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COMMENTARY

Climate change, young people, and the IPCC: The role of citizen science

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This commentary suggests that undertaking citizen science research with young people has the potential to play a significant role in contributing to the IPPC and related UN research and policy processes around climate change. Further, citizen science engagement can educate and empower children and young people in and through research by involving wider communities and groups in data collection, communication, and engagement. A persuasive body of literature suggests that children and youth can be and ought to be included in citizen science projects and that young people ought to and can have a greater say in their environmental and climate lives and futures. There is acknowledgment that certain populations, including young people, have been excluded from participation in citizen science, and strategies need to be developed to be more inclusive. Moreover, through inclusion of youth, there are opportunities for intergeneration collaboration leading to potential solutions. Our commentary is a call for the IPCC to be much more open and creative in its knowledge production work and to engage young people in climate-related citizen science.

Keywords: Citizen science, Young people, Climate change, IPCC

Introduction

In 2018, the Intergovernmental Panel on Climate Change (IPCC) issued a special report that warned of the need to mobilize all capacities, including local communities, Indigenous communities, state and national actors, and civil agents, to meet the goal of keeping warming below 1.5° (IPCC, 2018). The report emphasized that "[e]ducation, information, and community approaches . . . can accelerate the wide-scale behaviour changes consistent with adapting to and limiting global warming . . . " (IPCC, 2018, 5.6). Studies show that the impacts of a warming climate pose greater risks to the most vulnerable populations, including those who lack economic security, women, elders, and children (Stanberry, 2018).

In this commentary, we argue that an increasing body of scientific evidence can contribute to enhancing climate change mitigation, adaptation, behavioral change, policy development, and awareness-raising activities and that young people can and ought to be included in climate-related citizen science projects to this end. We propose that the IPCC and related UN bodies could do more to include different kinds of science, including citizen science,[1] in their work. The IPPC could also do much more to include specific constituencies, such as youth, the elderly, and disabled people. As the IPCC is a respected body with considerable science credibility, it can play an important role in promoting and encouraging inclusive citizen science at national, regional, or local levels. In offering our arguments, we are encouraged that the IPCC has a new gender inclusion policy as of May 2020 (IPCC, 2020), and we suggest that initially setting up an ad hoc or task force group working on young people and youth, citizen science or both, may be a good starting point, particularly as the identity and mandate of the IPPC seems to be evolving and open to change (IPCC, n.d.). We contend that inclusion and diversity in science and data collection can capture a range of evidence, experiences, impacts, and ideas for action that might be missed through more mainstream approaches, noting that "the main activity of the IPCC is the preparation of reports assessing the state of knowledge of climate change" (IPCC, n.d.). We advocate that young people as a distinct group ought to be explicitly included in data collection exercises.

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1. The term "citizen science" is attributed to Kerson, R. 1989. Lab for the environment. *Technology Review* 92(1): 11–12, as cited in Haklay, M, Dörler, D, Heigl, F, Manzoni, M, Hecker, S, Vohland, K. 2021. What is citizen science? The challenges of definition, in Vohland, K, Land-Zandstra, A, Ceccaroni, L, Lemmens, R, Perelló, J, Ponti, M, Samson, R, Wagenknecht, K eds., *The science of citizen science*. Cham, Switzerland: Springer. Available at https://doi.org/10.1007/978-3-030-58278-4_2.

As the IPCC continues to address the challenge of how best to communicate the science of climate change to a broad and diverse global audience, an opportunity exists here to leverage the momentum of the current youth climate movement and interest of youth in climate issues to develop strategies for diversifying engagement. While we recognize that the emphasis of the youth climate movement is on promoting activism and holding adults accountable for the climate emergency, we contend that citizen science can potentially improve policy outcomes. Thus, we suggest that the IPCC has a role in defining principles and practices for climate-related citizen science projects and activities that specifically target and engage young people, incorporating the unique needs and experiences of their local communities.

Hands-on projects in citizen science—defined as science conducted by nonspecialists under the supervision of trained scientists or experts—can benefit evidence, education, and communication outcomes and add to the IPCC's environmental and climate-related body of data and understanding. Youth, alongside adults, can learn from and contribute to an evolving body of environmental knowledge and scientific enquiry through organized citizen science research projects usually run with universities or formal research institutions with trained scientists—making this distinct from *community* science—while engaging in a scientific process to support research into climate and environmental health (Haklay et al., 2018; Makuch and Aczel, 2018; Cooper et al., 2021). Such engagement can potentially empower young people (and other participants) to understand the science and see themselves as individual actors in this largely adult-dominated space and can also potentially open up opportunities for young people as a potentially disenfranchised group to contribute to knowledge and discourses around climate change, climate science, and future policy making (Sorensen et al., 2019; Cooper et al., 2021). "Such community-based projects [can] strengthen scientific capacity, social capital, and inclusiveness of local decision making" as Dickinson et al. (2012) assert, and potentially, global decision-making. This fits nicely with the IPCC's "Activity" mandate: "to support the preparation of its reports, the IPCC organizes scoping meetings, lead author meetings, workshops and expert meetings. It also organizes various outreach events that communicate its findings, methodologies and explains the way the organization works" (IPCC, n.d.).

The benefits of incorporating young people and citizen science in the IPCC processes, assessments, and findings are threefold:

- **Scientific benefits**. Increasing access to scientific information and drawing science from a wider and more diverse body of sources
- **Policy benefits**. Potential for inclusion of wider opinions leading to more inclusive and robust policy development
- **Societal benefits**. Involvement with targeted science programs, under IPCC sponsorship, enhancing scientific literacy with benefits to the individual and the wider community

A. Citizen science: Children and young people

The burden of addressing climate change has profound implications across generations and particularly for the young people of today who will benefit from or suffer the consequences of actions taken to address the issues identified in the 2018 IPCC Special Report on Global Warming (UNICEF, 2015; IPCC, 2018). There is recognition that young people, as Greta Thunberg and her generation of climate activists have demonstrated, both have potential to be disproportionately harmed by inaction, and have the ability and interest in taking positive action such as demonstration for policy change, personal and community behavior change, lobbying of industry, and others on climate issues (Fridays for Future, n.d.; Hanna and Oliva, 2016; Marris, 2019; Thunberg, 2019; Boulianne et al., 2020; Holmberg, 2020; Wallis and Loy, 2021). Verlie and Flynn (2022) contend that behind the youth climate strikes is failure of current school-based education on climate, with young people assuming the role of educators through their participation. Citizen science engagement offers a useful conduit for young people to engage with information exchange and policy activism.

Citizen science is composed of "partnerships between scientists and non-scientists in which authentic data are collected, shared, and analyzed," according to Jordan et al. (2012, p. 307). While discussion of the full range of definitions of citizen science is beyond the scope of this commentary, we recognize that how the term is applied is broad and includes diverse types of projects and potential contributions (Eitzel et al., 2017). Citizen science links communication and public engagement in a way relevant for a pressing issue such as climate change (Wals et al., 2014; Bonney et al., 2016; Groulx et al., 2017). Citizen science can be designed to include young people and to view the science and environment from the child's perspective, through the gathering of useful data, which contributes to research. In some cases, citizen science can increase "scientific literacy, improve ecological knowledge, deepen connections to nature and place, strengthen social ties, and foster new knowledge networks" (Groulx et al., 2017, p. 53). These results can further improve communication and participation on climate change, leading ultimately to individual and social action (Schweizer et al., 2013; Haywood, 2016; McGreavy et al., 2016; Moser, 2016; Ranney and Clark, 2016; Kuo et al., 2019). We note, however, that there is lack of agreement on how "scientific literacy" as an outcome of citizen science is measured and that systematic studies, including those conducted in non-Western environments, are needed to determine the extent of impact (Cronje et al., 2011; Groulx et al., 2017; Aristeidou et al., 2020).

Below, we look at the scientific benefits, policy benefits, and societal benefits from engaging young people in climate change–related citizen science.

1. Scientific benefits

As the IPCC seeks to improve strategies to communicate the warnings found in the 2018 Report, an impediment is that there is widespread denial of the anthropogenic causes of a warming climate (Wong-Parodi and Feygina,

2020). A 2017 *New York Times* article, for example, reports the challenges of a high school science teacher in a former coal mining region of the United States in teaching his students about climate change, especially as many of the students had learned climate denial from their Trump-supporting parents and relatives (Harmon, 2017). The teacher's strategy, which was successful with many of these skeptical students, was to take them into the field to let them discover for themselves the clues in nature that pointed to a changing climate. There are important lessons in this experiential approach as the IPCC seeks to communicate its message to a broad public, including those who distrust science and scientists (Makuch and Aczel, 2018; Herman et al., 2019). The IPCC's website, in the section titled "Engage with the IPCC," lists opportunities to contribute to the science and review processes of the IPCC and acknowledges the roles and contributions of volunteers to the production of reports, by "hundreds of experts in different fields" (IPCC, n.d.). Such contributions can include data collected through citizen science projects run with expert scientists and young people.

Citizen science projects can be designed to align with the IPCC's goals and projects related to environment, climate change, and sustainability that seek to understand and communicate the science behind these areas of concern. Some examples designed for local needs and that could be adapted include surveys of animal populations and monitoring changes over time (Scotland, Argentina, Massachusetts, the United States),[2] monitoring weather patterns (the United Kingdom, North America),[3] and monitoring marine biodiversity and marine pollution (Scotland, California)[4] (Hidalgo-Ruz and Thiel, 2013; Locritani et al., 2019). The projects can be designed at a variety of age- and skill-appropriate levels and under the guidance of an experienced science professional to collect and analyze data, ask questions about the data, and learn how to think about the meaning of evidence in new ways and more (Makuch and Aczel, 2020). Even young children have the potential to participate. For example, in a project in Oslo, Norway, young people ages 6–12 in schools monitored local air quality with a simple and inexpensive method using paper and petroleum jelly (Castell et al., 2021). Developing age- and skill-appropriate programs requires staff training and targeted approaches and identification of resources within communities to work with scientists on appropriate goals for these young people.

We acknowledge that access to trained scientific experts and supervision of young people can take different forms within diverse communities. For example, it may be possible to leverage existing infrastructures including schools with "experts" to give guidance to projects. As an example, mobile cell phone networks have proven effective in improving diagnosis, screening, and therapies in developing countries and underserved communities lacking comprehensive medical resources but where mobile phones are widely used (Celi et al., 2009). One potential strategy for supervision in climate change–based citizen science is to take advantage of mobile phone networks to connect participants with local mentors, who in turn can be connected to trainers/advisors based at a distance from the home communities of young people and mentors. This approach can allow for incorporation of forms of knowledge other than "traditional" and take advantage of local mentors with extensive knowledge from experience of changes in biodiversity or other elements within communities. We emphasize the need for citizen science projects to be local in design and incorporate needs and interests of the communities—and be aware of ways that information is transmitted within these communities, including access (or lack of access) to computers or phones.

Citizen science can play an important role in promoting intergenerational dialogue and collaboration, acknowledging that climate change issues affect all members of a community, particularly youth and the elderly. For example, a participatory early warning monitoring program in Brazil created intergenerational dialogue on how to manage risk (Marchezini et al., 2017). Moreover, Mannion and Adey (2011) claim that place-based educational programs such as local scale monitoring provides a way for adults and youth to collaborate and communicate around issues of local concern. Additionally, there are key opportunities for enhancing intergeneration communication and co-creation of solutions around climate change (Brown and Lock, 2018; Albagli and Iwama, 2022).

The European Citizen Science Association (ECSA) has developed 10 Principles of Citizen Science to guide best practices. While not child, young person, or climate change specific, the principles include best practice related to ethics and participation. For example, Principle 1 states: "Citizen science projects actively involve citizens in scientific endeavour that generates new knowledge or understanding. Citizens may act as contributors, collaborators, or as project leader and have a meaningful role in the project" (ECSA, 2015). Further, "[t]he leaders of citizen science projects [should] take into consideration legal and ethical issues surrounding copyright, intellectual property, data sharing agreements, confidentiality, attribution, and the environmental impact of any activities" (Principle 10); Principle 9 encourages that, "Citizen science programmes are evaluated for their scientific output, data quality, participant experience and wider societal or policy impact" (ECSA, 2015).

Direct participation of citizens, including young people, can provide exposure to the scientific method and reduce public or community doubt in science (Follett and

2. For example, Urban Flora of Scotland, https://www.botanical-society-scotland.org.uk/Urban_Flora_of_Scotland; Firefly Watch, https://www.massaudubon.org/get-involved/citizen-science/firefly-watch; Penguin watch, https://www.zooniverse.org/projects/penguintom79/penguin-watch.

3. For example, Natures Calendar, https://naturescalendar.woodlandtrust.org.uk; Community Collaborative Rain, Hail, and Snow Network, https://www.cocorahs.org/.

4. For example, Community-led Marine Biodiversity Monitoring Project, https://www.nature.scot/communitymarinesurvey; Beach Watch, https://farallones.noaa.gov/science/beachwatch.html.

Strezov, 2015; Garcia-Holgado et al., 2020). Citizen science is by definition jointly created scientific knowledge and can have the advantage of including a wide range of actors in the process, including marginalized populations, women, Indigenous people, and young people (Groulx et al., 2017). Groulx et al. (2017, p. 69) explain that "[r]igorous science is an integral part of defining and promoting action in the face of climate change, but so are legitimate opportunities for citizens to engage with the climate change discourse, define local priorities, and meaningfully influence decisions. Citizen science is one model of communication and engagement that has the potential to create such opportunities."

2. Policy benefits

Studies have shown that citizen science is both an object of policy and an instrument leading to improved policy (Schade et al., 2021). Citizens at the local level could potentially both monitor and implement the UN's sustainable development goals (SDGs) (Fritz et al., 2019). Young people can gather research data and evidence that they might use to inform local decision-making on issues that address child-centric concerns and challenges, guiding adult decision-makers in a more inclusive and expansive way. Further, young people can potentially empower themselves (and others, such as their parents) through knowledge acquisition and skills in acquiring and interpreting scientific findings and contributing to a body of knowledge. They may also become equipped enough to engage with international processes in relation to relevant climate and environmental treaty processes. Citizen science projects can contribute to the active participation of young people in environmental decision-making, whether directly through reporting to a panel, or indirectly, through their contributions to a report or other form of evidence. Citizen science can thus arguably be linked to participatory democracy and accountability (Moran and Rau, 2016).

To this end, if young people are to participate as active decision-makers and contributors to conversations on reversing anthropogenic climate impact, they need opportunities to develop the skills and scientific knowledge that can make them effective in these roles. Regarding the contributions of citizen science to achieving the UN's SDGs, Fraisl et al. (2020) argue that "Citizen Science provides the means to inform policy, which could raise trust, credibility and ultimately accountability in the SDG monitoring process." This is particularly important as public distrust of science and the proliferation of "fake news" have been well-documented and arguably impedes public acceptance of a coherent and science-based strategy to address climate change (Prasad, 2019).

3. Societal benefits

While citizen science programs that target young people of various ages pose unique challenges, studies show that well-designed programs with clear aims can yield valuable benefits. For example, engaging younger audiences in environmental research can improve awareness of environmental issues, understanding of science and contribute to their becoming more "aware" and committed citizens of their communities through collecting data, such as on wildlife populations including birds in their local or nearby communities (Pitt and Schultz, 2018; Clark et al., 2020; Soanes et al., 2020). Recently, it has been suggested that a citizen science project aimed at youth to test the efficacy of face masks to prevent Covid-19 transmission could have social benefits by increasing mask use and reducing the community's risk of infection (Eichler et al., 2020).

Citizen science is a participatory process and an inclusive learning experience, with the opportunity to contribute to environmental justice, and young people can thus learn from and contribute to an evolving body of environmental knowledge and scientific enquiry, developing environmental responsibility as citizens (Butler et al., 2016; Moran and Rau, 2016; Liebenberg et al., 2017; Makuch and Aczel, 2018; Clark et al., 2020). Article 12 of the UN Convention on the Rights of the Child acknowledges the right of young people to participate in information exchange and have their concerns and perspectives acknowledged in a meaningful way (UN Committee on the Rights of the Child, 2009, 2017). The 1998 Aarhus Convention promotes the inclusion of young people in environmental decision-making (UNECE, 1998). Principle 21 of the Rio Declaration states: "The creativity, ideals and courage of the youth of the world should be mobilized to forge a global partnership in order to achieve sustainable development and ensure a better future for all" (UN Conference on Environment and Development [UNCED], 1992).

In this light, we argue that as citizens with the right to participate in decision-making in activities with profound impacts on their current and future well-being, young people have the right of access to information and participation in decision-making. Their participation in citizen science projects focused on climate science and sustainability has the potential to give them the tools to enact meaningful change as well as benefit their individual and collective development.

Youth-centered citizen science projects should be designed to be inclusive to accommodate the diverse needs, abilities, and socioeconomic geographies of participants (Senabre Hidalgo et al., 2021). Ideally, child-centered citizen science projects will not exclude young people who do not have access to the latest technology (such as a mobile device) or use able-ist methods that exclude people with disabilities, but can be codesigned with specific communities of young people and their guardians to accommodate the various forms of child contribution, including that of disabled children. Prior consent and ethical and safeguarding procedures need to be designed and followed to ensure that young people are not exploited intellectually, physically, or otherwise (Makuch and Aczel, 2018; Senabre Hidalgo et al., 2021). Protocols have to be agreed at the design stage of citizen science projects to ensure that young people and the contribution of their data through their labor is not exploited (such as being sold to third parties or written into research papers without acknowledgment). Allowances also need

to be made for the fact that the quality of data collected by young people may vary by ability and age, but a well-designed citizen science project can accommodate age and ability appropriately.

While young people may adopt and absorb information from their parents, there is evidence that information can go the other way, as well, as young people in turn may influence the thinking of their parents and other adults on climate issues (Lawson et al., 2019). We argue that hands-on environmental citizen science projects can potentially serve as educational and communication tools if a project is specifically designed with clear, and age-/ability-appropriate objectives, such as collecting data on species to determine extent of populations or coverage. Citizen science by definition engages the public in collecting robust scientific data and promoting the co-creation of scientific and environmental knowledge (Dickinson et al., 2012). Including young people in citizen science may further broaden the scope of the research due to the unique ways of young people viewing and enquiring about the world (Grover, 2004; Makuch and Aczel, 2018).

Young people are citizens of their communities and the world, as they have a stake in current and future sustainability of the planet and their local environment, and will be affected by climate change, arguably more so than adults due to the potential for greater impacts on their current and future lives (Nishiyama, 2017; Makuch and Aczel, 2018; Stanberry et al., 2018). Young people as citizens should be included in "decision-making and problem-solving processes with adults"—and not relegated just to "youth congress[es]" or similar (Nishiyama, 2017). Inclusion of young people in citizen science projects can help make public participation initiatives more capable and inclusive, something that has been called for in the evolution of environmental law and policy, including that related to climate change (UN Framework Convention on Climate Change, 2015).

B. IPCC—Current role and benefits of adopting a child/young person citizen science mandate

The IPCC provides a forum for joint expert and state collaboration on data production, evidence gathering, and analysis, largely following a top-down model of researching and disseminating information about climate change and its impacts. Shackley (1997) expressed concern over "whether the IPCC can make its knowledge more socially relevant and trusted by bridging the gulf which exists between scientific experts and on-the-ground decision makers and members of the public," a question relevant for us in this commentary. Hulme and Mahony (2010) note the lower percentage of social scientific studies (less than 10%) evaluated by the IPCC compared to those from the natural sciences as well as a deficit in research from the Global South. Sharma (2012) argues "that global climate change is primarily a societal issue that needs a societal response much more than a technological one." Beck and Mahony (2018) describe the IPCC as a "boundary organization" at the intersection of science and policy, namely a body that mediates the flow of knowledge between scientists and policy makers.

The IPCC, its parent organization being the World Meteorological Organization, is very data-driven on a macro monitoring scale. There have been 6 assessment cycles and reports (the final report from cycle 6 was published in 2021 and 2022) produced since the IPCC was established in 1988, and numerous special reports and working group reports, which have led to the development of multilateral environmental agreements, national policy changes, new forms of innovation and research, among other things (IPCC, n.d.). We see the contribution of citizen science studies as a potential enhancement to this formal work. Dudman and de Wit (2021) offer that the IPCC is not doing enough to include different knowledge forms or "alternative forms of contributions" or to make their information gathering more inclusive. Although not centered on citizen science and young people, per se, this assertion aligns with our proposal in this commentary. Citizen science can address this alleged deficit through a bottom up method of data gathering and science engagement, which can arguably complement the current IPCC approach, and capture a variety of data and a richness of evidence on climate change that may well not be the immediate focus, or even practically possible, within the current scope of work of the IPCC. There are 195 members of the IPCC, each with varying resources and capacity levels for undertaking formal science and assessment. There are thus 195 countries with a rich pool of data and evidence and experiences that can be encapsulated and assessed through citizen science. We aver that an opening up of the IPCC processes to include citizen science, and specifically one which engages young people, will broaden the data pool and evidence base of climatic change and impacts, particularly those that arise at the localized level, species level, and other micro levels, making science more democratic and not just for experts.

Through citizen science, a variety of data can be uploaded and reported to online repositories, projects can be monitored, and trends can be evaluated, through an expanded system of expert volunteers at the IPCC, to complement the current IPCC model. The IPCC can use this citizen science data much like it does with current "formal" scientific data, in providing its advice to governments (directly) and a myriad range of non-governmental actors (indirectly). Engaging with young people in this exercise also helps to build a future citizenry of emerging experts, analysts, observers, and guardians of nature. Further, such approaches to obtaining data may well have the power of persuading the current climate change deniers of the real urgency of climate change, more so if some of the study sites and data are localized and specific to the life and experience of individuals. Such data can also be made accessible to those engaging in citizen science research, so that projects might be emulated and educational benefits shared.

As the IPCC is mostly an institution that provides scientific advice to governments (hence, "*Inter Governmental*") and it does not take on the role of running any sort of educational initiative beyond the provision of reports that might be downloaded and studied in an

educational setting, without much extra effort and resources use, the IPCC could create a citizen science data hub/library and project portal to enhance its reach. There could be a concurrent educational and awareness-raising focus via this hub, particularly if the science and research findings of said projects are presented in a way that makes science accessible to young persons and the less-expert lay person. Further, projects can be openly evaluated and also replicated. Data can ideally be accessed for free, which may allow researchers to collaborate, spot trends, and anticipate environmental change. ECSA Principle 7 is aligned with these objectives: "Citizen science project data and meta-data are made publicly available and where possible, results are published in an open access format. Data sharing may occur during or after the project, unless there are security or privacy concerns that prevent this."

Lack of empathy or lived experience in relation to climate impacts, harm, and disasters may result in denialism, cognitive dissonance, lack of engagement, and minimal behavior change. This may be compounded if scientific data are abstract, remote, or inaccessible. Conversely, if scientific data are more accessible or localized this is likely to be more motivating for people. Moser and Dilling (2011) asserted in their work in 2011 "that people in a democratic society, are best served by actively engaging with an issue, making their voices and values heard, and contributing to the formulation of societal responses."

While the IPCC probably cannot do a lot to create and manage citizen science programs, it can still do a lot to diversify its sources of knowledge, recognize a broader range of knowledge production processes, and set examples and precedents for connecting inclusive citizen science with a wide array of national and subnational level educational and policy actions/actors. For example, we did not find any evidence of the inclusion of the citizen-derived data or contributions of young people in the 6 IPCC assessment reports.

We are not the only commentators who suggest including young people in the IPCC process. While writing this commentary, the IPCC Working Group III published their report.[5] A related letter to the Guardian Newspaper in light of the above demands that "Children must shape the global response to climate crisis": "We call on the national governments that direct the IPCC to recognize the importance of young people and future generations by commissioning an IPCC special report on young people and climate change. This can synthesize not only the evidence of impacts of climate change on young people, but also evidence on what works to protect their rights—including their ability to understand and take action on climate change" (Tanner et al., 2022).

Integrating citizen science projects undertaken with children and youth into the IPCC process can offer the following benefits:

1. Scientific benefits

Communicating the complex science behind climate change leading to individual and community behavioral changes as the desired outcome is challenging, as evidenced by the numbers of people who deny (or are skeptical about) human-induced climate change (Wong-Parodi and Feygina, 2020). Responding to the need to improve communication of complex findings, the IPCC commissioned in 2018 a handbook for its report authors: *Principles for effective communication and public engagement on climate change* (Corner et al., 2018). Moreover, in line with the emphasis on inclusiveness the IPCC has pro-actively included youth representatives at policy workshops and discussions on impacts of climate change and incorporated their input into policy recommendations. We aver that this process can be further enhanced by integrating child/youth citizen science projects into the IPCC process.

Many citizen science projects have contributed data useful in evaluating climate change—especially studies that require large data sets. For example, citizen scientists—hikers in New Hampshire's White Mountains—collected data on wildflower communities along hiking trails that was used to analyze climate impacts, as alpine flowers are sensitive to effects of climate (MacKenzie et al., 2017). In Sweden, 3,500 high school students, with basic science knowledge and in conjunction with their teachers, measured air and water temperature differences (Weyhenmeyer et al., 2017). This project not only contributed to valuable data on global warming but also reinforced classroom science learning. Other studies have shown a wide range of citizen science projects involving both young people and adults that can add to the body of climate science data (Pohle et al., 2019; Castagneyrol et al., 2020). Research has shown the benefit of contributions of even very young people to information on changes in ecosystems due to anthropogenic actions (Miczajka et al., 2015).

Changes in political and economic circumstances, in addition to global crises such as the Coronavirus pandemic, can impact both governmental budgets and cause fluctuations in the amount of investment available for environmental research and monitoring (Andrijevic et al., 2020; Ecker et al., 2020). In this context, and particularly within the context of the economic collapse following the COVID-19 pandemic, citizen science may increase capacity in data collection and evaluation through leveraging the contributions of volunteers (Ellwood et al., 2017; McKinley et al., 2017). Lack of coverage in certain geographic areas, or within economically disadvantaged communities, poses a problem for understanding and responding to climate impacts, with potential to close this gap through smartphone technologies that do not require literacy, for example, such as applications that use pictures or symbols (Liebenberg et al., 2016). Project design and engagement strategies can similarly be adapted for young people with different levels of literacy, or with physical or developmental or language barriers and can further be designed to consider cultural and socioeconomic factors, leading to a more inclusive approach to decision-making

5. *Climate Change 2022: Mitigation of Climate Change*, the third part of the Sixth Assessment Report, 4 April 14th Session of Working Group III and 56th Session of the IPCC, https://www.ipcc.ch/report/ar6/wg3/.

on climate issues (Hart, 1997; National Academies of Sciences, Engineering and Medicines, 2018).

Following from the aims of inclusive participation as defined in international agreements, a key objective of the IPCC is to engage the science community and citizens from developing countries and diverse socio-economic contexts—a goal that is not easy to attain due to lack of representation in science publications produced in certain regions (Yamineva, 2017). Incorporation of citizen science and, specifically, training of and encouragement of young people in science fields may have the benefit of moving toward a correction of this imbalance.

2. Policy benefits

Recent attention has focused on how to make the IPCC reports readable and understandable by target audiences, including policy makers, climate specialists, governance officials and the public (Harold et al., 2020). To better include diverse members of communities—including young people—in discussions and in decision-making on environment and climate issues, the IPCC needs to develop strategies to make findings and the science behind them accessible. This is turn will result in a broader, more comprehensive and inclusive approach to policy making. Having young people involved in "doing" science is one way to address the deficit. We are reminded here of the relevance of ECSA Principle 3: "Both the professional scientists and the citizen scientists benefit from taking part. Benefits may include the publication of research outputs, learning opportunities, personal enjoyment, social benefits, satisfaction through contributing to scientific evidence, for example, to address local, national and international issues, and through that, the potential to influence policy."

Amassing data that have been acquired through citizen science can arguably lead to broader, far-reaching and more impactful policy making if such data are from a variety of projects, a broader range of people, and a range of geographical areas.

3. Societal benefits

Making the IPCC more inclusive through citizen science and including young people can benefit society. The IPCC's work should include a wide range of diverse scientific views and perspectives, not only technical expert appraisals of peer reviewed science, from all over the world, and within a wide range of communities. Young people in particular have a unique and valuable outlook. For example, young people are naturally curious and inquisitive, ask insightful questions, and are open to new ideas—characteristics that can extend and strengthen their citizen science experience and are valuable in their participation in conversations about effective approaches to climate issues (Jenkins, 2011; Moore et al., 2018). Moreover, engagement of young people and incorporation of their unique perspectives can help broaden the scope of opinions and enhance the diversity of perspectives incorporated in the IPCC reports (Robertson and Tisdall, 2020).

In parallel, the IPCC should do more to support citizen participation in climate change through science. Principle 10 of the 1992 Rio Convention states that "[e]nvironmental issues are best handled with participation of all concerned citizens, at the relevant level. At the national level, each individual shall have . . . the opportunity to participate in decision-making processes. States shall facilitate and encourage public awareness and participation by making information widely available . . . " (UNCED, 1992). This statement of inclusive participation justifies the active involvement of young people in environmental decision-making, including collection of baseline data, observing species proliferation and decline, forming an opinion, and more.

Beyond contributing to a body of data on climate change, citizen science projects can benefit young people in both rural and urban environments. Collecting data related to climate change would typically take place outdoors. There is ample evidence that exposure to nature has wide-ranging developmental benefits for young people, including cognitive and mental health benefits (Tillmann et al., 2018; Dopko et al., 2019). Additionally, research shows that experience with nature can lead to life-long environmental stewardship (Wells and Lekies, 2006; Cheng and Monroe, 2012; Makuch and Aczel, 2018; Collado and Evans, 2019). Environmental citizen science, therefore, can be an important way for young people to experience nature—particularly important with increased urbanization and loss of many opportunities to participate in natural surroundings available to previous generations.

Encouraging interest in and opportunities for engagement in climate science research and communication amongst groups that may traditionally have been excluded from these fields or suffer from environmental discrimination or inequity—including young people—can bring about social, educational, health and developmental benefits to participation (Makuch and Aczel, 2020). Thus, engaging young people in citizen science projects that contribute to the IPCC goals can help to address these deficits by enabling young people to become engaged in a meaningful climate change-related hands-on science (Trajber et al., 2019; Makuch and Aczel, 2020).

Citizen science allows for young people to learn about nature and the environment in an immersive and structured way, benefiting from the solid disciplines and underpinnings of scientific inquiry, while being engaged in an experience that will impact the formation of their role as future custodians of the world and also as potential future scientists. Similarly, connecting citizen science with the IPCC, and in turn connecting the IPCC directly within school curricula can further enhance environmental education, encourage greater engagement, and enable schools to benefit from the data of the IPCC, in addition to contributing to the growing body of data.

Citizen science can aid in the communication of climate science. Children and young people, and researchers involved in the acquisition of data can "see" how the environment is being affected by climate change through the experiments and the data. This may have an educational benefit but may also influence behavioral change

and equip future guardians of the environment and future decision-makers.

C. Some practical ways in which the IPCC might support citizen science and youth participation

We are not asking the IPCC to think beyond its established boundaries and roles. It is not an educator, nor does it have partnerships with schools. The IPCC also is not a grant-making institution so it cannot disburse grants. However, it can do a lot to point to the need for these matters to be addressed, through other mechanisms such as the UN, the World Bank or the Global Environment Fund. The IPCC is about gathering, evaluating, assessing and applying evidence, in order to bring about change. In relation to our central thesis, we propose the following:

- The IPCC website could include a specific portal or section with simple language in addition to visual depictions to allow climate scientists to share data and ongoing research in a "citizen accessible" way. The portal could host contributions of citizen science studies that are on-going or have been completed including those with contributions from child/youth citizen scientists. This sends the message about inclusion, participation and engagement, and shares and distributes a range of climate data, as well as sharing knowledge and evidence and making it accessible.
- The IPCC website should include information on citizen science projects related to climate that young people can join and additionally provide best practice guidance for researchers on inclusive and accessible.
- The IPCC could host a portal of accessible citizen science data, designed to help others develop curricula partnerships with schools and universities on climate science, including opportunities for hands-on data collection/analysis.
- The IPCC portal could share and promote outreach activities designed by citizen science project leaders specifically for young people, with citizen science components and replicable citizen science projects and guidance.
- The IPCC could initiate a mentorship program with IPCC scientists, including early career scientists, with youth through schools or other formats; develop mentorship models specific to cultural and social environments with citizen science experiential components.
- Recognizing underrepresentation of particular groups of young people, IPCC could encourage citizen science projects in collaboration with schools, community organizations, and others, to improve effectiveness of participatory science and communication with diverse audiences, acknowledging learning differences, physical capacity differences, current underrepresentation of particular groups, and more.
- To motivate young people to participate in citizen science activities, IPCC could support projects at this scale and include mechanisms to include local mentors, particularly those with IPCC working experience, including those with Indigenous knowledge.
- The IPCC, in collaboration with the ECSA or other citizen science organizations could design online and hardcopy guidance documents for best practice in climate citizen science and specifically aimed to include young people. This ought to include ethics, safeguarding, safety, diversity, inclusion, age-appropriate and accessible research methods, cultural and social considerations, economic considerations, and geographic and country-/region-specific recommendations. There is much scope for *in-situ* collaboration with universities and research organizations in designing country-specific guidance, which can be linked to relevant authorities working on national climate change matters.
- The IPCC can make recommendations for the cofinancing of citizen science projects, through the existing Paris Agreement and other "climate" financial mechanisms where advanced technology or equipment may be needed for citizen science. This is in the spirit of common but differentiated responsibilities, benefit sharing and capacity building.
- The IPCC should promote diverse voices among youth citizen scientists, acknowledging that 'youth' is not a homogenous category and that there are differences in access to resources with youth in the global North having greater access (Yona et al., 2020).

D. Concluding remarks

ECSA Principle 6 reminds us that "Citizen science is considered a research approach like any other, with limitations and biases that should be considered and controlled for. However, unlike traditional [scientific] research approaches, citizen science provides opportunity for greater public engagement and democratization of science." We aver in our work that children and young people are able to undertake citizen science research if the projects are well-designed and executed (Makuch and Aczel, 2018). Climate change is anthropocentric in its causes and in its solutions. To this end, engaging a broader pool of scientific research and researchers can arguably accelerate the evidence base and policy-making in this space.

Citizen science has the capacity to bridge the gap between science and policy, and between generations. Moreover, it can operate on multiple scales from global monitoring schemes to local activities, enabling participants to *think global act local* (Schade et al., 2021). We can also teach future guardians of our planet how to 'do' science as well as raise awareness as to cause and effect of environmental harm. Broadening the remit of data and knowledge and evidence that is reviewed by the IPCC can bring huge benefits to the international scientific community, as well as law and policymakers. If citizen science projects are undertaken in a variety of locations, we can also show that no community is immune from the impacts of climate change. The recent April 2022 IPCC

Working Group Two Sixth Assessment Report recommends a greater role for citizen science in the IPCC process and there is no reason why this cannot, and should not, include children and young people (IPCC, 2022, Summary for Policy Makers). The benefits to sciences, policy and society are manifold.

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The authors have declared that no competing interests exist.

Author contributions

The coauthors contributed to this piece equally in the following ways:

- Contributed to conception and design: KM/MA.
- Contributed to acquisition of data: KM/MA.
- Contributed to analysis and interpretation of data: KM/MA.
- Drafted and/or revised the article: KM/MA.
- Approved the submitted version for publication: KM/MA.

References

Albagli, S, **Iwama, AY**. 2022. Citizen science and the right to research: Building local knowledge of climate change impacts. *Humanities and Social Sciences Communications* **9**(1): 1–3.

Andrijevic, M, **Schleussner, CF**, **Gidden, MJ**, **McCollum, DL**, **Rogelj, J.** 2020. COVID-19 recovery funds dwarf clean energy investment needs. *Science* **370**(6514): 298–300. DOI: http://dx.doi.org/10.1126/science.abc9697.

Aristeidou, M, **Herodotou, C.** 2020. Online citizen science: A systematic review of effects on learning and scientific literacy. *Citizen Science: Theory and Practice* **5**(1): 1–12.

Beck, S, **Mahony, M**. 2018. The IPCC and the new map of science and politics. *Wiley Interdisciplinary Reviews: Climate Change* **9**(6): e547.

Bonney, R, **Phillips, TB**, **Ballard, HL**, **Enck, JW.** 2016. Can citizen science enhance public understanding of science? *Public Understanding of Science* **25**(1): 2–16. DOI: http://dx.doi.org/10.1177/0963662515607406.

Boulianne, S, **Lalancette, M**, **Ilkiw, D**. 2020. "School Strike 4 Climate": Social media and the international youth protest on climate change. *Media and Communication* **8**(2): 208–218. Available at https://www.cogitatiopress.com/mediaandcommunication/article/view/2768.

Brown, SA, **Lock, R**. 2018. Enhancing intergenerational communication around climate change, in *Handbook of climate change communication: Vol. 3.* Cham, Switzerland: Springer: 385–398.

Butler, L, **Scammell, M**, **Benson, EB**. 2016. The Flint, Michigan water crisis: A case study in regulatory failure and environmental injustice. *Environmental Justice* **9**: 93–97. DOI: http://dx.doi.org/10.1089/env.2016.0014.

Castagneyrol, B, **Valdés-Correcher, E**, **Bourdin, A**, **Barbaro, L**, **Bouriaud, O**, **Branco, M**, **Centenaro, G**, **Csóka, G**, **Duduman, ML**, **Dulaurent, AM**, **Eötvös, CB**, **Faticov, M**, **Ferrante, M**, **Fürjes-Mikó, A**, **Galmán, A**, **Gossner, MM**, **Harvey, D**, **Howe, AG**, **Kaennel-Dobbertin, M**, **Koricheva, J**, **Löveï, GL**, **Lupaétean, D**, **Milanoviá, S**, **Mrazova, A**, **Opgennoorth, L**, **Pitkänen, JM**, **Popoviá, M**, **Roslin, TV**, **Scherer-Lorenzen, M**, **Sam, K**, **Tahadlová, M**, **Thomas, R**, **Tack, AJM**, **Eötvös, CB.** 2020. Can school young people support ecological research? Lessons from the Oak Bodyguard Citizen Science Project. *Citizen Science: Theory and Practice* **5**(1): 1–11. DOI: http://dx.doi.org/10.5334/cstp.267.

Castell, N, **Grossberndt, S**, **Gray, L**, **Fredriksen, M**, **Skaar, JS**, **Høiskar, BAK.** 2021. Implementing citizen science in primary schools: Engaging young people in monitoring air pollution. *NILU*. DOI: http://dx.doi.org/10.3389/fclim.2021.639128.

Celi, LA, **Sarmenta, L**, **Rotberg, J**, **Marcelo, A**, **Clifford, G.** 2009. Mobile care (Moca) for remote diagnosis and screening. *Journal of Health Informatics in Developing Countries* **3**(1): 17. Available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3149792/.

Cheng, JCH, **Monroe, MC.** 2012. Connection to nature: Young people's affective attitude toward nature. *Environment and Behavior* **44**(1): 31–49. DOI: http://dx.doi.org/10.1177/0013916510385082.

Clark, H, **Coll-Seck, AM**, **Banerjee, A**, **Peterson, S**, **Dalglish, SL**, **Ameratunga, S**, **Balabanova, D**, **Bhan, MK**, **Bhutta, ZA**, **Borrazzo, J**, **Claeson, M**, **Costello, A.** 2020. A future for the world's young people? A WHO–UNICEF–Lancet Commission. *The Lancet* **395**(10224): 605–658. DOI: http://dx.doi.org/10.1016/S0140-6736(19)32540-1.

Collado, S, **Evans, GW.** 2019. Outcome expectancy: A key factor to understanding childhood exposure to nature and young people's pro-environmental behavior. *Journal of Environmental Psychology* **61**: 30–36. DOI: http://dx.doi.org/10.1016/j.jenvp.2018.12.001.

Cooper, CB, **Hawn, CL**, **Larson, LR**, **Parrish, JK**, **Bowser, G**, **Cavalier, D**, **Haklay, M**, **Gupta, KK**, **Jelks, NTO**, **Johnson, VA**, **Dunn, R.** 2021. Inclusion in citizen science: The conundrum of rebranding. *Science* **372**(6549): 1386–1388. DOI: http://dx.doi.org/10.1126/science.abi6487.

Corner, A, **Shaw, C**, **Clark, J**. 2018. *Principles for effective communication and public engagement on climate change: A handbook for IPCC authors*. Oxford, UK: Climate Outreach. Available at https://www.ipcc.ch/site/assets/uploads/2017/08/Climate-Outreach-IPCC-communications-handbook.pdf.

Cronje, R, **Rohlinger, S**, **Crall, A**, **Newman, G.** 2011. Does participation in citizen science improve

scientific literacy? A study to compare assessment methods. *Applied Environmental Education & Communication* **10**(3): 35–145. DOI: http://dx.doi.org/10.1080/1533015X.2011.603611.

Dickinson, JL, **Shirk, J**, **Bonter, D**, **Bonney, R**, **Crain, RL**, **Martin, J**, **Phillips, T**, **Purcell, K.** 2012. The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment* **10**(6): 291–297. DOI: http://dx.doi.org/10.1890/110236.

Dopko, RL, **Capaldi, CA**, **Zelenski, JM.** 2019. The psychological and social benefits of a nature experience for young people: A preliminary investigation. *Journal of Environmental Psychology* **63**: 134–138. DOI: http://dx.doi.org/10.1016/j.jenvp.2019.05.002.

Dudman, K, **de Wit, S.** 2021. An IPCC that listens: Introducing reciprocity to climate change communication. *Climatic Change* **168**(2). DOI: https://dx.doi.org/10.1007/s10584-021-03186-x; https://rdcu.be/cQAdh.

Ecker, UKH, **Butler, LH**, **Cook, J**, **Hurlstone, MJ**, **Kurz, T**, **Lewandowsky, S.** 2020. Using the COVID-19 economic crisis to frame climate change as a secondary issue reduces mitigation support. *Journal of Environmental Psychology* **70**: 101464. DOI: http://dx.doi.org/10.1016/j.jenvp.2020.101464.

Eichler, SE, **Hopperton, AP**, **Alava, JJ**, **Pereira Jr, A**, **Ahmed, R**, **Kozlakidis, Z**, **Ilic, S**, **Rodriguez-Palacios, A.** 2020. A citizen science facemask experiment and educational modules to improve coronavirus safety in communities and schools. *Frontiers in Medicine* **7**: 486. DOI: http://dx.doi.org/10.3389/fmed.2020.00486.

Eitzel, MV, **Cappadonna, JL**, **Santos-Lang, C**, **Duerr, RE**, **Virapongse, A**, **West, SE**, **Kyba, CCM**, **Bowser, A**, **Cooper, CB**, **Sforzi, A**, **Metcalfe, AN.** 2017. Citizen science terminology matters: Exploring key terms. *Citizen Science: Theory and Practice* **2**(1). DOI: http://dx.doi.org/10.5334/cstp.96.

Ellwood, ER, **Crimmins, TM**, **Miller-Rushing, AJ.** 2017. Citizen science and conservation: Recommendations for a rapidly moving field. *Biological Conservation* **208**: 1–4. DOI: http://dx.doi.org/10.1016/j.biocon.2016.10.014.

European Citizen Science Association. 2015. *Ten principles of citizen science*. Berlin, Germany: ESCA. DOI: http://dx.doi.org/10.17605/OSF.IO/XPR2N.

Follett, R, **Strezov, V.** 2015. An analysis of citizen science based research: Usage and publication patterns. *PLoS One* **10**(11): e0143687. DOI: http://dx.doi.org/10.1371/journal.pone.0143687.

Fraisl, D, **Campbell, J**, **See, L**, **Wehn, U**, **Wardlaw, J**, **Gold, M**, **Moorthy, I**, **Arias, R**, **Piera, J**, **Oliver, JL**, **Masó, J**, **Penker, M**, **Fritz, S.** 2020. Mapping citizen science contributions to the UN sustainable development goals. *Sustainability Science* **15**(6): 1735–1751. DOI: http://dx.doi.org/10.1007/s11625-020-00833-7.

Fridays for Future. n.d. Fridays for Future School Strikes. Available at https://fridaysforfuture.org/.

Fritz, S, **See, L**, **Carlson, T**, **Haklay, MM**, **Oliver, JL**, **Fraisl, D**, **Mondardini, R**, **Brocklehurst, M**, **Shanley, LA**, **Schade, S**, **When, U**, **Abrate, T**, **Anstee, J**, **Arnold, S**, **Billot, M**, **Campbell, J**, **Espey, J**, **Gold, M**, **Hager, G**, **He, S**, **Hepburn, L**, **Hsu, A**, **Long, L**, **Masó, J**, **West, S.** 2019. Citizen science and the United Nations sustainable development goals. *Nature Sustainability* **2**(10): 922–930. DOI: http://dx.doi.org/10.1038/s41893-019-0390-3.

García-Holgado, A, **García-Peñalvo, FJ**, **Butler, P.** 2020. Technological ecosystems in citizen science: A framework to involve young people and young people. *Sustainability* **12**(5): 1863. DOI: http://dx.doi.org/10.3390/su12051863.

Groulx, M, **Brisbois, MC**, **Lemieux, CJ**, **Winegardner, A**, **Fishback, L.** 2017. A role for nature-based citizen science in promoting individual and collective climate change action? A systematic review of learning outcomes. *Science Communication* **39**(1): 45–76. DOI: http://dx.doi.org/10.1177/1075547016688324.

Grover, S. 2004. Why won't they listen to us? On giving power and voice to young people participating in social research. *Childhood* **11**: 81–93. DOI: http://dx.doi.org/10.1177/0907568204040186.

Haklay, MM, **Mazumdar, S**, **Wardlaw, J.** 2018. Citizen science for observing and understanding the earth, in Mathieu, PP, Aubrecht, C eds., *Earth observation open science and innovation*. Cham, Switzerland: Springer. (ISSI Scientific Report Series; vol. 15). DOI: https://doi.org/10.1007/978-3-319-65633-5_4.

Hanna, R, **Oliva, P.** 2016. Implications of climate change for young people in developing countries. *The Future of Young People*: 115–132. Available at https://www.jstor.org/stable/43755233#metadata_info_tab_contents.

Harmon, A. 2017. Climate science meets a stubborn obstacle: Students. *New York Times*. Available at https://www.nytimes.com/2017/06/04/us/education-climate-change-science-class-students.html.

Harold, J, **Lorenzoni, I**, **Shipley, TF**, **Coventry, KR.** 2020. Communication of IPCC visuals: IPCC authors' views and assessments of visual complexity. *Climatic Change* **158**(2): 255–270. DOI: http://dx.doi.org/10.1007/s10584-019-02537-z.

Hart, RA. 1997. *Young people's participation: The theory and practice of involving young citizens in community development and environmental care*. London, UK: Earthscan.

Haywood, B. 2016. Beyond data points and research contributions: The personal meaning and value associated with public participation in scientific research. *International Journal of Science Education: Part B* **6**: 239–262. DOI: http://dx.doi.org/10.1080/21548455.2015.1043659.

Herman, BD, **McKay, SK**, **Altman, S**, **Richards, NS**, **Reif, M**, **Piercy, CD**, **Swannack, TM.** 2019. Unpacking the black box: Demystifying ecological models through interactive workshops and hands-on learning.

Frontiers in Environmental Science **7**: 122. DOI: http://dx.doi.org/10.3389/fenvs.2019.00122.

Hidalgo-Ruz, V, **Thiel, M.** 2013. Distribution and abundance of small plastic debris on beaches in the SE Pacific (Chile): A study supported by a citizen science project. *Marine Environmental Research* **87**: 12–18.

Holmberg, A, **Alvinius, A.** 2020. Young people's protest in relation to the climate emergency: A qualitative study on a new form of resistance promoting political and social change. *Childhood* **27**(1): 78–92. DOI: http://dx.doi.org/10.1177/0907568219879970.

Hulme, M, **Mahony, M**. 2010. Climate change: What do we know about the IPCC? *Progress in Physical Geography: Earth and Environment* **34**(5): 705–718. DOI: https://doi.org/10.1177/0309133310373719.

Intergovernmental Panel on Climate Change. n.d. About the IPCC. Available at https://www.ipcc.ch/about/. Accessed July 13, 2022.

Intergovernmental Panel on Climate Change. 2018. Summary for policymakers, in Masson-Delmotte, V, Zhai, P, Pörtner, H-O, Roberts, D, Skea, J, Shukla, PR, Pirani, A, Moufouma-Okia, W, Péan, C, Pidcock, R, Connors, S, Matthews, JBR, Chen, Y, Zhou, X, Gomis, MI eds., *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.* Available at https://www.ipcc.ch/sr15/chapter/spm/.

Intergovernmental Panel on Climate Change. 2020. Agenda Item: 8. IPCC Gender Policy and Implementation Plan (Prepared by the Task Group on Gender). Fifty-Second Session of the IPCC, Paris, March 24–28, 2020, IPCCLII/Doc. 9 (3.II.2020).

Intergovernmental Panel on Climate Change. 2022. Summary for policymakers, in Pörtner, H-O, Roberts, DC, Tignor, M, Poloczanska, ES, Mintenbeck, K, Alegría, A, Craig, M, Langsdorf, S, Löschke, S, Möller, V, Okem, A, Rama, B eds., *Climate change 2022: Impacts, adaptation, and vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Available at https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_SummaryForPolicymakers.pdf.

Jenkins, LL. 2011. Using citizen science beyond teaching science content: A strategy for making science relevant to students' lives. *Cultural Studies of Science Education* **6**(2): 501–508. DOI: http://dx.doi.org/10.1007/s11422-010-9304-4.

Jordan, RC, **Ballard, HL**, **Phillips, TB.** 2012. Key issues and new approaches for evaluating citizen-science learning outcomes. *Frontiers in Ecology and the Environment* **10**: 307–309. DOI: http://dx.doi.org/10.1890/110280.

Kuo, M, **Barnes, M**, **Jordan, C.** 2019. Do experiences with nature promote learning? Converging evidence of a cause-and-effect relationship. *Frontiers in Psychology* **10**: 305. Available at https://www.frontiersin.org/articles/10.3389/fpsyg.2019.00305/full.

Lawson, DF, **Stevenson, KT**, **Peterson, MN**, **Carrier, SJ**, **Strnad, RL**, **Seekamp, E.** 2019. Young people can foster climate change concern among their parents. *Nature Climate Change* **9**(6): 458–462. DOI: http://dx.doi.org/10.1038/s41558-019-0463-3.

Liebenberg, L, **Steventon, J**, **Brahman, N**, **Benadie, K**, **Minye, J**, **Langwane, HK.** 2017. Smartphone icon user interface design for non-literate trackers and its implications for an inclusive citizen science. *Biological Conservation* **208**: 155–162. DOI: http://dx.doi.org/10.1016/j.biocon.2016.04.033.

Locritani, M, **Merlino, S**, **Abbate, M.** 2019. Assessing the citizen science approach as tool to increase awareness on the marine litter problem. *Marine Pollution Bulletin* **140**: 320–329.

MacKenzie, CM, **Murray, G**, **Primack, R**, **Weihrauch, D.** 2017. Lessons from citizen science: Assessing volunteer-collected plant phenology data with Mountain Watch. *Biological Conservation* **208**: 121–126. DOI: http://dx.doi.org/10.1016/j.biocon.2016.07.027.

Makuch, KE, **Aczel, M.** 2018. Citizen science & young people, in Hecker, S, Haklay, M, Bowser, A, Makuch, Z, Vogel, J, Bonn, A eds., *Citizen science: Innovation in open science, society and policy.* London, England: UCL Press: 391–409.

Makuch, KE, **Aczel, MR.** 2020. Eco-citizen science for social good: Promoting child well-being, environmental justice, and inclusion. *Research on Social Work Practice* **30**(2): 219–232. DOI: http://dx.doi.org/10.1177/1049731519890404.

Mannion, G, **Adey, C.** 2011. Place-based education is an intergenerational practice. *Children Youth and Environments.* **21**(1): 35–58.

Marchezini, V, **Trajber, R**, **Olivato, D**, **Munoz, VA**, **de Oliveira Pereira, F**, **Oliveira Luz, AE**. 2017. Participatory early warning systems: Youth, citizen science, and intergenerational dialogues on disaster risk reduction in Brazil. *International Journal of Disaster Risk Science* **8**(4): 390–401.

Marris, E. 2019. Why young climate activists have captured the world's attention. *Nature* **573**(7775): 471–473. Available at https://www.nature.com/articles/d41586-019-02696-0.

McGreavy, B, **Calhoun, AJ**, **Jansujwicz, J**, **Levesque, V.** 2016. Citizen science and natural resource governance: Program design for vernal pool policy innovation. *Ecology and Society* **21**(2): 48.

McKinley, DC, **Miller-Rushing, AJ**, **Ballard, HL**, **Bonney, R**, **Brown, H**, **Cook-Patton, SC**, **Evans, DM**, **French, RA**, **Parrish, JK**, **Phillips, TB**, **Ryan, SF.** 2017. Citizen science can improve conservation science, natural resource management, and environmental protection. *Biological Conservation* **208**: 15–28.

Miczajka, VL, **Klein, A-M**, **Pufal, G.** 2015. Elementary school young people contribute to environmental

research as citizen scientists. *PLoS One* **10**. DOI: http://dx.doi.org/10.1371/journal.pone.0143229.

Moore, TJ, **Tank, KM**, **English, L**. 2018. Engineering in the early grades: Harnessing young people's natural ways of thinking, in English L, Moore T, eds., *Early engineering learning. Early mathematics learning and development*. Singapore: Springer. DOI: http://dx.doi.org/10.1007/978-981-10-8621-2_2.

Moran, L, **Rau, H.** 2016. Mapping divergent concepts of sustainability: Lay knowledge, local practices and environmental governance. *Local Environment* **21**(3): 344–360. DOI: http://dx.doi.org/10.1080/13549839.2014.963838.

Moser, SC. 2016. Reflections on climate change communication research and practice in the second decade of the 21st century: What more is there to say? *Wiley Interdisciplinary Reviews: Climate Change* **7**: 345–369.

Moser, SC, **Dilling, L**. 2011. Communicating climate change: Closing the science-action gap, Part 3, in Dryzek, JS, Norgaard, RB, Schlosberg, D eds., *The Oxford handbook of climate change and society* (vol. 11, 161–174). Oxford, UK: Oxford University Press.

National Academies of Sciences, Engineering, and Medicine. 2018. Designing for learning, in Pandya, R, Dibner, KA eds., *Learning through citizen science: Enhancing opportunities by design*. Washington, DC: National Academies Press: 125–142. Available at https://www.nap.edu/read/25183/.

Nishiyama, K. 2017. Deliberators, not future citizens: Young people in democracy. *Journal of Public Deliberation* **13**(1): 1. DOI: http://dx.doi.org/10.16997/jdd.267.

Pitt, AN, **Schultz, CA.** 2018. Youth-based citizen science monitoring: Case studies from three national forests. *Journal of Forestry—Washington* **116**(2): 109–116. DOI: http://dx.doi.org/10.1093/jofore/fvx008.

Pohle, I, **Helliwell, R**, **Aube, C**, **Gibbs, S**, **Spencer, M**, **Spezia, L.** 2019. Citizen science evidence from the past century shows that Scottish rivers are warming. *Science of the Total Environment* **659**: 53–65. DOI: http://dx.doi.org/10.1016/j.scitotenv.2018.12.325.

Prasad, A. 2019, December. Denying anthropogenic climate change: Or, how our rejection of objective reality gave intellectual legitimacy to fake news. *Sociological Forum* **34**: 1217–1234. DOI: http://dx.doi.org/10.1111/socf.12546.

Ranney, MA, **Clark, D.** 2016. Climate change conceptual change: Scientific information can transform attitudes. *Topics in Cognitive Science* **8**: 39–75. DOI: http://dx.doi.org/10.1111/tops.12187.

Robertson, J, **Tisdall, EKM.** 2020. The importance of consulting young people and young people about data literacy. *Journal of Media Literacy Education* **12**(3): 58–74. DOI: http://dx.doi.org/10.23860/JMLE-2020-12-3-6.

Schade, S, **Pelacho, M**, **van Noordwijk, TC**, **Vohland, K**, **Hecker, S**, **Manzoni, M**, 2021. Citizen science and policy, in *The science of citizen science*. Cham, Switzerland: Springer: 351–371. DOI: http://dx.doi.org/10.23860/JMLE-2020-12-3-6.

Schweizer, S, **Davis, S**, **Thompson, JL.** 2013. Changing the conversation about climate change: A theoretical framework for place-based climate change engagement. *Environmental Communication* **7**(1): 42–62. DOI: http://dx.doi.org/10.1080/17524032.2012.753634.

Senabre Hidalgo, E, **Perelló, J**, **Becker, F**, **Bonhoure, I**, **Legris, M**, **Cigarini, A.** 2021. Participation and co-creation in citizen science, in Vohland, K, Land-Zandstra, A, Ceccaroni, L, Lemmens, R, Perello, J, Ponti, M, Samson, R, Wagenknecht, K eds., *The science of citizen science*. Berlin, Germany: Springer. DOI: http://dx.doi.org/10.1007/978-3-030-58278-4.

Shackley, S. 1997. The Intergovernmental Panel on Climate Change: Consensual knowledge and global politics *Global Environmental Change* **7**1: 77–79.

Sharma, A. 2012. Global climate change: What has science education got to do with it? *Science Education* **21**: 33–53. DOI: http://dx.doi.org/10.1007/s11191-011-9372-1.

Soanes, K, **Cranney, K**, **Dade, MC**, **Edwards, AM**, **Palavalli-Nettimi, R**, **Doherty, TS**. 2020. How to work with young people and animals: A guide for school-based citizen science in wildlife research. *Austral Ecology* **45**(1): 3–14. DOI: http://dx.doi.org/10.1111/aec.12836.

Sorensen, AE, **Jordan, RC**, **LaDeau, SL**, **Biehler, D**, **Wilson, S**, **John-Henry Pitas, J-H**, **Leisnham, PT.** 2019. Reflecting on efforts to design an inclusive citizen science project in West Baltimore. *Papers in Natural Resources, University of Nebraska*. Available at https://digitalcommons.unl.edu/cgi/viewcontent.cgi?Article=1876&context=natrespapers.

Stanberry, LR, **Thomson, MC**, **James, W**. 2018. Prioritizing the needs of young people in a changing climate. *PLoS Medicine* **15**(7): e1002627.

Tanner, T, **Narasimhan, G**, **Nimineh, F**, **Rudram, B**, **Wright, Y**, **Garrett, J**. 2022. Children must shape the global response to climate crisis. *Guardian Letters*. Available at https://www.theguardian.com/environment/2022/apr/11/children-must-shape-the-global-response-to-climate-crisis.

Thunberg, G. 2019. If world leaders choose to fail us, my generation will never forgive them. *The Guardian*. Available at https://www.theguardian.com/commentisfree/2019/sep/23/world-leaders-generation-climate-breakdown-greta-thunberg.

Tillmann, S, **Tobin, D**, **Avison, W**, **Gilliland, J.** 2018. Mental health benefits of interactions with nature in young people and teenagers: A systematic review. *Journal of Epidemiology and Community Health* **72**(10): 958–966. Available at https://jech.bmj.com/content/72/10/958.

Trajber, R, **Walker, C**, **Marchezini, V**, **Kraftl, P**, **Olivato, D**, **Hadfield-Hill, S**, **Zara, C**, **Fernandes Monteiro, S.** 2019. Promoting climate change transformation with young people in Brazil: Participatory action research through a looping approach. *Action Research* **17**(1): 87–107. DOI: http://dx.doi.org/10.1177/1476750319829202.

UN Committee on the Rights of the Child. 2009. General Comment No. 12. The right of the child to be heard. Available at https://www2.ohchr.org/english/bodies/crc/docs/AdvanceVersions/CRC-C-GC-12.pdf.

UN Committee on the Rights of the Child. 2017. Report: Day General Discussion 2016: Young People's Rights and the Environment. Available at https://www.ohchr.org/EN/HRBodies/CRC/Pages/Discussion2016.aspx.

UN Conference on Environment and Development. 1992. Rio declaration on environment and development (A/CONF.151/26 (vol. I), 31 ILM 874 (1992). Available at https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_CONF.151_26_Vol.I_Declaration.pdf.

UN Economic Commission for Europe. 1998, June 25. *Convention on access to information, public participation in decision-making and access to justice in environmental matters* (entered into force 2001). Aarhus, Denmark: UNECE. Available at https://www.unece.org/fileadmin/DAM/env/pp/documents/cep43e.pdf.

UN Framework Convention on Climate Change. 2015. *Adoption of the Paris Agreement*. Bonn, Germany: UNFCCC. Report No. FCCC/CP/2015/L.9/Rev.1, United Nations. Available at http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf.

UNICEF. 2015. *The challenges of climate change: Young people on the front line*. eSocialSciences. Available at https://econpapers.repec.org/paper/esswpaper/id_3a7920.htm.

Verlie, B, **Flynn, A**. 2022. School strike for climate: A reckoning for education. *Australian Journal of Environmental Education* **38**(1): 1–12.

Wallis, H, **Loy, LS**. 2021. What drives pro-environmental activism of young people? A survey study on the Fridays For Future movement. *ournal of Environmental Psychology* **74**: 101581.

Wals, AE, **Brody, M**, **Dillon, J**, **Stevenson, RB.** 2014. Convergence between science and environmental education. *Science* **344**: 583–584. DOI: http://dx.doi.org/10.1126/science.1250515.

Wells, NM, **Lekies, KS.** 2006. Nature and the life course: Pathways from childhood nature experiences to adult environmentalism. *Young People Youth and Environments* **16**(1): 1–24. Available at https://www.researchgate.net/publication/252512760_Nature_and_the_Life_Course_Pathways_from_Childhood_Nature_Experiences_to_Adult_Environmentalism1.

Weyhenmeyer, GA, **Mackay, M**, **Stockwell, JD**, **Thiery, W**, **Grossart, HP**, **Augusto-Silva, PB**, **Kirillin, G.** 2017. Citizen science shows systematic changes in the temperature difference between air and inland waters with global warming. *Scientific Reports* **7**: 43890.

Wong-Parodi, G, **Feygina, I.** 2020. Understanding and countering the motivated roots of climate change denial. *Current Opinion in Environmental Sustainability* **42**: 60–64. DOI: http://dx.doi.org/10.1016/j.cosust.2019.11.008.

Yamineva, Y. 2017. Lessons from the Intergovernmental Panel on Climate Change on inclusiveness across geographies and stakeholders. *Environmental Science & Policy* **77**: 244–251.

Yona, L, **Dixon, MD**, **Howarth, RB**, **Kapuscinski, AR**, **Virginia, RA**. 2020. Applying a leverage points framework to the United Nations climate negotiations: The (dis)empowerment of youth participants. *Elementa: Science of the Anthropocene*, **8**. DOI: https://doi.org/10.1525/elementa.433.

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