THE POTENTIAL FOR CITIZEN-GENERATED DATA IN CHINA

By Angel Hsu, Amy Weinfurter, and Chendan Yan

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EXECUTIVE SUMMARY

This paper explores the potential for citizen-generated data to address traditionally intractable gaps in China's environmental monitoring. In China, recent announcements by the government have signaled a new opportunity to scope the potential for novel data approaches to help address data challenges. A suite of inventive and cutting-edge techniques, which we dub "third wave data," has the potential to engage new actors and audiences in environmental data collection, improve linkages between policy-making and monitoring, and facilitate collaboration across private and public sectors in China. Third wave data sources range from the use of satellite data to monitor forest loss, to the mobilization of citizens to track environmental pollution. In this paper, we focus specifically on citizen science, which engages individuals to participate and collaborate in scientific research and data collection. A citizen science approach combines the rigor of science-based methods with democratic principles that engage citizens in data collection and empowers them to participate in the decisions that affect their lives.[i, ii, iii]

Citizen scientists and the data they collect can enhance a government's capacity to track environmental challenges

and to implement policies that address them. In doing so, citizen scientists can address some of the underlying conditions of "information-poor" environments, including China. When aggregated, citizen-generated data can provide a powerful large-scale dataset to fill spatial and temporal gaps in the country's existing monitoring infrastructure. Citizen-generated data can often be deployed relatively rapidly and inexpensively, allowing it to track the impact of specific policy or technology interventions, or to inform behavior modification by providing real-time information on threats such as air pollution. Citizen engagement in data collection could also push governments towards greater transparency, or towards a more robust and transparent implementation of existing monitoring and regulatory strategies.

This paper explores surveys the challenges and opportunities in leveraging citizen science data to strengthen environmental monitoring, management, and communication, drawing on a range of global case studies. It also explores the unique questions and context facing efforts to implement citizen science initiatives in China. A review of existing citizen science initiatives in China, along with a survey of gaps in government data, highlights areas where initiatives might be especially impactful. The paper concludes with a discussion of several possible next steps and project partners for exploring and expanding the role of citizen-generated data in China.

CITIZEN-GENERATED DATA'S ROLE IN SUPPORTING ENVIRONMENTAL MANAGEMENT

While citizen-generated data has contributed to environmental management and research for much of recorded history, the past two decades have witnessed a massive expansion in the number of citizen science projects, and the accompanying scientific reports and articles resulting from this data.[iv] Citizen science, "a form of research collaboration involving members of the public in scientific research projects to address real-world problems,"[v] encompasses "thousands of research projects [...] engaging millions of individuals [...] in collecting categorizing, transcribing, or analyzing scientific data," often at scales or resolutions unattainable by individual researchers or research teams.[vi] Citizen science efforts often overlap with efforts to engage the public in a government's environmental management. Advances in technology and the expansion of Internet access have enabled citizen science efforts to draw on the capabilities of big data and to crowdsource at greater scales (see "Executive Summary - From Citizens to Satellites: Third-Wave Data Approaches in China," Box 1 and Figures 1 and 2 for a more detailed description of the landscape of third wave data).

These advances, however, do not resolve many of the questions around citizen science, and, in many instances, generate new challenges. In this section, we review and synthesize the data on the opportunities and challenges facing the use of citizen science to inform environmental management. We draw on several case studies to better understand the drivers of successful strategies, common pitfalls, and remaining questions facing the integration of citizen science into environmental data collection and communication.

Opportunities and Advantages of Citizen Science

Citizen science carries a number of advantages in helping to implement or supplement traditional forms of environmental monitoring and communication. As Figure 2 in "Executive Summary - From Citizens to Satellites: Third-Wave Data Approaches in China," demonstrates, citizen science can enhance the communication of environmental information; the identification and troubleshooting of pollution hot spots or environmental problems; facilitation or reliance on citizens' participation and engagement in environmental monitoring; ability of the activity to fill data gaps in existing environmental information; and public consultation (in which the project sponsor requests feedback or input from the public). Citizen science also involves some unique advantages and opportunities, relative to traditional data collection, and to other forms of third wave data. Drawing from multiple case studies and examples, citizen-generated can:

Help validate or complement government data. User-contributed data can ground-truth government or top-down collected data, potentially reducing uncertainty in official accounts and statistics.[vii] This process of ground-truthing data could help fine-tune existing data collection and analysis processes, increase public trust in official statistics, and create more comprehensive datasets across large geographies and limited budgets. A study of the value volunteers contributed through their participation in seven data processing projects found that their contributions generated

an average $222,068 for each project over the first 180 days of its launch.[viii] While the applicability of this study to other types of projects is likely limited, it nevertheless suggests the immense value that can be captured by crowd-sourcing.

Provide detail on pollution hot spots. Citizen-generated data can reveal more localized, detailed environmental information. In cities, for instance, exposure to air pollutants can vary widely, according to factors such as the proximity to traffic and buildings' boilers and furnaces. Gathering more information on pollution hotspots, through initiatives like the New York City Community Air Quality Survey, can help identify especially polluted areas, and inform additional monitoring and/or place-specific solutions, such as implementing stoplight and transportation policies that reduce idling, or pressuring buildings to use cleaner heating fuels.[ix]

Help assess temporary, emergency, or episodic conditions. Citizen-generated data can providing a greater level of data depth around short-term events; OpenStreetMap, for instance, mobilizes a global network of volunteers in response to natural disasters. After the 2015 earthquake in Nepal, volunteers drew on high-resolution satellite imagery to update the status of 13,199 miles of road and 110,681 buildings. The United Nations, Nepal Army and the Red Cross drew on this information to identify routes into villages devastated by the earthquake.[x] In addition to leveraging global resources to help address a crisis, citizen science can also support efforts on the ground, to establish baselines and develop methods for communicating risks and responses to flooding, oil spills, major storms, and other natural disasters.

Reveal insights on individual exposure. Portable, wearable monitoring devices and low-cost sensors are being designed to facilitate environmental data collection. San Francisco-based start-up TZOA, marketing itself as a 'wearable enviro-tracker' has developed a wearable air-pollution sensor that sends behavior recommendations, such as opening windows to increase ventilation, or choosing less polluted routes through neighborhoods, to users' smartphones.[xi] These types of wearable sensors can help individuals collect data to understand personal exposure to pollution, tailored to their particular lifestyles and activities. At scale, massive collection of individual exposure data can help fine-tune epidemiological exposure models and better predict what kinds of pollution exposure have the most deleterious health effects.

Demonstrate the need for policy interventions. Citizen science can be used to trigger more detailed investigations from official sources, to enforce existing regulations or to further demonstrate the need for new policy interventions. For instance, a citizen science project used balloon mapping to estimate the volume and weight of petroleum waste piles near Southeast Chicago neighborhoods.[xii,xiii] Their findings contributed to a larger community-led effort that ultimately led the city to adopt new regulations for the enclosure of these waste piles.[xiv] This application leverages the quick, responsive use of citizen science to trigger more detailed or official monitoring efforts.

Measure the failure or success of policy interventions. Citizen-generated data can provide detailed information about local pollution sources, measuring, for instance, the air pollution benefits that result from shutting a coal-fired power plant. The i-Tree app allows communities and researchers to produce detailed inventories of local urban canopies to calculate the dollar value that trees provide by reducing air pollution and sequestering carbon.[xv] These kinds of resources can help track the relative failure and success of individual policies to tackle green urban spaces, reduce air pollution and mitigate and adapt to climate change. Using a common tool to collect data can also enable policymakers to identify cross-cutting trends or factors in the implementation of different policies. Widespread use of iTree, for instance, is helping city managers determine the ecosystem services that different species provide best and to track gaps in the urban canopy.[xvi] Over time, this dataset could generate more detailed and targeted recommendations to inform municipalities' planting strategies.

Communicate environmental information or risks. Citizen science initiatives can help communicate environmental information and environmental risks. For instance, the Pigeon Air Patrol, which used lightweight monitoring devices to track exposure to air pollution in London, first through pigeons, and then through 100 city residents, raise awareness and provided additional data on exposure to air pollutants.[xvii]

Citizen-generated data and initiatives also face a number of potential obstacles in both gathering reliable information, and in effectively utilizing it:

The need for education and awareness-building. Frequently, citizens may not be equipped with the training to accurately collect and report data.[xviii] Different investigations of the accuracy of citizen science yield a range of results. Some studies have cited data fragmentation, data inaccuracy, and participants' lack of objectivity as threats to the integrity of citizen-generated data.[xix] An assessment of citizen's biodiversity monitoring across several tropical locations, on the other hand, suggests that appropriate protocols, training, and oversight can enable volunteers can collect data of quality equal to those collected by experts.[xx,xxi] Determining how to educate citizens about appropriate data collection is crucial to the value of citizen science data, especially when many initiatives draw on contributions from a wide range of locations and may have limited resources to support on-the-ground training or guidance. In addition to shaping the content and delivery of any necessary training, citizen science initiatives also often need to consider personal exposure levels and risks involved to volunteers in collecting data.

Facilitating and ensuring quality assurance and quality control. Given the challenges involved in promoting effective data collection, data review and QA/QC is crucial to maintaining confidence in citizen science results. With large datasets, for instance, outlier points may require diagnostic procedures to identify a cause for anomaly; determining who will carry these out, and how, will shape the data's reliability. Initiatives have sought to tackle this challenge in a number of ways, such as identifying facilitators that act as "team captains," reviewing and addressing anomalies for designated portions of the data, and attempting to collect enough data that individual errors are outweighed by other data points. Initiatives also seek to reduce errors through training programs and data collection protocols, and or by designing foolproof data collection strategies.[xxii]

The need to incentivize and sustain data collection to engage citizens in a meaningful way. Many existing citizen science projects have struggled with the challenge of sustaining volunteer engagement. A study of seven citizen projects on the Zooniverse platform, for instance, found that project contributions were driven by a small core group of volunteers; 10 percent of contributors supplied between 71 percent and 88 percent of all contributions across projects.[xxiii] This assessment also found that most volunteers do not return to a project for a second time -- the share of contributors who return spans 17 to 40 percent (with an average of 27 percent).[xxiv]

Strategies for engaging citizens vary. Some efforts, such as rapid biodiversity assessments or Mexico City's Mapatón, a short-term project designed to map informal bus routes, develop short-term initiatives that harness high levels of early enthusiasm. An assessment of three citizen science initiatives in the United States, Mexico, and Costa Rica found that initial engagement in citizen science projects is often driven by: personal interests, particularly the project's connection to a hobby, or the opportunity it offers to spend time with friends and family; self-promotion, such as knowledge gain or resume-building; self-efficacy, through the chance to be deeply involved in the project; and social responsibility (though this was only a driving motivator in Costa Rica).[xxv] More complex motivations drive sustained participation in a project. Relatively "flat" projects, which facilitate frequent interactions between scientists and volunteers, help to build trust. The creation of common goals, level of acknowledgement and attribution, opportunities for mentorship and education and outreach were also correlated with longer-term involvement.

Guiding citizens' data interpretation and linking it to behavior modification. Many citizen science initiatives struggle to support accurate data interpretation. Wearable or consumer air quality sensors, for instance, can lose accuracy over time, experiencing a phenomenon known as "sensor drift." They can also return high pollution readings due to transient sources of pollution, such as passing buses or cars. While it's important to note these sources of pollution, the air quality a biker may experience in close proximity to a car's tailpipe is not necessarily reflective of the air quality across an entire block.

Translating data into recommendations for behavior modification can also prove challenging. Understanding the error and uncertainty around data sources, and navigating the sheer size and diversity of many different sources of information can make it difficult for citizens to access and act on the data they help to collect.

Making sense of disparate data sources, methods, and parameters. Challenges in comparing and aggregating citizen

science data can limit these initiatives' ability to create a comprehensive picture of environmental management challenges. For instance, many air quality monitors collect slightly different parameters -- while TZOA's wearable device gathers information on PM_{10} and $PM_{2.5}$, AirVisual tracks levels of $PM_{2.5}$ and CO_2. Different sensor designs also means data collected through these, and other, air quality maps may be subject to different levels of uncertainty. Conversely, many different projects collect similar data in similar locations, but a lack of coordination generates many incomplete or "patchy" data sets, rather than a larger, more useful, composite one.[xxvi]

Compounding the comparability of information sources is the difficulty in collating all of key initiatives collecting the same or similar types of data. While some platforms gather existing citizen science initiatives,[xxvii] a number of researchers have cited the need for networks or frameworks that more actively engage and facilitate coordination between different initiatives.[xxvii] For instance, many biodiversity-focused platforms feed into the Global Biodiversity Information Index (GBIF), allowing initiatives to customize their data collection process while still feeding this information to one central source.

Applying citizen-generated data to decision-making and policy contexts. Making sense of disparate data sources, methods, and parameters contribute, in part, to the challenges of applying citizen-generated data to decision-making and policy contexts. Stringent quality assurance and control requirements that govern the use of official data often limit governments' ability to treat voluntarily-collected data in the same way. Disentangling limitations based on governments' ability to collect and analyze data and develop indicators from political reluctance to engage with this data can be difficult. In data-poor environments, there is also a risk of "overloading" governments with data they are not equipped to incorporate.[xxix] Building the coordination necessary to foster cooperation between citizens, non-governmental organizations, businesses, and local and national governments can be a difficult and time-intensive process. There is a need to identify ways to legitimize or establish the credibility of citizen science data in official policy-making channels, a task that becomes especially fraught in contexts where competing official capacities already exist.

Ensuring privacy and protection of personal data. Protecting personal data, while still fostering accountability, can be a difficult balancing act for citizen science initiatives. Privacy concerns are an especially important issue for initiatives that collect information from cell phones, where the user's identifying information or locations may be unknowingly disclosed. The use of big data can also identify and reveal trends about individual participants that may endanger their privacy. Target's use of consumers' purchasing data to predict pregnancies, for instance, risked the loss of its customers' trust despite the company's compliance with privacy protection laws.[xxx]

Initiatives seeking to protect data contributors' identities also grapple with the fact that such steps could also enable false data reporting, if devices end up in unqualified hands.[xxxi] Establishing protocols or guidelines that protect individual rights and privacy are crucial to maintaining participation in citizen science initiatives.

DATA AVAILABILITY AND PUBLIC ENGAGEMENT IN CHINA

Data Access and Accountability

Recent announcements by the Chinese government have created a new window of opportunity to engage citizens in environmental monitoring, management, and communication.[xxxii] A suite of new laws and guidelines has reinforced a commitment to enhance access to environmental data and respond to pollution. In April 2014, amendments to China's Environmental Protection Law mandated that government departments further strengthen data-release mechanisms, and introduced a new system for fining pollution violations.[xxxiii] The law also gave NGOs the ability "to take legal action against polluters on behalf of the public interest." [xxxiv]

Other regulations have also raised the stakes of environmental performance. In July 2014, a number of key agencies[xxxv] issued the Implementation Guidelines for Regulation of Economic Accountability Audit on Leading Officials of Party, Government and State-owned Enterprises. These guidelines include officials' performance on environmental protection, natural resource management and improvement of people's livelihood, along with the quality and sustainability of economic and social development, in audits of officials' performance.[xxxvi]

Strengthening Data Collection

The Chinese government has introduced a number of measures to strengthen pathways of environmental data collection. In July 2015, the Chinese General Office of the State Council issued the Scheme for Building Ecological Environment Monitoring Network, which aims to establish a unified nationwide ecological and environmental monitoring network by 2020, with a particular focus on strengthening air and water quality monitoring; to enhance the use of advanced monitoring technologies; and to support domestic monitoring instrument industries.[xxxvii]

The MEP has also approved a high-level plan for "Ecological Big Data Construction," which proposes a science-based policymaking approach that incorporates a big data application platforms, cloud storage and management for big environmental data, and high-level plans for big data. This type of platform could form an entry point for integrating citizen-generated data, "big" data and traditional forms of government data, and more closely identifying key information gaps citizen science could help to close.

Public Engagement and Participation

In addition to enhancing data availability and to strengthening its consequences, the government has also increased its engagement of the public in environmental monitoring, enforcement, and communication. The MEP's "Guidance Opinion on Promoting Public Participation in Environmental Protection" (Guidance Opinion), released in May 2014, encourages government agencies to ensure citizens have the information to hold polluters accountable, and urges departments to use online platforms and popular media to share monitoring results with the public. In July 2015, the MEP released Measures for Public Participation in Environmental Protection (Trial Version), which clarifies the rights and obligations of the public, developers, and environmental groups in the Environmental Impact Assessment (EIA) process, and identifies five specific vehicles for public participation: opinion surveys, consultations, seminars, debates, and hearings.[xxxviii] Pan Yue, the deputy secretary for the Communist Party within the MEP, has emphasized the Ministry's commitment to information transparency, underlined the need for the creation of Internet-based tools to enable information disclosure, and collaboration with the general public on pollution monitoring activities.[xxxix]

While these initiatives and legislation represent a significant step towards leveraging more advanced and powerful data to inform environmental management, their implementation has been uneven. For instance, approximately 156 Environmental Protection Bureaus (EPBs) have created Weibo accounts dedicated to handling environmental affairs, a strategy in line with MEP's 2014 Guidance Opinion. Seventy of these EPBs use their accounts to respond to environmental complaints and reports the public posts through Weibo. These accounts are primarily based in Shandong Province, Zhejiang Province, and Jiangsu Province.[xl] However, only 36 of these 156 accounts release environmental supervision information, and 27 accounts are updated so infrequently that they are considered "zombie Weibo accounts."[xli] Even within active accounts, the level and type of engagement vary. For instance, the Shandong, Shanghai, and Beijing Weibo accounts typically post announcements or news articles (see Figures 1 and 2), and do not interact with their subscribers very closely. The City of Qingdao's Weibo account, on the other hand, frequently engages directly with public questions or complaints (see Figure 3).

Figure 1. Screenshot of the Shandong provincial Weibo account. The figures highlighted in the red box track the number of followers, subscribers, and the account's Weibo posts (box and translations added by authors).

Figure 2. The Shandong provincial Weibo account provides public environmental information and updates. For instance, the account redirects users to an environmental petition platform[xlii] (above left) and smoke dust emission reporting platform[xliii] (above right).
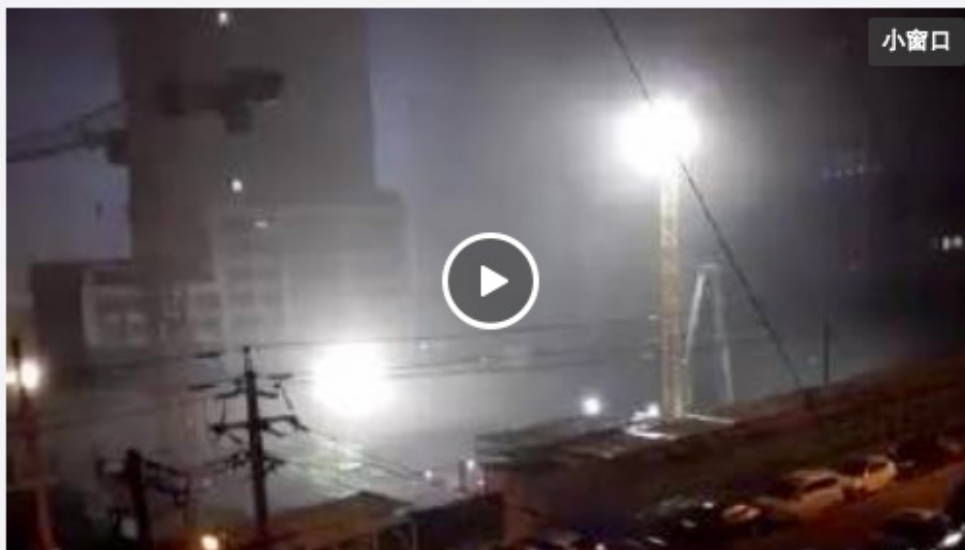
Figure 3. Screenshot of a Weibo interaction between a local resident, the Qingdao City Southern District's Weibo account, and the Qingdao Environmental Protection Bureau Weibo Account. A Weibo user posts a video and notes the location of a construction site still working at midnight. The post addresses the Qingdao EPB Weibo account in a humorous tone, calling the city's Weibo account "brother" and asking for help. The Qingdao City Southern District Weibo account forwards and re-posts the complaint first, and later reports that this construction site had been examined and approved. The Qingdao EPB Weibo account also forwarded and commented on the post, recommending the hotline 12345 as a resource for these types of complaints.

Outside of these accounts, some provinces and cities are helping to pioneer new strategies for public involvement. For instance, Hebei Province instituted the "Hebei Province Public Participation Regulations in Environmental Protection" in January 2015.[xliv] Hunan Province introduced public participation and consulted the public on the province's "Corporate Environmental Rating" assessment, and invited environmental organizations to participate in the oversight of the government's evaluation of companies' green credit scores.[xlv] Despite these examples, however, many local EPBs have yet to develop methods for communicating with or engaging the general public around environmental information disclosure.[xlvi]

Data Gaps

In addition to the uneven engagement of citizen input across different cities and provinces, the coverage of China's existing environmental data shifts across different sectors (see "Executive Summary - From Citizens to Satellites: Third-Wave Data Approaches in China," Table 1). Even when data is collected, efforts to analyze it more closely are often thwarted by the inability to access raw data, or by changes in methodologies over time and across different regions.[xlvii] Table 1 summarizes some of the key gaps in the existing data, and the potential application of citizen science.[xlviii]

As Table 1 of the "Executive Summary - From Citizens to Satellites: Third-Wave Data Approaches in China," notes, in many sectors—notably soil and climate change—the government is in the midst of introducing new modes of monitoring. These processes could draw lessons from existing methods for mobilizing public engagement, such as the EPB's strategies for enabling citizens to report suspected pollution violations though social media. There is also an opportunity for emerging environmental monitoring to incorporate existing citizen science efforts, using this information, for instance, to augment the scope and detail of biodiversity, air, and water quality datasets. Citizen science efforts can also help to shed light on and inform citizens' interactions with the environment in more targeted ways. For instance, social media platforms, mobile apps, and citizen science initiatives can provide tailored recommendations for limiting personal exposure to pollutants, based on water, soil, or air quality information. Mobile apps can aid and educate consumers as to how to identify and avoid purchasing threatened species. The exact use and integration of citizen science is likely to vary across sectors, scale of government, and regions of the country.

Existing Citizen Science Initiatives in China

A number of citizen science examples seek to fill current data gaps in China's environmental monitoring, or to improve the utility and transparency of existing data. Table 2 summarizes the characteristics of sample initiatives, which were chosen based on desk research and input from practitioners, researchers, and academics engaged in big and citizen-generated data during a March 1, 2016 workshop on Third-Wave Data for Environmental Policy in China.[xlix] Most initiatives focus on gathering information around water quality, air quality, or biodiversity. These projects demonstrate a range in their geographic focus and longevity; some projects, such as FLOAT Beijing, operate as temporary, proof-of-concept projects aimed at sparking longer-term discussions around environmental data. Others, particularly the Green Hunan Observation and Action Network and the Chinese Water School, build frameworks for durable regional monitoring networks. Several initiatives focus primarily on establishing national or international databases, to inform biodiversity management and protection (China Nature Watch Biodiversity Information Platform, Chinese Field Herbarium) or to enforce existing environmental regulations (The Public Participation Network of the Environmental Impact Assessment).

Information on these initiatives' approaches to quality assurance and quality control was scarce. Most initiatives that addressed this issue either focused on ensuring accurate data through careful training (i.e., the such of water testing kits in schools, or the use of online tutorials to guide air quality data collection) or encouraged citizens to flag issues for investigation and follow-up through established research or policy channels. Citizen science projects typically connect to public policy either by enabling or pressuring government agencies to further investigate citizen science claims. For instance, the forthcoming version of the Blue Map App will offer another venue, in addition to the existing WeChat platform, for citizens to flag polluted waters, as part of the MEP and Ministry of Housing and Urban-Rural Development's (MOHURD) Foul and Filthy Rivers Program.[l] The MEP has committed to responding to these notifications within seven days.

In contrast, The Public Participation Network of the Environmental Impact Assessment and the Green Hunan Observation and Action Network often work with media to pressure governments into enforcing or investigating pollution highlighted by their initiatives. In a 2012 interview, the Green Hunan Observation and Action Network noted the power of media in fostering public awareness and recruiting volunteers. They also used social media to help flag local pollution violations; a volunteer publication of a local company's illegal discharge into a river was re-tweeted 4,000 times on Weibo, contributing to intervention by the local EPB and an apology from the company chairman.[li] Incentives for participation are often tied to helping to ensure this kind of implementation, to secure public health, pave the way for ecotourism, or protect biodiversity. Some initiatives also build local and virtual communities—the Freshwater Watch website includes a public leaderboard recognizing active volunteers, and FLOAT Beijing recruited

many of its older volunteers by tapping into a strong communities built around a shared hobby of kite-building.[lii]

Key Questions for Citizen Science in China

Efforts to apply citizen science in a way that fits with China's political context and addresses its most pressing environmental data gaps will face a number of key questions:

1. ***How should competing data sources be reconciled and/or integrated?*** This question faces both (1) government agencies with overlapping missions, and (2) citizen science initiatives whose findings may challenge or diverge from official results. Clarifying the processes for evaluating the legitimacy of data, and for investigating and reconciling differences in information, will be crucial to building a more comprehensive and robust set of environmental data. Figure 4 in "Executive Summary - From Citizens to Satellites: Third-Wave Data Approaches in China," illustrates an example of a decision matrix that help policymakers determine when and how to use different sources of environmental data, highlights some of the criteria—such as data sensitivity, the urgency of data collection, and the ideal scale and resolution of the data—that policymakers may need to weigh in determining what kinds of monitoring strategies to employ.

2. ***How can citizen science initiatives with overlapping goals coordinate with each other to avoid further fragmenting environmental data and monitoring in China?*** The "central-local divide" between the central government and regional and provincial levels of government is one of the challenges facing environmental management and monitoring within the government. As citizen science initiatives continue to grow, finding ways to build complete and comprehensive datasets, while still enabling local projects to tailor initiatives to their surroundings, will be critical to preventing the additional fragmentation of environmental monitoring.

3. ***How will the credibility of citizen science be established, in regards to official policy-making channels?*** New data initiatives and collection modes will require a major shift in China's concentrated authority regarding "official" data. For instance, China's Statistics Law states that it is unlawful for any body, aside from those sanctioned by the government, to collect data.[liii] Will the government amend this regulation, decide to sanction key citizen science initiatives, or chose a different response or mix of responses? From the perspective of citizen science initiatives, which efforts are best suited to pressuring governments to investigate environmental challenges further, or to provide additional data, and which initiatives should be integrated into official channels? How can citizen science initiatives distinguish real data gaps from a political reluctance to monitor or share information?

Table 1. Comparison of China's citizen science initiatives. Initiatives were chosen based on desk research and on input from practitioners, researchers, and academics engaged in big and citizen-generated data during a March 1, 2016 workshop on Third-Wave Data for Environmental Policy in China.[liv]

Initiative	Description	Issue Areas	Developers	Data Submission	Quality Assurance/Quality Control Strategies	Participation	Data Application(s)	Incentives for Data Collection
Blue Map Mobile Map integration with Foul and Filthy Rivers Module	The Blue Map App provides data on air quality (including forecasting data), water quality, and pollution sources based on monitoring stations and historical data. The updated (3.0) version of the Blue Map App includes the following components to enhance citizen science: a sharing wall, that enables users to interact; modules for green choice to share information about brands' green supply chain management and promote consumers to make green purchasing decisions; and the eventual inclusion of foul & filthy river module (黑臭) that allows users to identify polluted rivers for further investigation by the Ministry of Environmental Protection (MEP).	Air Quality, Water quality	The Institute of Public and Environmental Affairs (IPE), in collaboration with China's Ministry of the Environment (MEP) and Ministry of Housing and Urban-Rural Development (MOHURD)	Photographs and descriptions of any waters participants believe should be designated as foul and filthy can be submitted via mobile app.	The Ministry of Environmental Proteciton guarantees that each report will receive an official response as to whether the river has been added to the list with seven business days (Process of verification unspecified).	Unknown. The current version of the Blue Map App has been downloaded by over 3 million users, suggesting a large potential user base. Outside of the app, citizens in more than 200 cities have added 2,000 rivers to the list. lv	MEP has opened a public account on We Chat where the public can submit photographs and descriptions of any waters they believe should be designated as foul and filthy. IPE's revised Blue Map app also includes a foul and filthy river module. The MEP informs citizens as to whether the river has been added to the list of Foul and Filthy Rivers.	Protection of local environment and environmental health (for citizens). Protection of reputation and avoidance of regulatory penalties and fines (companies). Enforcement of mandate (government agencies).
China Nature Watch Biodiversity Information Platform	Supports data collection around wildlife conservation, particularly in the western provinces of China.	Biodiversity	The Shan Shui Conservation Center	Species observations can be recorded via mobile app.	Unspecified. Aggregating dataset may reduce the impact of data errors.	Unspecified.	Fill data gaps in knolwedge of species distribution and location, to help inform research and management of biodiversity.	Personal interest and hobbies (i.e., bird-watching community). Creation of improved biodiversity database (NGOs and researchers).
Chinese Field Herbarium (中国公众科学项目平台)	A searchable online database that encourages naturalist enthusiasts to record observations of plants, and submit them the researchers, who then upload them to the Global Biodiversity Information Facility.	Biodiversity	Chinese Academy of Sciences	Online database.	Unspecified (though may occur as researchers upload information into the Global Biodiversity Information Facility).	13,318 registered users have uploaded over 7 million photos - 4 million of which have been tagged as accurate - as of June 2016.	Online search database with a virbant discussion forum and information exchange between users. Used mostly for research purposes. Submitted to researchers.	Personal interest and hobbies (i.e., site helps teach plant identification). Creation of improved biodiversity database (NGOs and researchers). Leaderboard on website recognizes those who contribute recent or high amount of data.
Sanjiangyuan Eco-system Monitoring (三江源)	Villagers collect data on water quality in their community, to improve the environment for activities such as tourism and agriculture.	Water Quality	Global Environment Institute	Unspecified.	Unspecified.	Ganda Village farmers will be piloting the project and other villages in the Sanjiangyuan area will follow.	Develop eco-system based economy in the region in partnership with local government and NGOs	Improving the environment for activities such as tourism and agriculture.
Freshwater Watch	Global project trains citizens in scientific field research, to investiagte the health of world's freshwater ecosystems.	Water Quality	Earthwatch Institute	Website or mobile app.	Citizen Science leaders help train and coordinate water testing.	Outreach programs target corporate partners, research institutions, schools, volunteers and members of the public. Globally, the program has collected 14,806 data points; in China, it has collected 1,640.	Combining locally-collected data with satellite data helps identify drivers and predict the future of the water body's condition. Information to help inform local policy decisions.	Protection of local environment and environmental health. Leaderboard on website notes those who contribute most data points.
FLOAT Beijing	A collaborative, short-term project to map Beijing air quality through the use of kites.	Air Quality	Xiaowei Wang (student at the Harvard Graduate School of Design) and Deren Guler (student at Carnegie Mellon University)	Online submission.	Four workshops with Beijing residents taught them how to build the sensors themselves. Online tutorials demonstrated how citizens could collect their own data and readings.	Unspecified.	Demonstrate and generate discussions about the need for accurate air quality data.	The focus on kite flying helped draw many of the projects' older participants, some of who were active kite hobbyists, into the project. Others joined to learn more about or help facilitate a discussion around local air pollution and public health.
The Public Participation Network of the Environmental Impact Assessment (EIA) (环评公众参与网)	This database platform gathers environmental impact assessment (EIA) data, promotes public participation in EIA processes, and inspects the illegal actions of EIA, in order to support the development of the EIA industry and lessen pollution risks. lvii	Water quality, Air Quality, Waste Management	Chongqing Liangjiang Voluntary Service Center	EIA Website.	EIA team investigates citizen concerns	Unspecified.	The center has professional staff, with backgrounds in the sciences and engineering, who work with various NGOs, government agencies, and private enterprises in implementing sustinable practices for various projects in the area.	Protection of local environmental and of local environmental health.

Table 1. Con't.

Initiative	Description	Issue Areas	Developers	Data Submission	Quality Assurance/Quality Control Strategies	Participation	Data Application(s)	Incentives for Data Collection
Green Hunan Observation and Action Network	This civil society organization focuses on basin-wide environmental issues in Hunan Province's Xiang River watershed. A network of volunteers collects data that Green Hunan uses to protect water resources, spur government responses to pollution, and raise awareness about pollution sources in partnership with the media.	Water Quality	Green Hunan	Online	Follow-up research and investigation by staff.	Over 60 frequent volunteers (also called Stewards of the Xiang Rivers) involved in the Network, who are from 23 local cities and counties by the river. Their professional backgrounds include industrial workers, farmers, students, professors and public officials. These volunteers support 63 on-site monitoring stations on six upper tributaries of the Xiang River and long-term monitoring on two heavy polluted areas in the Xiang River watershed.	Data is placed in database for long-term research and investigation, and the results of data analysis are published in public reports. Water quality monitoring data is also sent directly to the environmental protection bureau as evidence of pollution events. The organization also works with the media and with social media platforms to draw attention to and encourage the government to address sources of pollution.	Protection of local environmental and of local environmental health.
Chinese Water School/ Shangri-la Institute for Sustainable Communities	The initiative seeks to educate school students and engage communities throughout the Yangtze basin in ways that enable them to become active participants in sustainable water resource management, and to help restore the ecological integrity of the basin's rivers.	Water quality	Chinese NGO Shangri-la Institute for Sustainable Communities. Key partners of the programme include the National Centre for School Curriculum and Textbook Development: Ministry of Education of China (MOE-NCCT), UNESCO Beijing Office, and Education for a Sustainable China (the National ESD Association).	Unspecified.	Unspecified.	103 schools currently participate. The program reaches 3,000 teachers, 197,000 students and 300,000 community members across 12 provinces and 4 major river basins (Yangtze River basin; Pearl River; the Yarlung Tsampo River in Tibet and the Hai River at China's capital, Beijing) in China. Over 1,100 interactive and innovative water education activities have been carried out, involving a broad range of stakeholders with many activities winning awards at both national and provincial levels. Experiences from the project have been disseminated at a broader level with over 200 media outlets reporting on Waterschool activities.	The Ministry of Education in China administers volunteer certificates for children who participate in activities outside of their school.	Educational tool. Protection of local environment.

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[B] Towards the end of the project, the Chinese government asked FLOAT Beijing to make a choice: to either take down all of the data from their website, or be more broadly censored. The project decided to take down the data in order to ensure the tutorials remained accessible. Source: DataShift. n.d. FLOAT Beijing Citizen-Generated Data on Air Quality. Retrieved from: http://civicus.org/thedatashift/wp-content/uploads/2015/07/Float-Beijing-case-study.pdf.

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Table 2. Comparison of citizen science initiatives globally. Initiatives were chosen to include a representative range of initiatives that demonstrated varying degrees of integration with government efforts to collect, communicate and respond to environmental data. Source: Initiatives' websites (unless otherwise specified).

Initiative	Description	Issue Areas	Developers	Data Submission Process	Quality Assurance/ Quality Control Strategies	Participation	Data Access	Data Application(s)	Incentives for Data Collection
Project Repositories									
Public Lab	Organization that supports the use of inexpensive DIY techniques to investigate environmental concerns.	Air Quality, Water Quality, Biodiversity	Public Lab, variety of project partners (civil society and research organizations)	Varies by project.	Varies by project.	Over 22,000 Public Lab Kits, which support citizen air, water, home testing for formaldehyde, and aerial mapping, have been distributed since the organization's founding in 2010. Initiatives span 8 countries.	The science, technology and data in Public Lab are open source.	Many projects focus on demonstrating the need for additional information, monitoring, or enforcement.	Protection of local environment. Participation in community around environmental stewardship.
CitSci	A collaborative platform for citizen science. Provides tools for the research process, and enables participants to either join or to initiate projects focused on species observation or the environment. Aims to support citizen science needs, and to elevate the rigor of citizen science data, improving data standardization, interoperability, integration, accessibility, and dissemination.	Biodiversity	Natural Resources Ecology Lab (NREL) at Colorado State University, Citizen Science Central, DataONE	Website or mobile app.	Provides online tools for the research process, including: creating new projects, managing project members, building custom data sheets, analyzing collected data, and gathering participant feedback. Option for participating projects to allow open participation, or to approve membership.	Volunteer coordinators have started 326 active projects, with 2,445 members, that have contributed over 68,407 species observations and 144,470 site characteristics.	Publically available via website (with project approval).	Answer local, regional, and global questions, inform natural resource decisions, advance scientific understanding, and improve environmental education. Support projects' ability to ask questions, select methods, submit data, analyze data, and share results.	Dependent on project.
SciStarter	A platform for finding, joining, and contributing to formal and informal citizen science research projects and events.	Wide range of environmental issue areas	SciStarter, Arizona State University's Center for Engagement and Training	Website.	Varies by project.	Lists more than 1,600 formal and informal research projects and events. Supports over 65,000 volunteers.	Varies by project.	Support and grow participation in citizen science projects.	Matchmaking between projects and volunteers. Participation in larger community of volunteers and researchers.
Zooniverse	A platform that provides opportunities for people around the world to contribute to real discoveries in fields ranging from astronomy to zoology. Projects draw on crowdsourcing strategies to complete data analysis that would not be possible otherwise.	Biodiversity, Climate and Weather	Zooniverse	Website.	Varies by project. Volume of crowdsourcing participants may reduce impact of errors.	As of 14 February 2014, the Zooniverse community consisted of more than 1 million registered volunteers.	Varies by project.	Data used in a large number of published research papers, as well as several open source sets of analyzed data. In some cases, Zooniverse volunteers have made unexpected and scientifically significant discoveries.	Access to crowdsourcing capacity. Participation in larger community of volunteers and researchers.
Citizen Science Central	A searchable list of citizen science projects, with an aim to help projects connect, learn, and share ideas and	Biodiversity, Water Quality, Air Quality, Weather, Climate Change	Cornell Lab of Ornithology	Website.	Varies by project.	Project registry lists 179 projects.	Varies by project.	Varies by project.	Matchmaking between projects and volunteers.
Federal Crowdsourcing and Citizen Science Catalog (CitizenScience.Gov)	This website acts as a database for federal citizen science and crowdsourcing projects, and aims to improve cross-agency collaboration, reveal opportunities for new high-impact projects, and enable	Wide range of environmental issue areas	United States General Services Administration and the Commons Lab at the Woodrow Wilson International Center for Scholars	Website.	The site includes a toolkit to assist with designing and maintaining projects, and a gateway to a federal community of practice to share best practices.	Lists 301 projects across 25 agencies.	Publically available via website. The Commons Lab is developing a suite of APIs to support data access and sharing.	The database aims to improve cross-agency collaboration, reveal opportunities for new high-impact projects, and enable volunteers to find and join projects, to accelerate the use of crowdsourcing and	Matchmaking between projects and volunteers. Identifying opportunities for collaboration across agencies.
Atlas of Living Australia Citizen Science Central	A collaborative national project that aggregates biodiversity data from multiple sources and makes it available and usable online.	Biodiversity	National Research Infrastructure for Australia	Website.	Varies by project.	Contains more than 50 million occurrence records, based on specimens, field observations and surveys.	Via website.	Data informs biodiversity management and research efforts. Data is fed into Global Biodiversity Information Database.	Matchmaking between projects and volunteers. Improving the national biodiversity database.

Table 2. Con't.

Initiative	Description	Issue Areas	Developers	Data Submission Process	Quality Assurance/ Quality Control Strategies	Participation	Data Access	Data Application(s)	Incentives for Data Collection
Specific Initiatives									
eBird	eBird draws on the vast numbers of bird observations made each year by recreational and professional bird watchers to provides rich data sources for basic information on bird abundance and distribution at a variety of spatial and temporal scales.	Biodiversity	Cornell Lab of Ornithology, National Audubon Society, and other affiliates and sponsors.	Website or mobile app.	Automated data quality filters, developed by regional bird experts, review all submissions before they enter the database. Local experts review unusual records flagged by these filters. Peer-reviewed literature compares eBird data to other measures of species abundance and diversity.	As of June 17, 2016, 316,586 eBirders across every country in the world contributed a third of a billion bird sightings (333,333,333 sightings).	eBird data are stored in a secure facility and archived daily, and are accessible via the eBird website and other applications developed by the global biodiversity information community.	Data is used in scientific research and publications, and entered into the Global Biodiversity Information Facility. More research is needed to determine the dataset's managment applications and ability to be applied at smaller spatial scales.	Internet tools maintain personal bird records and enable users to visualize data. Interest in protecting biodiversity.
Open Street Map	OpenStreetMap is built by a community of mappers that contribute and maintain data about roads, trails, cafés, railway stations, and much more, all over the world.	Land Use, Urban	Operated by OpenStreetMap Foundation. Hosting supported by the UCL VR Centre, Imperial College London and Bytemark Hosting, and other partners.	Website.	Contributors use aerial imagery, GPS devices, and low-tech field maps to verify that OSM is accurate and up to date. Distirbutions of improved data must be done under the OpenStreetMap lisence (allowing others to access it).	Includes 2,197,057 participants.	Online OpenStreet-Map database.	Applications vary by project, but include disaster response and transportation and infrastructure analysis.	Collective improvement of mapping resources and information.
Air Quality Egg	The Air Quality Egg is a sensor system designed to allow anyone to collect very high resolution readings of NO2 and CO concentrations outside of their home.	Air quality	The Air Quality Egg is developed by a community effort, born out of groups from the Internet of Things Meetups in NYC and Amsterdam and New York City.	Indoor or outdoor sensor transmits data to a website.	Unspecified.	Unspecified.	Website.	Collection of air quality data.	Concern or interest in air quality (and its implications on health and environment).
Water Reporter	Mobile app and website that enables users to map their experiences on the world's rivers, lakes, and oceans, and help resolve water quality threats transparently, within a community of environmental professionals.	Water quality	Cheasapeake Commons, Waterkeepers Cheseapeake, Viable Industries	Mobile app or Water Reporter website.	Issues followed up on by 18 waterkeepers in Chesapeake Bay region.	Over 400 reports focused on the Chesapeake Bay watershed were submitted as of September 2015.[A]	Website. Community maps track photos and reports.	Data is publically preserved, to help the public, local watershed groups, and government agencies track and respond to incidences of water pollution.	Participating in community focused on water recreation. Protection of local environment.
Creek Watch	Mobile app that allows users to flag water pollution for additional investigation by local agencies and watershed groups.	Water quality	IBM Research - Almaden, California State Water Resources Control Board's Clean Water Team	Mobile app.	Data is shared with water control boards.	Unspecified.	Website.	Data is aggregated and shared, to help water control boards, watershed groups, agencies and scientists track pollution, manage water resources, and plan environmental programs.	Protection of local environment.
Mapatón CDMX (Mapathon, Mexico City)	Competition for citizens to use smart phones to map bus routes in Mexcio City, to solve the problem of Mexico City's lack of data on its bus system. At a hackathon will invite collaborators to use the data gathered in the competition to generate visualizations, maps and mobile apps.	Bus Routes	Government bodies, nonprofits, think tanks, engineering firms and consultancies (total of 34 people from 14 organizations) [B]	Mobile app.	Algorithms address challenges of crowdsourcing, by cleaning GPS data in real time, correcting place names, and detecting strange behaviors.[B]	Unspecified.	The collaborators expect to use the data to generate visualizations, maps and mobile apps.	Mexico City has one of the largest bus systems in the world - it's 15,00 routes account for 60 percent of the city's commutes, an estimated 14 million rides a day - but has no official route map. [B] [C] Data from the Mapaton, and a hackathon that follows the event, will aim to create visualizations, maps and mobile apps to make these routes more accessible.	The most active mappers win prizes and could earn up to 30,000 pesos in cash. Development of improved transit system.

Table 2. Con't.

Initiative	Description	Issue Areas	Developers	Data Submission Process	Quality Assurance/ Quality Control Strategies	Participation	Data Access	Data Application(s)	Incentives for Data Collection
Air Visual	Mobile app that provides forecast air quality and weather data for more than 5,000 cities around the world. The app can be used alone or synced with the AirVisual Node air quality monitor. The monitor compares indoor and outdoor air quality to suggest when to ventilate	Air quality	AirVisual	Mobile app, which can be used alone or can be synced with the AirVisual Node air quality monitor.	Unspecified.	Reports on air quality in 5,000 cities in more than 25 countries.	Website or mobile app.	A ranking of different cities' AQI levels, to potentially facilitate a race to the top. Air pollution forecasts and comparisons of indoor and outdoor air quality help guide individual exposure decisions.	Knowledge of current air quality and suggested behavior changes.
TZOA	TZOA uses internal sensors to measure your air quality, temperature, humidity, atmospheric pressure, ambient light and UV (sun) exposure all in one wearable device. Connecting a TZOA sensor to a smartphone makes it possible to receive recommendations based on the sensor's readings.	Air quality	TZOA, MistyWest	Air monitoring devices.	Crowdsourcing; unspecified.	Unspecified.	Purchase of a TZOA device includes unlimited access to personally-collected data and crowd sourced maps.	Guides individual expose decisions, through recommendations, such as opening windows for ventilation, choosing less polluted routes, and suggesting when to increase or decrease sun exposure. Creation of a crowdsourced map of real-time environmental data.	Knowledge of current air quality and suggested behavior changes. Collective improvement of local air quality knowledge and resources. Creation of real-time air pollution maps.
Speck	The Speck is an air quality sensor which detects fine particulate matter (PM2.5) in an indoor environment and informs users about changes and trends in particle concentration.	Air quality	Speck is a product of Airviz Inc., which is a spinoff from the CREATE Lab at the Carnegie Mellon University Robotics Institute. Speck is manufactured under license from Carnegie Mellon University.	Air monitoring devices.	Firmware or software updatescan be uploaded remotely to monitoring units via a Wi-Fi connection.	Unspecified.	Website (optional to share personal data).	Guide individual exposure decisions, through real-time information on indoor air quality. Collect data on exposure in specific regions; for instance, The Southwest Pennsylvania Environmental Health Project, which investigates the health effects associated with natural gas drilling, has deployed 115 Speck devices to investigate health complaints of residents near drilling sites. [D]	Knowledge of current air quality and suggested behavior changes. Collective improvement of local air quality knowledge and resources.
Pigeon Air Patrol	Initiative to use lightweight monitoring devices to track exposure to air pollution in London, first through pigeons, and then through 100 city residents, to raise awareness and provide additional data on exposure to air pollutants.	Air quality	Plume Labs, DigitasLBi, Imperial College in London	Wearable air monitoring devices. Twitter account takes request for locations of air quality readings.	Unspecified.	App currently covers New York City, San Fransisco, Los Angeles, London, Beijing and Mumbai.	Webiste and mobile app.	Behavior modification to avoid dangerous exposure to air pollution.	Information on real-time information on your exposure to air pollutants. Support of new ways to measure pollution. Creation of real-time air pollution maps.

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Table 2. Con't.

Initiative	Description	Issue Areas	Developers	Data Submission Process	Quality Assurance/ Quality Control Strategies	Participation	Data Access	Data Application(s)	Incentives for Data Collection
MyShake App	Mobile app for Android phones that harnesses personal/ private smartphone sensors to collect data and analyze earthquakes. The app has a long-term goal of eventually creating a worldwide seismic detection network that could warn users and facilitate the rapid analysis of earth-quakes' impacts.	Natural disasters	Berkeley Seismologi-cal Laboratory, University of California, Berkeley	Mobile app.	The application sends information back to a processing center where a network detection algorithm confirms that an earthquake is under way.	170,000 downloads of mobile app have occurred.	Unspecified.	Initiative aims to build a worldwide seismic network and use the data to reduce the impacts of earthquakes. MyShake could be used to enhance early earthquake warning systems in regions with traditional warning networks and could provide warning systems in regions that lack them. Recorded seismic waveforms could be used to deliver rapid information on the impact of the quakes.	Creation of an earth-quake early warning system to protect local and global communities.
i-Tree	This tool allows communities and researchers to produce detailed inventories of local urban canopies, and calculate the dollar value that planting trees provides by re-ducing air pollution and sequestering carbon.	Urban	United States Department of Agriculture Forest Service	Website or mobile app.	Project-specific; a suite of online guides and resources helps aid idenfication and troubleshoot quality assurance and con-tral questions.	Since its launch, thousands of com-munities, non-profit organizations, con-sultants, volunteers and students have used i-Tree to report on individual trees, parcels, neighbor-hoods, cities, and entire states.	Via website or mobile app	Using GIS and a complex set of algorithms, tool allows communities and researchers to produce detailed inventories of their urban canopies, and calculate their dollar value. Also supports canopy mangement (for instance, by tracking pests of disease, and identifying gaps in	Protection of local environment. Participation in community around environmental stewardship. Interest in the ecosystem services trees provide.
iNaturalist	A biodiversity data-base that functions as an online tool for crowdsourcing species identifica-tion, recording observations, and networking with others interested in biodiversity.	Biodiveristy	The iNaturalist Department of the California Academy of Sciences operates iNaturalist.org from the United States, the Comisión nacional para el conocimiento y uso de la biodiversidad operates NaturaLista in Mexico, the New Zealand Bio-diversity Recording Network operates NatureWatchNZ in New Zealand, the Canadian Wildlife Federation and Royal Ontario Museum operates iNaturalist Canada in Canada, and the Instituto Humboldt operates Naturalista in Colombia.	Website or mobile app.	Scientists and taxo-nomic experts can volunteer to support the" ID Please" sec-tion, searching for observations with-out identifications, or searching for ob-servations that still need to get down to species. Website includes biodiveristy guides for specific locations.	Lists over 2,500 spe-cific citizen science project sand over 1,000,000 biodiver-sity observations.	Website, open source software. Data also often ac-cessible via Creative Commons) and through the Global Biodiversity Informa-tion Facility.	Encourage personal engagement and awareness of biodiversity. Support global efforts to monitor biodiversity - for instance, the network supports many BioBlitzes, and licensed, research-grade observations data is entered into the Global Biodi-versity Information Facility.	Enables users to connect with other naturalists, and with experts who can identify the organ-isms they observe. Online tools help participants track and record their observations.
ThinkHazard!	Online disaster risk visualization tool that allows users to quickly find informa-tion on 8 different types of hazards in their search area. The tool generates a non-technical interpretation of the hazard environ-ment, to enable non-experts to determine the level of natural hazards in their locality and encourage greater incorporation of risk management into project planning and design.	Natural Disasters	Global Facility for Disaster Reduction and Recovery	Website.	Unspecified.	Unspecified.	Via website.	Empower users of non-technical backgrounds to build a better understand-ing of local risk. Support efforts of government agen-cies, multilateral organizations, the private sector, non-governmental organizations, research institu-tions, academia, community-based organizations in designing and imple-menting resilient projects.	Enhance local safety and protect investments in local infrastructure and development initiatives.

Table 2. Con't.

Initiative	Description	Issue Areas	Developers	Data Submission Process	Quality Assurance/ Quality Control Strategies	Participation	Data Access	Data Application(s)	Incentives for Data Collection
WildTrack	Process for using an automated footprint identification technique (FIT) to monitor endangered species.	Biodiveristy	WildTrack	Unspecified.	Unspecified	Unspecified	FIT database, once established, will provide a reference base of raw material (footprints) for the development of species-specific footprint algorithms for monitoring endangered and elusive species. The database would be developed as an open-access source, primarily for use by wildlife professionals and researchers, conservation and/ or environmental protection organisa-tions.	Provide lower-cost, less invasive method of tracking endan-gered species.	Improve biodiversity monitoring and protect high-risk species.
LeafSnap	Mobile app that acts as an automated field guide for plant identification, through photos of leaves.	Biodiveristy	Columbia University, University of Mary-land, Smithsonian Institution	Mobile app.	Recognition by app software.	Data set includes 7,719 images taken by mobile apps.	Via website.	Facilitating educa-tion about surround-ing biodiversity. Supporting research efforts around biodiversity.	Access to a more user-friendly field guide.
iSpot	A biodiversity data-base that combines learning technology with crowdsourcing, allowing participants to upload, share, and discuss their biodiversity observa-tions, and to help identify species across the database. Aims to build a social network that con-nects beginers and experts in species identifcation, across geographic and social barriers.	Biodiveristy	The Open University, The OpenScience Laboratory	Website.	Uses a 9-dimension-al reputation system to motivate and reward participants and to verify users' expertise. Taxon-specific reputation points are earned when a participant proposes an identifi-cation that achieves agreement from other participants, weighted by the agreers' own reputa-tion scores for the taxon.	From its launch through mid-2014, iSpot crowdsourced the identification of 30,000 taxa in more than 390,000 observations, with a global commu-nity numbering over 42,000 registered participants. As of May 2015, the platform has over 50,000 registered users and almost a million photographs associated with over 500,000 wildlife observations.	Via website.	Faciliate education around biodiversity, and foster accurate species identifica-tion skills that are fundamental to biodiversity science, but often neglected in formal education.	Connections with other citizen scien-tists. Improvement of species identifica-tion skills.
Treezilla	An initiative that aims to map every tree in Britan, to create a data-rich platform on which a wide range of citizen science investiga-tions can be built. Once the trees in a particular area have been recorded and measured, Treezilla will provide an esti-mate of the various services that the trees provide, such as carbon dioxide storage and water conservation.	Biodiveristy	The Open University, The OpenScience Laboratory	Website or mobile app.	Online resources and crowdsourcing support tree and pest identification.	Unspecified.	Via website.	Support research efforts around biodiversity, especially around the epidemiology of new and emerging tree diseases, evalu-ation of ecosystem services provided by trees, effects of climate change on tree growth and condition and macroecology. Support biodiversity education and citizenship.	Investment and interest in biodiver-sity. Desire to track and help prevent diseases that cause tree mortality. Interest in the eco-system services trees provide.
OpenTreeMap	A collaborative platform for crowdsourced tree inventory, ecosystem services calculations, urban forestry analy-sis, and community engagement. Org-naizations customize softward to specific projects or goals.	Biodiveristy	Azavea	Website or mobile app.	Unspecified.	Over 56,000 trees counted, and 9 million total benfits calculated.	Via website.	Facilitate public engagement, such as community planting events, educational outreach, tracking of stewardship activities, and other neighborhood initia-tives. Support educa-tion around tree ID and environmental stewardship.	Protection of local environment. Participation in community around environmental stewardship.

Table 2. Con't.

Initiative	Description	Issue Areas	Developers	Data Submission Process	Quality Assurance/ Quality Control Strategies	Participation	Data Access	Data Application(s)	Incentives for Data Collection
CitiSense	CITI-SENSE aims to develop "citizens' observatories" to empower citizens to contribute to and participate in environmental governance, to enable them to support and influence community and societal priorities and associated decision making. CITI-SENSE develops, tests, demonstrates and validates a community-based environmental monitoring and information system using innovative and novel Earth Observation applications.	Air Quality, Noise and Development of Public Spaces	Consortium of 29 partner institutions, including universities, research institutions, and businesses. Case studies developed in collaboration with local citizens' groups and decision makers.	A mix of wearable and mobile sensors, connected with mobile phones or other devices, gathers data that is uploaded via website or mobile app.	Unspecified, and likely to vary by indicator and technology.	9 participating cities in the EU (Barcelona, Belgrade, Edinburgh, Haifa, Ljubljana, Ostrava, Oslo, Vienna and Vitoria).	Via website.	Raise environmental awareness in citizens. Increase user participation in societal environmental decisions and provide feedback on the impact that citizens had in decisions.	Increase knowledge of exposure to environmental pollutants. Improve local air quality through greater engagement in policy decisions.
USA National Phenology Network	A national, online program where amateur and professional naturalists regularly record observations of plants and animals to generate long-term data sets used for scientific discovery and decision-making, particularly around understanding the impacts of climate change on plants and animals.	Biodiviersity, Climate Change	U.S. Geological Survey, U.S. Fish & Wildlife Service, National Park Service, The University of Arizona, National Science Foundation	Website or mobile app.	Online guides and resources.	Approximately 1,260,000 observations as of July 2016.	Via website.	Support of phenology research, which can help predict the timing of environmental threats such as wildfires, drought or flooding, and guide the timing of natural resource managment, such as when to harvest or irrigate land or conduct controlled burns in forests.	Support research efforts. Gain knowledge about local environment. Connection to local community organization or NGO using platform for an event or initiative.
FloodCrowd	Floodcrowd aims to draw on citizen science to better understand patterns of flooding in the UK.	Natural Disasters	Loughborough University (PhD research project)	Website.	Unspecified.	Unspecified.	Via website.	Identify previously unreported floods, to inform flood risk management.	Supporting improved flood risk management.
Tomnod	Tomnod is a team of volunteers who identify important objects and interesting places in satellite images. Initiatives and researchers use Tomnod to solve real-world problems	Application-dependent	DigitalGlobe	Website.	Uses tools that rely on large-scale participation to filter out errors.	The current 2 campaigns include 1,658 participants, who have completed 289,284 tagging tasks. 3 prior campaigns completed 1,066,002 tagging tasks.	Unspecified.	Fill in gaps in existing maps. Specific application varies by project, but often used to support responses to natural disasters.	Supporting responses to disaster management. Access to and experience working with satelitte imagery.

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