoke technologies that are designed for a specific purpose and audience (e.g. NatureLocator smartphone apps http://naturelocator.org/ and the online databases of many extant citizen science projects), and 2) adaptable template-type platforms where the project leader can modify the content within the bounds of the fixed parameters of the platform. The template-type platforms have the advantage of ease-of-use for content management by the project team , but may lack sufficient flexibility to allow content and design to be targeted to specific audiences (e.g. Epicollect http://www.epicollect.net/ for mobile applications, PyBossa http://crowdcrafting.org/ for crowd-sourcing, CitSci.org http://www.citsci.org/ for data collection and visualisation, Ushahidi http://www.ushahidi.com/ for crowd-sourced mapping, OpenTreeMap http://www.azavea.com/products/opentreemap/ for mapping trees). Some platforms do provide a hybrid of these approaches; allowing instances of the technology to be incorporated into local websites etc., but providing tools and code that can be repurposed, e.g. Google code (http://code.google.com/) or Indicia (a database toolkit developed by the Centre for Ecology & Hydrology http://www.indicia.org.uk/, which is purpose-designed for the collection, visualisation, verification and sharing of biodiversity data and could, with adaptation, be used for the collection of environmental data as well). We strongly recommend that data are stored in a way that makes it easily accessible and easy to share. Often open-source tools can be used to reduce costs, though we recommend the use of fairly mature and well-supported technologies.

Data protection needs to be considered when storing personal data online. It may be possible to overcome this by not collecting any personal information, but this limits the potential for communication with people and personalised feedback. Advice must be sought to make sure that any online data storage in the UK complies with the Data Protection Act.

2.3.4 Quality assurance and verification

One of the key aspects of data collected by citizen science projects is that to be useful it needs to be 'of known quality'. 'Known quality' can be either 'guaranteed to be accurate' or having had quantified the degree of error or bias.

One of the most cost-efficient ways of ensuring high data quality is to have thoroughly tested protocols (Tweddle *et al.* 2012) so that errors of interpretation can be identified and errors in measurement/identification can be quantified. For some projects, the only data that is accepted is that which is guaranteed to be correct. In such cases, records may only be accepted if there is accompanying information (e.g. a photograph). Alternatively, accompanying information may be only required for unusual records (e.g. extreme measurements). This conservative approach may result in the discarding of genuinely interesting data points, so should be undertaken with care.

For other data, random error and bias are two reasons why data are of less-than-perfect quality. Random error will increase the 'noise' in the data (for example, inaccuracy in making counts), thus making it more difficult to accurately discern signals in the data. However, most error is likely to be some form of bias, in which the error is systematic (e.g. people tending to over-estimate counts) and this can vary due to many different factors, including people's level of experience. This bias needs to be quantified and explicitly accounted for in the analysis. One hidden, and so often overlooked, source of error is the interpretation of an absence of records. People are most likely to record the presence of something, rather than record its absence, which may create systematic bias in the data.

2.3.5 Participant safety

Although citizen science should only be considered if it can be undertaken by volunteers safely, no activity is risk-free. Therefore risk assessments should be undertaken and sources of risk in the instructions to participants should be removed, as far as possible. The risk, and its reduction, should be communicated clearly and succinctly to participants. The level of support and training will influence the types of risk that are acceptable. For example, when assessing water quality, members of the general public might be asked to make observations from the bankside only (e.g. as with the Algal Bloom Pilot project http://www.fba.org.uk/algal-bloom-pilot-project), while actually wading in the water might be deemed to be acceptable if personal training was provided (e.g. as with the Riverflies Partnership (http://www.riverflies.org/).

2.3.6 Communication

Communicating with the target audience is clearly a vital aspect of citizen science. Communication via the mass media is appealing for many organisers of citizen science. Promoting projects in this way can be effective (if the intended audience is the general public). However the risks are high; whether stories are picked up by journalists depends on their perception of the interest of the story, and whether they are ultimately reported upon will partly depend on circumstances outside of the project organiser's control (e.g. other news items on that day). We would recommend exploring alternative, more stable, routes of communication in addition to (or instead of) relying on the mass media. For example, communication to potential target audiences could be via organisations' newsletters. Social media (e.g. Twitter and Facebook) has opened up new opportunities for promoting projects and communicating with participants; it can allow communication to be targeted to potential audiences, but also provides the opportunity for promotion to be enhanced via 'word-of-mouth'. Workshops and training sessions can provide invaluable face-to-face contact with project participants. Varied approaches to communication will ensure projects are promoted in a way that meets the requirements of the diverse range of potential participants.

It is also important to consider what and how you communicate (Common Cause 2013). Not only do you need to communicate the 'why?' and 'how?' of your project, but you should also communicate the 'so what?'. For some projects, participants might expect action in response to their observation but this may be beyond the scope of the initiative e.g. getting littered water courses cleaned on their behalf. For some other projects, participants might be asked to collect data that leads to a response they find unacceptable, e.g. eradication of an attractive but invasive non-native species. It is important to consider and address people's expectations early in the project.

2.3.7 Legislative implications

There is growing awareness of the legal policies and codes of conduct that may be relevant to citizen science. These include data ownership and intellectual property, privacy, legal compliance and liability. For example, what are the implications of volunteers being asked to report notifiable diseases on someone else's land, both on the landowner and the agency given the task of responding? If the citizen science data leads to action by regulatory authorities, then are the data sufficiently accurate and robust? If the citizen science data is used to derive an indicator on which government or agencies commit to act, then are the data sufficiently accurate and robust? Is the promoting organisation responsible if someone is injured while participating in citizen science?

These are complex issues, so for more information we recommend you consult the guide to best practice in this area, recently published by Bowser et al. (2013).

Part 3. Citizen science and environmental pressures relevant to SEPA

In this part of the report, our remit was to consider environmental pressures relevant to SEPA. However, much of the content will also be relevant to other organisations active in environmental/biodiversity monitoring, although they will need to take in account their own circumstances and requirements.

3.1 Is citizen science useful to SEPA?

As we have determined in the report so far, citizen science is a potentially valuable tool for organisations such as SEPA. When monitoring the impacts of environmental pressures, citizen science may be a very suitable approach. However, for some other impacts, citizen science may not be suitable. Here, we consider the environmental pressures relevant to SEPA; assess the likely impacts of the pressures and provide a commentary on the likely suitability for a citizen science approach in monitoring these impacts.

We note that the suitability of citizen science can depend substantially on the specific aim of the project. Two proposed projects could differ dramatically in their suitability for a citizen science approach depending on subtle differences in their aims. These subtle differences would be exposed when using the decision framework. Perfectly specifying the question in advance is unlikely to be the way in which the decision framework is used (as we highlighted in Section 2.2.1). This, therefore, makes it difficult to apply the decision framework to potential citizen science projects without detailed knowledge of SEPA's priorities, policies and practice. Therefore, instead we have provided general guidance about the likely suitability of citizen science in each case.

The pressures that we have considered are those relevant to environmental monitoring in Scotland as detailed in Appendix 1 of the Scottish Environmental Monitoring Strategy (The Scottish Government 2011) supported by the Coordinated Agenda for Marine, Environment and Rural Affairs Science (CAMERAS) initiative. However, many of these pressures are relevant across the world in countries from across the economic spectrum.

3.1.1 Using citizen science as part of a monitoring strategy

In our commentary below (Section 3.2) we assess the potential for a citizen science approach, but we want to re-iterate our comments in Section 1.3.2 that professional and citizen science monitoring are not mutually exclusive. (We define a 'professional' as someone who is contracted, and usually paid, to collect the data. They will have the expertise, or have been trained, to collect data to a standard deemed acceptable to the contracting organisation.) There is considerable scope for a minimum level of monitoring to be conducted 'professionally' but for it to be augmented extensively with a citizen science approach. There are many ways in which professionally-collected data can be augmented by a citizen science approach. Citizen science could add generality by sampling in a much wider range of sites, albeit less frequently. Also, citizen science could add precision by sampling much more frequently than professional monitoring in a few key sites.

3.1.2 Developing indicators from citizen science data

Typically the collection of data for indicators needs to be supported in the long-term for it to be useful. The support of participants over a long time period is challenging and can be expensive. For example, 7 out of 26 UK headline biodiversity indicators rely on citizen science data, at an approximate cost of £100, 000 per indicator per year (Roy *et al.* 2012). In each case these data are based on structured data collection with a systematic design, which makes them statistically rigorous. Although the 26 UK headline biodiversity indicators include aspects of environmental change in general (e.g. water quality or pressures from climate change), each indicator that relies on volunteer-collected data depend on people's observations of wildlife (e.g. birds or butterflies) and the participants are mainly recruited from groups already engaged with wildlife recording (e.g. birdwatchers). This ensures that the volunteers already have a high degree of commitment and expertise. All projects leading to the development of UK headline biodiversity indicators have grown incrementally, with a relatively long phase of testing (often several years), and are run by established conservation organisations. In contrast to this approach, mass participation can be an excellent way to gather a 'snap shot' of the state of an aspect of the environment with extensive spatial coverage. When considering the development of environmental indicators, it is also important that participants collect data for which there is a known and quantified link to the pressure of concern.

3.2 The citizen science approach to monitor environmental pressures

Up to now in this report we have considered ***how*** to make a decision whether citizen science might be useful. We have introduced broad issues that make a citizen science approach more or less suitable (Section 2.1) and we have provided a decision framework that we expect will be used interactively to allow the suitability of a citizen science approach to be assessed (Section 2.2). Here we provide a commentary on ***whether*** a citizen science approach is likely to be suitable in monitoring a wide range of environmental pressures (summarised in Table 1, overleaf).

Pressure	Suitability for a citizen science approach
Greenhouse gas emissions	2
Ozone depleting substances	1
Acidic substances	2
Nutrient enrichment	3
Hazardous substances	2
Ozone precursors	3
Particulates	2
Radioactive substances	1*
Odorous substances	1
Noise and vibrations	3
Waste management	2
Abstractions and flow modifications	2
Impoundments / barriers	3
Hydrological impacts of discharges	2
Forestry	2
Urban development	2
Agriculture	2
Recreation	3
Fishing and aquaculture (freshwater)	2
Invasive non-native species	3

Table 1. A summary of the suitability of a citizen science approach for assessing impacts of the environmental pressures which were listed in Appendix 1 of the Scottish Environmental Monitoring Strategy (The Scottish Government 2011).

* except in exceptional circumstances

Key	Suitability for a citizen science approach and overall suitability for SEPA
1	Not likely to be suitable
2	Worth considering further
3	Well worth considering further

Pressure:	Greenhouse gas emissions
Potential impacts:	Mostly indirect impacts via climate change: changes in growing, breeding and migration seasons; shifts in species abundance and diversity; increased flood risk (rivers, drains); extreme weather (rainfall, drought).
Suitability for a citizen science approach	**Worth considering further.** Although surveillance of emissions *per se* is generally not suitable for a citizen science approach, there is a possibility that gas sensors could be employed by people. CO_2 sensors are probably of dubious value for monitoring such a diffuse pollutant, but they may be useful for identifying point sources of methane, for instance. In a report to SEPA on urban air quality citizen science, Reis et al. (2013) consider a range of different sensors that may be applicable. See that report for further information. Odours from landfill (a possible indication of greenhouse gas emission) could also be reported. Over the long-term people could contribute to assessing impacts on climate

Pressure:	Greenhouse gas emissions
	change on weather by making weather observations to augment official observations from meteorological stations, e.g. CoCoRaHS monitoring rain, hail and snow in the USA and the Weather Observations Website, in which meteorological observations can be automatically uploaded to an online database. Citizen science approaches could be used to engage people in detecting subtle changes in climate averages and increases in the incidence of extreme weather events, especially where these are very localised, although the value of engaging people with the issues (i.e. helping them to be aware of the potential impacts of climate change) is possibly greater than the value of the data, given that useful data are long-term, large-scale and already collected by meteorological organisations. Observations of wildlife through biological recording could 'determine' temporal (phenological) trends (birds nesting and hatching, flowers flowering, or budburst of trees).
Examples of extant projects	Met Office - Weather Observations Website http://wow.metoffice.gov.uk/ Community Collaborative Rain, Hail and Snow Network http://www.cocorahs.org/ Woodland Trust – Nature's Calendar http://www.naturescalendar.org.uk/ British Geological Survey – flood events http://www.bgs.ac.uk/flooding/reportAFlood.html
SEPA's role	SEPA has a supporting role in delivery of management of this pressure. SEPA is not responsible for and does not have a focus on this pressure.
Related pressures	Ozone precursors; Odorous substances; Hydrological impacts of discharges; Abstractions and flow modifications

Pressure:	Ozone depleting substances
Potential impacts:	Ozone in the stratosphere (high level ozone) works like a sunscreen blocking out harmful ultraviolet rays (UV-B) which can damage DNA. Effects can be seen in vegetation, human health (skin cancer, increased risk of cataracts and snow blindness, accelerated aging of skin and damage to the immune system in animals). Unicellular algae, plant hormones and chlorophyll are especially sensitive and reductions in plant productivity can be expected. In freshwater bodies phytoplankton is very sensitive.
Suitability for a citizen science approach	**Likely to be unsuitable.** Could report incidences of skin cancer but this could equally reflect the public's failure to take measures to protect themselves i.e. suncream use. Given that UV-B causes some plastics to degrade, this process could be calibrated and used as a sensor. However, UV-B is so widespread that it is unlikely that citizen science could add substantially to the professional monitoring already in place.
Examples of extant projects	Due to its unsuitability for citizen science, no relevant projects are known.
SEPA's role	SEPA has a supporting role in delivery of management of this pressure. For this pressure SEPA has a shared remit with other partners (Scottish Government).
Related pressures	Greenhouse gas emissions; Radioactive substances

Pressure:	Acidic substances

Potential impacts:	Acidification affects biological processes in soil and water via enzymes, changes in nutrient availability, and increases in mobility of toxic cations e.g. metals especially aluminium. Impacts will depend on whether the pressure is chronic or acute (event based). If released as a gaseous acid plume, these substances could be toxic and cause direct damage to sensitive surfaces e.g. vegetation, or over the long-term building materials made of calcareous rock. Acid lesion browning of young foliage is relatively distinctive. In freshwaters effects of chronic acidifying inputs e.g. 'acid rain' and afforested catchments, acidity can be monitored using absence of sensitive invertebrates in soil and water.
Suitability for a citizen science approach	**Worth considering further.** Possibility of surveillance of pH (in soil or water) regularly to get time trends. Indicator papers could be used, although specialist equipment and training would be better. Sensors suitable for citizen science could be developed, but the need to have a rigorous protocol for sample collection would limit the uptake (the protocol would be too complex). pH is highly variable for many reasons, so not necessarily a link to pollution. Species, especially plants, that are indicative of acid environments or species which are sensitive to acidity could be monitored through a citizen science approach. Event-based damage to foliage might lend itself to mass participation citizen science.
Examples of extant projects	Riverfly Partnership http://www.riverflies.org/ provides training for volunteers, including anglers, to systematically sample for macro-invertebrates which may be affected by acidification World Water Monitoring Day distributes chemical test kits to children globally for water monitoring: http://www.worldwatermonitoringday.org/
SEPA's role	SEPA has a clear legislative remit to address this pressure: ▪ Pollution Prevention & Control Regulations (PPC) For this pressure SEPA has a shared remit with other partners (Local Authorities)
Related pressures	Forestry; Hazardous substances

Pressure:	Nutrient Enrichment
Potential impacts:	Nitrogen (N) enrichment in semi-natural systems causes reductions in species richness, change in species composition, loss of key species, acidification, increased nitrate leaching, with knock on effects on drinking water quality. Phosphate (P) enrichment (fertilisers, septic tank discharges: human excrement and detergents) can lead to toxic algal blooms: nutrient enrichment can predispose lakes to algal blooms when the temperature increases. There is a cascade of indirect effects on phenology (budburst, flowering, egg-laying), greenhouse gas emissions, increased susceptibility to abiotic (climate) and biotic (pests and pathogens) stress. Indicators of nutrient enrichment are changes in plant and lichen composition, including changes in the abundance or presence of known nitrophiles and nitrophobes, increases in the nutrient Ellenberg score (Pitcairn et al. 2006) and diatom composition (Kelly & Whitton 1995).
Suitability for a citizen science approach	**Well worth considering further.** Observations on algal blooms could be made through citizen science; daily records of presence and extent of algal blooms could be made relatively easily, so it is highly relevant for freshwater that is used for amenity purposes. Recording of species, especially lichens and plants, which respond to N/P may also be feasible, and the

Pressure:	Nutrient Enrichment
	nitrophiles/nitrophobe classification of plants, bryophytes and lichens (Pitcairn et al. 2006) could be developed into indicator taxa/types used to assess eutrophication. Many lichens are very difficult to identify to species-level, but the OPAL Air Survey has used easily-identifiable nitrogen-sensitive and nitrogen-loving lichens. Currently there is a trial project that links the mobile collection of photos of lichens (via Epicollect) with repeatable measurement of their growth (via Crowdcrafting, which allows anyone to be involved in this analysis, whether or not they contributed photos) to infer air quality. To use these data for monitoring purposes rigorous protocols are required coupled with long-term coordination and infrastructure support. Soil nutrient status is difficult to measure and especially to interpret. For projects assessing indicators of the nutrient quality of water there are important health and safety considerations that need to be considered.
Examples of extant projects	Methods for monitoring water quality through citizen science http://disc.sci.gsfc.nasa.gov/education-and-outreach/additional/science-focus/locus/index.shtml/amateur_scientist_guide_000.shtml Water Action Volunteers http://watermonitoring.uwex.edu/wav/ Algal Bloom pilot project http://www.fba.org.uk/algal-bloom-pilot-project Riverfly Partnership http://www.riverflies.org/ Epicollect linking to Crowdcrafting for the collection and assessment of lichen size to indicate pollution: http://plus.epicollect.net/lichens and http://crowdcrafting.org/app/airquality/ OPAL Air survey http://www.opalexplorenature.org/AirSurvey specifically sought to survey for nitrogen-sensitive and nitrogen-loving lichens. World Water Monitoring Day distributes chemical test kits to children globally for water monitoring: http://www.worldwatermonitoringday.org/ See also Case Study 2 (Section 4.2)
SEPA's role	SEPA has a clear legislative remit to address this pressure: ▪ Pollution Prevention & Control Regulations (PPC) ▪ Waste Management Licensing (WML) ▪ Controlled Activity Regulations (CAR) For this pressure SEPA has a shared remit with other partners (Local Authorities).
Related pressures	Acidic substances; Agriculture; Forestry; Fishing and aquaculture (freshwater)

Pressure:	Hazardous substances
Potential impacts:	Depends on a variety of factors including: the specific substance, receptor exposure/sensitivity, distribution, concentration, fate, persistence. Hazardous substances include: toxic substances, carcinogens, substances causing heritable damage, harmful to living organisms (corrosive, irritants e.g. dust).
Suitability for a citizen science approach	**Worth considering further.** Hazardous substances are difficult to quantify and describe. Additionally there are health and safety implications which render citizen science unsuitable for direct monitoring of hazardous substances. Dust could be monitored using sticky pads which are subsequently analysed (potentially by expert facility) but considerable infrastructure would be required. However, monitoring the impacts of hazardous substances could possibly suitable (e.g. hazardous substances in

Pressure:	Hazardous substances
	water courses impacting on freshwater invertebrates).
Examples of extant projects	See Particulates for some relevant citizen science projects, although the likely unsuitability of monitoring non-particulate hazardous substances is demonstrated by a lack of other relevant citizen science projects.
SEPA's role	SEPA has a clear legislative remit to address this pressure: ▪ Pollution Prevention & Control Regulations (PPC) ▪ Waste Management Licensing (WML) ▪ Contaminated Land Regulations Issues related to this pressure are predominantly within SEPA's domain.
Related pressures	Particulates

Pressure:	Ozone precursors
Potential impacts:	Indirect impacts affecting both air quality O_3 (ozone) concentrations and climate; O_3 concentrations have been linked to detrimental effects on human health, reduced crop yields and damage to leaf crops (reducing value), reduced tree yields and negative effects on semi-natural ecosystems: changes in species composition, reduction in N fixation. Lesions and loss of chlorophyll, yellowing i.e. premature senescence.
Suitability for a citizen science approach	**Well worth considering further.** Precursors linked to anthropogenic nitrogen pollutants, methane and climate probably not suitable for citizen science in part because source and effects not coupled locally. Impacts of O_3 could be monitored using O_3 sensitive plants. In ozone sensitive plants a distinctive pattern of foliar browning is a sign of ozone damage. In the USA, ozone-sensitive plants have been identified, both native species (http://www.nrs.fs.fed.us/fia/topics/ozone/species/) and ornamental plants that have been planted in 'ozone gardens'. For a more systematic approach, it could be possible to use specific varieties/cultivars of clover and tobacco (planting both ozone-sensitive varieties and ozone-tolerant controls) to assess foliar damage and hence indicate peak concentration episodes in particular localities. There are also passive samplers available for the public to expose and return on a regular basis but this would require coordination and analytical resources. Reis et al (2013) highlight that for the application of air quality sensors in a citizen science context, two main use cases can be identified: (1) small, lightweight portable sensors worn or carried by individuals can provide a good measure of personal exposure and at the same time generate a spatially and temporally resolved picture of urban air quality; and (2) a network of fixed monitoring sites, for instance a smaller version of an AQ Mesh type network, which could be deployed to and operated by citizens across an urban domain, providing a spatially better resolved network than current fixed site reference installations. For a review of options for low-cost sensors see Reis et al (2013).
Examples of extant projects	Ozone biomonitoring http://www.handsontheland.org/environmental-monitoring/ozone-bio-monitoring.html Ozone gardens http://handsontheland.org/data/documents/ozone_monitoring_guide_2011.pdf
SEPA's role	SEPA has a clear legislative remit to address this pressure:

Pressure:	Ozone precursors
	▪ Pollution Prevention & Control Regulations (PPC) For this pressure SEPA has a shared remit with other partners (Local Authorities).
Related pressures	Hazardous substances; Odorous substances; Particulates

Pressure:	Particulates
Potential impacts:	Atmospheric aerosols exhibit chemical heterogeneity, spatial and seasonal variability, and result in a wide range of health impacts (mortality, respiratory disease from PM 10, 2.5, cardiovascular disease, eye irritation etc). Aerosols affect climate, exerting warming effects (black carbon), cooling effects (sulphate and organic carbon), and precipitation and cloud cover (nucleus for formation). Direct impacts: issues concerning human health associated with chemistry of the dust e.g. toxic or carcinogen.
Suitability for a citizen science approach	**Worth considering further.** Issues are transnational; source and receptor may be borders apart. However volcanic ash and its distribution, or Saharan dust could be monitored through mass participation citizen science using various approaches such as iDust which utilises the *Arduino* open-source electronic prototyping platform and a *Shinyei* PPD42 particle sensor (Reis et al 2013), or adaptations of the clip-on smartphone sensor iSpex for recording atmospheric aerosols
Examples of extant projects	British Geological Survey – monitoring volcanic ash http://www.bgs.ac.uk/research/volcanoes/GrimsvotnAshCollection.html http://www.bgs.ac.uk/research/volcanoes/ashMap.html iSPEX http://ispex.nl/en/
SEPA's role	SEPA has a clear legislative remit to address this pressure: ▪ Pollution Prevention & Control Regulations (PPC) ▪ Waste Management Licensing (WML) For this pressure SEPA has a shared remit with other partners (Local Authorities).
Related pressures	Hazardous substances

Pressure:	Radioactive substances
Potential impacts:	Direct effects on DNA, causes mutations in chromosomes expressed phenotypically leading to disabilities, malfunction. Uptake in to food chain and secondary contamination e.g. from nuclear reactors, Chernobyl.
Suitability for a citizen science approach	**Likely to be unsuitable, except in exceptional circumstances.** There are health and safety implications rendering citizen science unsuitable. However, in extreme situations, such as the failure of a nuclear reaction in Japan, mobile sensors provided a citizen science approach to undertake surveillance.
Examples of extant projects	Radiation Watch http://www.radiation-watch.co.uk/
SEPA's role	SEPA has a clear legislative remit to address this pressure: ▪ Radioactive Substances Act (RSA) For this pressure SEPA has a shared remit with other partners (Nuclear Installations Inspectorate, Department of Transport).
Related pressures	Hazardous substances; Noise and vibrations

Pressure:	Odorous substances
Potential impacts:	Indicator of presence of toxic gas or substance. The presence and strength of the odour will be concentration related.
Suitability for a citizen science approach	**Possibly worth considering further.** It is unlikely that there will be sensors sufficiently general to detect and quantify odorous substances for use by volunteers (unlike for sound, e.g. the WideNoise project http://cs.everyaware.eu/event/widenoise or NoiseTube http://www.noisetube.net/) and the detection of toxic gases clearly has health and safety concerns. However, the detection of nuisance odours by nose is straightforward, and responses could be reported and mapped via participatory mapping techniques (e.g. Mapping For Change). This could work especially effectively in local situations, giving people the ability to record their responses to smells (as with the Royal Dock Noise Mapping project). However, it will be important to manage people's expectations as to when and how a response will occur.
Examples of extant projects	Participatory mapping projects could be used to record people's perception of nuisance smells, e.g. Mapping for Change http://www.mappingforchange.org.uk; and Royal Dock Noise Mapping http://www.mappingforchange.org.uk/portfolio/royal-docks-noise-mapping/ which is an example of local participation in mapping nuisance noise
SEPA's role	SEPA has a clear legislative remit to address this pressure: ▪ Pollution Prevention & Control Regulations (PPC) ▪ Waste Management Licensing (WML) For this pressure SEPA has a shared remit with other partners (Local Authorities).
Related pressures	Ozone precursors; Noise and vibrations

Pressure:	Noise and vibrations
Potential impacts:	Indicator of potentially damaging activities e.g. industrial machinery, mining. Possible direct impacts on human, animal health and activities, depending on frequency and persistence.
Suitability for a citizen science approach	**Worth considering further.** People could record instances of severe noise, though making sense of gaps in the data could be problematic (lack of reporting noise versus a lack of noise?). Smartphones could be used as sensors to passively record noise (including characteristics of frequency), or identify extreme noise events and hence build up soundscapes.
Examples of extant projects	Widenoise http://cs.everyaware.eu/event/widenoise Noisetube http://noisetube.net/ Eye on Earth http://watch.eyeonearth.org/?SelectedWatch=Noise
SEPA's role	SEPA has a clear legislative remit to address this pressure: ▪ Pollution Prevention & Control Regulations (PPC) For this pressure SEPA has a shared remit with other partners (Local Authorities).
Related pressures	Radioactive substances; Odorous substances

Pressure:	Waste management
Potential impacts:	Indirect effects: waste is often toxic (electrical: heavy metals, organo-pollutants), can initiate increases in greenhouse gas emissions e.g. from landfill; food waste can lead to vermin problems and spread disease, non-sustainable for metals due to global use exceeding demand. Fly tipping especially of industrial, building waste can lead to metals etc can leaking into and contaminating water courses.
Suitability for a citizen science approach	**Possibly worth considering further.** Potential for citizen science in mapping litter or fly tipping but impacts rather indirect, variable and difficult to describe. Making sense of gaps in the data could be problematic (lack of reporting litter versus lack of litter), although in the Creekwatch project, litter is just one aspect of what is recorded, so the results are probably less biased. Some projects allow mobile reporting of fly tipping (Love clean streets), but this is more to target responses by local councils. Managing participants' expectations is key; some projects are focussed on monitoring the state of the environment, while others (e.g. Love clean streets) are focussed on action and responding to reports.
Examples of extant projects	Love clean streets http://www.lovecleanstreets.org/, which is a network of local authorities in the UK Creekwatch http://creekwatch.researchlabs.ibm.com/, which is a project run by IBM in collaboration with the California State Eye on Earth project (run by the European Protection Agency) is in development for monitoring marine litter Open source platforms, such as Ushahidi https://crowdmap.com/, could be used for reporting litter or flytipping, and a pilot of this has been commissioned by SEPA.
SEPA's role	SEPA has a clear legislative remit to address this pressure: ▪ Waste Management Licensing (WML) For this pressure SEPA has a shared remit with other partners (Local Authorities).
Related pressures	Urban development; Fishing and aquaculture (freshwater); Recreation

Pressure:	Abstractions, flow modifications
Potential impacts:	Indirect effects: Implications for water flow rates, sedimentation / flooding; downstream sensitive sites that depend on water.
Suitability for a citizen science approach	**Worth considering further.** Water depth and or flow could be implemented through a citizen science approach and targeted at specific user groups such as anglers. Mapping where water courses have run dry during periods of drought (e.g. in southern England) could use a mass participation citizen science approach. Water height could be assessed with the submission of time-stamped and GPS-referenced photographs of river level gauges (e.g. through a smart-phone app), with reading of the water level by SEPA staff for the latter. Water flow could be assessed qualitatively (e.g. smooth or turbulent) but, as with any project around water, health and safety issues must be considered and will probably restrict the monitoring that is possible.
Examples of extant projects	Creekwatch http://creekwatch.researchlabs.ibm.com/ British Geological Survey – flood events http://www.bgs.ac.uk/flooding/reportAFlood.html

Pressure:	Abstractions, flow modifications
SEPA's role	SEPA has a clear legislative remit to address this pressure: ▪ Controlled Activity Regulations (CAR) Management of this pressure is predominantly within SEPA's domain.
Related pressures	Impoundments/barriers; Greenhouse gas emissions; Hydrological impacts of discharges

Pressure:	Impoundments / barriers
Potential impacts:	Impoundments and barriers are permanent or temporary structures constructed to regulate water flow. Potential impacts are: (1) alteration of upstream and downstream river flow, sediment transport, hydromorphology and flood risk; (2) barrier to fish migration (e.g. salmon, trout, lamprey, eel).
Suitability for a citizen science approach	**Worth considering further.** The presence of impoundments could be directly observed, while their effects may be monitored through recording of river level gauges or fish distributions. Both could be as simple as the submission of time-stamped and GPS-referenced photographs from a smartphone app of a) impoundment structures, and b) river level gauges with reading of the water level by SEPA staff for the latter. Generic apps could also be used to estimate the height of impoundments (e.g. SmartMeasure), although each additional step of complexity will reduce the number of people likely to participate. Citizen science could be used for reporting the location of potential barriers to fish migration, and this information then used to focus surveys by professionals to assess these obstacles. Anglers and walkers regularly visit riverbanks, and so could provide citizen science monitoring. In particular, anglers are organised with associations and Fisheries Trusts and strongly interested in the potential impacts of impoundments. They could be engaged to participate in citizen science by submitting catch data on species affected by barriers or making other measurements. Indeed, RAFTS already run a project on barriers to fish migration and monitor fish catches. However, anglers or walkers are likely to be biased in the places that they visit, with some sites being much more popular than others. This may limit the effectiveness of citizen science monitoring. Safe observation from the riverbank should be possible in most cases, but participants' safety must be stressed (especially for keen participants who may take risks to try to gain a better view or picture of a barrier). Consideration should also be made about how to engage with members of the public who are not anglers about the importance of this subject. This project would be ideally suited to data collection via smartphones because they provide the ability to upload photographs and location from GPS. Given that mobile connectivity could be poor in many areas, apps would need to be designed in such a way submissions are stored offline and uploaded when connectivity (3G or WiFi) is available. This approach has been implemented in the PlantTracker app It is possible that some barriers could be identified from remote sensing, making it suitable for a crowd-sourced approach, as with ForestWatchers.
Examples of extant projects	PlantTracker http://planttracker.naturelocator.org/ ForestWatchers http://forestwatchers.net/

Pressure:	Impoundments / barriers
	See also Case Study 1 (Section 4.1)
SEPA's role	SEPA has a clear legislative remit to address this pressure: ▪ Controlled Activity Regulations (CAR) Management of this pressure is predominantly within SEPA's domain.
Related pressures	Abstractions and flow modifications; Hydrological impacts of discharges

Pressure:	Hydrological impacts of discharges
Potential impacts:	Impacts depend on the nature, amount, frequency, intensity of the discharges, in addition to the dilution power and, nature of the receptor and the life that it supports. Impacts are wide ranging for water quality and flooding. Deforestation increases discharge of water after rain and increases flood risk
Suitability for a citizen science approach	**Worth considering further.** There are a wide range of variables that could be monitored and large-scale spatial and temporal coverage would be useful. Making sense of gaps in the data could be problematic (lack of reporting floods versus lack of floods). Except for extreme floods, there may be problems with the definition of a flood, and so data may be of variable quality. However, it could provide presence-only ground-truthing to validate hydrological models. There is the potentially to link this to other pressures.
Examples of extant projects	British Geological Survey – flood events http://www.bgs.ac.uk/flooding/reportAFlood.html Riverfly Partnership http://www.riverflies.org/
SEPA's role	SEPA has a clear legislative remit to address this pressure: ▪ SEPA is Scotland's flood warning authority, plus other duties under the Flood Risk Management Act (FRM) For this pressure SEPA has a shared remit with other partners (Local Authorities, Scottish Water).
Related pressures	Impoundments and barriers; Abstractions and flow modifications

Pressure:	Forestry
Potential impacts:	Commercial forestry is a significant land use in Scotland, with coniferous woodland accounting for 76% of national forest cover (compared to 52% across the UK). Potential impacts are: (1) fertiliser, pesticide and herbicide contamination; (2) soil and water acidification; (3) canopy closure leading to loss of ground flora diversity; (4) loss of native tree species impacting biodiversity
Suitability for a citizen science approach	**Worth considering further.** There is a huge diversity of potential impacts of forestry, so here we can only summarise the suitability for a citizen science approach. Given how widespread forestry is, and that people's recreation visits will be biased towards specific types of forestry sites, it is likely that visits to systematically selected sites/plots would be necessary to properly assess the impacts of the pressure. Some impacts could possibly be assessed with citizen science approach, e.g. photos taken pointing upwards at posts set up at predefined sites to assess canopy closure – posts could carry the invitation to passing ramblers, or be

Pressure:	Forestry
	the subject of orienteering challenges. Some impacts could be assessed if there were useful proxies, e.g. for soil acidification. Alternatively people could be invited to collect samples for laboratory analysis, but careful consideration would need to be given to the incentives for people to do it, and the prompts (otherwise why would a rambler collect soil from this patch of ground rather than another patch?). For some impacts, such as ground flora loss, long-term biodiversity datasets collected by volunteer experts, could be used to provide indicators (i.e. relying on the results of other people's citizen science). For some impacts, e.g. ground flora or chemical contamination, it is likely that professional surveys, e.g. site condition surveys or forestry surveys, provide better data (standardised and more cost-efficient) than would be possible with citizen science.
Examples of extant projects	Picture post http://picturepost.unh.edu ObservaTREE is a recently-funded EU LIFE project (Forest Research, Food and Environment Research agency and the Woodland Trust) that will seek to provide early warning of tree health incidents.
SEPA's role	SEPA has a supporting role in delivery of management of this pressure. For this pressure SEPA has a shared remit with other partners (Forestry Commission).
Related pressures	Acidic substances; Agriculture; Invasive non-native species; Nutrient enrichment

Pressure:	Urban development
Potential impacts:	There is increasing demand for new housing and commercial and industrial development, leading to pressure to expand urban areas and redevelop brownfield sites across Scotland. Potential impacts are: (1) changes to run-off regime, (2) run-off pollution; (3) reduced air quality; (4) traffic noise; (5) loss of habitats, leading to increased fragmentation, decreased connectivity, and loss of biodiversity
Suitability for a citizen science approach	**Worth considering further.** Impacts of this pressure overlap with several other pressures, so these should be considered together. Indicators of urban development impacts that might be well suited to citizen science monitoring include direct observation of litter, traffic flow and urban wildlife or biodiversity. Citizen sensing has potential for monitoring air quality (comprehensively reviewed by Reis et al 2013) and noise monitoring (see other sections). However, citizen science is probably not suited to impacts on run-off and pollution as this requires pollutant sampling and observing and modelling flow in drainage systems. Urban citizen science may be particularly well-suited to establishing fixed sites, regularly visited by the same observers to provide long-term monitoring of trends in urban indicators. Most people live in the urban environment and have an interest in their local area, so could be engaged to take part in citizen science. Working through community organisations (e.g. schools) could be an efficient way to engage the urban population with monitoring the impacts of urbanisation.

Pressure:	Urban development
	When metrics can be extracted from analysis of remote sensed images (e.g. habitat fragmentation based on identification of habitat patches from satellite images), then this could be suitable for a crowd sourcing project However, traditional biological recording schemes probably under-record urban areas, as most naturalists are more interested in rural settings. Engaging with biological recording stakeholders to increase urban citizen science recording would therefore probably be useful. There are also potential safety issues relating to traffic or crime that require consideration for citizen science schemes in urban environments.
Examples of extant projects	Forestwatchers http://forestwatchers.net/ is a crowd-sourced project seeking to quantify deforestation. See related pressures for examples of other projects.
SEPA's role	SEPA has a supporting role in delivery of management of this pressure. For this pressure SEPA has a shared remit with other partners (Local Planning Authorities).
Related pressures	Ozone precursors; Particulates; Noise and vibrations; Waste management; Hydrological impacts of discharges; Recreation; Invasive non-native species

Pressure:	Agriculture
Potential impacts:	Three quarters of Scotland is used for farming, spanning lowland arable and horticultural production to sheep grazing in the Highlands. Potential impacts include: (1) fertiliser leaching to freshwater; (2) pesticide and herbicide contamination; (3) soil erosion; (4) waste and litter; (5) diffuse pollution from slurry; (6) point source pollution, especially by ammonia, from intensive livestock units and manure heaps; (7) over-grazing; (8) reduced biodiversity and population declines in key species (e.g. pollinators) because of habitat loss and modification, (9) loss of semi-natural habitats through draining, liming, grazing or use of agrochemicals.
Suitability for a citizen science approach	**Some aspects likely to be suitable.** There is a huge diversity of potential impacts of agriculture, so here we can only summarise the suitability for a citizen science approach. Biological citizen science recording has already proved extremely useful in showing long-term trends in species of agricultural habitats related to changes in agricultural practices. However, most other impacts of agriculture (fertiliser leaching, pesticides and herbicides, soil erosion and diffuse pollution) are probably less well-suited. These require professional surveys, systematic sampling and chemical analysis for accurate monitoring. Although there are potential indicators of some of these impacts (e.g. increased Ellenberg nitrogen values of vegetation indicating fertiliser pollution) it is unlikely that citizen science-derived measurement of these properties could contribute to statutory monitoring of agricultural impacts. However, point sources of ammonia could be monitored in the short-term by sensors and in the longer term by lichen abundance (see Nutrient Enrichments for more detail).
Examples of extant projects	Several UK projects provide information on biodiversity changes in the 'wider countryside', thus especially indicative of impacts of agriculture: UK Plant Atlas, showing large-scale changes in the flora

Pressure:	Agriculture
	http://www.brc.ac.uk/plantatlas/ Breeding Bird Survey http://www.bto.org/volunteer-surveys/bbs Wider Countryside Butterfly Monitoring http://www.ukbms.org/wcbs.aspx BeeWalk http://bumblebeeconservation.org/get-involved/surveys As yet there is no UK pollinator monitoring scheme, but discussions are currently under way.
SEPA's role	SEPA has a supporting role in delivery of management of this pressure For this pressure SEPA has a shared remit with other partners (Scottish Government).
Related pressures	Invasive non-native species; Nutrient enrichments; Forestry

Pressure:	Recreation
Potential impacts:	The land and water are very important resources for recreation by the Scottish population and tourists. Potential impacts include: (1) footpath erosion, (2) disturbance to ground-nesting breeding birds, (3) alteration to ecosystems through management for recreation (e.g. heather burning and game management), (4) increased risk of fires, (5) humans, pets or vehicles acting as vectors of disease and seeds, (6) increased presence of litter.
Suitability for a citizen science approach	**Well worth considering further.** There is a huge diversity of potential impacts of recreation, so here we can only summarise the suitability for a citizen science approach. Although many recreational impacts are generally felt in remote areas, a large population of recreational users visits these areas on a regular basis, e.g. hikers, mountaineers, kayakers, skiers. These users could provide direct surveillance through a citizen science approach. Many recreational users will have a strong interest in the natural environment so could be motivated to record indicators of recreational pressure, such as footpath widths (to monitor erosion), litter or the presence of ground-nesting birds near footpaths (to monitor disturbance). Such schemes might benefit from the establishment of fixed sampling points on walking routes, marked with posts and instructions for recording and online data submission. Observer skill needs range from low (footpath width, litter) to high (species recording). Collaboration with a range of recreational organisations would be beneficial to engaging users in recording. Crowd-sourcing could also potentially be used to map long-term change in muirburn patterns or footpath width from historic and ongoing aerial photography. Any such scheme should consider the best way to interest and motivate members of the public to get involved in this kind of activity. Other crowd-sourcing schemes offer a 'reward' to participants, e.g. puzzle-solving game in Fold-it (a game to design ways of folding proteins). A lack of reward may be a barrier to crowd-sourcing in this case. Some impacts of recreational activities are already monitored through citizen science, but are extremely difficult to accurately record, e.g. wildlife persecution monitored through collection and reporting of found carcasses and, indirectly, road kill of some mammals. As an index of recreational pressure it may also be possible to harvest data that people have uploaded about their exercise regimes (e.g. MapMyRun and

Pressure:	Recreation
	Strava). This is not strictly citizen science (because people are not actively choosing to participate in the project), and it would require ground-truthing, but it is a potential source of crowd-sourced data.
Examples of extant projects	BGS Report a landslide http://www.bgs.ac.uk/landslides/report.html It may be possible to harvest data from exercise websites (e.g. MayMyRun and Strava) to gain an index of recreation pressure. Mammals on roads (roadkill monitoring) http://www.ptes.org/?page=455
SEPA's role	SEPA has no direct or indirect statutory driver to address this pressure. SEPA is not responsible and does not have a focus on this pressure (Scottish Government).
Related pressures	Urban development; Invasive non-native species; Forestry; Fishing and aquaculture (freshwater)

Pressure:	Fishing and aquaculture (freshwater)
Potential impacts:	Freshwater fisheries include angling for migratory species (Atlantic salmon and trout) and coarse fishing (e.g. pike and perch). Fishing for wild species may cause: (1) depletion of commercial stocks through over-fishing; (2) disturbance to riverbanks, promoting colonisation by invasive plants; (3) litter (e.g. discarded lines and floats). Freshwater aquaculture in Scotland includes farming of rainbow trout, and to a lesser extent brown trout and Arctic charr. Aquaculture may cause: (1) disease and parasite transfer to wild fish; (2) odour; (3) water and land pollution from chemical spills and waste disposal; (4) litter.
Suitability for a citizen science approach	**Worth considering further, especially for wild fishing.** Angling associations and Fisheries Trusts are already involved in citizen science monitoring of wild fish catches, as these organisations and the angling community are strongly interested in the sustainability of fish stocks. There may be potential for tapping into this resource for recording litter and disturbance to riverbanks. For example, anglers that regularly visit a fishing spot could provide a long term record of the level of litter on the bank or number of clearings in the bank for angling. However, there may be a certain resistance to monitoring negative impacts of angling by the angling community. Safety issues associated with open water should also be considered. Impacts of aquaculture may be less well-suited to citizen science as they require specialist scientific analysis (e.g. parasite bioassays from wild fish, chemical analysis of water samples). Some impacts of aquaculture on river quality could be detected through changes in macro-invertebrate composition, which is monitored through participants in the Riverflies partnership.
Examples of extant projects	Rod catches of salmon and trout in Scotland are submitted to river owners and ultimately passed on to the Scottish Government and so provide a form of monitoring, although is obligatory rather than volunteered data as with citizen science. Riverflies partnership www.riverflies.org
SEPA's role	SEPA has a clear legislative remit to address this pressure: ▪ Controlled Activity Regulations (CAR)

Pressure:	Fishing and aquaculture (freshwater)
	For this pressure SEPA has a shared remit with other partners (Crown Estate, Scottish Government, Fish Health Inspectorate, Veterinary Medicines Directorate)
Related pressures	Impoundments/barriers; Waste management; Recreation; Acidic substances

Pressure:	Invasive non-native species
Potential impacts:	At least 915 non-native species are established in Scotland but only a fraction of these (approximately 30) are considered invasive, i.e. constituting a threat to biodiversity, human health or the economy. Potential impacts are: (1) out-competing native species (e.g. Himalayan balsam); (2) grazing/predation of natives (e.g. sika deer, North American signal crayfish), (3) spread of disease (e.g. grey squirrel and parapoxvirus); (4) crop yield loss (e.g. sterile brome); (5) disruption of ecosystem functioning and services (e.g. New Zealand pygmyweed); (6) damage to buildings/infrastructure (e.g. Zebra mussel); (7) costs of biosecurity and control (e.g. Rhododendron); (8) human health impacts (e.g. contact blistering of giant hogweed). Invasive non-native species are estimated to cost Scotland £251 million per annum (Williams et al 2010).
Suitability for a citizen science approach	**Highly suitable in many cases.** Many non-native species invade highly modified habitats and so tend to be in close proximity to the potential observer population. Furthermore, naturalists and several other organisations (e.g. angling associations) have a strong interest in invasive non-native species so could be engaged with recording them. This would be especially useful for less-easily identifiable species or arrivals of new invasive species, where specialist knowledge is required. Citizen science for mapping the location and extent of invasive non-natives is further aided by established surveys for specific species and existing web portals for general biological recording. One area where citizen science could be potentially beneficial would be in targeting monitoring around sites known to be key entry points for imports of new non-native introductions (e.g. ports, horticultural nurseries, etc.). Invasive species control is much easier if they can be intercepted early and so deployment of skilled citizen science recorders able to identify new non-native species could be very useful. Potential drawbacks include safety issues relating to aquatic habitats and particular harmful species (e.g. giant hogweed). Also, monitoring the impact of invasive non-native on native biodiversity or ecosystem services, rather than simply reporting the spread of invasives, is more difficult and is probably beyond the scope of citizen science, except in specific cases where hypotheses are addressed at large spatio-temporal scales.
Examples of extant projects	Recording Invasive Species Counts https://secure.fera.defra.gov.uk/nonnativespecies/index.cfm?sectionid=81 Plant Tracker http://planttracker.naturelocator.org/ Conker Tree Science www.conkertreescience.org.uk SeaLifeTracker (for marine INNS) https://itunes.apple.com/gb/app/sealife-tracker/id663800293?mt=8 AquaInvaders is an app for upload and mapping of freshwater INNS (https://play.google.com/store/apps/details?id=uk.ac.bris.ilrt.aqua&hl=en_G

Pressure:	Invasive non-native species
	B) ObservaTREE in development to monitor tree health incidents (http://www.forestry.gov.uk/fr/INFD-97sd3n)
SEPA's role	SEPA has a supporting role in delivery of management of this pressure. For this pressure SEPA has a shared remit with other partners (Forestry Commission Scotland, Scottish Natural Heritage, Marine Scotland, Scottish Government). SEPA is Habitat Lead for still and flowing freshwater habitats in Scotland under the Code of Practice on non-native species and key partner in the Scottish Working Group on Non-Native Species. SEPA is also interested to direct action via the River Basin Management Plan Area Advisory Groups to address invasive non-native species where they threaten or actually cause a downgrade of watercourse or waterbody ecological status to less than good on the basis of bank morphology.
Related pressures	Agriculture; Forestry; Recreation; Urban development

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Part 4. Case studies

We have provided two detailed case studies as worked examples of using our decision framework to inform the delivery of a citizen science project. We do not anticipate that SEPA will uncritically accept our conclusions in these case studies; the delivery of individual projects will be subject to stepwise review by SEPA.

The two case studies are:

1. Identifying and locating barriers to fish migration in rivers;
2. Monitoring the effect of the Seven Lochs Wetland Park on water quality.

4.1 Case study 1: Identifying & locating barriers to fish migration in rivers

1 Background:

The free passage of migratory fish is a key requirement of the Water Framework Directive, because watercourses which are accessible to migratory fish often contain a more diverse and abundant fish community than areas not accessible to migratory fish (Environment Agency 2013). Free passage of migratory fish can be hindered where barriers cause a water level difference upstream versus downstream of 50cm or more (Environment Agency 2013).

Although many dams and weirs serve a valuable socio-economic purpose (and are licensed), many are abandoned. SEPA estimates that there may be as many as 1800 unlicensed dams and weirs across Scotland (quoted from Scottish Government (2013)). Barriers may also be associated with culverts and bridges, but these are more complex to assess (SNIFFER 2012). However, the presence of barriers is contributing to the classification of many water bodies as being at less than 'good status' under the Water Framework Directive (Scottish Government 2013).

The Rivers and Fisheries Trusts of Scotland (RAFTS) is currently coordinating work to identify and assess barriers to fish migration through a desk-based exercise, but this requires best-quality information from field surveys on the presence and type of fish barrier. There is a well-developed manual for standardised surveys of potential obstacles to fish migration (SNIFFER 2012). This protocol is complex, but it does allow the prioritisation of the response to barriers.

Response to the presence of the barrier would need further assessment based on the porosity of the barrier to fish migration and upstream habitat, but could involve the removal of the barrier and the improvement of the water course quality under the Water Framework Directive.

2 Specific aim:

The identification of potential barriers to fish movement.

3 Precursor to the decision framework

3.1 Clarity of aim

A fairly clear aim. We have considered this as a static aim (the identification of fish barriers) rather than a dynamic aim (the change in presence of fish barriers over time), but with sufficient data the change in time could be assessed.

Keen participants could be trained to use the complex SNIFFER (2012) protocol to ***assess*** fish barriers, but given the training required and the likely low rate of recruitment this is unlikely to be an efficient use of resources. Instead we suggest that the main knowledge gap that could be filled by members of the public is to ***identify the location*** of putative fish barriers. Volunteers could make initial assessments of the barrier, including identification of barrier type (e.g. natural vs man-made, bridge, culvert, dam, waterfall etc.) and assessment of barrier height and width, which could even be undertaken with smartphone apps such as Smart Measure or iHandy Carpenter and then potentially followed by an assessment of the putative barrier by trained staff.

3.2 Importance of engagement

Engagement is very important, because the project will only be possible if a large number of people from across the country take part, to provide wide geographic coverage.

3.3 Resources available

Not fully known. There would be quite a substantial need for the development of database technology in order to make best use of the data (see below for comments on the need for area sampled to be recorded as well as the location of putative barriers). Resources would also need to be devoted to communications to recruit participants. If verification/assessment of the reported barriers is carried out by professionals, then resources would need to be available for this. Verified records would then need to be incorporated with the SEPA Morphology database and SEPA GIS layer for use in the Water Framework Directive.

3.4 Scale of sampling

In rivers across Scotland. Rivers near centres of population are probably already well-surveyed, but this does not preclude participation in these areas. The most valuable data will be from areas away from centres of human population.

3.5 Complexity of protocol

The protocol is likely to be simple – if fish barriers can be easily identified. This supposition would need to be tested rigorously.

3.6 Types of data

A clear (and short) definition of a fish barrier will have to be provided. If fish barriers can be accurately identified with this description then reporting presence/absence will be sufficient (and could be done simply with a hand-held GPS). However, it would be valuable to have a photograph of the fish barrier with an estimate of height. If needed, height could also be assessed with apps such as SmartMeasure. Each barrier would only need to reported once by a single person but, of course, the same barrier could be reported numerous times by different people and although it may be possible to determine (e.g. from submitted photographs) if the barriers are the same, this might not always be possible; this may be addressed using an automated rule of comparing the location of a new record with that of existing data points, flagging up where it is within a specified distance of any known barrier. If verification and assessment is later carried out by visiting professional staff then the total number of barriers could be confirmed.

4 Decision framework

Can some/all of the project be virtual tasks completed entirely online?	No. By definition, the observations must be collected in the field.
Can observations by made safely?	Yes, observations can be made safely. Instructions should be given about being careful near rivers and not to take risks.
Is a sensor needed?	No. Existing tools to estimate the height of the barrier could be built into a bespoke smartphone app.
Spatial scale: is sampling restricted to a single site?	No. Need data from across rivers across Scotland.
Temporal visits: repeat visits made by the same individual(s) important?	Here we consider two options, because either could be relevant to the question. **Option 1.** No. Wide geographical coverage is most

	important, so do not need sites revisited regularly. Recruiting participants across a wide geographic range is important. **Option 2.** Yes. Although repeat visits are not strictly required, this question is partly about the distinction between retention and recruitment. Engaged participants can continue making observations at many sites – therefore retention of engaged people is also key, so the answer to this question would be 'yes'. Therefore in this example we continue down both branches in the decision framework. Also, reports of the same barriers at different times could provide information about the effect of river flow on the permeability of the barrier. Gaining this information in a systematic way would require a different approach to working with volunteers, but obtaining time-stamped photos may provide sufficient information for some barriers.
Option 1. Short-term large scale	**Very worthwhile considering citizen science.**
Are there pre-selected sites (or special types of sites) that need to be visited?	Yes. Records can only be made along rivers.
Site accessibility: Are sites located where people are present/visiting/passing?	Yes. Though in more remote areas the only 'passers-by' are likely to be hill walkers or anglers, making this a likely target group. Local people may have a vested interest to report fish barriers.
Is it easy to make a report/observation?	Yes. A camera, smartphone or GPS would be useful for capturing geolocated photos, but these are often carried by people walking in the countryside. Capturing the information will only take a moment or two.
	Very good potential for mass participation citizen science.
Option 2. Long-term large scale	**Worthwhile considering citizen science.**
Can you work with volunteers who already have expertise?	No. Identifying fish barriers does not require expertise (if the instructions on identifying barriers are easily understood).
Are there groups of potentially interested people who could be recruited for the long term?	Yes. Walkers and anglers are likely to be ideal target groups.
Is the protocol complex, or very prescriptive?	No.
	Potentially suitable for a citizen science approach.

Conclusion: Although the overall answer differs depending on how one of the questions is answered, this project does appear suitable for a citizen science approach. Whilst working through the framework it became clear to us that targeting a specific group of people (walkers and anglers) is the best way of providing the wide geographical coverage needed (although this would not preclude the involvement by other people).

5 Subsequent issues

5.1 Resources: the organisers' time

There would be time required to:

- Test the protocols: can people identify fish barriers fairly accurately? Are people prepared to make the report while out on a walk?
- Develop the data/image upload portal and storage (database) technology (see below).
- Thoroughly test the technology.
- Ensure that recorded data can be viewed.
- Promote the project to walkers (and maybe other members of the public).

5.2 Resources: infrastructure and data protection

One of the big challenges with a citizen science approach to locating fish barriers is knowing which rivers, and which parts of rivers, have been surveyed. In other words, are the gaps in the maps of reported fish barriers due to a lack of barriers, or a lack of reporting of barriers that are present? What is the best way to record negative results and unsurveyed stretches?

This problem is the same whether considering professional surveys of fish barriers (e.g. that shown on SEWeb http://www.environment.scotland.gov.uk/map.aspx) or considering volunteer reporting of barriers. It is therefore valuable to have a record of which stretches of rivers have been surveyed. There are several approaches to achieving this:

1. One option would be to allow submission of GPS trails from smartphones (e.g. similar to MapMyRun or Strava apps). The disadvantage of these is that they require 3G connectivity to work, and so would need to be developed to record GPS locations offline. The other disadvantage is that GPS is costly to battery life of smartphones.

2. A second option would be to allow people to report on a map (via a website or app or uploading tracks from hand-help GPS devices) which stretches of river they had surveyed after they had walked it. If the reporting of fish barriers is done via smartphone then it could be possible to link website and smartphone via a login option. Capturing this information is a technological innovation that might be a challenge and may be costly to implement. It would also mean a drop off in reporting, because a proportion (probably quite high) of people would not record the lengths of rivers that they have surveyed.

3. The third option would be not to collect information on the rivers surveyed, but only collect reports of barriers. This could be done using an approach such as that adopted by Nature Locator in developing apps such as Plant Tracker (http://naturelocator.org/). This allows users to submit time-stamped photographs with auxiliary data (e.g. for Plant Tracker, the amount of ground covered by the plant) and location derived from GPS. Data is stored by the app for later submission when 3G/wifi connectivity is restored, which is important when using the app in remote locations. Development of an app such as this would be relatively straightforward, but lack of information on the rivers that had been surveyed means that it would be difficult to assess the completeness of the dataset. Data from Plant Tracker is submitted to an Indicia database

(http://www.indicia.org.uk/), which allows easy access to the data for verification by professionals, mapping, providing feedback to participants and sharing data with other systems (e.g. SEWeb http://www.environment.scotland.gov.uk/ map.aspx). Indicia has been developed for biodiversity records, but is a flexible open-source development, so could be adapted for non-biodiversity records. Other approaches could be Google code (http://code.google.com/) or bespoke databases, but these would require more expertise in software development to implement.

Data protection is subject to the usual issues. A good online database should provide sufficient security – but this must be checked as the online tools are developed. Currently available online databases/apps could provide a framework.

5.3 Quality assurance and verification

The identification of a real barrier to a fish could be problematic. Participants will need really clear instructions as to how to identify a barrier and what to include in a photograph (e.g. a reference height). Records will need to be validated. If this could be done by photo then participants could submit photos for assessment by a professional member of staff. Alternatively reports could be classified as 'pending' until visited by a professional and verified for inclusion in official datasets. It would be important to ensure that volunteers receive feedback when barriers have been verified.

5.4 Participant safety

Need to give clear instructions: Don't enter the water and view only from the bank. Be aware of bank side conditions and do not take risks.

5.5 Communication

Ideally should target walking groups and anglers. Focus on articles in walking magazines about the value of this recording in order to enlist people. In time, it may be worth specifically focussing promotion on regions that are likely to have barriers but away from popular areas for walking in order to gain comprehensive coverage. Conceivably the project could have a competitive aspect in which people try to gain most coverage, or coverage of remote areas – in order to give a focus to their walking. A smartphone app could be developed to be similar to the Nature Locator family of apps (http://naturelocator.org/), which have a proven track-record in reliable, usable technology for recording aspects of the environment.

It is important to communicate to participants in order to manage their expectations. If it is decided that 'pending' data (submitted by members of the public) need to be verified and action on removing barriers needs to be prioritised, then this should be communicated to the participant who submitted the record, and more generally. A project blog and updated map could be used by people undertaking barrier removal, so that the benefits of making reports can be clearly seen by members of the public. It is also important that the benefits are communicated to the public, for instance, anglers might understand the benefits of removing fish barriers, but why should walkers care? One approach would be to focus on conservation benefits, e.g. for charismatic species such as salmon.

5.6 Legislative implications

It is important to understand who is responsible for the removal/ management of the barriers, and who will bear the cost? Does the fact that members of the public make these reports on someone else's land have legal implications?

6 Delivery of the project

If the project targets walkers, then the data collection needs to be made as straightforward as possible. This is especially so to engage with serious hill-walkers who might provide information in remote sites that would otherwise be unvisited, but may not want to stop regularly to turn on smartphones to take photos.

We suggest that the project ought to be developed as follows:

Step 1. Testing the protocol.

The definition of fish barriers is absolutely vital to the success of this project. Can fish barriers be identified by members of the public? Are there limits – e.g. dams and weirs can be accurately identified, but obstacles associated with culverts and bridges cannot? Even though more thorough photographic identification guides could be provided in apps and websites, it will be important for these to be tested; most people will not read detailed text, especially on smartphone handsets, so it is important to have clear, simple and usable descriptions of barriers for participants.

Step 2. Identifying suitable technology to capture records of fish barriers and record the sections of rivers that have been surveyed.

Reporting fish barriers is likely to be best served via a two-stage process:

(1) photographic, time-stamped, geo-located reports of the presence of putative fish barriers. This could be done easily via a smartphone app, or new technologies such as GPS units with the capability of taking photos, or cameras with GPS capability;
(2) a record of the stretch of river that has been surveyed. This could be done most easily by uploading GPS traces, but could be done via a website interface in which water courses have been already mapped. This could be done by sharing current technology, e.g. OpenStreetMap and GoogleMaps already provide the facility to upload GPS traces. People could alternatively select which sections they surveyed along the river network, by selecting from a pre-installed map of the water courses. An assessment of the potential participants and their willingness to engage with this aspect of the project is important.

Step 3. Identify behaviours of target groups to identify which front-end technologies are most suitable.

There are two possible routes to achieve this. It could use off-line smartphone technology (i.e. the phone works as a GPS and camera without needing mobile connectivity). Will walkers/anglers have smartphones and will they keep them on for a day while out walking/fishing? It would need to work off-line due to poor connectivity out of the towns and cities, but that has been achieved for apps such as PlantTracker. Images can then be uploaded when the person has connectivity (via WiFi or 3G/4G). Alternatively, GPS handsets might be more frequently used by walkers in remote locations, but few have a camera capability. Options to enter records via a website would also be necessary to enhance the opportunity for as many people as possible to take part.

When people upload their records it would be ideal if people could then be prompted to report the length of river that they walked along and surveyed (as described above). This information is important to allow accurate interpretation of gaps in the maps of records (are they due to no barriers being present, or due to no people surveying that stretch of river?). This could be implemented through the app, by using GPS to record a trace of the route walked, although the drain on smartphone battery life could be a dis-incentive for participants, this would be an application of cutting-edge technology for this purpose. Alternatively a trace of the route walked from a dedicated GPS unit could be uploaded, e.g. as can be done with OpenStreetMap (http://www.openstreetmap.org), when combined with maps of the river network. Currently, though, it might be simpler to implement this via a website (e.g. accessed in the app when upload occurs, or a prompt could be given to record the route walked via a tablet/computer at a later time), however, this would need to be thoroughly tested to ensure ease-of-use by participants.

Step 4. Promote the project and provide feedback.

It is important to provide feedback to participants. Given the target audiences it may be appropriate to provide information about SEPA's response, and how participants' records are contributing to an improvement in the quality of rivers in Scotland. It will be important to manage participants' expectations, specifically that work to remove barriers will be prioritised. Maps on the website could be updated as work has been done to remove barriers, and a project blog could be maintained with stories of barrier removal and river improvements. Feedback could also be given directly to participants who reported those barriers.

Step 5. Provide an opportunity for progression (optional).

Although the formal assessment of barriers is quite complex (SNIFFER 2012), if there are very keen volunteers, then they could be given the opportunity to be trained (e.g. via a local Rivers and Fishery Trust http://www.rafts.org.uk/) and undertake this assessment. It would provide an opportunity for volunteers to have progression in their experience of the project.

7 Key references

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4.2 Case study 2: Monitoring the effect of the Seven Lochs Wetland Park development on water quality

1 Background:

The Seven Lochs Wetland Park is currently in development and will connect existing parks and nature reserves to become Scotland's largest urban wildlife site. The vision of the park is:

> *'To create a new wetland park of national significance between Glasgow and North Lanarkshire, and to deliver, manage, and sustain a high quality innovative wetland environment that will protect and enhance the biodiversity of the area as a national resource that promotes the general health and wellbeing of both visitors and residents alike, and contributes to the environmental, economic and social regeneration of the area'.*

Over the coming years, active management will develop and restore wetland, woodland, burns, ponds, lochs, raised bog, meadows and canal habitats over an area of 16.5 km^2. In addition, a network of paths, trails and visitor centres will allow local people to access and use the Park's green space. There are also plans to integrate proposed new housing developments into the Park and develop strong links with existing greenspace and community projects in the area.

Long-term monitoring of the condition of the Park would provide an evidence base for assessing how well it is meeting its vision of protecting and enhancing the biodiversity of the area. Monitoring could focus on long-term trends in biodiversity, public attitudes and use, hydrology and water quality. Water quality is highly relevant to SEPA, and will form the focus of this case study.

It will be essential for organisers to be clear of the aims of this monitoring. Some attributes of water quality could be monitored more cost-efficiently or reliably by other means, such as remote sensing or immersed sensors and data-loggers. If the aim is as much about public engagement with their environment as it is about monitoring, then professional monitoring of water quality alongside excellent public engagement might be more amenable than a citizen science approach. These are important questions, but in this case study, we assume that these questions have been addressed and that citizen science is considered worthwhile.

A large number of citizen science water monitoring projects run in the USA (see the USA National Directory of Volunteer Monitoring Programs http://yosemite.epa.gov/water/volmon.nsf/Home) but there are no similar examples from the UK, apart from the Riverflies Partnership. In the USA there is a tiered approach to volunteer involvement in water quality monitoring (http://www.state.nj.us/dep/wms/bwqsa/vm/docs/WatershedWatchFinal.pdf) and there are standardised protocols for sampling and quality control (http://water.epa.gov/type/rsl/monitoring/index.cfm).

SEPA currently do very little monitoring in the Park area (previous water chemistry sampling stopped in 2006) as much of the Park falls below the Water Framework Directive water body size criteria. However the park will be well-used by the public and so it will be valuable to ensure that water quality is adequate so that the health of people and pets is maintained and that the environment remains pleasant for people's recreation activities. Some of this monitoring could be done remotely via remote sensing (e.g. for algal blooms) or remotely deployed sensors. Using a citizen science approach will have the added value of actively involving residents in the assessment of their local environment – this will give a focus to engagement activities and will support scientific monitoring. This approach has been successfully adopted in many watercourses in the USA.

There are many potential ways in which Park water quality and wetland health could be measured through Citizen Science, including:

1. Water sampling, followed by analysis of the sample in the field or laboratory. The collection and simple testing of water samples could be done by volunteers from the shore. (Sampling from boats is possible though carries health and safety implications making it less likely to be acceptable to project organisers.) However, using volunteers to conduct laboratory analysis is possible (e.g. *E. coli* monitoring in the USA http://www.usawaterquality.org/volunteer/EColi/index.html) but may be more challenging in this context due to the need to train volunteers and provide suitable facilities.
2. Surveying groups of plants or animals known to be indicators of wetland quality (e.g. macroinvertebrate, diatom or macrophyte communities; Stroh & Hughes 2010; Riverfly Partnership http://www.riverflies.org/). A high degree of volunteer specialist knowledge (either pre-existing or through training provided by the organisers) would be desirable for this, although it may be possible to design more accessible citizen science schemes based on easily-identifiable indicator species. As with option 1, this option does carry health and safety considerations, because sampling needs to take place in the water.
3. Recording the incidence of events indicative of poor quality, such as algal blooms which occur at high nutrient levels. Volunteers may be able to report the location and extent of algal blooms relatively simply, even using generic tools such as Crowdmap https://crowdmap.com/ or Epicollect http://www.epicollect.net/. We note the algal bloom pilot project (funded by the Environment Agency) may provide lessons that can be learned using this approach: http://www.fba.org.uk/algal-bloom-pilot-project.

We have elected to consider option 1 (direct water quality sampling by Citizen Science) in this case study. The reason for this is that option 2 is an approach that has already been well-established in the UK through the Riverflies Partnership and option 3 is currently being trialled. Option 1 is an approach that is widely adopted in the USA, but has not been adopted in the UK, so we use this opportunity to learn from experience elsewhere in the world.

2 Specific aim:

To use Citizen Science to monitor trends in water quality within the Park over time, in order to assess whether development and management of the Park habitats is associated with improved quality.

3 Precursor to the decision framework

3.1 Clarity of aim

The aim is fairly clear, although advice from a freshwater scientist would need to be sought about (1) which water measurements are most informative, and (2) how frequently they should be taken to provide a robust approach to monitoring.

3.2 Importance of engagement

Very important. The Park Development has been built around community and stakeholder engagement and is in close proximity to a large urban population. Long-term monitoring of the Park should be based on strong links with the local community as the retention of volunteers is essential to justify the investment in this approach and gather large volumes of data to robustly assess long-term trends.

3.3 Resources available

A number of other systems or conditions could potentially underpin the project:

- A range of organisations have staff working in the Park (e.g. GCV Green Network Partnership, TCV, Gartloch Gartcosh Green Network) who could provide coordination for citizen science.
- There is an established Seven Lochs Volunteers group that meets twice monthly to carry out habitat management and conduct wildlife surveys. This may provide a base of engaged and skilled volunteers.
- The general public and school parties are likely to visit to the Park in increasing numbers as development progresses. This could provide a resource for volunteer sampling, recording or analysis.
- Development of leisure activities (e.g. canoeing) may be considered as a means of collecting water samples. Health and safety concerns associated with this are likely to make it an unappealing approach, although deploying sensors on boats that would otherwise be used for leisure may not add any risk to the public. There would also need to be consideration about restriction to the tourism season and particular lochs used for leisure activity.
- New Visitor Gateways and other developments may allow storage of equipment and could potentially provide basic laboratory facilities.
- SEWeb provides a platform for visualising data, with the data residing in a suitably accessible form in other databases.
- The organisation Thames 21 is developing a Citizen Science network for water quality recording in East London, based on training local people in water quality testing to become 'sentinels' for their local river (http://www.thames21.org.uk/water-quality-testers-citizen-scientists/). This could be a model for Citizen Science at the Park.

3.4 Scale of sampling

Long-term monitoring of water bodies within the Park. To reliably assess long-term trends, monitoring must be standardised, inexpensive, easily repeated and robust and there should be an ambition to monitor over at least 10 years. During the design of the scheme, the ideal and achievable spatial coverage of monitoring should also be considered – is it necessary and feasible to monitor all lochs, or can a subset of waterbodies (e.g. inflow and outflow channels) provide informative data more cost effectively?

3.5 Complexity of protocol

Sampling – Relatively simple, but requires standardised collection of samples. Any use of boats will add complexity and raise health and safety concerns, but may be necessary for robust sampling of lochs. Shore-side sampling is simpler but more limited. Throughout, health and safety has to be given high consideration. By training a group of keen volunteers (as is done with the Riverflies

Partnership), rather than asking anyone to get involved in sampling, health and safety considerations can be managed more effectively. Precautions such as specifying that sampling is to be done by pairs of trained volunteers rather than single individuals could also reduce the risk.

People could also undertake measurements of water clarity, such as has been done in the Secchi Project for seafarers (making Secchi disks and recording with a smartphone app when the disk becomes occluded http://www1.plymouth.ac.uk/marine/secchidisk/Pages/default.aspx). However, this would necessitate sampling from a boat, which raises health and safety implications, and there would need to be a clear rationale for the value of the data.

Analysis – Varying from simple (e.g. pH indicator strips and assessment of water colour) to more detailed (e.g. indicator solutions for nitrate analysis) to highly specialised (laboratory assays for specific chemicals), depending on the water quality measure used. This could be undertaken by professionals, if budgets and available facilities permit or if the protocol complexity necessitates it.

3.6 Types of data

Hand held instruments could measure properties such as pH, alkalinity, conductivity and temperature relatively simply in the field. These could be loaned or hired to committed volunteers, although this does depend on a high commitment from volunteers. Such commitment is demonstrated in the volunteers for many watershed monitoring schemes in the USA (e.g. New Jersey Watershed Watch http://www.state.nj.us/dep/wms/bwqsa/vm/), but such an approach has not yet been tested in the UK. Project organisers would need to give a commitment to quality control, which may include standing costs for calibrating, repairing and replacing equipment (although this may still be very resource-efficient for the data gained). Instrument measurements may require recording and inputting into databases. More sophisticated laboratory analysis of samples collected from the Park may also be used (e.g. nutrients, colour, DOC, dissolved metals, microorganisms). It would also be useful to have information on the sampling conditions (e.g. location, time, date).

4 Decision framework

Can some/all of the project be virtual tasks completed entirely online?	No. Direct sampling from water bodies is necessary.
Can observations by made safely?	Yes, observations can be made safely. Although if this was a mass participation project, then health and safety would have a very strong emphasis. If working with and training volunteers then health and safety issues can be managed better. Instructions should be given about being careful near water bodies and not to take risks.
Is a sensor needed?	No. Sample collection does not require a sensor.
Spatial scale: is sampling restricted to a single site?	Yes, although we wish to ensure sampling throughout open water habitats of the Park.
Temporal scale: Do you need repeat observations over a long time period?	Yes. Long-term trends in water quality must be assessed by repeat observations made over a substantial time period, ideally decades or more.
Long-term single site	**Possibly worthwhile considering citizen science. A key issue is retention of volunteers**
Are there groups of potentially interested	Yes. Several organisations have staff working in the

people who could be recruited for the long term?	Park, there are volunteer groups and the Park is actively engaging with local community groups.
Is the protocol complex, or very prescriptive?	Yes. Sampling may be simple, but must also be highly standardised to ensure data quality. Laboratory analyses (if necessary) are complex.
Are you willing to work with interested people and invest in training etc?	Yes
	Potentially suitable for a citizen science approach.

Conclusion: The project appears suitable for a citizen science approach. It will rely on targeting skilled volunteers with a strong connection to the Park to ensure standardised and robust water sampling over the long-term. Because we are proposing working with and training committed volunteers (which is also the approach adopted by the Riverflies Partnership), issues of quality assurance and health and safety are much more manageable than with mass participation projects. Initial targeting of the Seven Lochs Volunteers for this seems sensible. Consideration of the level of volunteer involvement is also required – will volunteers just collect samples or can they also be involved with sample analysis? In either case, some level of training must be provided. Some volunteer coordination will also be necessary to ensure adequate spatial and temporal coverage of the data. For example, it would probably be desirable to establish fixed recording points and frequencies rather than allow volunteers to choose sampling points themselves. This would need to be established by organisers after consultation with freshwater scientists.

5 Subsequent issues

5.1 Resources: the organisers' time

Time would be required to:

- Develop and test standardised sampling protocols.
- Review the most appropriate measures of water quality.
- Recruit and train volunteers.
- Collate database of results and analyse long-term trends.
- Communicate project progress to volunteers, the public and stakeholders.

5.2 Resources: infrastructure and data protection

There are a range of options available, depending on the resources available. Collecting samples could require:

- Low resources – Water sampling equipment for use from the shore.
- High resources – Boats and sampling equipment for deep open water. Collaboration with proposed leisure users of the park may aid this, although serious health and safety considerations will apply (see below).

Making water quality measurements could require:

- Low resources – Hand held instruments that can be used to make direct measurements in the field. (Care would need to be taken to avoid meters becoming lost or stolen. People could place a deposit for instruments, returned to on-site wardens, or they could purchase their own meters – though this would make the citizen science less inclusive. Instruments would have to be checked regularly to ensure they were accurately calibrated).

- High resources – Laboratory facilities for more sophisticated measurements. Samples could potentially be sent to SEPA or other laboratories for professional testing, if essential quality measures are beyond the capability of the volunteers.

Any supporting organisations (e.g. on-site wardens) will need to comply with data protection requirements in working with this group, but data protection should not be too complex.

5.3 Quality assurance and verification

Robust assessment of long-term trends is likely to require:

- Adequate training of the volunteers.
- Consistent use of the same equipment (e.g. same type of sampling vessels) to control for any contamination effects.
- Regular calibration of instruments.
- Repeat sampling from fixed points and standard depths.
- Consideration of sampling strategy. If boats are not available then shore-side sampling of lochs will be less reliable than sampling from flowing streams (with more mixing).

5.4 Participant safety

Safety issues are perhaps the greatest barrier to the scheme and so the organising agency should assess all risks and the ways they could be managed before deciding whether they are willing to support the scheme. The greatest danger comes from working in open water environments. If it is decided that the use of boats is too dangerous (or too costly) then the scheme should plan to only use shore-side measurements. Working on the shore-side could still have dangers, so all participants would need to be trained and reminded of their responsibility to their safety. Sampling should be designed in such a way that it does not require more risky activities like reaching far across the water. Also people should be made aware of the dangers of working with water (Weil's disease, colliform contamination, toxic algal blooms). Advice should be given in advance about minimising this risk (e.g. working in groups, not sampling in specific high risk locations or at high risk times). At such times professional sampling could augment the volunteer-led sampling. The scheme coordinator could also contact volunteers when sampling conditions are too dangerous.

The legal ramifications of a project such as this, including liability, are complex and these issues are only beginning to be formally considered within much of citizen science. Best practices are considered in detail in the primer by Bowser et al. (2013).

However, while health and safety is of genuine concern, the communication of these risks needs to be conducted wisely; the Common Cause for Nature report (2013) emphasises how conflicting messages can be communicated when asking people to be engaged with nature (appealing to their sense of discovery and wonder) while listing safety risks (appealing to their sense of security and caution). See the Common Cause for Nature report for more discussion of this.

5.5 Communication

Communication of project aims, results and implications to the volunteers will be vital to ensuring their long-term engagement and participation. It will also be important to build in opportunities for ‘progression’ so that people can see their skills and education enhanced. This could include giving accessible talks about what, how and why data are collected, or given keen individuals specific responsibilities within the management of the project. The Park’s visitor centres provide a perfect opportunity for communicating the project work to the general public.

5.6 Legislative implications

Given that members of the public are collecting data that may possibly be used in prosecutions (e.g. in pollution incidents), it would be wise to seek legal advice. Given that people are gathering data in a way that poses some risk, it would be wise to consider insurance cover and chains of responsibility (who is ultimately responsible for the people involved in the project; is it SEPA or someone else?).

6 Delivery of the project

We suggest that the project ought to be developed as follows:

Step 1. Developing and testing the protocol.

Designing the protocol should involve consideration of:

- Resourcing levels.
- The relative merits of different quality indicators and the complexity and cost of measurement.
- Laboratory facilities available.
- Volunteer training requirements and number of volunteers that can be supported.
- The sampling strategy (e.g. sampling from shore or boat, where to sample, frequency of sampling).
- Health and safety.

SEPA experts in water quality monitoring would provide valuable input to this.

Thorough testing of the protocol by Park staff and a small number of volunteers from the Seven Lochs Volunteers group should then be performed. Once approved, full equipment purchasing would proceed.

Step 2. Recruiting and training volunteers.

It seems sensible to initially canvass the Seven Lochs Volunteers to recruit initial participants. If more are needed, advertising the project via the Park visitor centres would be a way to attract wider participation.

Training needs will depend on the protocol, most notably the complexity of using instruments to make measurements. If simple then Park staff could train groups of participants together. A highly complex protocol may require individual-level training by third parties.

Step 3. Roll out the project

Deploy volunteers to collect the samples or data and commission any professional sample testing. Data must be captured in a secure database, ideally managed by the Seven Lochs Wetland Park to compare water quality trends with records of biodiversity or habitat condition. Electronic data from field or laboratory instruments may be automatically imported, while readings made by volunteers will require manual digitisation. Web-based systems may facilitate data entry by the recorders themselves, or this responsibility may fall to the project coordinator.

The project coordinator must work to ensure that volunteers are actively engaged in the long-term nature of the project. To achieve this, it is advised to hold regular progress meetings, share periodic analysis of results and discuss interesting patterns that emerge from the data. As some volunteers will inevitably leave the project over time, it will be necessary to maintain a level of recruitment of training throughout the project.

7 Key references

Bowser, A., Wiggins, A. & Stevenson, R. (2013). Data policies for Public Participation in Scientific Research: A primer. DataONE: Albuquerque, NM. Available at: http://www.birds.cornell.edu/citscitoolkit/toolkit/policy/Bowser%20et%20al%202013%20Data%20Policy%20Guide.pdf

Common Cause (2013) Common Cause for Nature: Full Report. Public Interest Research Centre, Machynlleth, Wales. http://valuesandframes.org/initiative/nature/

Stroh, P. & Hughes, F. (2010) Practical Approaches to Wetland Monitoring: Guidelines for landscape-scale, long-term projects. Anglia Ruskin University.