

# Enhancing national environmental monitoring through local citizen science

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## Highlights

- Citizens are highly motivated to contribute to air quality measurements that complement existing measurement networks because of their high spatio-temporal resolution;
- Data needs to be assimilated, for example, using models;
- Low-cost sensors need to be developed further, and their application calibrated and validated;
- Easily accessible expert information and feedback is needed to support participants;
- Environment protection agencies (EPAs) can both support and benefit from citizen science using small sensor networks.

## Introduction

A key motivation for national environmental protection agencies (EPAs) to support and participate in citizen science is to allow these knowledge institutes to get out of the well-known scientific ‘ivory tower’. Citizen science is one way to shape science-society relationships in a more interactive and reflexive way. Reflexivity means scientists being aware of the potential societal effects of their research and taking these into account in their choice of research objects, methods and approaches. It is assumed that the reorganisation of governmental scientific advice along the lines proposed by reflexive scholars will increase the accountability, quality, effectiveness and legitimacy of scientific expertise in society (Funtowicz & Ravetz 1993; Nowotny, Scott & Gibbons 2001; Jasanoff 2003; and see also Smallman; Mahr et al., both in this volume).

At the same time, EPAs can be useful partners to more local citizen science projects because this relationship facilitates better data collection (see also Owen & Parker in this volume). Often, the initiative for an air quality citizen science project is (at least partly) taken by a municipality. For municipalities, citizen science provides the opportunity to improve the connection between citizens and their living environments by studying the environmental conditions of their direct local vicinity. For EPAs to support this, however, a lot of learning is needed, including about the governance of long-term data collection, the dissemination of results and the use of platform technology with open data (see Williams et al. in this volume).

Citizen science is not only beneficial for its organisers, but also provides participants with the opportunity to democratise science, and to learn about the scientific topic of focus. In a relatively recent literature review, Haywood (2014) collects claims about the benefits of citizen science for its participants (table 23.1). These benefits are dependent upon interactions at the local level and the way collected data is made available to participants (e.g., in maps and with adequate explanation).

This chapter summarises the involvement of the Dutch National Institute for Public Health and the Environment (RIVM) in a series of citizen science projects, to draw out some of the potential benefits and challenges of EPA involvement. It then describes the RIVM’s roadmap to further develop the use of citizen science in its national monitoring programme, to provide an example for other official, national-level institutions that may seek to benefit from citizen science.

## From ad hoc citizen science to national measurement networks

The RIVM began its involvement in citizen science around 2012 with its ad hoc participation in several air quality citizen science projects. The projects were varied, and it took a while before the significance of the citizen science movement was fully recognised. In 2016, the RIVM and the Dutch Ministry for Infrastructure and the Environment (responsible for air quality in the Netherlands) agreed to start a programme to innovate its national air quality measurement network (LML). The project should enable small sensors and citizen science to become an integral part of the monitoring procedures. The innovation programme has a timeframe of five years (2016–2020).

In short, the ambition is to make citizen science data an integral part of standard procedures and models for determining air quality. This is a way to not only motivate participation in citizen science, since it is more rewarding when the measurements are actually used, but also to make citizen science sustainable, which is often lacking. The final goal is to have a hybrid, flexible network using data from different types of sensors, including reference instruments, intermediate- and low-cost, and satellite observations. The data can be contributed by different parties, including citizen groups, cities, non-governmental organisations (NGOs) and official measurement institutes.

There are several reasons why the RIVM decided to participate in citizen science. Innovation of the air quality monitoring network is in part affected by the fact that such a network is expensive, making better and more cost-efficient solutions welcome. In addition, advances in micro technology (especially sensor technology) and the spread of smartphones have democratised the ability to perform air quality measurements. This means that practically all stakeholders and citizens can do air quality measurements if they want to, perhaps because they do not trust the model-based data from the authorities or because data for their specific location are not available. For EPAs this presents an opportunity as well as a challenge. Environmental protection agencies may profit from the high spatial and temporal resolution observations in the urbanised environment, if they find a way to assimilate these data in air quality and meteorological models to provide forecasts to the public. The involvement of citizens brings the prospect of having the dense coverage of observations needed for this purpose.

The next section describes several citizen science projects RIVM took part in and reflects on lessons learned and experiences gained. It also provides a brief description of innovations in environmental monitoring, and how these will help to ensure the continuity and effectiveness of citizen science measurements.

## Collaboration with stakeholders and local initiatives

### Measuring Ammonia in Nature

Since 2005 the Measuring Ammonia in Nature (MAN) network has monitored atmospheric ammonia concentrations in nature reserves in the Netherlands. The monitoring network is an example of citizen science even if it never was explicitly identified as such. Measurements are performed with commercial passive samplers, which are calibrated monthly against ammonia measurements of active sampling devices. The sampling is performed by an extensive group of local volunteers, mostly rangers, which minimises the cost and enables the use of local knowledge (Lolkema et al. 2015).



**Fig. 23.1** A ranger exchanging a passive ammonia sampler.  
(Source: Erik Noordijk)

Without the unpaid help of the rangers, a monitoring network like this would not be affordable. The network provides countrywide coverage, crucial input for policy and a community of committed rangers.

*Lesson learned:* Including the voluntary help of societal partners may be a cost-efficient way to build a monitoring network on a scale that simply would not be feasible without trusting measurement devices to non-experts.

### NO<sub>2</sub> measurements by Friends of the Earth Netherlands

One of the first citizen science projects RIVM had a small role in was led by Friends of the Earth Netherlands. Since 2012, Friends of the Earth and local community groups have been measuring nitrogen dioxide (NO<sub>2</sub>) concentrations with Palmes tubes, a rather simple but well-established method to obtain monthly averages, at about 100 locations in the Netherlands. Friends of the Earth wanted to get an impression of local air quality and subsequently ask local authorities to take responsibility for good air quality. RIVM contributed in two ways. First, the Palmes tubes measurements were calibrated by mounting them next to official measurement stations of the RIVM, the Municipal Health Services (GGD) of Amsterdam and the Environmental Protection Agency of Local and Regional Authorities in the Rijnmond region (DCMR). Expertise from RIVM was used in the quality control of the measurements and subsequent calibration. Second, RIVM provided standardised procedures to calculate the air quality at the different measurement locations. These model results were compared to the measurements to independently assess the quality of the models used in the Netherlands.

The measurements show that NO<sub>2</sub> concentrations are still high in several locations in large cities, and sometimes exceed the legal limit for yearly averages. The NO<sub>2</sub> concentration measurements in the citizen science project were compared with the values calculated by RIVM using the official Dutch modelling system, and found to correspond well (Knol & Wesseling 2014).

Despite of the different roles of RIVM and Friends of the Earth, both parties benefit from this collaboration. Addressing the quality of the measurements together at the outset, sorting out differences in methodology and other potentially confusing issues, means that the final discussion is about the values measured rather than concerns about the *quality* of the measurements.

*Lesson learned:* Even if citizens, NGOs and EPAs have different goals, they all want reliable data, which is a good reason to work together.

### Measuring air pollution with your iPhone – iSPEX

The iSPEX project (<http://ispex-eu.org>), initiated in 2012, played a decisive role in changing RIVM's views on the way that citizen science can contribute to environmental science. The project uses state-of-the-art technology and citizen science on an unprecedented scale for environmental monitoring, with more than 3,000 participants and over 10,000 contributed measurements. The iSPEX project propagated a relatively new type of citizen science, where a large group of participants turn their smartphones into measurement devices. Within this innovative type of citizen science, iSPEX distinguished itself by collecting and transmitting data to a central database. In the Netherlands, the data collection was organised in two large-scale, nationwide measurement campaigns (scaling up in 2015 to 11 major European cities). Alongside the scientific project partners Leiden University, Netherlands Research School for Astronomy (NOVA), Netherlands Institute for Space Research (SRON), the Royal Netherlands Meteorological Institute (KNMI) and RIVM, societal partners played an important role, especially the Lung Fund (a patient organisation for lung diseases), which supported publicity and the distribution of iSPEX add-ons.

The project measured the properties of particulate matter (aerosols) with iPhones supplemented with a small add-on for the camera. Together with a special iSPEX app that explains the measurement process and transmits the data, this add-on transforms the iPhone into an advanced measurement device. Only iPhones were used because of the uniform position of the camera and the calibration of the add-on. The participants' measurements were compared with, and complemented by, measurements from scientific equipment. One of the primary project goals was to find out how accurate the massive iSPEX measurements were, and what kind of additional information the measurements can provide. The experiment was successful and the scientific results have been published by [Snik et al. \(2014\)](#).

A study of the Dutch participants was conducted in close collaboration with the department of science communication of Leiden University ([Land-Zandstra et al. 2016](#)). The study aimed to examine (1) citizens' motives and conditions for (continued) participation in iSPEX; and (2) the impact of participation on citizens' understanding of both science and aerosols. An online survey showed that the project had attracted an older,



**Fig. 23.2** The iSPEX add-on on the left; instructions for taking measurements on the right. (Source: iSPEX Team)

male, well-educated audience, typical for many citizen science projects. However, the project did attract people with limited previous experience with science and scientific research. There were two dominant reasons for participants joining the iSPEX project: (1) a desire to contribute to scientific research, the environment or health; and (2) an interest in science or more specifically in aerosols and their impact on health and the environment.

Respondents reported that their participation in the iSPEX project taught them how citizens can contribute to science and iSPEX was the first time many had participated in a citizen science project. Although there was agreement that they learned more about aerosols and their impact on health, understanding of the science behind the project was rather low. Respondents were primarily motivated by the prospect of contributing to a larger goal and liked that the measurements took a limited amount of time and could be done individually. Most importantly, the participants were motivated to contribute frequent measurements, including for longer projects. However, continuing the project would require significant investment in technology and operational costs. Therefore, additional funding would be necessary to establish a stable monitoring network for iSPEX observations.

*Lessons learned:* In principle it is feasible to have a large group of citizen participants performing measurements, and the results can be scientifically valuable and complement professional measurements (mostly in terms of spatio-temporal resolution). The limited amount of self-reported learning and understanding of the science imply that projects based on complex science need to find ways to ensure their participants understand what their measurements mean. Projects that use smartphones as measurement devices have the potential to attract a new audience to citizen science.

### Waag Society Amsterdam Smart Citizens Lab

To experiment with more bottom-up citizen science approaches, the RIVM participated in the Amsterdam Smart Citizen Lab initiated by Waag Society in 2015 (Henriquez 2016). The idea behind the project was for citizens to develop tools and instruments that enabled them to register, measure and understand aspects of their direct living environment. The environmental focus was decided by participants themselves. Waag Society provided the facilities to build the tools in its Fab Lab, which included laser cutters and 3D printers. Other project partners included Wageningen University and the municipality of Amsterdam.

Over seven months citizens could participate in six workshops in which researchers from Waag Society and RIVM gave in-depth lectures concerning the large number of affordable DIY sensors and measuring kits available, and their differences compared to professional sensors. Participants were introduced to successful online citizen science platforms, technologies and additive manufacturing techniques that together make DIY sensing networks possible. Three teams were formed that focused on wind energy, air quality and noise pollution.

The outdoor-air-quality group included air-quality scientists from RIVM and Wageningen University, and the combination of both ordinary people and air-quality-sensor professionals helped the project progress (Jiang et al. 2016; Henriquez 2016). Initially, RIVM experts intended to be observers but soon became motivators and trusted sources of information. Their involvement increased confidence in the project and motivated participants; and their expertise helped participants assess ideas. The group succeeded in developing and testing new sensors and a sensing platform. The NO<sub>2</sub> sensor developed was significantly cheaper than those currently installed at official air quality-measuring stations. A flaw of the sensors was that they were over-sensitive to many factors and it was difficult to solve all hardware and software issues. An upgraded version of



the same sensor was used in another citizen science project, Urban AirQ (see <http://waag.org/en/project/urban-airq>).

*Lessons learned:* The support of experts is often welcome and the chances of success increase if experts take citizen science seriously by providing support and information. Timing is crucial as participants need *enough* information at an *early* stage, when the plans can still be adapted and improved. Nevertheless, too much information limits their freedom: participants have different goals from EPAs and may want to measure with new technologies, or measure other pollutants for which there is not (yet) legislation.

### Nijmegen Smart Emission project

RIVM is a partner on the Smart Emission project in the city of Nijmegen, initiated as a pilot project by Radboud University and the municipality. The project has its origin in Geographic Information Systems (GIS) and participatory mapping and planning, outside of RIVM's usual disciplines. The project aims to create and test the concept of a citizen sensor network, including a feedback loop of information from interested participants to sensors and back. It involved data analysis by students, information and communication technology companies providing the new sensor technology (hardware and software) and (geo-) professionals creating the necessary spatial data infrastructure.

As the pilot progressed, plans were continuously adapted to the needs of the project partners (with increasing enthusiasm from the municipality), technical possibilities (including the challenges of battery life and long-range data transmission) and wishes of participating citizens (through feedback processes). The first sensors were developed by SME companies 'Intemo' and 'CityGIS' and 34 were installed at the time of writing following advertisement for volunteers to accommodate a sensor (requiring a power-supply and Wi-Fi) in a local door-to-door magazine. The sensors not only register air quality, but also noise, light intensity, low-frequency vibrations, temperature, air pressure and relative humidity. Challenges remain, including need for the dataflow and data algorithms to work with the downtime of individual sensors, which may shut off temporarily when the interior gets too moist.

The project will compare local data from small and cheap sensors with the data from the RIVM air quality measurement network. A clear decision was also made for the project to be open and transparent. The

research team shared the information portal and raw measurements with participants and other researchers as soon as they were available, and asked for direct feedback. In this way, the citizens were taken on board as co-working participants. For example, a digital forum for questions and answers was added to the portal, at the request of participants, so that discussions could take place between researchers and participating citizens in between meetings. In this way, the research team learned a lot about participants' needs and wishes, including the fact that there are large differences in their information needs: Graphs and pictures satisfy some, but others prefer the data behind the visuals. This shows the importance of transparency and flexibility in presenting information in various ways. Participants also learned about the process of gathering raw data, the construction of a data infrastructure, etc., and overall this feedback approach increased mutual trust (see also Hecker et al. 'Stories' in this volume on communicating with participants).

*Lessons learned:* Flexibility can be the key to success. It is possible to create a relatively low-cost network to monitor environmental parameters with citizen participants. Open data and transparency can create trust and a better understanding for both citizen participants and experts.

Ik heb last (I suffer now) app <http://ikheblastapp.nl/>

The Ik heb last (I suffer now) app is innovative because it directly uses the health complaints of individuals as indicators for environmental issues. The air quality in the Netherlands is continuously improving, but a significant number of people suffer from air pollution. Information about air pollution can help people to match their activities and medicine use with geographical locations. Estimates can be made for the Dutch population as a whole, but this may mean something different at the individual level.

The purpose of the 'I suffer now' app is to enable citizens to indicate that they have issues with their respiratory system. Reports can be matched with different air quality conditions and patterns derived using 'big data', which enables a forecast of sensitivity at the individual level. This forecast provides the user of the app the opportunity to plan activities and medicine intake. For RIVM and its partners, Friends of the Earth Netherlands, Lung Fund, Utrecht University and Hogeschool Rotterdam, the data gathered could improve the identification of causes and exacerbations of respiratory symptoms. Moreover, the project tests citizen participation and which incentives might drive this.

*Lessons learned:* Projects of this kind are innovative but complex, and participants require more feedback. However, they have the potential to directly measure effects on health, including on an individual level. The coming years will show how this approach may best be deployed.

## Innovation for national EPAs

Recurring themes emerge from the various citizen science projects above that are relevant for an EPA and its societal partners:

1. Citizens are motivated to contribute to air quality measurements that complement existing measurement networks because of their high spatio-temporal resolution.
2. Data needs to be assimilated, for example, in models.
3. Low-cost sensors need developing.
4. Low-cost sensors require application calibration and validation.
5. Easily accessible expert information is needed.

The second point – about the assimilation of data in models – is perhaps the most challenging, and vital to ensure continuity in the measurements and motivation of citizen participants. Applying the data requires flexibility; this includes coping with data that do not meet the high-quality standards of official monitoring networks. Data science may help in dealing with cross-sensitivity or instability in measurements. Modelers may also be able to include data with a lower accuracy or of a different nature from official measurements (see Williams et al. in this volume). RIVM has concluded that citizen science measurements should be an integral part of the existing national monitoring network and employed in real-time modelling procedures. The current innovation of the monitoring network is intended to provide a stable basis for the testing, calibration and use of citizen science data.

A natural role for the EPA as a reference institute is to assess the quality of the data. In practically all the citizen science projects above, the quality of the data was a big issue. Although most relatively cheap sensors measure at least something, the relationship with official air quality measurements can be poor or even absent. The measurements by national EPAs can serve as a reference to aid the calibration of cheap sensors used in citizen science projects.

It is also important to recognise that citizens' need for information and data is diverse. In the Smart Emission project in Nijmegen, for

example, some participants demanded more information and detailed insight into the underlying raw data, but others wanted less information. Although some wanted the data in a simplified form (e.g., good/bad rankings using colour codes or emoticons), making the underlying ‘complicated’ data available gave participants more confidence in the data and project. It is therefore crucial that data is open and available at a basic level, and that it is presented at different levels of complexity and in different forms (numbers, graphs, colour codes, etc.).

RIVM is currently developing an interactive knowledge and data portal for citizen science related to air quality monitoring (see also Brenton in this volume). This portal will be made in open collaboration with citizen participants and aims to connect with them by supplying knowledge and data in a way that is understandable to the interested public, and that has been adapted to their needs. The aim is to become an important source of information for air quality-related citizen science in the Netherlands. There is also a YouTube channel (Samen milieu meten) to experiment with short videos, for example to answer frequently asked questions, to introduce or explain different types of innovative measuring devices, or explain background information (e.g., What is particulate matter composed of? How can it be measured?). Tutorials will also be available showing how to build a sensor kit or download data). The focus is on air quality because of the interest of citizens, technological innovations and the authoritative role of RIVM in monitoring air quality. However, the generic knowledge and experience gained may be used for other environmental domains like noise, light, radiation, soil and water. Providing a knowledge and data portal will encourage and support long lasting data collection by citizen science projects. Consequently, citizen science will be an essential element of Dutch national monitoring networks.

Sensors for, among others, air quality and Internet of Things applications are developing at a rapid pace. Hence, RIVM expects that within five years, its network for measuring air quality could evolve from a network with a limited number of high-quality (reference) measurement stations to a hybrid system that uses a much larger number of sensors that are cheaper and of lower quality. Where possible, satellite data will also be integrated in this network and a limited number of high-quality measurement stations will still form the reference base of this system. Combining all these data of varying quality and levels of uncertainty with models is a cost-efficient way of monitoring. This results in a crowdsourcing system that provides local communities with trusted local environmental data and at the same time enriches the national system for air quality monitoring. In this evolution, RIVM has identified different phases to provide

a roadmap for the innovation of environmental monitoring, as illustrated in [figure 23.3](#). The different steps may overlap and timelines are not strict but help target innovation over five years.

### Phase 1

The first phase, started in 2016 at RIVM, involves implementing efficiency actions (e.g., automating some steps in the validation process) and planning to decrease the number of measurements (and/or stations), which will create the capacity for innovation while still complying with international requirements (e.g., EU directives). This means difficult decisions about what measurements or stations may be discontinued. The RIVM innovation programme aims at balancing the effects of the foreseen reduction of the monitoring effort on monitoring quality by introducing new lower-cost sensor technology into the network. The goal is to keep or even increase the quality level of the monitoring programme in this way. Six official measurement stations belonging to RIVM and its monitoring partners will be equipped with a facility to test small sensors. These will be used by RIVM and its partner institutes to test sensors (such as the AirSensEUR; see <http://www.airsenseur.org>), and the facilities are open to citizen science communities and sensor builders to test and calibrate their own sensors. The locations of the small sensor test stations represent a broad range of measurement situations. There is a rural site, an urban traffic station, two highway sites (one urban, one rural) and an industrial site. A test facility for small sensors will also be developed in a climate chamber.

### Phase 2

In the second phase, around 2018 for RIVM, advanced yet relatively cheap (though still expensive for citizen science projects) sensors will be included in the national air quality monitoring system. The use of satellite data will also be included, where possible. Extensive tests will have to be performed to see how these sensors behave over longer periods such as a year. The practical effect of trading a limited number of reference measurements for (many) cheaper sensors on air quality monitoring will be determined.

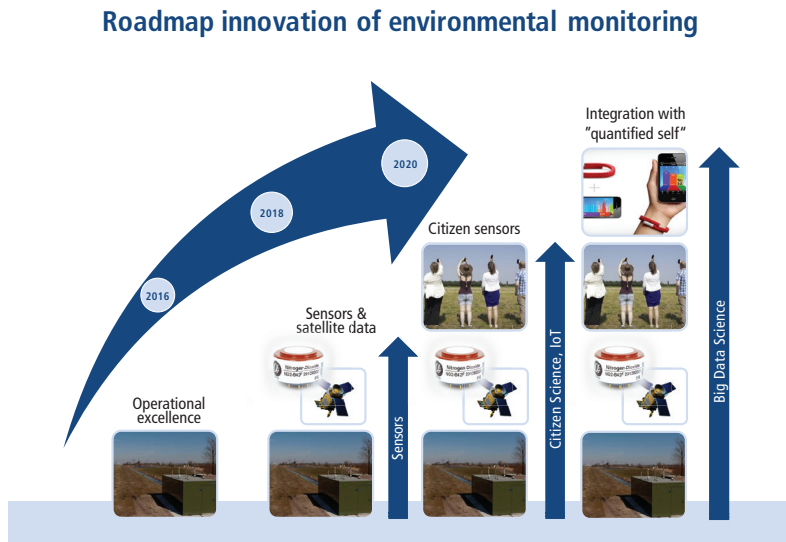
### Phase 3

In the third phase, envisioned to be fully implemented around 2020 at RIVM, a crowdsourcing platform will be developed to enable citizen science projects with low-cost sensors to participate in national monitoring.

The second and third phase will ask for creative solutions that enable the simultaneous use of data with different quality levels. Planning for the crowdsourcing platform will start with pilot projects with different degrees of citizen involvement. A limited number of reference measurement methods will act as the backbone of the national monitoring programme, supplemented with a flexible layer of alternative, low-cost sensor devices. Continuous validation cycles of these low-cost sensors with reference data will result in the gradual improvement of available sensor technologies.

### Beyond phase 3

Health monitoring technologies are evolving at the same time as environmental monitoring, with technologies related to mobile health care rapidly maturing (e.g., GIS tracking to support individual exposure modelling, personal health measurements like heart rate or spatio-temporal tracking of medication use). They provide an excellent opportunity for environmental health research to become a key innovation partner in health transition technologies. Integrating environmental and health monitoring offers the potential for important follow-up innovation.



**Fig. 23.3** Innovating a traditional measurement network towards a hybrid crowdsourcing platform. (Source: Erik Tieleman)

Beyond phase 3, RIVM anticipates combining its static air quality monitoring network with personal exposure and health monitoring.

## Conclusion

This chapter has explored the potential benefits and challenges of an EPA incorporating citizen science into its national monitoring. It has shown the important possibilities of this arena in improving the scale and scope at which data is available by supplementing limited and expensive monitoring equipment with widespread, low-cost sensors led by citizen monitoring. Participants in this field are highly motivated due to the societal importance of environmental issues, but EPAs and citizen science project leaders need to address issues of data quality and sensor calibration, and to provide appropriate feedback to reward and motivate participation. The trial projects RIVM has been involved in clearly point to the potential advantage of these methods for EPAs, such that it has now adopted a framework to further incorporate citizen science in its monitoring processes. This roadmap and lessons learned from the case studies may provide ways forward for other EPAs and official government agencies seeking to improve their traditional practices by engaging with the potential of citizen science.

## Appendix A

**Table 23.1** Claims about citizen science participant benefits

Citizen science participant benefit	Citation
<i>Enhanced science knowledge and literacy (e.g., knowledge of science content, science applications, risks and benefits of science, and familiarity with scientific technology)</i>	Braschler et al. (2010); *Brewer (2002); *Danielsen, Burgess & Balmford (2005); Devictor, Whittaker & Beltrame (2010); *Evans et al. (2005); *Fernandez-Gimenez, Ballard & Sturtevant (2008); *Jordan et al. (2011); Krasny & Bonney (2005); Sullivan et al. (2009)
<i>Enhanced understanding of the scientific process and method</i>	Bonney (2004); Bonney and Dhondt (1997); Braschler et al. (2010); Devictor, Whittaker & Beltrame (2010); Sullivan et al. (2009); *Trumbull, Bonney & Grudens-Schuck (2005)

(continued)

**Table 23.1** (continued)

Citizen science participant benefit	Citation
<i>Improved access to science information</i> (e.g., one-on-one interaction with scientists, access to real-time information about local scientific variables)	*Fernandez-Gimenez, Ballard & Sturtevant (2008); Sullivan et al. (2009)
<i>Increases in scientific thinking</i> (e.g., ability to formulate a problem based on observation, develop hypotheses, design a study and interpret findings)	*Kountoupes & Oberhauser (2008); *Trumbull et al. (2000)
<i>Improved ability to interpret scientific information</i> (e.g., critical thinking skills, understanding basic analytic measurements)	Bonney (2007); Braschler et al. (2010)
<i>Strengthened connections between people, nature, and place</i> (e.g., place attachment and concern, establishment of community monitoring networks or advocacy groups)	*Devictor, Whittaker & Beltrame (2010); *Evans et al. (2005); *Fernandez-Gimenez, Ballard & Sturtevant (2008); *Overdeest, Orr & Stepenuck (2004)
<i>Science demystified</i> (e.g., reducing the 'intimidation factor' of science, correcting perceptions of science as too complex or complicated, enhancing comfort and appreciation for science)	Devictor, Whittaker & Beltrame (2010); *Kountoupes & Oberhauser (2008)
<i>Empowering participants and increasing self-efficacy</i> (e.g., belief in one's ability to tackle scientific problems and questions, reach valid conclusions and devise appropriate solutions)	*Danielsen, Burgess & Balmford (2005); Lawrence (2006); Wilderman, Barron & Imgrund (2004)
<i>Increases in community-building, social capital, social learning and trust</i> (e.g., science as a tool to enhance networks, strengthen mutual learning and increase social capital among diverse groups)	Bell et al. (2009); *Danielsen, Burgess & Balmford (2005); *Fernandez-Gimenez, Ballard & Sturtevant (2008); *Overdeest, Orr & Stepenuck (2004); *Roth & Lee (2002); Wilderman, Barron & Imgrund (2004)
<i>Changes in attitudes, norms and values</i> (e.g., about the environment, about science, about institutions)	*Danielsen, Burgess & Balmford (2005); *Ellis & Waterton (2004); *Fernandez-Gimenez, Ballard & Sturtevant (2008); *Jordan et al. (2011); *Melchior & Bailis (2003)

Source: Haywood 2014

\* Studies that have empirically tested outcome hypotheses and reported results are noted with an asterisk.