Chapter 19
Creating Positive Environmental Impact Through Citizen Science

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Abstract Interest in citizen science is growing, including from governments and research funders. This interest is often driven by a desire for positive environmental impact, and the expectation that citizen science can deliver it by engaging the public and simultaneously collecting environmental data. Yet, in practice, there is often a gap between expected and realised impact. To close this gap, we need to better understand pathways to impact and what it takes to realise them. We articulate six key pathways through which citizen science can create positive environmental change: (1) environmental management; (2) evidence for policy; (3) behaviour change; (4) social network championing; (5) political advocacy; and (6) community action. We explore the project attributes likely to create impact through each of these pathways and show that there is an interplay between these project attributes and the needs and motivations of target participant groups. Exploring this interplay, we create a framework that articulates four citizen science approaches that create environmental impact in different ways: place-based community action; interest group investigation; captive learning research; and mass participation census.

Keywords Change theory · Climate and biodiversity emergency · Behaviour change · Policy influence · Environmental management · Political advocacy

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Introduction

The unprecedented environmental crises the world is facing require urgent action from society, policy, and business. Citizen science has the potential to help generate the environmental data needed to understand and address these challenges and increase public interest and engagement, which are essential for societal change. Citizen science has already established itself as a critical source of biodiversity (Chandler et al. 2017a) and water quality (Hadj-Hammou et al. 2017) data. It has been identified as a key instrument to measure progress towards the United Nation's Sustainable Development Goals (SDGs) (Fritz et al. 2019) and as an excellent tool to generate public interest and engagement on air pollution (Van Brussel and Huyse 2019).

The field of citizen science is vast, with project types, engagement approaches, and project aims ranging from educating citizens to community activism and specialist scientific investigations (see Haklay et al., this volume, Chap. 2). Environmental and biodiversity research, which are the focus of this chapter, make up a large proportion of existing citizen science activities and include tasks such as wildlife monitoring, water monitoring, image classification, and historical record transcription.

As the field of citizen science has expanded over the last decade, various authors have attempted to define and describe the different types of citizen science approaches (Ceccaroni et al. 2016). These typologies have focused on how projects are managed, the role of citizens within the project, and the research topics and tasks. However, these project attributes do not work independently, and it is the interplay between them that determines the lasting impact of a project.

Given the vast array of project types, it can be difficult to talk about the impact of citizen science in general. Different projects will achieve different outcomes and impacts based on multiple factors, for example, geographic scale, depth of participant engagement, timescale, available resource, and project partnerships. To maximise the benefit of citizen science as a tool for creating positive environmental change, it is fundamental to understand *how* citizen science leads to *positive environmental impact* – actual change on the ground – and what type of projects are best suited for different contexts.

Impacts of citizen science projects can be broad, affecting the environment, society, the economy, science, and governance (Hecker et al. 2018). In this chapter, we focus on impacts on the environment; specifically, how can citizen science projects improve the environment, in areas such as biodiversity, water quality, and pollution. Impact on other domains is only included where this leads to environmental impact further down the line. We do not consider the impact on society and governance per se, but analyse how citizen science can create *behaviour change* (society) and the evidence that feeds into *environmental policy* (governance).

In this chapter, we explore the different pathways through which citizen science projects can create positive environmental impact and then identify distinct project types that deliver such impact. A framework of four citizen science approaches is presented that articulates the interplay between various project attributes, including participant appeal, task complexity, impact pathway, and project governance. We believe that this framework will help citizen science practitioners, research funders, and government agencies to create impactful projects and hence unleash the full potential of citizen science for the benefit of our shared environment.

Background

Environmental Impact

The impact of citizen science projects is often divided into three core aspects: *scientific*, *individual*, and *socio-ecological and economic* (Shirk et al. 2012). Environmental impact is a subset of the socio-ecological and economic impact and occurs when changes are made to resource management and practices that affect the natural environment. This includes changes to institutional practice (activities of organisations, businesses, and governments); collective practice (the actions of a group of people, e.g. a local community); or individual practice (activities of individuals). Each of these practices is, in part, governed by policies and can influence other practices (e.g. changes in institutional practice can inspire individuals to change their behaviour) (Fig. 19.1). An impact framework has been developed that articulates six pathways through which citizen science projects can create environmental change (Wehn and Gharesifard 2020). This framework is based on impact frameworks commonly used in research, community organising, and education, including the citizen science toolkits developed by Cigliano et al. (2015).

Pathways to Impact

Citizen science projects can change the *environmental management* performed by institutions, in much the same way as any other (applied) research can lead to management change. This change can include a shift in conservation management plans (Chandler et al. 2017b) or the use of citizen science to detect and address pollution incidents (Brooks et al. 2019; Hadj-Hammou et al. 2017; Owen and Parker 2018).

Another way in which citizen science projects can create environmental impact is by creating *evidence for policy*, which can modify institutional, individual, and collective practice. For example, marine citizen science data, shared with policymakers, has informed the design of marine protected areas (Hyder et al. 2015). Again, this pathway to impact is similar to those for other types of applied research.

Engagement in a citizen science project can inspire *behaviour change* among participants (Cigliano et al. 2015). We define behaviour change here as a measurable

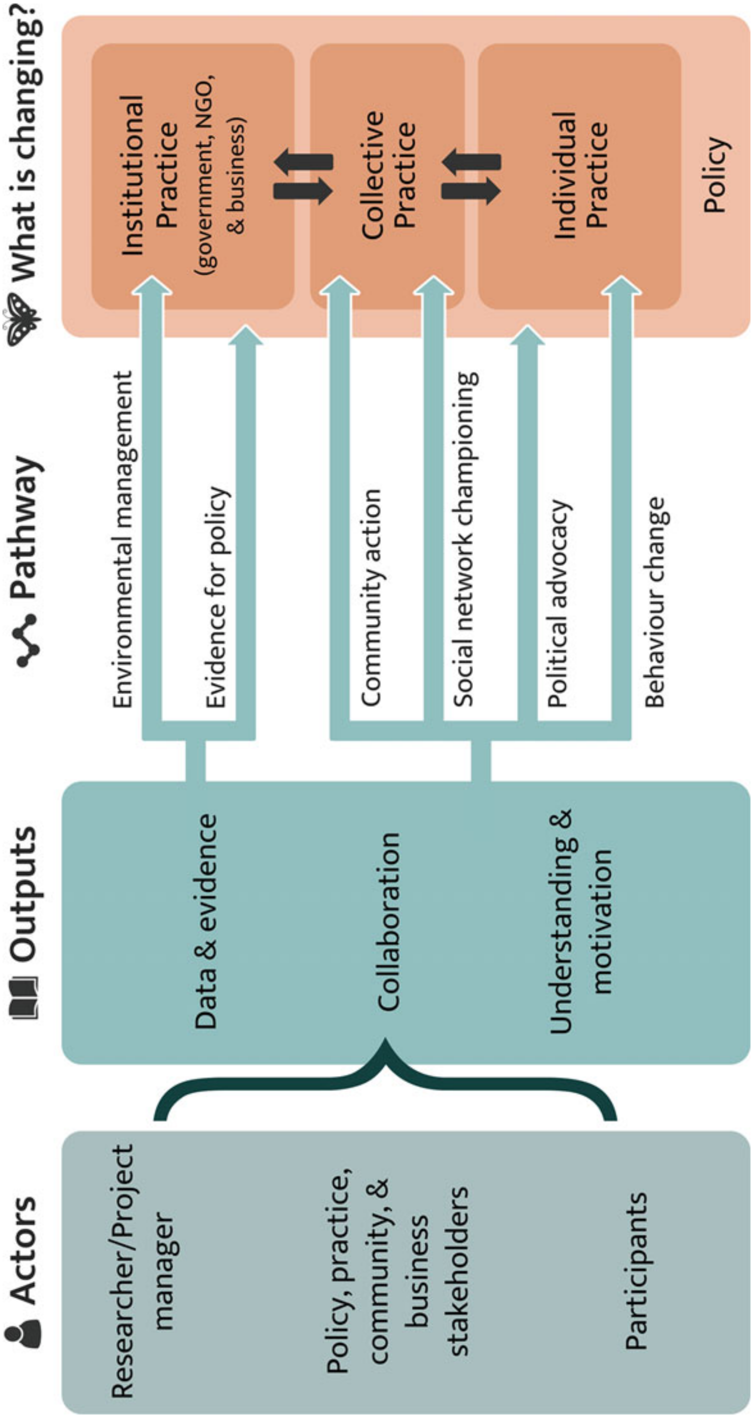

Fig. 19.1 Impact framework outlining six key pathways through which citizen science can lead to environmental change

action resulting from engagement in citizen science that is external to the protocol activities of the citizen science project (Phillips et al. 2018). Examples include increased political activism, local conservation action, and lifestyle changes. Behaviour change ranges from a one-off direct action (e.g. putting up a bird box) to incremental changes in attitude and long-term behaviour change (e.g. no longer using single-use plastic).

Another pathway that individuals can pursue to generate environmental impact is *social network championing*. Here, participants influence friends, neighbours, and colleagues to encourage them to change their behaviour. If projects can support participants to influence their wider social network, then the effect can radiate far beyond the original set of participants and, by extension, potentially change norms within a social group or in society more broadly (Johnson et al. 2014; Syberg et al. 2018).

Political advocacy sees individuals and communities involved in citizen science inspired to publicly support causes and advocate for policy change. Such pressure can push issues up the political agenda and can lead to more rapid change than through presentation of new scientific evidence alone (Van Brussel and Huyse 2019).

Finally, participation in a citizen science project can lead to *community action*. Here, participants come together to effect direct environmental change (e.g. planting trees or removing plastic waste). The citizen science project can deliver research findings that inform the action. It can also facilitate the collaboration needed for collective action and can contribute to the motivation that leads individuals to act together (Jordan et al. 2019).

Impact Framework

The positive environmental impact created through these six pathways relies not only on the scientific data and evidence produced by citizen science projects. It also relies on increased understanding and motivation among engaged individuals and collaborations between the different actors it enables. These outputs (*data*, *motivation*, and *collaboration*) can be used by all involved – including researchers, government agencies, NGO partners, participants, and industry or community stakeholders – to drive change. In researcher-led projects, data and evidence are mostly used by researchers to push for changes to policy and practices, while participants can create change through increased personal understanding and motivation. However, participation in a citizen science project can also inspire researchers to change their own behaviour and data can be directly used by participants to influence policy and practice.

The framework presented here outlines how a project *can* influence the environment. In practice, it is challenging to establish the extent to which specific environmental changes can be attributed to individual projects (Schaefer et al., this volume, Chap. 25). This framework should, therefore, be used to understand how to maximise *opportunities* to effect positive environmental change, rather than to accurately predict the changes that will occur.

Matching Impact Objectives and Participant Motivations

Across all six pathways to impact outlined, sufficient participation in a project is key to maximising its impact. Good uptake is crucial to both the amount of data collected – leading to robust scientific results that can feed into policy and practice; and the number of participants engaged – reaching more people who can be inspired to change their behaviour, influence others, advocate for change, and drive community action.

Impact, in turn, can be an important driver of uptake. Wanting to make a difference, for example, to wildlife or to science, are among the most prevalent motivations for participation in citizen science projects (Geoghegan et al. 2016). Hearing how the data will be used to make a difference and what impact the project has already achieved are among the most important motivations to sustain participation.

To maximise impact, project designers need to understand who their potential participants are, what motivates them, what barriers to participation they face, how these barriers can be overcome, and how their motivations align with the intended project impact (Land-Zandstra et al., this volume, Chap. 13).

State of the Art

Project Types

Existing citizen science typologies (Ceccaroni et al. 2016) describe two distinct participant groups: *captive learning groups* (often in schools or museums) and *place-based community groups*. Other projects are generally defined by their core aim (e.g. conservation versus investigation) or methodology (e.g. field based versus online) and primarily reach existing *interest groups*. Yet, some projects manage to buck this trend and achieve more diverse *mass participation* (e.g. Van Brussel and Huyse 2019).

Dividing participants into these four groups is a simplification of reality. Each group can be diverse and consists of individuals with complex identities. Yet, understanding the predominant motivation for engagement with a project – which differs markedly between these four participant groups – provides key insights into the types of activities that will appeal to them and the consequent opportunities for impact.

Each participant group is tied to a distinct project type which we will now explore.

Place-Based Community Projects

Place-based community projects are generally focused on improving the environment in a specific area, with participation from the local community. Participants join the project through an attachment to 'their' location or potential benefits to their personal life (e.g. health benefits from improved air quality). Another important aspect is the opportunity for social interaction. These citizen scientists may not have a pre-existing interest in the project topic or in science in general, but they may still be prepared to invest considerable time and effort for personal benefit (e.g. social contacts or health benefits).

To effect impact, community projects require the support of local stakeholders and the local population. Projects are most likely to succeed if participants feel ownership and have agency, e.g. through co-creation and opportunities to be involved throughout the research process. Projects are often community initiated. Alternatively, they can be led by scientists if scientists dedicate time to build a relationship of reciprocal trust with the local community. Working with existing community groups and community leaders is an effective way to build relationships and encourage participation from the wider community.

Projects can be long-term (e.g. ongoing monitoring and stewardship of water quality) or a single event aimed at raising awareness about a specific issue. Participation of the wider community is highest when the research tasks are simple and do not require prior subject knowledge. Given the potential diversity of the participant pool, long-term projects can benefit from having a variety of tasks and offering learning opportunities.

Captive Learning Projects

Citizen science has long been used as a learning tool in schools, informal learning groups (e.g. scouts), and museums. It is also used as part of employee learning programmes, for example, within Earthwatch's Sustainability Leadership Programme. Collectively, we refer to these as *captive learning projects*, referring to both the objective to educate participants and to the fact that participation happens through gatekeepers (e.g. teachers or employers).

Captive learners can participate in citizen science without a pre-existing interest in the research topic if they are enrolled by a gatekeeper (e.g. teacher or employer). The level of engagement largely depends on the group leader's skills and capacity to motivate. Educational projects require a citizen science leader (scientist, teacher, or engagement officer) and have a limited participant group size to allow for effective engagement. Projects can be scaled up by running multiple consecutive sessions with different participant groups or by employing train-the-trainer methods, with groups of educators trained to take the project into their respective educational settings. Captive learning projects have a high potential to engage and inspire new participant groups and can expose participants to new issues and experiences. Tasks need to be simple enough for novice participants but can increase in complexity if training is provided by the group leader.

Interest Group Projects

Many citizen science projects primarily attract participants who are already skilled or at least interested in a specific research topic. Interest group participants (e.g. birdwatchers) are more likely to stay engaged in projects and are generally prepared to commit more time to projects. Where projects offer an opportunity to meet like-minded people, this can act as an additional driver to enrol and stay engaged. Interest group projects can span a wide geographic area and often run for a long time, with individual participants making repeat observations. As participants tend to have pre-existing knowledge of the subject, they can often handle more complex and time-consuming tasks.

Interest group projects have generated reliable, high-quality data for decades, especially when projects invest in support and training for participants. The downside of this project type is that the pool of potential participants is limited and often lacks diversity. In particular, short-term projects often struggle to recruit sufficient participants, unless project leaders collaborate with existing volunteer networks.

To date, many projects have mainly white, highly educated, and affluent participants (Pandya 2012). However, some projects have reached different demographic groups, for example, where projects are initiated by specific communities and cover topics that are particularly relevant to them, but few have achieved truly diverse participation.

Mass Participation Projects

If the project task is simple, has clear societal relevance, requires limited time commitment from participants, and is widely advertised, then citizen science projects can achieve mass participation (Van Brussel and Huyse 2019). People may take part out of curiosity, because the research is relevant to their own health or local environment or because they are intrigued by the opportunity to take part in scientific research. As these projects have low barriers for participation in terms of time commitment and pre-existing knowledge, they can attract participation from a wide section of society. Whether they actually attract participation from diverse groups depends on a range of factors, including where the project is advertised; whether participation requires access to assets that are not equally distributed (e.g. travel to a national park or having a garden); and whether the organisers convey that the project is open, welcoming, and of benefit to traditionally under-represented groups.

The majority of successful outdoor mass participation projects are conducted over a short time frame, for example, performing an environmental census such as a bird count or a freshwater blitz on a specific weekend. Participants may take part because it is a fun activity or through a desire to help science or the environment. Mass participation projects can be local and place based or conducted over a large geographic area.

Large-scale projects have the potential to collect data across large geographic areas within a short time frame, generating unique datasets that cannot easily be generated otherwise. They also provide an opportunity to raise awareness of a specific issue among a mass audience. Successful recruitment of mass participation requires substantial marketing and communication, clear instructions for participants, and extensive project management.

Achieving Environmental Impact through Different Pathways

The four project types do not all lend themselves to creating impact through all six impact pathways. Below, we explore the project attributes commonly associated with each of the impact pathways and which participant groups these can attract.

Environmental Management

Many environmental citizen science projects aim to contribute data to inform management decisions, but much of this potential remains untapped (Newman et al. 2017). Chandler et al. (2017b) showed that citizen science projects are most likely to feed into management plans if they are:

- Place based and firmly rooted in the local context
- Carried out over multiple years, management impacts on average peak 6–8 years into a project's life cycle
- Deliberately designed for management purposes with scientifically robust protocols
- Co-created with stakeholders to identify their needs and decision-making timelines

In addition to such place-based projects, large-scale projects (e.g. national biodiversity recording schemes) can feed into (local) management decisions if data and metadata are made open access and have sufficiently granular spatial and temporal resolutions (Hadj-Hammou et al. 2017).

To make evidence-based management decisions, projects need to deliver high-quality data on specific metrics that are repeated over time. To collect such data, participants need to follow prescriptive and often complex sampling protocols and invest time in the project over a longer period. This is likely to be most attractive to participant groups who are already interested in or have a connection to the research topic or the research location – interest groups and place-based community groups (Owen and Parker 2018). Alternatively, such data can be collected by consecutive captive learning groups hosted at a single location (Chandler et al. 2017b).

Evidence for Policy

Evidence gathering activities can support policy change at different levels (e.g. local, national, and international government) and at different stages of the policy cycle (see also Schade et al., this volume, Chap. 18). In addition to delivering evidence that informs the formulation of new policy, citizen science can be used to evaluate policy effectiveness and inform policy implementation. In some areas, there is a long history of using citizen science data to evaluate policy, including in biodiversity monitoring and in relation to invasive species.

Bio Innovation Service (2018) conducted an in-depth evaluation of 45 citizen science projects which revealed that projects were most likely to influence policy if they:

- Received government support, not only in the form of funding, but also through active participation in the design and implementation of the project
- Had a straightforward engagement process for participants, requiring limited effort and a priori scientific skills

Scientific complexity did not appear to affect the policy uptake per se, but projects with high scientific standards and endorsed by scientists served more phases of the policy cycle.

Policymakers benefit most from large data sets that provide extensive evidence at the appropriate geographical scale. Local policy formulation can benefit from place-based community projects but can also draw information from projects operating at a larger scale. National policy formulation is best served by large data sets with extensive coverage of space and time. Such large data sets can be created through either interest group projects or mass participation projects. The latter is particularly suited for capturing a snapshot of a single moment in time across a large geographic area but requires straightforward and rapid sampling methodologies. Captive learning projects are generally less effective in informing policy due to their limited geographic coverage and clustered sampling, unless a large number of events are conducted as part of a concerted effort.

The involvement of policy stakeholders in project design helps to improve the alignment of project outputs to policy priorities. However, the potential for policy impact doesn't necessarily translate into actual policy change. The science-policy interface is complex, and many factors contribute to whether findings are adopted by policy stakeholders and lead to policy change (Rose et al. 2017). A major challenge in getting evidence-generating citizen science to create policy impact is the lack of alignment between research, community, and policymaker timelines. Policy horizons and project outputs may not coincide, and relevant results can fly under the policy radar. Researchers should be proactive in their output plans to maximise the potential for impact.

Behaviour Change

Engagement in a citizen science project and experiencing first-hand how a specific issue affects the environment can motivate and inspire participants to change their behaviour. Whether such behaviour change is realised depends on a number of factors.

People are most likely to take action or make changes to their routines as a consequence of engagement in a citizen science project if the project has a clear *call to action*. In line with general behavioural psychology principles, action is most likely to occur if the requested action is simple, fun, and complies with social norms. Literature within behavioural economics has highlighted strong biases which lead people to maintain the status quo (Rare and the Behavioural Insights Team 2019). Therefore, to maximise impact through behaviour change, it is essential to make recommended changes as convenient and accessible (physically and financially) as possible.

People are driven by different motivations and are most likely to change behaviour or take action if they care about the issue or location. Interest groups tend to have a strong connection with the research topic. They are also generally already aware of the actions they can take and may display the desired behaviours before joining the project. Captive learning groups are more likely to be exposed to new topics and information. Moreover, the guided approach of many such projects can help to take these groups on a journey, open their eyes, and inspire them to take action. Place-based community projects also have potential to inspire behaviour change, especially as the social context of the project can shift social norms. Once certain members of the community have changed their behaviour others may follow to comply with social norms. Finally, mass participation projects are likely to reach new participant groups, but as people's involvement in these projects typically remains light touch, they are likely to only lead to incremental changes rather than long-term behaviour change.

Social Network Championing

To influence non-participants via social networks and inspire them to change their behaviour, it is crucial that projects establish clear pathways for communication and dissemination across social networks (Reed et al. 2010). This can include both digital platforms – like Facebook, Twitter, and Instagram – and offline communication within communities. Influencing and awareness-raising through digital channels and traditional media can be done centrally by project leaders. However, people are more often inspired to change their behaviour if they are influenced by their own social contacts, including friends, family, colleagues, and neighbours. Projects can, therefore, increase their impact through social network championing if they inspire and facilitate participants to directly influence their wider social circles, both online and offline.

Mass participation projects are more likely to have access to the resources required to make strategic use of conventional and social media. In contrast, place-based community projects often rely on the participants themselves to use their existing networks to influence others.

Increasing public environmental awareness through social networks, also called *network environmentalism*, is most effective if projects can tap into existing networks of interested and motivated people (Johnson et al. 2014). Projects need to be engaging to a wide and diverse audience, even if only a few people are directly involved in data collection. The audience needs to be able to relate to the material being communicated; stories which are of personal relevance to the public are more likely to gain such traction (Hecker et al. 2018). Mass participation projects are often designed with a diverse audience in mind and use methods which are easy to understand. Smaller projects can also be very successful at social network championing if they invoke a strong connection to an emotive (local) issue.

For social network championing to result in environmental impact, it needs to go beyond awareness-raising and lead to behaviour change. In particular, a clear, well-defined call to action, communicated through social networks, is a powerful way to achieve environmental impact that extends beyond the bounds of the project.

Political Advocacy

Project design and framing can motivate volunteers to shape political outcomes through advocacy (Cornwall 2008). Aoki et al. (2008) identified the following criteria for citizen science to result in successful environmental activism:

- The data collected must be 'credible enough' to engage policymakers
- The project must be appealing and inspiring to a wide audience in order to mobilise action
- The project must be personally relevant to participants
- Mechanisms must be in place for advocates to be heard by the actors who can action change

For advocacy to occur, the project must be framed in a way which allows participants to fully comprehend the project topic and its relevance to current policy and practice. Participants must also find the project appealing and inspiring enough to motivate them to extend their activity beyond the bounds of the project and into advocacy. Participants need to feel that the project and related outcomes are of personal relevance to them.

Place-based community projects seem most effective at generating political advocacy – people are more likely to be motivated towards, personally relate to, and actively participate in *local* civic agendas. At local levels, it can also be easier for participants to reach policy actors and make their voices heard. Interest group projects can also inspire participants to become political advocates as participants tend to already have a keen interest in the research topic and can feel passionate about protecting species or ecosystems. Political advocacy seems to be rarer in captive learning and mass participation projects.

It is important to note that the issues that lead people to act as advocates are often extremely emotive, and a 'policing logic' guides the work of some citizen science groups, focusing on observing and reporting suspicious activity (Kinchy et al. 2014). Project leaders should operate ethically and not (inadvertently) mislead participants to endorse a specific agenda. To avoid such situations, projects need to operate transparently, uphold high data and project design standards, and ensure that the issue or solution they advocate for is evidence based. The data collected through the project can provide this evidence; political advocacy is, therefore, best combined with the evidence for policy pathway. At the same time, pictures and stories often elicit a much stronger public response than data alone. Data and stories should thus be used in tandem to affect evidence-based political activism.

For any citizen science project that can lead to political advocacy, it is key that the motives of participants are acknowledged, and checks are put in place to ensure data quality. For example, during the Flint, Michigan, water crisis, the desire of some participants to support lawsuits led to the falsification of some citizen science data (Bonney 2019).

Community Action

Citizen scientists take collective action to directly address environmental issues mainly in place-based community projects. These projects bring together people who are interested in improving a *specific* location, and people involved in these projects are more likely to have agency to contribute to such changes. According to Pandya (2012), community action is most likely if:

- Research and education goals are well aligned with community priorities
- Communities have a role in project management and project design
- Multiple kinds of knowledge are incorporated (e.g. Indigenous knowledge)
- Results are widely disseminated

As with behaviour change, projects are most likely to lead to community action if they have personal relevance for participants, align closely with their motivations, and have a clear call to action. In addition, community action projects need to build on or create collaborations that bring people together. A citizen science project can act as a community catalyst – offering a common goal for the community and agency to take local environmental management into their own hands. In other cases, a community may already function as a group and the citizen science project will provide an opportunity to support a local cause, which strengthens its cohesion (Chari et al. 2019).

A key strength of impact through community action is that the social network can be a strong external motivator for individuals to get involved and stay active in environmental issues.

Interactions Between Project Types and Impact Pathways

The overview provided so far has shown how certain pathways to impact are more likely to be associated with certain project types. Taking the links between impact, participant groups, and project attributes into account helps set realistic expectations and enables practitioners to design more impactful citizen science projects. Based on this, we have created a framework that articulates four common citizen science approaches aimed at creating environmental impact: *place-based community action*; *interest group investigation*; *captive learning research*; and *mass participation census*.

The impact and attributes of each of these citizen science approaches are summarised in Tables 19.1, 19.2, 19.3, and 19.4. Although this framework is based on citizen science literature, it is not the result of a quantitative data analysis or a systematic literature review; this framework is derived from our experience as citizen science practitioners and the need to better drive environmental impact through our work.

Case Study: FreshWater Watch

FreshWater Watch is a global citizen science programme, run by Earthwatch, that engages participants in the collection of water quality data in freshwater ecosystems. The programme has used all four citizen science approaches to engage different audiences and achieve environmental impact through a multitude of impact pathways.

Table 19.1 Place-based community action citizen science: impact pathways, key attributes, and example projects

Place-based community action	
Impact pathways: • Mainly local impact through: • Environmental management • Evidence for policy • Behaviour change • Political advocacy • Social network championing • Community action	**Key attributes:** • Focused on improving the environment in a specific location • Mainly attracts local participants. Can engage and motivate a diverse range of people who feel connected to the local area and personally benefit from environmental improvement, including communities who are traditionally under-represented in science and environmental movements • Can be citizen or community initiated and led and/or researcher led but most likely to succeed if participants feel ownership and agency, e.g. through co-creation • Requires local collaboration and support from or creation by community leaders who support uptake in the community • Benefits from simple tasks and a variety of opportunities to get involved, to cater to diverse interests and abilities in the community • Potential for long-term engagement and data collection, although projects can also be short-term, especially when taken up by an existing community network
Example projects: Flint, Michigan water study (Hanna-Attisha et al. 2016) Naturehood www.naturehood.uk	

Table 19.2 Interest-group investigation citizen science: impact pathways, key attributes, and example projects

Interest group investigation	
Impact pathways: • Mainly impact through: • Environmental management • Evidence for policy • Political advocacy • To a lesser extent through: • Behaviour change • Social network championing	**Key attributes:** • Focused on researching a specific topic, species, or ecosystem; e.g. long-term biodiversity monitoring • Can be local, national, or international with regular monitoring or ad hoc data collection • Mainly attracts participation from people with a pre-existing interest in and knowledge of the research topic. The potential participant pool is, therefore, more limited and often less diverse • Tasks can be more complex and time-consuming • Potential for long-term engagement and data collection, especially if opportunities for progression, sharing, and recognition are provided, and projects invest in support for their participants
Example projects: Anglers' Riverfly Monitoring Initiative (Brooks et al. 2019) Earthworm Watch www.earthwormwatch.org	

Table 19.3 Captive learning research citizen science: impact pathways, key attributes, and example projects

Captive learning research	
Impact pathways: • Mainly impact through: • Behaviour change • Social network championing	**Key attributes:** • Focused on educating participants and raising awareness of environmental issues • Requires a citizen science leader (scientist, teacher, or engagement officer) and has a limited participant group size per session • Can include schools, informal education groups, and other learning settings (e.g. businesses). Potential to engage and inspire new audiences as participants are often signed up to the activity through a gatekeeper (e.g. a teacher) • Tasks need to be simple but can require some instruction from the leader • Projects can be scaled up by using train-the-trainer approaches or providing online training for existing group leaders (e.g. teachers or scout leaders) • Potential for impact if topics are personally relevant and experiences are immersive and carried out over a longer period rather than as a one-off
Example projects: Wytham Woods climate research (Crockatt and Bebber 2015) Teatime4Science www.teatime4science.org/schools/	

Participants across the world collect the same core measurements (phosphate concentration, nitrate concentration, turbidity, and various visual indicators) and upload the data to a common online platform. Data collection started in 2012, and, to date, over 24,000 data sets have been collected globally. The method is simple and engaging for volunteers but also produces robust data (Thornhill et al. 2018).

Table 19.4 Mass participation census citizen science: impact pathways, key attributes, and example projects

Mass participation census	
Impact pathways: • Mainly impact through: • Evidence for policy • Behaviour change • Social network championing	**Key attributes:** • Focused on informing a large audience and creating a snapshot of a single moment in time across a large geographic area • Potential for mass data collection, generating a unique data set that cannot easily be generated any other way • Potential to reach new audiences and to engage them with a new topic. The audience can be more diverse if the project takes steps to actively include different groups • Requires very simple tasks with low time investment and needs to be relevant to a diverse audience • Can be repeated, e.g. annually • Requires extensive communication and intensive central project management.
Examples: *CurieuzeNeuzen* (Van Brussel and Huyse 2019) FreshWater Watch WaterBlitz www.earthwatch.org.uk/waterblitz	

FreshWater Watch was originally designed as a *captive learning research* project, targeting banking employees enrolled in a corporate sustainability programme (the HSBC Water Programme). Groups of participants in this programme were paired with university researchers focusing on a specific local research challenge. In partnership with the university researchers, Earthwatch ran training sessions covering the research purpose, sampling methodology, and opportunities for personal action in the context of the global water challenge. In this first phase of FreshWater Watch, environmental impact was primarily achieved through behaviour change. Nearly all volunteers (99%) reported a better understanding of their personal environmental impacts and 95% reported having reduced their impacts as a result (Earthwatch 2017).

A number of participants became highly engaged in the programme. They continued to collect data at regular intervals and recruited others to join them. Regular communications between Earthwatch, the local researcher, and the participants kept these 'Citizen Science Leaders' engaged, and many enjoyed being part of this global water community. FreshWater Watch had become a network of *interest group investigations*, and the participants' commitment led to valuable data sets and a large number of scientific publications (Thornhill et al. 2019). Some Citizen Science Leaders also started to influence their social networks to raise awareness about water quality issues and share opportunities for behaviour change.

As FreshWater Watch became better known, Earthwatch was contacted by increasing numbers of local groups who wanted to use it to monitor and address local water quality issues. Rivers Trusts, wild swimming groups, and local communities started to use FreshWater Watch as a *place-based community action project*. Each of these groups had specific local concerns and had slightly different needs in terms of data collection. Local leaders coordinated data collection and acted on the results.

To accommodate these groups, Earthwatch incorporated co-design sessions into training programmes. They also adapted the online platform and app to allow for group accounts and to provide flexibility for groups to measure additional variables beyond the FreshWater Watch core method. These place-based community action projects create impact through a wide range of pathways. Where evidence for policy and political advocacy are identified as key impact pathways, Earthwatch works with the group leaders to establish links with the relevant stakeholders early in the project design process. Many projects are also used to inform environmental management. For example, the Lincolnshire Rivers Trust used FreshWater Watch to identify industrial pollution sources along a small river.

Many FreshWater Watch participants take measurements in locations that are not routinely monitored by statutory agencies. Because of this, FreshWater Watch has the potential to supplement ongoing regulatory water quality monitoring (Hadj-Hammou et al. 2017). With this in mind, Earthwatch recently initiated *mass participation censuses* in the form of 'WaterBlitz' events. These are time-limited campaigns where as many people as possible are asked to take measurements in a target river catchment over the course of a weekend. The WaterBlitzes are advertised through a wide range of media channels and participants receive a short online training session, where the methodology has been simplified. This approach has been particularly successful where the project tapped into existing public concern about water quality. The first Dublin WaterBlitz in 2019, for example, attracted over 1000 sign-ups in the course of a few days.

The different project types within FreshWater Watch are not stand-alone. By applying the same basic FreshWater Watch method to different project types, we have been able to integrate data from multiple different approaches into one consistent global data set. An added benefit of this adaptive approach is that it has allowed us to 'funnel' participants towards different project types that are most relevant to their developing interests and motivations. Several place-based community projects have arisen from initial participation in WaterBlitzes, which act as an entry point into the programme.

Experience has shown that each participant group and citizen science approach requires different project organisation, sampling method complexity, training, IT infrastructure, and communication channels. By adapting the programme in these ways, FreshWater Watch has been able to grow and create environmental impact through nearly all of the pathways outlined in this chapter.

Implications

Application of the Framework

The many examples highlighted in this chapter demonstrate that citizen science can create positive environmental change in numerous ways. Indeed, citizen science is often promoted for its ability to engage the public, raise awareness, and collect valuable environmental data. The framework we present here reflects our experience that impact is seldom achieved at scale through all the pathways to environmental impact simultaneously. Different approaches lend themselves to different pathways. Another layer of complexity is added by the fact that participants' motivations vary, and the same approach is unlikely to appeal to all audiences. By clearly articulating the pathways to impact and the project attributes that support them, we have highlighted four citizen science approaches that have strong potential to lead to positive environmental change. The insights provided in this chapter should help citizen science practitioners, research funders, and stakeholders to set realistic expectations and to make more informed decisions about, for example, task complexity, and target audience.

Relation to Existing Typologies

There are numerous typologies of citizen science, but our framework is the first that consistently articulates who participates in citizen science projects and links this to the pathways and scale of impact. In particular, the framework presented here is the first to articulate the difference between mass participation projects and interest group investigations. Our framework doesn't explicitly examine what role citizens play within the projects, but many of the examples in this chapter highlight that both place-based community action and interest group investigation projects can span from contributory and crowdsourcing approaches to extreme citizen science and collegial collaborations (Haklay 2013; Shirk et al. 2012). Captive learning and mass participation projects are often organised in a top-down manner and are predominantly contributory.

Overlap Between Project Types and Approaches

Our framework is not designed to be exhaustive or have mutually exclusive categories. Instead, it articulates some of the most common citizen science approaches and how their impacts and participant groups are interlinked. Some projects can fall into more than one of these project categories. For example, *CurieuzeNeuzen* (Van Brussel and Huyse 2019), to some extent, satisfies the conditions of both a place-based community action project and a mass participation census project. It has done so by being locally relevant, working with an existing community group, investing in extensive communication, and making it easy to participate. Citizen science programmes can also combine approaches to cater for different participant groups and generate a bigger movement, as is illustrated in the FreshWater Watch case study.

Key Knowledge Gaps

The framework presented here articulates how projects can influence the environment. To learn from past experiences and refine this framework, it is essential to measure the exact impact individual projects have and to analyse how this is influenced by project attributes and the specific project context. Such impact monitoring is rarely done, and, without targeted research, it remains challenging to establish exactly how large the contribution of a citizen science project has been in the context of all the other socio-economic factors that simultaneously affect environmental decision-making (Schaefer et al., this volume, Chap. 25).

In addition, there is a need to further research the mechanisms that drive some of the impact pathways, in particular, social network championing (Reed et al. 2010). There may, for example, be opportunities to focus more heavily on social network championing in the design of citizen science projects if these mechanisms were better understood. Effective knowledge exchange and collaboration between the citizen science community and other fields of science, for example, behavioural psychology, is key to unlocking this knowledge.

Next Steps

The potential for citizen science projects to achieve positive environmental impact is increasingly recognised and evidenced in this chapter. To fully understand the contribution of citizen science to environmental change, targeted tools and shared impact evaluation frameworks to measure and evaluate the outcomes and impact of citizen science projects are urgently needed. Some of these tools are already being developed, for example, within the Horizon 2020 MICS (Measuring Impact of Citizen Science: Developing metrics and instruments to evaluate citizen-science impacts on the environment and society) project.

A significant proportion of the impact of projects happens after the data collection stage, while funding rarely extends beyond this point. Therefore, dedicated funding streams will need to support thorough impact evaluation of citizen science projects. Such funding tools would also support the sharing of learning from place-based community action projects, which are currently under-represented in the scientific literature (Miller-Rushing et al. 2012). This project type is the only one that we found likely to support each of the six impact pathways we identified. Dedicated research into the functioning and impact of such projects would enable upscaling the learning from successful initiatives and unleash the empowerment value of citizen science.

To appreciate the impact of citizen science, traceability of citizen science data usage, both in science and for policy, is essential. This can be achieved by including persistent identifiers to uniquely locate citizen science data and tools to track policy development. These tools should reference both the data and participant groups involved in monitoring of environmental indicators in policies, for example, using the framework presented in this chapter. Once necessary identifiers and tools are in place, requirements to evaluate citizen science impacts can be embedded in financing agreements to facilitate impactful citizen science projects.

In the meantime, we hope that the framework presented in this chapter will lead to new opportunities to use the outlined citizen science approaches – place-based community action, interest group investigation, captive learning research, and mass participation census – to deliver urgently needed environmental change.

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