Tracking a Changing Climate:
Citizen Science Contributions to the National Climate Assessment
WORKSHOP REPORT

Executive Summary

On November 18 and 19, 2014, the U.S. Global Change Research Program, The Wilson Center, and the Federal Community of Practice on Crowdsourcing and Citizen Science hosted a workshop to explore the ways in which crowdsourcing efforts could be used to support indicators of climate change. Indicators systematically measure, summarize, and communicate the status, trend, or performance of a given system. Climate-related indicators can help communicate relevant impacts of climate change, whether they are physical, biological, or societal.

The two-day workshop consisted of a half-day public panel and a one-day invitation-only working session. Participants were invited from many different sectors. Major discussions included the purpose of using indicators; existing citizen science efforts; managing data and analysis; indicators that could most easily engage citizen scientists or include citizen science data; technological aspects of crowdsourcing (e.g., social media); improving spatial and temporal scale of efforts; and potential new frontiers in citizen science for climate assessment.

The roundtable produced several conclusions about the state of citizen science in contributing to climate-related indicators. Discussions revealed that improvements are needed to better use citizen science as part of indicator datasets, development, visualization, and evaluation. To prioritize efforts, citizen science programs could be categorized based on their readiness level, i.e. the resources needed and time required to develop a program to the point where its outputs can inform an indicator, and whether they could be used alongside existing national or regional indicators to provide additional local information. Most currently-used examples of citizen science linked to indicators are related to distributed observations of weather events and species prevalence. Very little data and few indicators exist for response indicators and citizen science data analysis activities. Addressing these two deficiencies together may prove fruitful because contributions to response indicators will likely come in the form of analysis. In addition, citizen science infrastructure ought to develop to meet specific data needs, such as national-scale datasets.

This report was written by the workshop steering committee and planning team (see Appendix A), and a select group of participants (see Appendix B for list of participants).

Introduction

A forum on indicators and citizen science

In November 2014, the U.S. Global Change Research Program (USGCRP), the Commons Lab of the Woodrow Wilson International Center for Scholars (The Wilson Center), and the Federal Community of Practice on Crowdsourcing and Citizen Science co-hosted a roundtable titled “Tracking a Changing Climate: Citizen Science Contributions to the National Climate Assessment”. The roundtable explored ways in which crowd-based approaches, such as citizen science and community-based monitoring, are and can be used to support indicators or indicator systems of climate change, impacts, and response. More specifically, the roundtable was motivated by a proposed set of climate indicators to support a sustained U.S. National Climate Assessment process -- a system of key physical, ecological, and societal indicators

that would inform and support decision-making about climate change, impacts, vulnerabilities, and responses.

In order to elicit a robust conversation on indicator development and use, citizen science methods and applications, and crowdsourcing approaches, a mix of Federal, academic, public sector, and private sector experts were invited to a two-and-a-half hour public forum[1] on November 18, 2014 and a day-long, invitation-only, working session[2] on November 19, 2014.

The goals of the roundtable were to:

- Identify opportunities to use citizen science to provide data at decision-relevant scales or to help verify data and information used to construct climate-relevant indicators;
- Assess challenges of collecting and integrating crowd-generated information into climate indicators; and
- Brainstorm possible solutions for the use of citizen science data sources and engagement in indicators to support the sustained National Climate Assessment process and other environmental indicator efforts.

Questions discussed during the roundtable included:

- Why use indicators?
- What contributions are citizen scientists already making to indicator and assessment efforts?
- What indicators are "low hanging fruit" for engaging citizen scientists in tracking climate change drivers, impacts, and responses?
- How are web applications and social media being used to promote citizen science contributions to climate science?
- What are key indicators and which indicators are feasible for incorporating citizen science?
- What are the existing data collection and analysis streams from citizen science?
- How might we connect indicators and citizen science efforts across spatial scales (i.e., local to regional to national to international) and temporal scales (i.e., historic to current to future)?
- What potential areas or new frontiers should be prioritized for citizen science concerning climate and societal indicators?

What is the National Climate Assessment and the Sustained Assessment?

Scientific assessments are essential tools for linking science and decision making. They survey and synthesize science within and between disciplines and across sectors and regions. They highlight key knowledge that can improve policy choices and identify significant gaps that can limit effective decision making. Assessments also track progress by identifying changes in the condition of the Earth, changes in human response, and advances in science over time.

Assessments have been integral components of USGCRP since its inception. USGCRP has a legal mandate to conduct a National Climate Assessment every four years;[3] the third and most recent National Climate Assessment was released in May 2014.[4] The goals of the National Climate Assessment are:

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[1] Information about the public forum, including a video of the event, is available from http://www.wilsoncenter.org/event/tracking-changing-climate-citizen-science-contributions-to-the-national-climate-assessment

[2] Information about the working session, including speakers' presentations and graphic recordings of the discussions, is available from https://sites.google.com/a/usgcrp.gov/tracking-a-changing-climate/

[3] http://www.globalchange.gov/what-we-do/assessment

[4] http://nca2014.globalchange.gov

- to inform the U.S. about observed changes, the current status of the climate, and anticipated trends for the future;
- to integrate scientific information from multiple sources and sectors to highlight key findings and significant gaps in knowledge;
- to establish consistent methods for evaluating climate impacts in the U.S. in the context of broader global change; and
- to encourage its use by U.S. government, citizens, communities, and businesses as they create more sustainable and environmentally sound plans for the future.

An emerging area of focus for USGCRP is strengthening its capacity to conduct assessments on a sustained basis. USGCRP is building a sustained assessment process that will ultimately facilitate continuous and transparent participation of scientists and stakeholders across regions and sectors, enabling new information and insights to be synthesized as they emerge[5]. As part of the sustained assessment process, one of the supporting products proposed and recently implemented as a proof-of-concept by USGCRP is a system of indicators to understand changes, impacts to natural systems and human sectors, and responses.[6]

What are indicators?

Indicators measure, summarize, and communicate the status, trend, or performance of a given system. They are typically used in large, complex systems or to describe complex phenomenon when the tracking and interpretation of every system variable would be impractical. For example, many businesses look at the unemployment index to gauge the health of the economy. Similarly, climate-relevant indicators—whether ecological, physical, or societal—can help communicate key aspects of the changing environment, point out vulnerabilities, and inform decision making at local, state, and national levels.

Indicators are an important part of the vision for the sustained National Climate Assessment. USGCRP plans to build a set of climate indicators over time, starting with a preliminary set meant as a prototype for evaluation by scientists and user communities.[7] Ultimately, these indicators are recommended to go beyond documenting physical climate changes and to additionally encompass climate-related impacts for natural systems and human sectors as well as adaptation and mitigation responses[8]. USGCRP will provide scientifically rigorous indicators and associated metadata, with the goal of supporting sustained assessment and supporting decisions to prepare for and to respond to climate change.[9]

What is citizen science?

Citizen science refers to the engagement of volunteers in scientific investigations, which can include asking questions, collecting data, or interpreting results[10]. Projects usually involve a partnership between non-scientists and professional scientists; although, in some programs an expert volunteer can reduce or remove the need for a professional scientist. Citizen science provides the opportunity for the public to

[5] http://nca2014.globalchange.gov/report/response-strategies/sustained-assessment
[6] http://www.globalchange.gov/explore/indicators
[7] The preliminary set of climate indicators (released May 2015) is available from http://www.globalchange.gov/browse/indicators
[8] http://www.globalchange.gov/sites/globalchange/files/Pilot-Indicator-System-Report_final.pdf
[9] Kenney, M. A., Janetos, A. C., & Lough, G. C. (2016). Building an integrated US national climate indicators system. *Climatic Change*, *135*(1), 85-96.
[10] http://scistarter.com/page/Citizen%20Science.html
https://www.nwf.org/Wildlife/Wildlife-Conservation/Citizen-Science.aspx

contribute to large datasets and engage in authentic scientific research, often through a convenient online interface or smartphone application. Though some experts have concerns that citizen-derived data may be relatively less reliable, citizen science data has been found to be nearly as accurate as data collected by professional scientists and could serve as a useful supplement to professionally collected data[11].

Incorporating citizen science projects into scientific studies allows those studies to collect data across larger spatial extents and with finer resolution than would otherwise be possible. Since climate is a phenomenon that occurs at all spatial levels, broad and dense data sets collected systematically over a long period of time are needed to derive national and global trends. Linking volunteer data collection with climate trends can also encourage awareness of specific climate dynamics. Instead of relying on professional scientific data, participants can see a trend emerge in real-time as they collect their own data, empowering them to take action on a local scale.

Opportunities and Challenges

The first day of the workshop began with a public forum, which included two keynote addresses by Virginia Burkett, Acting Associate Director of Climate and Land Use Change for the U.S. Geological Survey, and Richard Spinrad, Chief Scientist of the National Oceanic and Atmospheric Administration. The addressees discussed the depth of Federal vision, investment, and leadership in citizen science, highlighting work in their respective organizations.[12] Panelists[13] highlighted the contributions of climate change to research and monitoring of phenology, weather, birds, and more. Much attention was also paid to the ways in which networks and relationships might be built through citizen science, including opportunities for public co-ownership of climate knowledge, and the potential for citizen science to facilitate climate resilience. In summarizing, the panelists invited the audience to take a deeper look at the diversity of public understandings of climate change, scientists' interests in citizen science, and the roles agencies are playing in mediating complex social-technical concerns. The audience discussion and questions developed conversational ideas around international collaborations, roles for youth and schools, connecting datasets, and looking beyond solely natural sciences.

The working session commenced with presentations and discussion on the preliminary climate indicators proposed as part of the Sustained Assessment[14] and opportunities and challenges[15] associated with citizen science and indicator development. Special attention was paid to indicator selection criteria and development, geographical scale, participation and engagement, and "low-hanging fruit." The following sub-sections summarize converging threads of discussion.

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[11] Fore, L., Paulsen, K., and O'Laughlin, K. (2001). *Freshwater Biology* 46:109-123; Lowry, C. and Fienen, M. (2013). *Groundwater* 51:151-156.

[12] Following the roundtable, the keynote speakers developed two blog posts that summarized their presentations and expanded on key points.

[13] Duncan McKinley (U.S. Forest Service), Julia Parrish (University of Washington), Jennifer Shirk (Cornell University), and Tim Watkins (U.S. National Park Service). Moderated by Jenn Gustetic (U.S. Office of Science and Technology Policy).

[14] Tony Janetos (Boston University), Richard Pouyat (U.S. Forest Service), and Jake Weltzin (U.S. Geological Survey). Moderated by Melissa Kenney (University of Maryland).

[15] Kathy Dale (National Audubon Society), Nolan Doesken (Colorado State University), Greg Newman (Colorado State University), Timothy Stryker (U.S. Office of Science and Technology Policy), and Andrea Wiggins (University of Maryland). Moderated by Brian Wee (NEON, Inc.).

[11] Please see this workshop summary to learn about efforts to share project meta-data among the following inventories/databases - SciStarter, CitSci, Citizen Science Association and the Commons Lab Federal Database: https://www.wilsoncenter.org/publication/citizen-science-and-crowdsourcing-metadata-workshop-summary

Selection criteria and development

During discussion it was suggested that a useful point-of-departure is an inventory of existing projects. This inventory can be used to identify where new, expanded, or augmented projects can fill a gap, and where there are opportunities to align existing projects with proposed indicators. A resource repository of protocols, related software, and scripts would be an invaluable extension of a comprehensive project inventory. The repository would help maintain efficient growth of the field by reducing duplication of effort whenever it is feasible to repurpose or revive existing projects, designs, protocols, and tools. Currently, there are multiple citizen science project inventories that exist under slightly different goals. These databases are an excellent starting point for generating an understanding on what already exists and how to capitalize on existing efforts.

Citizen science project organizers will need to continue to demonstrate robust data quality by maintaining transparent and well-documented protocols, information management processes, and data. Rising to this challenge would place citizen science in an open science leadership role -- a movement that aims to make science accessible and transparent to all. In considering projects as candidate data providers for indicators, their economic sustainability, infrastructure reliability, and capacity for production-level performance should be taken into consideration.

Data integration remains a challenge, as does encouraging professionals to openly share scientific data, but both have potential to create new opportunities for establishing data quality through triangulation of data sources. By combining multiple sources of data, indicators can also represent both public and private lands and more aspects of climate change.

Geographic scale

Spatial scale introduces challenges at multiple levels: (i) achieving adequate geographic coverage at smaller scales, (ii) bridging geographical scales in data integration, (iii) data analysis, (iv) protocol alignment, and (v) helping volunteers understand how their contribution fits into the bigger picture. Scale also brings exciting opportunities; as the cost of sensors inevitably decreases, developing volunteer sensor networks will become more feasible, especially using the models of successful staged-growth initiatives such as CoCoRaHS[16]. Using citizen science to ground-reference remote sensing data is already beginning to develop, and existing volunteers can be mobilized to link additional data collection to ongoing activities and provide just-in-time support.

Participation and engagement

Citizen science support in indicators will bring a unique set of stakeholders to the table, and with them, opportunity for social progress in addition to scientific developments. Project organizers should seek innovative ways to communicate more effectively with volunteers, increase the range of participation opportunities, experiment with project designs that may appeal to new demographics, and engage volunteers in inquiry development. When project leaders embrace this complexity, volunteers can assist in volunteer management and training, leverage their existing social networks for project recruitment, and help take the message to their communities more effectively. In order to achieve most of these goals, however, supporting technologies need substantial improvement to encourage involvement from less technologically-literate potential participants.

[16] http://www.cocorahs.org/

An indicator system supports long-term eco-social-physical monitoring goals. Unfortunately, this time-scale is often mismatched with citizen science efforts, which already face challenges in keeping participant engagement beyond single events. Opportunities to encourage sustainable engagement would be to incorporate low-effort and low-cost monitoring, such as in the Christmas Bird Count.

Low Hanging Fruit

Low-hanging fruit for the development of indicators include capitalizing on existing health and economic indicators, and partnering with industry associations that maintain relevant monitoring systems. Many such indicators could be enhanced with self-report projects and coupled volunteer sensor networks.

Key Indicators

In the afternoon of the workshop's second day, a world café-style discussion was held around key indicators of physical climate changes, impacts and vulnerabilities, and responses[17]. Participants were encouraged to discuss indicator readiness both currently as well as what could be feasibly developed in the next 10 years, as well as existing citizen science data collection and analysis streams. A broader conversation was also held on new uses of citizen science, including opportunities to connect indicators and citizen science efforts across scales (e.g., local to regional) and how indicators and citizen science could be used to improve public understanding and engagement of climate change science.

Physical Climate Changes

Indicator readiness for physical climate changes was categorized around whether time and/or money was needed to expand upon or begin a project. The first category consists of indicators that are either ready today or have an existing program (Table 1). Among those identified are well-known and organized programs such as CoCoRaHS, National Phenology Network, and Audubon Society Christmas Bird Count.

Table 1. Extant programs for informing physical climate change indicators

Indicator	On-going Citizen Science Program
Precipitation	CoCoRaHS, GLOBE, WeatherBug, Cooperative Observer Program, mPing
Snow Cover	CoCoRaHS, GLOBE, Cooperative Observer Program
Air and Surface Temperature, Humidity	GLOBE, WeatherBug, Cooperative Observer Program
Soil Moisture	CoCoRaHS, GLOBE
Wind	WeatherBug
Water Body Temperature, pH, and salinity	National Water Research Program Multiple regional and local programs
Albedo	GLOBE

[17] A quick reference guide on the world café method can be found at http://www.theworldcafe.com/wp-content/uploads/2015/07/Cafe-To-Go-Revised.pdf

The next category consists of indicators that would require 5 years or less to develop or need financial support to expand. This subset includes indicators such as number of days above mean temperature, surface area of deforestation, stream flow, air temperature, and cloud cover/type. Trout Unlimited was highlighted as a program that monitors stream flow. However, it only operates in Pennsylvania and is primarily focused on the nexus between hydraulic fracturing and water quality. Still, there is an opportunity to mine data via citizen science funding into expanding this program. Another indicator from this second-tier of readiness was surface area deforestation, which could be used in ground-truthing data for REDD[18] initiatives or other programs. However, this would require more funding to improve coverage/data quality. Lastly, expanding upon NASA's SCOOL program[19] (Cloud type identification) would be a way to allow data mining of this information.

The last category consists of indicators that needed 10 or more years of development to reach completion and/or significant financial support. This subset includes surface water temps, tropical precipitation, and air pollutant concentrations (PM, NO_x, SO_x, and CO_2). Regarding surface water temperature, utilizing and expanding COADS[20] to an international level could be a possible option. The CoCoRaHS program could provide a framework for data mining tropical precipitation data at an international level. For pollutant concentrations, cutting-edge air monitors, which can be worn on an individual, could be utilized on a national or international level.

Impacts/vulnerabilities

A broad range of climate change impacts and vulnerability indicators were identified that could benefit from citizen science programs that only require modest investment (Table 2). Many of the identified sectors are congruent with USGCRP's Third National Climate Assessment[21], and also demonstrate alignment with the Societal Benefit Areas utilized for OSTP's National Plan for Civil Earth Observations.

There is high potential for citizen science to contribute to these programs. However, very few programs were identified as being "low hanging fruit"; health, infrastructure, and weather sectors were found to not have ready programs to inform impacts and vulnerabilities. The few that satisfy most of the requirements for ready integration are characterized by a number of shortcomings, including biases in geographical and temporal coverage and limitations posed by human subject research practices. The latter is especially relevant given the socio-economic nature of impacts and vulnerability indicators, which extend beyond the realm of biotic and abiotic variables that can be measured by instruments or trained personnel. To this point, social science research could be better utilized to design effective ways to collect socio-economic data with the help of citizen scientists. For example, partnering with the National Institutes for Environmental Health Sciences[22], which has decades of experience working with the topic, could be an excellent entry point into collecting this type of sensitive information.

A few programs would require more investment. At the mid-level of additional investment, CrowdHydrology could help inform flooding indicators and the Leaf Snap app could provide information for species migrations. At higher levels of investment, the GLOBE project could be utilized for monitoring water quality.

[18] http://redd.unfccc.int/
[19] https://scool.larc.nasa.gov/
[20] http://icoads.noaa.gov/
[21] http://nca2014.globalchange.gov/
[22] http://www.niehs.nih.gov/research/supported/dert/programs/peph/podcasts/air_quality/index.cfm

Table 2. Programs with modest investment to inform impact and vulnerability indicators

Sector	Sub-sector or Indicator	Program
Water	Drought	UNISDR
	Flooding	Census data, insurance
Ecosystems	Endangered species, habitat	Thriving Earth Exchange
	Invasive species	Garlic Mustard app, iSeeChange
	Species range and migrations	Hummingbirds at Home, Audubon Society Christmas Bird Count, USGS Breeding Bird Survey, eBird, iNaturalist
	Phenology	National Phenology Network, Project Budburst, GLOBE
Economic/Cultural	Recreation	Seasonality (snow, water temp., access) Adventurers and Scientist for Conservation
	Cultural heritage	Thriving Earth Exchange, BLM Site Stewards
	Fisheries	Fisherman reporting
Agriculture	Pollinators	Great Sunflower Project
	Growing season and yield	Maple Watch

Responses

Suggested response indicators fall into four broad categories: (i) recognition of climate change as an issue, (ii) incorporating climate change into individual and collective decision-making and policy, (iii) implementing adaptation or mitigation measures in response to climate change, and (iv) measuring resilience to climate change (Table 3). In comparison to physical climate change and impacts/vulnerabilities indicators, response indicators lack ready citizen science programs related to data collection. This is likely because information and activities related to responses are often costly. Citizen science could contribute to analysis and reporting of response data, especially now that free, open-source analytical platforms such as R or Python are widely available. However, such efforts might be constrained by limited access to response data.

Table 3. Response Indicators

Category	Indicator
Recognition	Media reports
Incorporation	Risk planning
	Insurance
	Real estate prices
	Voting behavior
Implementation	Transportation choices
	Energy efficiency choices
	Food purchases
	Infrastructure changes
Measuring resilience	Disaster impacts and recovery
	Social and environmental justice
	Domestic population changes
	Change in agricultural inputs

Conclusions

While there are many burgeoning areas of citizen science involvement in climate indicator development and assessment, much potential remains to be fulfilled. To prioritize efforts, citizen science programs could be categorized based on the resources needed and time required to develop a program to the point where its outputs can inform an indicator or could be used alongside existing national or regional indicators to provide additional local information. The "Tracking a Changing Climate: Citizen Science Contributions to the National Climate Assessment" roundtable has begun this process, but further input from the broader community will be required. In addition, efforts to link citizen science, remote sensing, observational networks, and indicators are already underway through Federal efforts like GLOBE.

Most examples of citizen science that require less effort to link to indicators tend to be related to distributed observations of weather events and species prevalence. Very little exists for response indicators and citizen science focused on data analysis. Addressing these two deficiencies together may prove fruitful because contributions to response indicators will likely come in the form of analysis. Some opportunities for broader participation in citizen science include bringing science into the classroom and connecting to science standards and a focus on inclusion and demographic, economic, and geographic diversity of contributors.

Furthermore, there is a demand for the development of generic citizen science infrastructure that can be instantiated for specific needs. Small-scale local projects often do not have the capacity to transform their data for input into a national system. Similarly, if citizen scientists were aware of data needs, they may be willing to adapt their protocols to make their data useful for national scale indicators. People are interested in local and regional indicators because they care about events at those scales, especially events that happen in their own backyards. The health and economic implications of such events provide the motivation to understand how livelihoods are impacted. They also provide the motivation to design and implement strategies that ameliorate the anticipated deleterious effects of such events.

Appendix A: Committee Members

Committee Chairs
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Emily Cloyd, U.S. Global Change Research Program

Steering Committee
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Elizabeth Tyson, Wilson Center
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Appendix B: Workshop Participants

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