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Citizen Science

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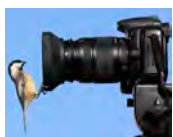
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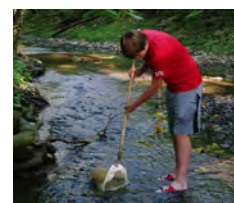
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Citizen Science

Russ Barnett
Director, Kentucky Institute
for the Environment and
Sustainable Development

Citizen science over the past decade has grown exponentially and has become a tool for researchers whose studies require large amounts of data, data collection over large geographic areas, data that needs to be interpreted and formatted to allow study, or where monitoring and data collection costs are beyond available financial resources. The term ‘citizen science’ refers to public participation in organized research efforts around scientific topics. Individuals participating in citizen science are not necessarily trained in the sciences. Acronyms for citizen science include “crowdsourced science,” “open science,” “volunteer monitoring,” “grassroots,” or “lay science.” The key characteristic that defines citizen science is that it be based and guided by scientific research principles. The concept is simple: use the power of many to gather data on a scale that no single scientist could gather in a lifetime. A citizen science project can involve a few or millions of people collaborating towards a common goal. In a typical project, a research question is identified, methods of data collection determined, volunteers sign up to collect data, volunteers may receive some training, data is collected, and then the data is analyzed by scientists and the participants themselves. This contributory model has citizens collect and submit data under the guidance of a science researcher or advisory group.

The environmental/sustainability fields that citizen science advances are diverse: ecology, biology, hydrology and water quality, astronomy, public health, computer science, statistics, geography, meteorology, engineering and many more. There are almost 1000 projects listed within the ‘Zooniverse’, the home of Citizen Science on the web. *Scientific American* magazine lists over 200 citizen scientist programs (www.scientificamerican.com/citizen-science), www.SciStarter.com, catalogs over 600 citizen science projects, but there are more likely thousands of citizen science programs and studies going on nationally.

The scope of topics being addressed by citizen scientists is boundless, but generally fall into a few categories: monitoring, inventory, assessment, discovery, trend analysis, mapping and interpretation. Table 1 provides examples of existing citizen science projects currently underway. Monitoring the environment

includes measuring the quality of air, water, soil, biodiversity, and habitats. Long a public agency responsibility, with budget stagnation and cuts, the ability to measure the quality of our environment is limited by a shrinking number of monitors who can be supported. Citizen science has been successfully implemented to conduct inventories of flora and fauna to allow scientists and land managers to understand the geographic scope and populations of specific species. Since 1980, amphibians have dramatically declined in populations with 32% of the world’s amphibian species now classified as threatened. Habitat loss, climate change, pollution, introduced species, destruction of the ozone layer all may have contributed. Citizen scientists conducting inventories provide a way to understand the status of amphibians and what can be done to protect them. Nationwide FrogWatch programs exist in the US and Canada where citizen scientists are reporting observations of frogs. Assessments are the evaluation or estimation of the nature, quality, or ability of something to survive. Season Spotter is asking volunteers to help identify changes in plants, shrubs, and trees over the seasons, to better understand and assess the impact of climate change on vegetation. Citizen scientists are working to discover new celestial objects. Citizen science, by monitoring, inventorying, assessing and discovering, can begin to measure trends and changes in the environment. In many ways, measuring trends may be one of the most valuable outcomes of citizen science. With a wide variety of participants with diverse skills, citizen science projects are able to map and interpret data being collected in ways to best communicate issues of concern, the significance of the problem, and optimal solutions.

The size of citizen science projects may range from one person to millions of people. In the winter of 1881-82, Wells Cooke, a member of the American Ornithologists’ Union, asked for bird watchers in Iowa to send him lists of winter bird residents and the dates of the first arrivals of spring migrants. The data collected from this citizen science effort led to a long-term study of bird migration in the Mississippi River corridor. The project was started through the efforts of one person. With more inclusive communication systems and ability to store and analyze



Table 1. Examples of Citizen Science Topics

Topic	Action	Examples
Environmental Quality	Monitoring	Water, air, soil quality, habitat assessment, biological assessment, air visibility
Fauna Atlas	Inventory	Birds, bats, butterflies, fire flies, horseshoe crabs, scallops, roadkill, seals, bees, whale sharks, frogs, turtles, loons, cicada, amphibians
Flora Atlas	Inventory	Trees, heritage trees, sunflowers, wild flowers, algal blooms, kelp forests,
Invasive Species	Tracking	Emerald ash borer, garlic mustard, mitten crab, Asian carp
Public Health	Assessment	Beach monitoring, flu survey, sleep patterns, light pollution, genetics, microbial diversity, mapping defibrillators, dental health
Astrometry	Discovery	Stars and galaxy, planets, comet tracking
Climate Change	Monitoring	Season spotters, cloud observations, changes in orchids, snow depth, orchid range, site location of power plants
Meteorology	Monitoring	Weather, precipitation, hurricane/tornado, dark skies
Large Data Bases	Interpretation	Response to climate change, scanning texts, transcribing historic texts, recording historic weather observations

large volumes of data, projects today can include millions of participants. There are citizen science projects that involve entire cities, states, nations and some are even global in scope. Since 1900, the National Audubon Society has conducted Christmas Bird Counts throughout the Western Hemisphere (South and Central America, Canada, Caribbean). Over 70,000 citizens participate in this program between December 14 and January 5 each year. In the 2014-15 count, almost 69 million birds were counted. The strength of citizen science is in the fact that large numbers of participants can be channeled to address a scientific question.

The geographic scope of citizen science projects can range from a small tract of land to the universe. Bioblitz is an intense period (usually 24 hours) of biological surveying in an attempt to record all the living species within a designated area. The primary goal of a bioblitz is to get an overall count of the plants, animals, fungi, and other organisms that live in a place. Citizen scientists and scientific experts are used in conducting a bioblitz. The concept was developed by the US National Park Service and has been adopted and supported by the National Geographic Society. The University of Connecticut, Storrs Campus, conducted a bioblitz July 24-25, 2015. Over the 24 hours of the effort, 400 citizen scientists and a cadre of scientists collected and identified 1,181 species and an estimated 7,000+ different bacteria and prokaryotes. This effort illustrates the value of citizen science. Without 400 citizen scientists, a biological inventory using faculty and graduate students would have taken years and would have cost hundreds of thousands of dollars.

A number of different factors support the expansion of citizen science projects. Foremost is the expansion of internet access. Internet access in 2015 is over 3.2 billion worldwide. In 2013, 83.8 percent of U.S. households reported computer ownership,

with 78.5 percent of all households having a desktop or laptop computer, and 63.6 percent having a handheld computer. The US Census Bureau in 2013, documented that 74.4 percent of all households reported Internet use. The Internet provides a low-cost means of recruiting, sharing and contributing information, and disseminating research results. Following a similar trajectory is the growth in mobile phone access. As of 2013, a majority of American adults (56%) own smartphones, 35% have mobile phones that aren't smartphones, leaving 9% owning no mobile phone at all. The widespread use of smartphones also means citizens have cameras, GPS, and access to the Internet. The average mobile phone user spends approximately 30 hours per month accessing 25 or more Apps. The popularity of citizen science is pushing the commercial development of Apps that are allowing smartphone owners to access Apps to measure noise and light pollution, air pollutants, water pollutants, air pressure, altitude, radiation, temperature and relative humidity.

Citizen science can involve large data sets, which in the past would have created a barrier to scientists interested in storing and analyzing huge amounts of information. Technological advances in chip development has increased processing capabilities. In 2000, Intel reached a milestone by producing a 1 Ghz chip, i.e. a chip capable of 1 billion cycles per second. Since then chip processing capabilities have increased 2 to 3 fold. Storage costs have dropped to a few cents per gigabyte of data (one billion bytes, each byte consisting of 8 bits), and cloud storage promises to provide "unlimited storage". The commercial market is providing citizen scientists with specialized cameras (Go Pro, UV, motion detector triggers), 3D printers, parabolic microphones, low cost air and water monitors, hand held meteorological equipment, and improved astronomy equipment. The improvements and lowered costs make it easier for individuals to be as well-equipped as environmental scientists.



As citizen science projects grow in number, there are new programs to assist in their success. SciStarted.com and other web sites list the various projects that provide a one-stop source of information about opportunities. They act not only as an information source, but a recruiter for the projects. SciStarter has developed a class to train individuals on how to be citizen scientists. The website <http://publiclab.org/> is an open network source of information sharing ideas on how to use inexpensive, do-it-yourself, low cost solutions for monitoring air, water and land. Zooniverse provides a web platform for citizen scientists to share ideas and to crowd source comments and reviews (see <https://www.zooniverse.org/>). A blog for citizen scientists is available at <http://blogs.plos.org/citizensci/>. Citizen science is now being taught at academic institutions including Arizona State University. Oregon State University is recruiting citizen scientists to work with faculty on research projects. Cornell University has created a Citizen Science Research Lab that conducts research on the effectiveness and organization needs of citizen science projects.

A common concern with citizen science is the fact that it is being conducted by lay persons without formal training. This is particularly true in those citizen science projects involving monitoring. Concerns about the accuracy of equipment being used to conduct the monitoring, the technical abilities of the citizen scientist being “inferior” to a formally trained scientist, and whether approved protocols are followed are typical concerns. The Kentucky Watershed Watch program is a citizen science program monitoring water quality throughout the state and receives technical support from the state environmental protection agency. Even though it has been working in the Commonwealth over a decade, these concerns are still expressed by the agency and the data collected is used only to help identify future stream monitoring studies required under the Clean Water Act.

Initially citizen scientists were recruited from individuals who as a hobby were birdwatching, fishing, weather watching, hiking, mountain climbing, or other amateur groups. In many cases these were the experts in their area of interest. Citizen science programs now typically take any individual who expresses an interest in participating, but will conduct training to help assure that there is a minimum level of knowledge of each volunteer. The Kentucky Watershed Watch program, for example, conducts a one to two day training program for all volunteers to certify their readiness to be a volunteer. They require each volunteer to take a refresher course every four years, and have recently developed a “graduate” course for those volunteers who want to learn more about monitoring water quality. Instruction manuals are provided electronically to each volunteer on sampling protocols and how to interpret sampling results. Some citizen science programs that are conducting inventories or simple assessments may not need formal training or minimal training on how to identify what is being inventoried.

Concerns over the accuracy of equipment used in monitoring is a concern shared by citizen scientists. Quality assurance/quality control measures are those activities one undertakes to demonstrate the accuracy (how close to the real result one is) and precision (how reproducible the results are) of one’s monitoring. Citizen science groups conducting monitoring activities can only work to strengthen their QA/QC measures. This includes the development of written protocols that are rigorously followed.

Citizen science provides an opportunity to conduct inventories and assessments of our environment at scales that are not realistically achievable by academic and public officials. Budget limitations have resulted in scaled-back environmental monitoring. Monitoring is typically conducted only at a few locations. Environmental conditions are dynamic, with diurnal changes, season changes, and vagaries in meteorological conditions. Increasing citizen monitoring and assessment will help scientists to better understand the nature of the environment by filling in data gaps.

In the past, collecting large samples of data for research was a challenging and expensive task of any research project. In today’s interconnected world, thousands of people from around the globe can remotely contribute to a study and provide, analyze, or report data that researchers can use. Public participation enables investigations that would not otherwise be possible, including ones that push new frontiers in our understanding of our world. The future of citizen science appears bright. The number of inquisitive individuals concerned about the environment and wanting to do more than donate money to environmental groups or talk about protecting the environment, guarantee that citizen science will play an increasing role in our understanding of our environment.



Water Quality Sampling Yields Powerful Data and Inspires Action

John Lipscomb, Riverkeeper Patrol Boat Captain
Dan Shapley, Riverkeeper Water Quality Program Manager

Filling a bottle with 100 milliliters of water is an act as small and powerful as casting a ballot. That's what teams of citizens in New York are finding each time they go out to capture just a bit more information to further the goal of cleaner water.

Riverkeeper's water quality monitoring program has grown to include both samples taken by our own boat patrol along the Hudson River and those taken by community scientists along New York City's waterfront and Hudson Valley streams. The effort, which began in 2008, generates a trove of data, posted and updated monthly on our website, www.riverkeeper.org. Swimmers and kayakers use the information regularly to make educated choices about where and when to enter the water. Community groups and municipalities use the test results to identify problems and solutions for the health of their waterways.

And there is a larger goal, too. As people grow more engaged and better informed about water quality as it affects humans, they will become more engaged in other issues in the river that need humans' attention: pharmaceutical and industrial pollution, habitat degradation – problems that affect habitat in this giant living organism called the Hudson River.

Riverkeeper samples for fecal contamination using *Enterococcus* (Enteroc), the only Environmental Protection Agency (EPA)-recommended indicator for use in both fresh and salt waters.¹ The EPA has estimated that as many as 3.5 million Americans are sickened each year from contact with recreational water,² primarily due to pathogens associated with sewage and other fecal contamination. While Enteroc is not usually harmful in itself, it indicates that disease-causing pathogens associated with fecal contamination are likely to be present.

Since 2008, in collaboration with our science partners at CUNY Queens College and Columbia University's Lamont-Doherty Earth Observatory, Riverkeeper has sampled 74 locations on 150 miles of the Hudson River Estuary³ between New York Harbor and Waterford, monthly from May to October. The samples were processed using an IDEXX EnteroAlert⁴ system aboard the Riverkeeper patrol boat, the *R. Ian Fletcher*. Our water quality study also measures salinity, oxygen, temperature, turbidity and chlorophyll using a Hydrolab DS5 data sonde.

Building on this core study, Riverkeeper works with a variety of community groups and individuals⁵ to sample Enteroc, as of 2015, at nearly 300 sample points. Project areas in 2015 include approximately 50 miles of New York City waterfront, the Ossining waterfront, and more than 500 miles in nine tributary creeks and rivers⁶. Samples taken by community scientists are processed in Riverkeeper's lab, commercial labs, or labs managed by the River Project, O'Mullan lab/CUNY Queens College, McGillis Lab/Columbia Earth Institute, Durand lab/LaGuardia Community College, the Bronx River Alliance and the Center for the Urban River.

These surveys are the most extensive assessment of recreational water quality in the region.

Riverkeeper's sampling protocols in the Hudson River Estuary and its tributaries are consistent with Quality Assurance Project Plans⁷ approved for the 2014 sampling season by the New England Interstate Water Pollution Control Commission.

Riverkeeper bases assessments of water quality on the EPA's science-based 2012 Recreational Water Quality Criteria,⁸ which defines recommended concentrations of Enteroc per 100



ml of water (“Enteroc count”) consistent with “primary contact recreation,” which includes swimming, bathing, surfing, water skiing, tubing, skin diving, water play by children and other activities where ingestion of water is likely.⁹ The EPA guidelines used here are designed to prevent more than 32 illnesses per 1,000 people,¹⁰ and are protective regardless of whether the fecal contamination source is primarily human or animal.¹¹ They are recommended for use in any waters designated for primary contact recreation, even if there are no designated public beaches.¹²

In 2014, nearly 6,500 people swam in organized public swim events in the Hudson River Estuary and New York Harbor,¹³ and thousands more swam at public beaches or other water access points.¹⁴

While the people of the Hudson Valley have made much progress toward achieving the Clean Water Act goal of making the watershed safe for swimming, we are failing to adequately protect these waters—the public’s beach. There is a documented immediate need for more than 315 Hudson Valley and New York City wastewater projects, at a cost of \$5.9 billion¹⁵ and in 2008, the Department of Environmental Conservation (DEC) estimated the 20-year need for public wastewater infrastructure investment at \$36 billion. The total today is presumed higher.¹⁶

This sampling project demonstrates the cost of failing to make those investments, and of failing to adequately enforce the Clean Water Act, particularly in the tributaries of the Hudson. Based on more than 6,000 water samples collected through 2014 in the Hudson River estuary and its tributaries, as measured against the Environmental Protection Agency’s recommended Beach Action Value (BAV)¹⁷ for safe swimming:

- 23% of Hudson River estuary samples fail.
- 72% of Hudson River tributary samples fail.
- 48% of New York City water access points fail.

After periods of dry weather, the Hudson River Estuary is safe for swimming in many locations. But after rain, the water is more likely to be contaminated, and to a higher degree, especially in areas affected by combined sewer overflows and streetwater runoff.¹⁸ The BAV failure rate in the Hudson River Estuary, based on more than 3,100 samples in the core Riverkeeper study, increases from 12% in samples taken after dry weather to 35% after rain, defined by ¼ inch, cumulative, over three days prior to sampling.

Rain also dramatically increases the frequency of fecal contamination in the tributaries. In the Hudson River Estuary, the overall BAV failure rate is 18% at both mid-channel and near-shore sample sites, but 36% in tidal tributaries. In tidal tributaries, the failure rate increases from 17% for dry weather samples to 57% for wet. The failure rate in non-tidal portions of tributaries sampled to date varies, but all tributaries sampled through 2014

show higher frequency and degree of contamination than the Hudson River Estuary. Rain also increases contamination in the non-tidal portions of tributaries, with the BAV failure rate increasing from 59% to 85%.

The sources of this contamination are likely complex, which points to the steep challenge of achieving improvements in water quality. Sources are known or suspected to include—each to an unknown degree—nearly 1,000 permitted wastewater discharge outfalls, thousands of streetwater outfalls, hundreds of thousands of septic systems, thousands of farms and countless wild animals. There are also potential non-fecal sources of *Enterococcus* to consider. Presumed sources of fecal contamination in the Hudson River Estuary and Watershed are presumed to include:

Combined Sewer Overflows: Combined sewers carry both sewage and streetwater in the same pipes, and when rain or snowmelt overwhelms wastewater treatment plant or pipe capacity, untreated sewage and streetwater will overflow into waterways. In the Hudson River Watershed, including the Mohawk, East and Harlem rivers, there are more than 660 Combined Sewer Overflow (CSO) outfalls. To reduce these discharges, CSO Long Term Control Plans are being implemented under the Clean Water Act over the next decade or more in the Capital District, New York City and several other river cities.

Sewage Infrastructure Failures: There are over 190 publicly owned systems that collect and treat sewage in the Hudson River Estuary watershed (and more in the Upper Hudson and Mohawk watersheds). Well-run plants with sufficient capacity and good collection systems effectively treat sewage. But most were built decades ago, and today rely on aging, leaking pipes. In some cases these systems fail to treat all sewage. Overflows from sewer systems can be triggered by bypasses of treatment processes to alleviate streetwater inflow and infiltration, as well as pipe breaks and blockages. Further, some treatment plants are held to inadequate monitoring requirements, requiring only one sample of effluent per month to demonstrate compliance with pollution limits. At least 29 of these wastewater treatment plants have had effluent violations within the past three years.¹⁹ In addition to municipally owned plants, 850 other permits allow discharges of sewage or other wastewater into the Hudson River Estuary watershed from private, commercial or institutional facilities. More than 50 of these private, commercial or institutional facilities have had effluent violations in the past three years.²⁰ Hundreds of the plants designed to treat sewage do not disinfect effluent before discharge, allowing the ongoing discharge of potentially harmful microbes. Effluent violations are typically identified only if self-reported by a facility. More than 175 facilities in the Hudson River Estuary watershed violated reporting requirements in the last three years.²¹ (EN-15) Each year only a fraction of these permits are reviewed or facilities inspected.²²

Urban Stormwater Runoff: Other studies have documented extremely high levels of fecal indicating bacteria in discharges of streetwater from storm sewer outfalls.²³ In addition, streetwater



carries litter, sediment, salt, oil and other contaminants that can damage environmental or public health. In addition to at least 3,500 streetwater outfalls in New York City²⁴ there are thousands of regulated outfalls in 150 Hudson River Estuary watershed communities²⁵ and northern New Jersey, as well as many unregulated outfalls. Sources of fecal indicating bacteria in streetwater may include:²⁶

- human waste, including from illicit sanitary sewer connections or leaky sanitary sewers that infiltrate stormwater pipes, illegal dumping, or encampments of homeless or transient people;
- dog and other domestic pet waste;
- Dumpsters, garbage cans and garbage trucks;
- urban wildlife such as pigeons, raccoons, feral cats and squirrels; and,
- biofilms, decaying plant matter, litter and sediment and in storm drains (and on streets).²⁷

Agricultural Stormwater Runoff: Runoff from farms and animal feeding operations (AFOs) can be a significant source of pathogens²⁸ and other pollutants, if manure spread as fertilizer or generated by livestock is not managed to avoid contaminating water. There are thousands of farms in the Hudson River watershed²⁹, with varying degrees of regulation and investment in best management practices to avoid runoff and erosion, exclude cattle from streams, and manage manure and manure applications. The risk of exposure from water contaminated by cattle is comparable to the risk of exposure to water contaminated by humans.³⁰

Septic System Failures: There are hundreds of thousands of septic systems³¹ in the Hudson-Mohawk watershed³². All but the largest require no state permit, and despite the availability of voluntary EPA management guidelines,³³ only a handful of communities regulate operation and maintenance of systems at private homes. The failure rate has been estimated at 10% nationwide,³⁴ and as high as 70% in some communities. The local failure rate is unknown, but the state has identified failing septic systems as a top water quality issue.³⁵ Most failures are identified when odors or pooling of sewage in yards is reported to county Departments of Health—which typically occurs long after the system has been polluting groundwater, and potentially nearby surface water. Routine inspection and maintenance would catch these problems earlier, at lower cost to homeowners and the environment.

Wildlife: Even in relatively urbanized areas of the Hudson River Estuary watershed, our waterways provide habitat for geese, deer and other animals. The degree to which fecal indicators reflect wildlife sources is not known, but given the degree of human development in the watersheds we have studied, and the increase in contamination seen in more urbanized watersheds

relative to less urbanized watersheds, Riverkeeper's working assumption is that human and human-related sources (agriculture, pets) are often dominant. Environmental Protection Agency (EPA) water quality criteria used by Riverkeeper were developed to protect public health, whether the source of contamination is human or animal, and stopping human sources is the first priority because of the known public health risks.^{36,37}

The Hudson River Valley has been a laboratory for the environmental movement since its inception, and our ingenuity will be tested by this problem. The good news is that there are success stories for reducing contamination from complex sources such as these³⁸—but success relies on the full implementation of the Clean Water Act. To make progress, we must:

1. **Improve monitoring, modeling and public notification**, both so the public is well informed about present risks associated with known contamination, and so water quality is properly assessed so investments can be prioritized.
2. **Invest in clean water**, including sewage infrastructure; watershed protection plan implementation; green infrastructure; and pollution management of animal feeding operations, farms and septic systems.
3. **Enforce the Clean Water Act** by verifying impairments identified by citizen water sampling, tightening pollution discharge permit conditions and enforcing compliance, and prioritizing projects to reduce pollution.
4. **Develop new science-based tools** to better understand pollution sources, wastewater contaminants, and their impacts on human and environmental health.

Riverkeeper's work gathering and publicizing water quality data has led to enforcement against polluters, the passage of the Sewage Pollution Right to Know Law; and millions of dollars in infrastructure investments from New York City to the Capital District. Riverkeeper's water quality program has also invigorated grassroots water-protection efforts. To be effective partners to these efforts, environmental and health departments need sufficient staffing, budget and leadership. And yet at the Department of Environmental Conservation, staffing is down 10% over the past decade, and budget is projected to decline 25% by 2020.³⁹

While Riverkeeper's unique water-quality program has been in place for eight years, Riverkeeper has been New York's clean water advocate for nearly 50 years, defending the Hudson River and its tributaries and protecting the drinking water supply of nine million New York City and Hudson Valley residents.

Riverkeeper began as the Hudson River Fishermen's Association, an environmental watchdog and enforcement organization founded by a group of concerned fisherman in



1966 under the leadership of Bob Boyle. Tom Whyatt served as HRFA's first "Riverkeeper" in the early 70's, monitoring the Hudson for pollution. In 1983 the HRFA launched a patrol boat, and hired John Cronin as the first full-time Hudson Riverkeeper, creating a Riverkeeper organization based on his work. The HRFA changed its name to Riverkeeper in 1986. Today, Paul Gallay serves as Hudson Riverkeeper and Robert F. Kennedy Jr. is our Chief Prosecuting Attorney.

Since its inception, Riverkeeper has brought hundreds of polluters to justice and forced them to spend hundreds of millions of dollars remediating the Hudson. The Hudson, once condemned as an "open sewer" in the 1960s, is today one of the richest water bodies on earth. Not only has Riverkeeper played a role in the rebirth of the Hudson, the organization has helped to establish globally recognized standards for waterway and watershed protection and serve as the model and mentor for the growing Waterkeeper movement that includes nearly 200 "Keeper" programs across the country and around the globe. We have also inspired many community groups to take action on a grassroots level.

This year, for example, our water-quality data has encouraged residents near the Wallkill River to take action. The river has been notorious for its contamination, and testing on the Wallkill found it to be one of the most consistently polluted of the Hudson River's tributaries, with 87% of samples taken through 2014 failing the EPA's recommended BAV. In April, a new grassroots organization, the Wallkill River Watershed Alliance was formed by people that want their river to be "fishable and swimmable." Among the actions the group is taking is a monthly boat brigade along the Wallkill that not only brings people onto the waterway, but allows them to observe and report any problems they find.

These tributaries face a variety of issues other than fecal contamination, and these community scientists help maintain focus on varied problems, from erosion and flooding to nutrient overload, plastic litter, and toxic pollution.

On the Hudson, huge progress can be made with investments in aging and outdated wastewater systems, especially those designed to discharge combined sewage overflows, and the runoff of polluted street water, in rain. Addressing these issues in New York City, northern New Jersey, the Capital District and a number of river cities is overdue.

We've already seen the water sampling effort drive government investment to stop water pollution. Some notable examples: sewer investments in Westchester and Rockland Counties to correct longstanding problems, enforcement against illegal discharges in the East River and Catskill Creek, and long-term investments to control combined sewage overflows in New York City and the Capital District.

The data – and the communities gathering it – are making an increasingly persuasive argument for boosting state funding for wastewater infrastructure, which has suffered from billions of

dollars in deferred maintenance and upgrades; and for restoring needed staff and budgets for environmental law enforcement by the Department of Environmental Conservation. The challenge for Riverkeeper in the coming years will be to play an effective role in channeling the human energy inspired by our monitoring projects, and to strategically support citizen-led efforts to address the multifaceted problems our monitoring has helped bring to light.

The good news is that we have a growing number of allies wading in to do that work with us.



John Lipscomb patrols the Hudson for Riverkeeper aboard Riverkeeper's "R. Ian Fletcher," a 36-foot Chesapeake Bay style wooden vessel. From April into December each year, he travels approximately 4,000 to 5,000 nautical miles between New York Harbor and Troy, searching out and deterring polluters, monitoring tributaries and waterfront facilities, conducting a sampling program to measure fecal contamination and supporting other scientific studies, and taking regional decision makers and media out on the river so that "the river has a chance to advocate for itself."

Dan Shapley is Riverkeeper's Water Quality Program Manager.

References

- 1 "U.S. Environmental Protection Agency (EPA) recommends using the fecal indicator bacteria (FIB) enterococci and *Escherichia coli* (*E. coli*) as indicators of fecal contamination for fresh water and enterococci for marine water." USEPA Recreational Water Quality Criteria, 2012, Page 2, <http://water.epa.gov/scitech/swguidance/standards/criteria/health/recreation/upload/RWQC2012.pdf>
- 2 EPA, Notice of Proposed Rulemaking, NPDES Permit Requirements for Municipal Sanitary Sewer Collection Systems, Municipal Satellite Collection Systems, and Sanitary Sewer Overflows, January 4, 2001, withdrawn January 20, 2001.



- 3 The Hudson River Estuary includes the East River, Harlem River, Newtown Creek and Gowanus Canal in New York City, as well as the tidal portions of tributaries like the Rondout Creek and Catskill Creek. The estuary stretches north approximately 150 miles to the federal dam at Troy.
- 4 IDEXX Enterolert, <https://www.idexx.com/water/products/enterolert.html>
- 5 Catskill Creek Watershed Awareness Project; Center for the Urban River, Gardiner Environmental Conservation Commission; Montgomery Conservation Advisory Council; New York City Water Trail Association and The River Project, which partner with more than 20 community boathouses, community groups, and waterfront parks, and labs; Ossining High School; Quassaick Creek Watershed Alliance; Rochester Environmental Conservation Commission; Rosendale Commission for Conservation of the Environment; Sparkill Creek Watershed Alliance and Wawarsing Environmental Conservation Commission, Yonkers Paddling and Rowing Club.
- 6 Routine monitoring is done on the Catskill, Esopus, Quassaick, Rondout and Sparkill creeks; and Pocantico, Saw Mill and Wallkill Rivers, and a one-day snapshot of water quality in the Mohawk River was conducted in 2015 as a pilot.
- 7 “Quality Assurance Project Plan Citizen Science Water Quality Testing Program” and “Quality Assurance Project Plan Hudson River Water Quality Testing Program” are available at <http://www.riverkeeper.org/water-quality/testing/>
- 8 EPA, 2012 Recreational Water Quality Criteria, <http://water.epa.gov/scitech/swguidance/standards/criteria/health/recreation/upload/RWQC2012.pdf>
- 9 “Primary contact recreation typically includes activities where immersion and ingestion are likely and there is a high degree of bodily contact with the water, such as swimming, bathing, surfing, water skiing, tubing, skin diving, water play by children, or similar water-contact activities.” Ibid. Page 6.
- 10 Ibid. Page 6
- 11 Ibid. Page 38
- 12 “EPA’s 2012 RWQC are for all waters in the United States including marine, estuarine, Great Lakes, and inland waters that are designated for primary contact recreation.” Ibid. Page 6.
- 13 Riverkeeper research, based on published result and personal communications with the organizers of 36 swim events.
- 14 Riverkeeper has documented swimming and other primary contact recreation throughout the Hudson River estuary during 15 years of monthly boat patrols of from New York City to Waterford.
- 15 Riverkeeper, “Communities Need \$12.7 billion in State Aid to Protect Clean Water,” analysis of 2015 Multi Year Intended Use Plan for State Clean Water Revolving Loan Fund, <http://www.riverkeeper.org/news-events/news/water-quality/communities-need-12-7-billion-in-state-aid-to-protect-clean-water/>
- 16 The EPA Clean Watersheds Survey, based on 2012 data, has not been released by the Office of Management and Budget.
- 17 The EPA recommends a Beach Action Value of 60 Entero per 100 mL as a single-sample result to be used to post beach advisories.
- 18 We use the term “streetwater” instead of “stormwater” because it evokes the mix of contaminants found in urban runoff.
- 19 EPA Enforcement Compliance History Online (ECHO), analysis February-March 2015. <http://echo.epa.gov/>
- 20 *ibid*
- 21 *ibid*
- 22 State Pollution Discharge Elimination System (SPDES) Permits are renewed every five years (or 10, for groundwater discharges), with full technical reviews done of a subset of permits based on the DEC’s Environmental Benefit Permit Strategy. Modifications are proposed for this subset of permits based on “a change in regulations, a change in the operation of the industry or compliance issues.” http://www.dec.ny.gov/docs/water_pdf/togs122.pdf
- 23 “FIB concentrations in wet weather urban discharges from separate storm sewer systems are typically orders of magnitude above primary contact recreation standards, regardless of the land use.” “Pathogens in Urban Stormwater Systems,” August 2014, Urban Water Resources Research Council of the Environmental and Water Resources Institute of the American Society of Civil Engineers, Page xix
- 24 New York City Department of Environmental Protection, “2013-2014 MS4 Draft Annual Report,” www.nyc.gov/html/dep/pdf/ms4/nycdep_ms4_annual_report_2014_draft.pdf
- 25 In addition to New York City and northern New Jersey communities, the DEC identifies 475 regulated municipal separate storm sewer system (MS4) areas in 150 Hudson River Estuary watershed communities. Each has multiple outfalls, and there are also many unregulated separate stormwater systems.
- 26 “Pathogens in Urban Stormwater Systems,” August 2014, Urban Water Resources Research Council of the Environmental and Water Resources Institute of the American Society of Civil Engineers
- 27 Based on unpublished research by Dr. Greg O’Mullan.



- 28 “Pollutants that result from farming and ranching include sediment, nutrients, pathogens, pesticides, metals, and salts.” EPA, Nonpoint Source Factsheet http://water.epa.gov/polwaste/nps/agriculture_facts.cfm
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- 31 Increasingly, regulators refer to these as “onsite wastewater treatment systems.”
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- 33 EPA, “Voluntary National Guidelines for Management of Onsite and Clustered (Decentralized) Wastewater Treatment Systems,” http://water.epa.gov/scitech/wastetech/upload/septic_guidelines.pdf
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- 35 Top Ten Water Quality Issues in New York State, http://www.dec.ny.gov/docs/water_pdf/305btopten10.pdf
- 36 “The first step in addressing [fecal indicating bacteria] impairments is to inventory the various [fecal indicating bacteria] sources specific to the watershed, and prioritize human [fecal indicating bacteria] sources first, given the greater public health risks they may present.” Urban Water Resources Research Council of the Environmental and Water Resources Institute of the American Society of Civil Engineers “Pathogens in Urban Stormwater Systems,” August 2014, page xix
- 37 “Human pathogens are present in animal fecal matter, and there is, therefore, a potential risk from recreational exposure to human pathogens in animal-impacted waters that must be accounted for in the 2012 [Recreational Water Quality Criteria]. For waters dominated by nonhuman sources and in the absence of site-specific criteria, EPA recommends that the national criteria be used to develop [Water Quality Standards] for all waters including those impacted by point and nonpoint sources.” EPA, 2012 Recreational Water Quality Criteria, page 38 <http://water.epa.gov/scitech/swguidance/standards/criteria/health/recreation/upload/RWQC2012.pdf>
- 38 Riverkeeper, Boat Blog, “Using the Clean Water Act to Address Pathogen Pollution” <http://www.riverkeeper.org/patrol/using-the-clean-water-act-to-address-pathogen-pollution>
- 39 “The size of the DEC workforce declined 10.4 percent, from 3,256 full-time equivalents (FTEs) in SFY 2003-04 to 2,917 FTEs in SFY 2013-14,” New York State Comptroller, “Environmental Funding in New York State,” December 2014. www.osc.state.ny.us/reports/environmental/environmental_funding_nys_2014.pdf

Can Evolutionary Design of Citizen Science Networks Make It Easier to be Green?

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The social Web is swiftly becoming a living laboratory for understanding human cooperation on massive scales. It has changed how we organize, socialize, and tackle problems that benefit from the efforts of a large crowd. A new, applied, behavioral ecology has begun to build on theoretical and empirical studies of cooperation, integrating research in the fields of evolutionary biology, social psychology, social networking, and citizen science. Here, we review the ways in which these disciplines inform the design of Internet environments to support collective pro-environmental behavior, tapping into proximate prosocial mechanisms and models of social evolution, as well as generating opportunities for ‘field studies’ to discover how we can support massive collective action and shift environmental social norms.

Harnessing the power of the crowd

The Internet has transformed how we obtain and share information, interact, display our identities, and perform tasks at home and at work. It expands our social networks and extends our reach, allowing collaboration at massive scales. Examples include the crowdsourcing of knowledge creation for Wikipedia.org and the classification of more than 50 million images of galaxies in year one of GalaxyZoo.org. In the environmental sciences, citizen-science projects now engage large crowds to collect biological data across the globe^{1,2}.

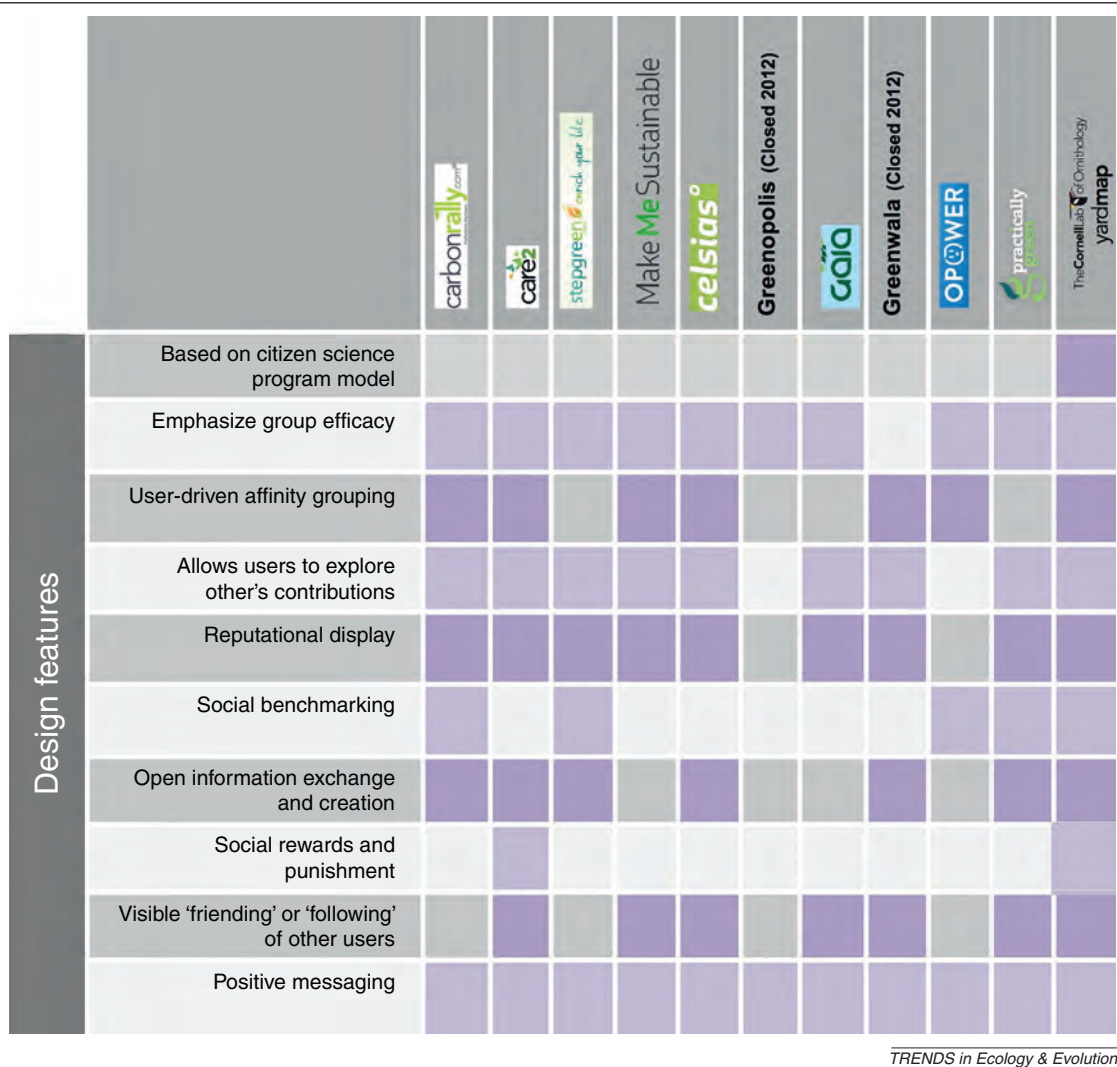
Our ability to engage in cooperative social and entrepreneurial activities has been further enhanced by social networking tools; such tools provide an increasingly fluid system of highways through which information and ideas travel, doing so with a speed and fidelity never before seen in human society. The question we raise in this review is: how might social networking be combined with citizen science and new understandings of human cooperation to support massive shifts in pro-environmental

behavior and social norms? Progress toward answering this question requires the deliberate design and testing of new citizen-science Web applications informed by evolutionary biology, social psychology, and social networking research to support sustainable practices.

The successful design of Internet communities to support environmental collective action is a nontrivial problem. It is not for lack of trying that we have failed to achieve voluntary, substantive changes in how we consume and use resources; there are numerous examples of ‘green’ social networks that have simply failed to take hold (Figure 1). Neither are the potential effects small. Universal adoption of 17 practices to reduce carbon emissions could reduce the national carbon footprint of the United States by 7.4% without downgrading quality of life³. This reduction is equivalent to the national emissions for all of France. The potential for small acts to make a big difference when summed over a large crowd argues for more research on how we can tap into prosocial behavior to address conservation problems household by household⁴. Citizen-science projects provide a trustworthy scaffolding for purposeful, conservation-based social networks because they are grounded in science and provide both leadership and opportunities for entrepreneurial action. We argue that their established methods for collecting and managing environmental data can be augmented with social networking to support pro-environmental collective action, providing unique opportunities for both theoretical and applied research in evolutionary behavioral ecology and social psychology as they relate to conservation behaviors.

The social Web’s capacity to support collective behavior

The social Web has emerged at a time when direct human effects on ecosystems are so great that we have effectively entered a new geological epoch⁵. With seven billion people on the



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Figure 1. Graphic showing which features are included in a sample of online green social networks. Features correspond to hypothesized aspects of green networks that are most likely to facilitate and sustain collective action.

planet, never before have the collective behaviors of individuals been so important⁶. Although we face such formidable problems as population growth, climate change, landscape change, and changes in the chemistry of our oceans and terrestrial systems, we are also in the possession of tools that can tap into prosocial tendencies on a global scale. These tools, if designed based on evolutionary understandings of human cooperation, have the potential to sustain shifts in behaviors and social norms at scales sufficient to generate meaningful, positive effects⁷.

Our thesis is that to be effective in supporting collective changes in pro-environmental lifestyles, Web environments must harness both ultimate and proximate drivers of cooperation. These terms describe different levels at which behaviors can be analyzed; hypotheses do not compete across levels but are complementary, and both levels are important for understanding what sorts of behavioral changes are feasible. Ultimate drivers of cooperation explain why people have evolved to cooperate and what fitness benefits cooperation provides. Proximate drivers

are the built-in, underlying mechanisms that humans possess to achieve cooperation, ranging from how cognition, attitudes, motivations, and emotions play into social life to how people use social information when adhering to social norms, managing their reputations, or copying the behaviors of others. In order to test theoretically informed hypotheses and design field experiments that will lead to new insights, Web environments must allow researchers to introduce interventions that are thought to facilitate collective action. These interventions, when informed by research on how prosocial behaviors play out in face-to-face and computer-mediated interactions, can make a real difference if they prove effective in large citizen-science networks.

Cooperation and environmental goods

Early studies of environmental collective action supported a negative perspective on the human potential for cooperative management of environmental goods^{8,9}. Many environmental goods, such as air quality or climate, can be modeled either



as public goods or common goods. Public goods are non-excludable, meaning everyone can use them, and non-rivalrous, meaning one person's use does not preclude another's. Common goods are also non-excludable but are rivalrous in that the resource is gradually depleted as the number of users increases. In considering householders' contributions to environmental goods as a collective action, it makes sense to see contributions in terms of restraint, such as reduced use of water, energy, and pesticides, and restoration, such as planting native trees or investing in other enhancements to habitat for wildlife.

Cooperative management of common and public goods is a classic social dilemma because the strategy of cooperation that yields the greatest payoff for the group is not in the self-interest of individuals. This result, known as the 'zero contribution thesis', is based on the mathematical impossibility of maximizing short-term self-interest and group interest at the same time⁹. Without the external enforcement of rules, rational self-interest renders public and common goods vulnerable to free riding, cheating, defection, and, potentially, collapse of the resource, a phenomenon known as 'the tragedy of the commons'^{8,10,11}. In spite of this, both in real life and in a large number of behavioral games, people contribute far more than expected on the basis of short-term self-interest¹¹.

High levels of cooperation can be tied to an evolutionary history in which humans lived in small groups where cooperation was fundamental to the survival of an individual and its kin^{7,12}. Comparison of Western contemporary societies with Tanzanian hunter-gatherers indicates that we retain many of the very same features of cooperation that were critical for survival and reproductive success in small ancestral social networks¹³. In many contexts, ranging from political views to innovation, health, and happiness, we are influenced not just by immediate friends but by friends of friends of friends, a pattern known as the 'Three Degrees Rule'⁷. Human behaviors, including cooperative behaviors, are contagious in social networks, especially among individuals who are no more than three degrees apart. Today, social costs and benefits are widely recognized as playing a substantial role in structuring the relative payoffs of cooperation and competition, and we see widespread recognition of the role of reputation in sustaining cooperation in public and common goods contexts^{11,14–16}. Although evolutionarily stable cooperation is still difficult to achieve at large scales, evolutionary stability is made more likely: (i) when group members have repeated interactions and thus an ability to retaliate against free-riders¹⁷; (ii) when people can choose when and with whom to cooperate^{11,18–20}; and (iii) when inter-group competition aligns the genetic interests of group members²¹. Each of these possibilities is likely to be augmented in electronic social networks. Recent evolutionary theory has unveiled not only the social and environmental conditions that promote evolutionarily stable cooperation but also the conditions that speed up the appearance of cooperators (e.g., altruistic volunteers) in time²². For example, evolutionary game theory shows that such volunteers, that is, 'brave leaders' who secure social benefits for the group at a cost to themselves, emerge sooner in smaller groups than in larger groups²². Thus,

prosocial volunteerism can emerge sooner when electronic networks are strategically subdivided into smaller subnetworks.

Reputation and sensitivity to third-party assessment

People are more likely to form ties and cooperate when others are similar to themselves in both electronic and real-life social networks^{23,24}. The possibility of breaking ties with non-cooperators (one mechanism for punishing defection) and forming new ties with cooperators appears to foster cooperation in experiments with humans²⁵. Where ties persist, reputation is a critical mediator of cooperative interactions^{16,26–28} in that individuals who cheat, defect, or free-ride will experience peer-to-peer punishment^{15,29}, whereas those who cooperate will receive social rewards³⁰. People are willing to pay a cost to punish others³¹, and they are extraordinarily sensitive to reputation^{15,27,32–34} and to social norms comparisons, including the 'norm of reciprocity', as seen in conventional gift exchange³⁵. Violations of social norms can cause embarrassment and negative reputational consequences^{11,36,37}.

Current research on indirect reciprocity, in which people only need to interact once and can decide whether or not to cooperate on the basis of what they see others do, indicates that the requirement of repeated interactions is not always necessary²⁶. Cooperation can be maintained when people cooperate with others they observe cooperating or when they cooperate with new people on the basis of having been the recipient of a different party's cooperative act²⁶. Sensitivity to third-party assessment, which underlies cooperation in indirect reciprocity and some public-goods games³⁸, can be triggered with visual symbols of human peer-policing or surveillance, as when an image of watching eyes decreased free-riding and increased the level of monetary contributions that people made at a communal coffee and tea station³⁹. New models of cooperation and accompanying experiments suggest that reputation, social rewards, and punishment by peers are more powerful at promoting cooperation than are institutional rewards and sanctions. In some situations, strong institutional governance is thought to undermine cooperation¹⁴.

Prosocial mechanisms governing reputation-based cooperation

Recent findings indicate that human beings exhibit cognitive, behavioral, emotional, and neurological mechanisms that function to support reputation-based cooperation (Box 1). These include proximate mechanisms that generate strong responses to inequity and motivate individuals to restore equity when a line has been crossed⁴⁰. People make equitable decisions, not just because they fear social consequences; they also do so in anonymous situations in which there are no repercussions of being selfish⁴¹. Neuroscience research combining behavioral games with functional magnetic resonance imaging has shown that making equitable decisions and having an aversion to inequity on the part of others engage neural structures in the brain



Box 1. Mechanisms that function to support reputation-based cooperation

- Proximate mechanisms involving social cognition and social emotions support cooperation and exhibit sufficient activity in computer-mediated interactions to be effective in online environments [40].
- *Sense of fairness.* Inequity aversion or aversion to unreciprocated cooperation or unfair offers helps to increase the social costs of defection.
- *Sensitivity to norms violations.* Helps to stabilize cooperative behavior and allows individuals to detect less-engaged members of a social group.
- *Impulse control.* Cognitive mechanisms that increase adherence to social norms and reduce selfish behavior.
- *Ability to learn.* Remembering the generosity and trustworthiness of others.
- *Painful social emotions.* For example, envy of others whose competitive status is elevated, guilt and fear associated with betrayal, shame at violating social norms, and pain in response to ostracism.
- *Intrinsic neurological rewards.* Social approval, praise, mutual cooperation, helping others, experiencing compassion, and generosity (even toward anonymous others) activate neurological structures associated with pleasure and subjective value.
- *Drive to restore equity.* A mechanism for restoring cooperation.
- *Tendency to choose similar partners.* Facilitates conditional cooperation by maximizing social returns.

that are associated with intrinsic rewards (e.g., pleasure)^{42–44}. Such ‘intrinsic’ rewards of prosociality are not limited to humans; they are also found in tufted capuchins (*Cebus paella*)⁴⁵. Together, this body of research points to prosocial, proximate mechanisms that, if supported in online environments, can lead to scalable increases in pro-environmental behavior (Box 1).

Overcoming proximate barriers to pro-environmental behavior

The fields of communication, economics, and social psychology have been at the forefront of discovering potential barriers to pro-environmental behavior⁴⁶. Designing effective, simple, universally successful interventions has proven difficult^{47–50}. First, even people with strong pro-environmental attitudes often choose not to act on the basis of situational factors such as cost or normative factors such as low expectations that others will join in the activity^{48,51–54}. Interventions designed to mitigate situational factors, such as lack of access, lack of knowledge, and lack of funding, are popular because they are intuitive and relatively simple, but emphasizing awareness, subsidies, and convenience rarely results in widespread adoption. For instance, people report high costs as the reason that they fail to purchase high-efficiency appliances or gas-efficient vehicles, but programs designed to subsidize costs have done little to increase environmental purchasing. Campaigns to raise awareness have not improved these outcomes, and some have even proven counterproductive. For example, a California utility company spent more money advertising insulation upgrades on television than it would have cost to install new insulation in the

target homes themselves⁵⁵. Communications designed with an awareness of evolved prosocial mechanisms could provide the support required to increase the effectiveness of incentives. As in other contexts (e.g.,⁵⁶), use of negative or fearbased messages tends not to elicit increased interest in taking pro-environmental action⁵⁷, indicating a need to craft messages that are not too threatening or to couple fear-based messages with effective and readily implemented response recommendations⁵⁸. Most people believe they have little self-efficacy when it comes to positively influencing the environment and believe that their actions have no substantial impact⁵⁹. Calculating a carbon footprint, as is popular on myriad websites (but only three of the projects in Figure 1), can reinforce feelings of insignificance. When it is necessary to convey negative messages, communications focusing on dangers for non-human organisms (e.g., birds for birdwatchers) can elicit increased interest in taking action, as can positive messages focused on group-efficacy and group identity⁶⁰. As actions are stored as data and participants can visualize their cumulative effects in real time, citizen-science environments can be designed to bolster a sense of group efficacy.

Proximate drivers of pro-environmental behavior

Social psychology provides important clues for how placing conservation issues within a social-networking environment can help to support pro-environmental behavior. A substantial body of evidence indicates that descriptive social norms play a large role in determining people’s environmental behavior. In a well-known study of hotel towel reuse, people were much more likely to reuse their towels when told that 75% of previous hotel guests had reused theirs than when told that reusing towels helps the environment⁶¹. In general, conveying that others actually engage in pro-environmental behaviors (the descriptive norm) has stronger behavioral effects than conveying that people should do so (the injunctive norm)⁶². Social influence is also apparent in behavioral economics research, which indicates that purchasing decisions are based on social status and relative, rather than absolute, material wealth⁶³. In many contexts, this moves people toward ever-higher levels of consumerism. Online or off, when communities become more green, green behaviors can become the new social norm, and investment in green behavior can begin to function as a costly signal of status⁶⁴. In one study, the use of solar panels added about 3% to the expected sale price of a house, but in communities with a higher percentage of registered Toyota Priuses, which indicate a green social norm, the price of houses with solar panels was proportionally higher⁶⁵. The idea that green purchases act as cooperative signals is further supported by a study of homeowners, many of whom installed solar panels on the less-effective, shady sides of their houses just to make their investments more conspicuous to their neighbors⁶⁶. These findings suggest that it is possible to shift green norms, which can then produce cascading positive effects on pro-environmental behaviors in social networks.



The nature of social interaction in online social networks

Given the importance of social rewards and punishment to sustained cooperation, it is reasonable to question whether cues and information delivered in online social networks are sufficiently potent to support collective action. This question arises, in part, from various studies, including behavioral games, demonstrating that face-to-face interactions are more potent than computer-mediated interactions⁶⁷. Early research suggested that computer-mediated communications tend to be task-oriented and egalitarian but impersonal⁶⁸. Impersonality was attributed to the filtering out of cues by electronic media⁶⁹. Although facial expression, body language, vocal tone, touch, and complex pairings of these different modalities are missing in computer-mediated transactions, the ‘cues filtered out’ idea was challenged by a more general ‘social information processing’ perspective, which examined critically the methods used to demonstrate impersonality⁶⁸. Although exchange of social information may be slower in computer-mediated interactions, potency is not necessarily limited, providing there is enough time to communicate. Walther and colleagues proposed that given time, people learn new ways to convey online what is communicated nonverbally offline (e.g., by using emoticons to communicate facial expressions of emotion)⁷⁰.

Experiments measuring individual levels of trust, generosity, reciprocity, tendencies to punish, reputational sensitivity, and tendencies to cooperate or not indicate that computer-mediated interactions elicit many of the same patterns of cooperation that are important in real life⁴⁰. Although face-to-face experience appears superior at generating cooperation in behavioral games and also allows participants to better predict whether their partners will cooperate, a large number of behavioral experiments indicate that high levels of cooperation can be achieved via

communication without face-to-face interaction^{40,71}. When participants in behavioral games think they are engaging in social exchanges with real people via computers, they demonstrate social cognition with regard to partner choice, whom to trust, the potential for punishment, and the long-term rewards of cooperation^{40,72}. Experiments also indicate that people interacting on computers exhibit prosocial emotions, such as feeling good when they experience social approval or mutuality, experiencing the ‘warm glow’ of generosity, fear of betrayal, inequity aversion, and status-related emotions, such as envy^{40,43}. In addition, the experience of being ignored or excluded in minimally social online environments (‘cyberostracism’) elicits negative affect and reduced feelings of belonging⁷³ and increases neural activation in areas of the brain associated with the experience of physical pain^{74,75}. Together, this research suggests that electronic social networks can support the proximate mechanisms underlying human prosocial behavior and peer-policing to support collective action (Box 2).

Social networks not only increase the number of connections people have, they make connections, actions, and reputations visible and enable people to form homophilous groups⁷. People tend to form strong ties (bonding ties) with similar others, creating pockets of social contagion. Weak ties (bridging ties) spread ideas and actions (memes) broadly, especially through influential people (leadership effects)^{22,76}. Cooperative social norms and behaviors exhibit high degrees of social contagion online⁷; this should be especially true when individuals have a large number of strong connections⁷⁷ and are connected to other highly connected people⁷. These special properties of social networks are thought to have enabled the rapid social and political changes in the ‘Arab Spring’⁷⁸.

Box 2. Properties of online social networks that amplify potential for large-scale cooperation

- *Between-group competition.* Competition between groups via contests can increase potential for within-group cooperation [21].
- *Connections.* Increased number of connections to others (degree) [7,14].
- *Density.* The sheer density of network ties is thought to foster cooperation [82].
- *Diversity.* Weak ties that connect people to dissimilar others foster innovation and collective intelligence, and enhance leadership effects [22,81].
- *Fidelity.* Electronic social networks transfer information with a high level of fidelity via exact replication, averting the filtering of information during transfer; this is in contrast with spoken interchange, which has less fidelity [83].
- *Homophily.* Tendency to connect with and have strong ties to similar others, which increases social capital and persistence of engagement [14,84].
- *Influence.* Potential for leadership or influence facilitated by homophily, bonding (strong) ties, and number of bonding and bridging ties [7,84].
- *Opportunities for social rewards and punishment.* Electronic networks allow people to distribute social rewards (e.g., friend, like, interact frequently or comment) and mete out punishment (e.g., dislike, reduce level of interaction or ‘tie strength’, hide comments of friends, and, more rarely, unfriend).
- *Rapid diffusion.* Weak ties increase transmission of ideas and information [82].
- *Reputational mechanisms.* Reputation can be displayed using leaderboards, badges, or metrics calculated from behavior in electronic social networks [85].
- *Small-world phenomenon.* With only a few weak ties, the path connecting individuals to a large share of the other individuals in a network is extremely short; also known as ‘six degrees of separation’ [86].
- *Social contagion.* Imitation of and social influence on others within three degrees; behavioral cascades through the network [7,87].
- *Soft governance.* In citizen-science networks, project leaders organize activities, but the structure also allows leadership to emerge from the participant base [2].
- *Transparency.* Connections, actions, badges earned, place on leaderboard, identity, number of friends, social identity, and frequency of interactions are all potentially visible in electronic social networks.



Box 3. Description of YardMap.org, a socially networked citizen-science project designed to support pro-environmental behaviors

YardMap.org is a citizen-science project that allows participants to use simplified mapping tools to make their residential practices visible in a Google Map interface. First, they outline and name a site, which can be a residential property, school, park, or corporate campus. Then they specify set of characteristics for their site, including whether they let a cat outdoors, whether they use herbicides or pesticides, the structural diversity of their plantings, and where their property sits along the urban-to-rural gradient.

After a site is characterized, participants cover the entire site with abutting polygons representing habitat types (such as forest, lawn, grassland, vegetable garden and water features). These data can be used to automatically calculate relevant summary statistics, such as percentage of lawn size, behind the scenes (lawn reduction is one of YardMap's goals). Each polygon can be characterized further, depending on what type of habitat it is representing. For example, a lawn polygon can be characterized for 'irrigation frequency', 'mower type', 'clippings management', or whether it is 'native'. These data constitute detailed information about each polygon that can be used to better understand how people are managing their land and how management changes over time as participants are exposed to new sustainable practices.

The third layer is based on a palette of objects, which allows participants to provide information on their practices at a fine level of detail. Trees can be dragged onto the map and identified to species,

gardens can be filled with icons for individually identified plants, water catchment systems can be placed just where they occur, and solar roof panels can be dragged onto rooftops.

Participants can peek at information about sites, polygons, and objects drawn by others and leave comments, ask questions, 'like' or 'follow' a site, or view photos and share information in comment fields. When people change their maps, these changes are visible in the social network. 'Seeds of Change' badges also appear in the social network's news feed, advertising that named participants have succeeded in adopting a specified set of sustainable practices, for example, 'Cat-free Zone', 'Green Power', 'Healthy Yard', and 'Soil Smith' badges. Participants can then click on the news feed to get to the relevant map.

After a map and its growing body of data are stored in the database, summary statistics and comparison tools can be developed, allowing participants to see where they fit next to specific benchmarks or social norms (see Figure 3A in main text) and making visible the number of people who are following them (see Figure 3B in main text). Because practices are stored as data, the application allows researchers to ask how new interventions or social network connections influence adoption of new behaviors. The social network itself provides opportunities to better understand attitudes via close analysis of discourse, including discourse related to controversial issues (e.g., keeping cats out of the wild).

Testable hypotheses for using the Internet to facilitate environmental collective action

In her final year, Ostrom⁷⁹ made a plea for more field studies of cooperation to extend current knowledge beyond the laboratory and behavioral games and into the real world. The hypotheses that we discuss in this review are in need of field testing to discover the social Web's capacity to amplify real life environmental collective action beyond what is possible using conventional communications tools. Interventions that are hypothesized to drive pro-environmental behavior in online environments, which are listed in Figure 1, can only be field tested by first integrating them into project designs and engaging a large participant base. In general, we suggest the following guidelines, which can be reframed as specific, testable hypotheses for how to develop Internet platforms to resolve social dilemmas in support of environmental collective action:

- Create rich, citizen-science Web platforms that are explicitly tied to sense of place⁸⁰, translate the best science, and gather people through a common interest that bridges a wide range of ideological groups.
- Integrate social networking into project designs to decentralize governance. Research on collective action suggests that weak governance can work well¹¹, providing that the environment can support reputational mechanisms.
- Craft messages carefully, avoid fear appeals, and display visualizations that highlight self and group efficacy, social identity, and joint sense of purpose.

Foster individual identity and efficacy by allowing individuals to compare their efforts with clear, specific benchmarks and display those efforts to others in the network. Foster group efficacy by allowing participants to visualize the collective effect of the crowd and by displaying new practices or solutions arising from collective intelligence⁸¹.

- Make the social nature of the project apparent with visible following, friending, and scorekeeping so that participants can monitor their own connections, actions, and reputations, as well as those of others.
- Provide and test mechanisms for reputational display, reputational sensitivity, scorekeeping, social rewards, and punishment.
- Use online gamification to elicit competition, including leaderboards, benchmarks, and badges.
- Use machine learning, a computer science methodology related to artificial intelligence, to develop algorithms that expose noncooperators, such as cheaters or freeriders.

Develop group functionality to divide networks into subgroups that compete with each other for extrinsic rewards tied to the group's contribution to the global public good; theoretically, encouraging inter-group competition can lead to potent within-group cooperation²¹. Allowing participants to form smaller subgroups should also reduce the average time until leaders volunteer within groups²².



Figure 2. A completed YardMap showing site outline (yellow), polygons, and objects. See Box 3 for an explanation.

Field research is required to determine which design features of green networks can be successful, but the Web tools required to test these recommendations are costly to produce. We suggest that projects such as YardMap.org, a socially networked mapping environment, can serve as testing grounds for ideas on cooperative environmental stewardship (Box 3, Figure 2). YardMap is different from the other projects in Figure 1 in that it begins with the scientific and educational content of citizen science and taps into a popular earth-stewardship hobby that involves landscaping to support birds and other wildlife. Every activity is stored as data, allowing for the creation of dynamic tools to calculate where people are relative to benchmarks or social norms (Figure 3A). Following a beta launch in spring 2012, YardMap is being redesigned to test mechanisms underlying prosocial behavior with the aim of furthering understanding the Web's potential for supporting sustainable lifestyles and behaviors (Figure 3A,B).

Concluding remarks

Electronic social networks are ripe for research that harnesses evolutionary theory and social psychology to better understand and design Web strategies to support cooperative pro-environmental behavior. This review suggests that to be successful, projects will need to provide opportunities for people to develop a social identity and group affiliation, assess their own relative status and the reputations of others, and visualize the collective's impact on the future. Also important will be providing opportunities for people to advertise their altruism, reward and punish others, and engage in game-like, between-group competitions.

For the first time in human history we have the potential to create tools that can support massive ideological communities focused on earth stewardship across vast geographic regions. This review is a call for the expansion of cross-disciplinary thinking and field studies to discover the Web's potential for providing robust support for the shifts in behavior and social norms that are required for tackling the householder's share of environmental stewardship, with the assumption that this is one way to grow earth-stewardship from the ground up, starting with households and moving into schools, workplaces, towns, cities, and government agencies.

Acknowledgments

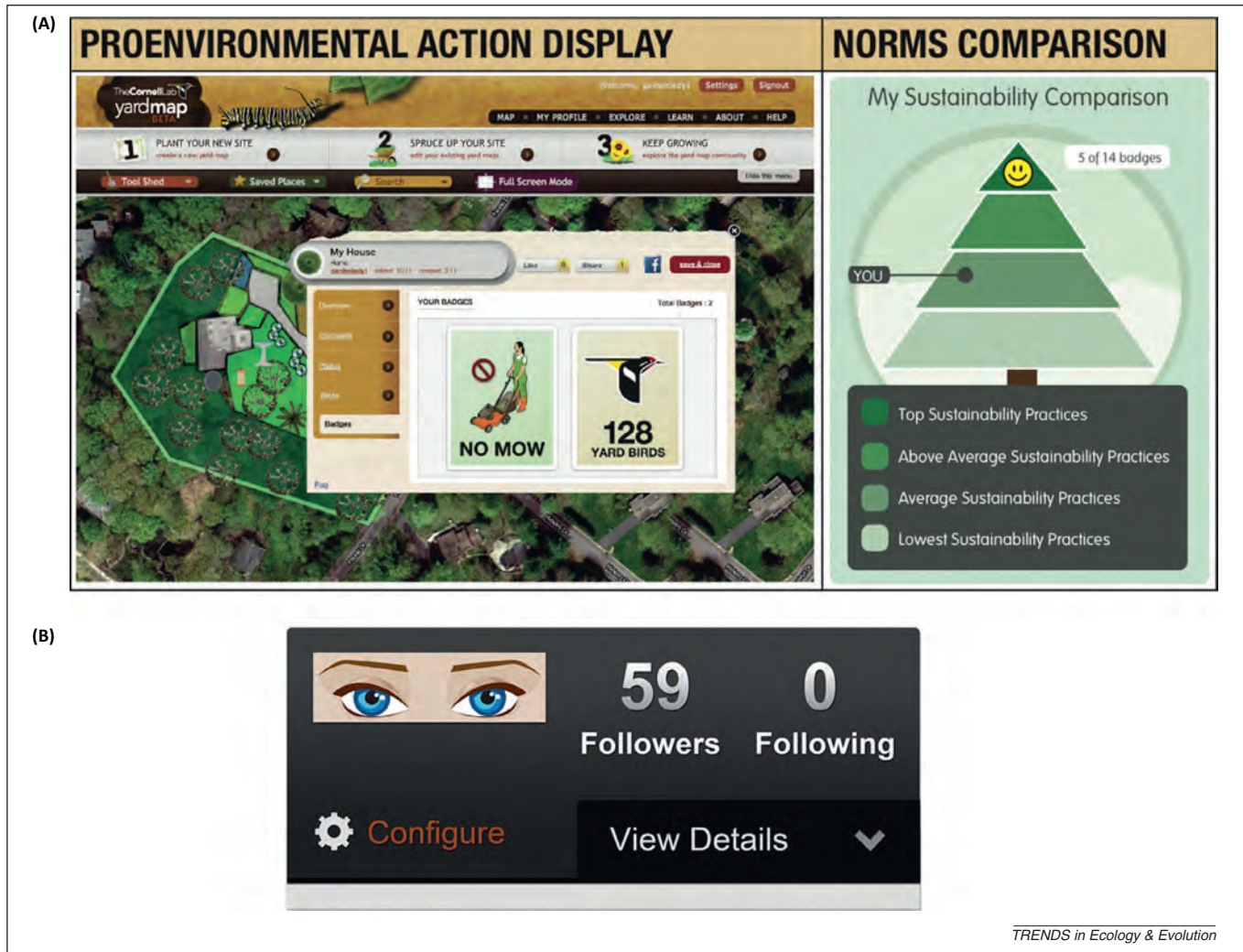
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TRENDS in Ecology & Evolution

Figure 3. Interventions to test the efficacy of proximate drivers of prosocial environmental behavior in YardMap. (A) Experimental badge display and norms comparison designed for YardMap. On the left is a prototype of a badge display system designed to promote copying behavior (social contagion) and reputational mechanisms. On the right is a prototype of a social comparison tool that allows participants to see where they are relative to the norm (average) and to see that it is desirable to rise above the norm (smiley face). The expectation is that adding the smiley face will help to shift the social norm upward, reducing the likelihood that individuals will gravitate downward, not just upward, toward the norm [88]. (B) Enhancement of reputational effects. Example of an intervention designed to test the effect on cooperation of adding a visual image of eyes to the number of followers in YardMap's social network profile.

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Citizen Health Scientists For Chronic Disease: From Disease Management in Isolation to the Power of the Community in Louisville and Beyond

Kelly Henderson, Meredith Barrett, Olivier Humblet, Chris Hogg and David Van Sickle

The increasing challenge of chronic disease

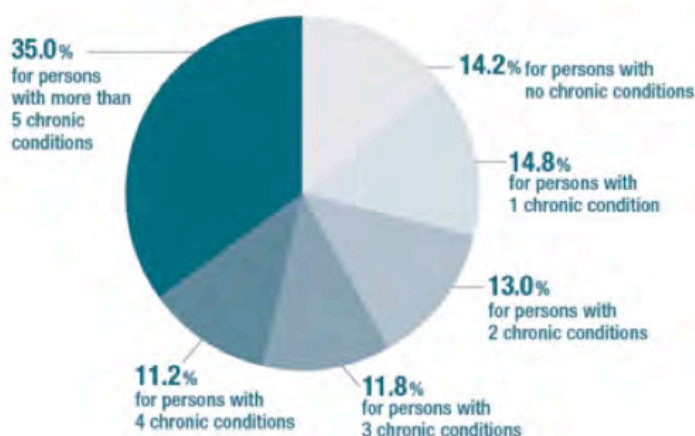
Public health challenges are characterized by multiple interacting behavioral, social, and environmental causes that go beyond traditional sectors or organizational divides. From obesity to respiratory health, addressing complex public health problems that affect diverse populations requires broad community participation. The rising prevalence of chronic diseases represents one of the most pressing public health problems facing the United States. According to recent reports, chronic disease accounts for 86% of the total healthcare costs (see Figure 1) and 7 of the top 10 causes of death in the US.^{1, 2} With the prevalence of chronic disease projected to increase to nearly 48% of the population by 2020,³ public health officials and healthcare providers are seeking new approaches to combat these alarming trends.

Limitations of current chronic disease management

The current model for chronic disease management relies largely on primary care physicians to provide care to patients within increasingly shorter face-to-face visits. A physician spends just 15 minutes on average with each patient, which limits the opportunities for patients and physicians to go over their treatment plan, talk about lifestyle changes and root causes of their disease,⁴ or engage in collaborative decision-making about treatment modifications.⁵ Physicians also rely on self-reported data from patients about their medication and treatment adherence. These recall-based assessments of chronic disease are often susceptible to bias and errors, which limit providers from accurately understanding their patients' current health status and their opportunities to optimize care. Additionally,

patients often receive treatment plans and advice that include medical jargon or language beyond their reading comprehension, which makes following treatment plans challenging, especially for patients with limited English proficiency or literacy. Together, these factors, among others, have undermined the capacity of primary care providers and patients to address the growing chronic disease epidemic across the country.

Total U.S. Healthcare Spending by Number of Chronic Conditions in 2010



DATA HIGHLIGHTS

86% of healthcare spending is for patients with one or more chronic conditions.

71% of healthcare spending is for patients with multiple chronic conditions

- Said another way, 71¢ of every dollar of healthcare spending goes to treating people with multiple chronic conditions.

Figure 1. Cost of Chronic Disease in the United States. Source: Multiple Chronic Conditions Chartbook 2010 Medical Expenditure Panel Survey Data <http://www.ahrq.gov/professionals/prevention-chronic-care/decision/mcc/mccchartbook.pdf>.

People living with chronic diseases face similar, numerous barriers to successfully manage their condition. As such, people managing a chronic disease can feel frustrated, overwhelmed by the many obstacles, and exhausted from the required behavior changes, activity limitation,

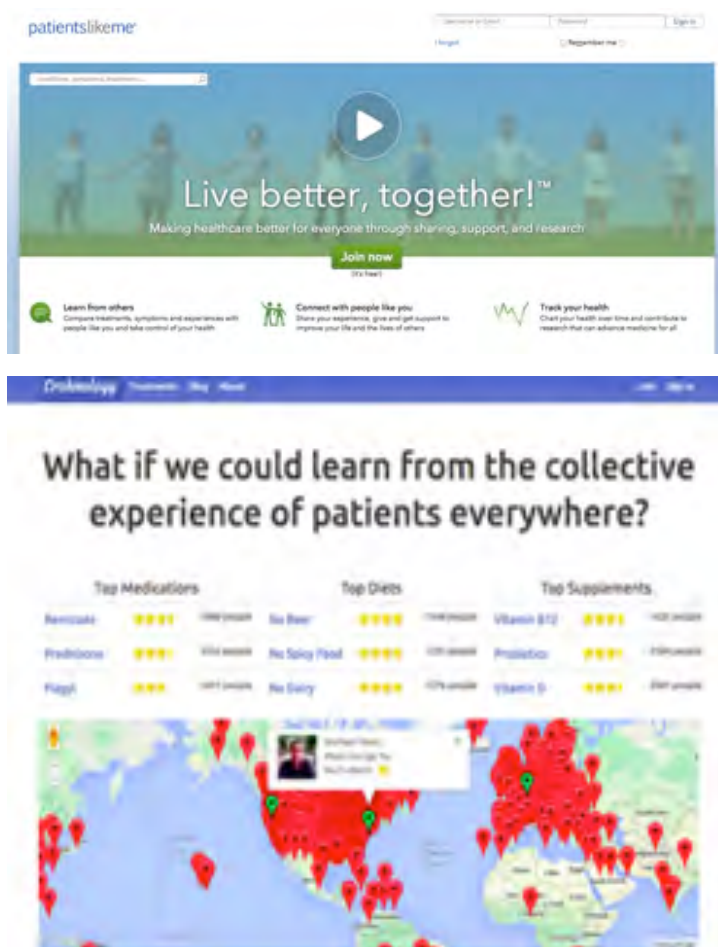


Figure 2. Online Chronic Disease Communities. PatientsLikeMe and Crohnology websites.

and medication regimens, and the emotional or psychological burden that results from living with the disease. This is all compounded by the fact that many people manage their chronic disease in relative isolation, further magnifying feelings of frustration and lack of control.

Mobile health tools to track and support disease self-management

One way that providers and patients have attempted to overcome these challenges and to support chronic disease self-management is through the use of technology to track health indicators and symptoms outside of office visits. Using a variety of digital tools, from clinical decision support software to portable diagnostic technologies or sensors, providers can integrate the information to deliver more data-driven care. Through remote monitoring, providers are able to track patients' symptoms in real time, better prioritize patient outreach, collect patient-reported outcomes, and make medication and treatment adjustments, without requiring an in-person visit. Learning about patients' disease status and experience in between office visits can enhance providers' ability to deliver more personalized care,

which is especially valuable when caring for patients who live in rural settings or who have multiple chronic diseases that may limit their mobility.

Patients also now have many digital tools at their fingertips that have helped transform the way that they are able to manage their chronic diseases. An estimated 500 million people have installed health applications on their mobile devices,⁶ which support self-management, track symptoms and medication use, provide tailored education, feedback, and reminders, and connect with peers through larger social networks. Beyond mobile health apps, more sophisticated tools including wearable devices and medical sensors, such as those developed by Propeller Health (propellerhealth.com), now allow real-time, passive tracking of medication use, symptoms, and other relevant health data, all of which can be shared between patients and their providers. Using these digital health tools, patients are able to monitor and track their condition in a way that positions them as active participants in their treatment plan, ultimately helping to strengthen the partnership between the patient and provider teams.

From the individual to the collective: how data sharing leads to improved understanding and self-management

These types of tools have begun to revolutionize how patients share and participate as active citizen scientists in their own health experience. From websites and patient social networks to blogs and social media, patients now have multiple avenues to learn, share, and gain insight from other people living with the same chronic disease. A recent survey suggests that 80% of Internet users have looked on the Internet for health information, 34% have read about someone else's experience about health or medical issues on a website or blog, and 25% have watched an online video about a health issue.⁷

Online chronic disease communities represent one way that patients have used technology to shift from monitoring and managing their chronic disease in isolation to benefiting from insights generated by people living with the same disease around the globe. In recent years, a number of online chronic disease communities have been created by patients, patient organizations, providers, and nonprofits, which have helped fulfill the informational and social needs of patients and amplified the discoveries and experiences of individual patients in a way that has never been possible before.

One of the most successful online communities, PatientsLikeMe, currently supports 2,500 different disease communities and serves over 350,000 members. Founded over a decade ago, PatientsLikeMe was created to promote information-sharing between patients within disease-specific communities and to provide an online quantitative personal research platform to share patient-reported outcomes, find patients who have similar demographic and clinical characteristics, and learn from aggregated data reports.⁸



Figure 3. Propeller Health sensor and mobile app
Applying digital health tools from the individual to the
community: the value of citizen health scientists in
the AIR Louisville program.

From PatientsLikeMe to many other online communities and platforms, patients are beginning to explore how the health data that they collect can contribute to and help inform research studies. One site in particular, Crohnology, a self-described “patient-powered research network” for patients with Crohn’s disease and colitis, offers patients the ability to ask and help answer research questions and participate in studies.⁹ With over 7,000 patients in 87 countries around the world, Crohnology has helped capture 53,980 years of patient experience—significantly enhancing our collective understanding of self-management strategies for Crohn’s disease and colitis and contributing patient collected data towards a cure. These types of technology-based platforms can enable data collection at a more rapid pace and at a larger scale than traditional clinical studies. In a similar way, the Patient-Centered Outcomes Research Institute developed a national research network, PCORnet, which includes multiple patient-powered research networks that allow patients and family caregivers to help prioritize research questions, investigate their own health experience, and support the dissemination of results.¹⁰ We are only just beginning to see how patient-driven health data collection and research can transform the rate and scope of knowledge creation and rapidly move chronic disease research forward.

The value of digital health tools and asthma

The use of digital tools to collect patient-generated data and to inform health research is gaining particular traction within the respiratory disease community. Asthma, one of the most prevalent respiratory diseases in the country, has received significant attention recently from healthcare providers, public

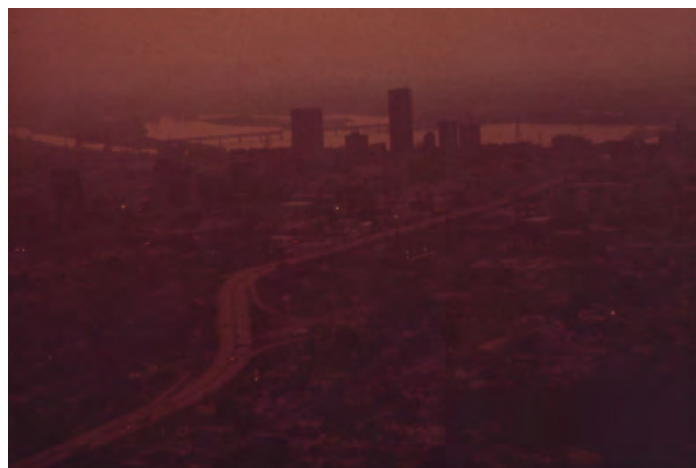


Figure 4. Smog Over Louisville and Ohio River,
September 1972.

health officials, academic researchers, and patients for the opportunity to use digital health to empower patients to improve their self-management, reduce symptoms, and learn more about individual and community level asthma burden. Despite the availability of effective medications and compelling national guidelines, many studies have shown medication adherence rates to be under 30%,¹¹⁻¹⁴ and nearly 60% of adults with asthma are uncontrolled.¹⁵ Poor adherence and the corresponding negative health impacts contribute to \$56 billion in direct and indirect healthcare costs,¹⁶ making it one of the costliest diseases in the country.

This issue is further magnified by the fact that traditional data sources and data collection methods available for asthma management are severely limited in scope, time sensitivity, and functionality. Asthma diaries, which require patients to write down their symptoms, remain the primary mode of data collection, yet are completely dependent on unreliable patient recall. On a population level, reports from healthcare organizations on emergency room visits and hospitalizations remain limited despite the existence of an active and robust National Asthma Control Program. When available, these sources of data are often aggregated at the zip code level, have limited to no geographical information, and typically are over a year old, which limits the ability of public health departments to address local respiratory disease burdens.

In order to combat the variety of data limitations, digital tools have emerged to fill these gaps and to better support asthma management. From SMS-based medication reminder systems to multi-component management platforms that provide education, feedback, and communication between patients and providers, digital tools for asthma management play an important role in supporting patients to track and collect data about their disease status, and ultimately reduce symptoms, improve control, and enhance management. A growing body of literature has demonstrated positive results in self-management and clinical outcomes among patients using digital tools for asthma.¹⁷⁻²⁰

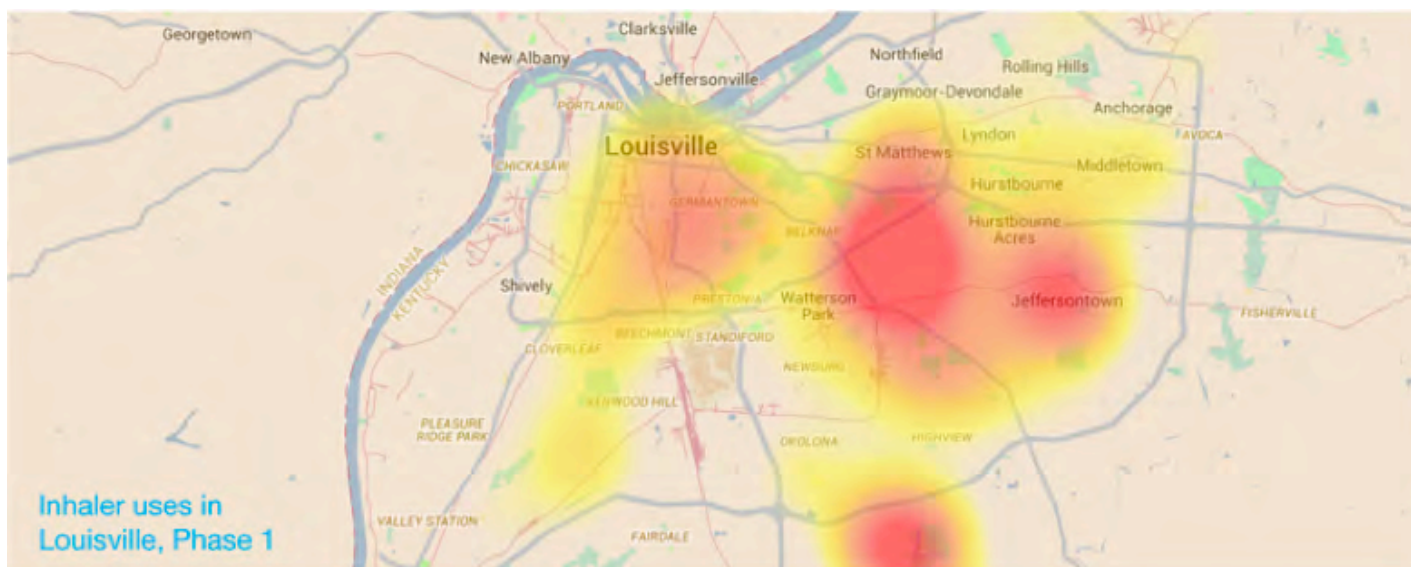


Figure 5. Hot Spot Map of Rescue Inhaler Use in Jefferson County.

With advances in technology, new opportunities now exist to support real-time remote monitoring of asthma symptoms without burdensome diaries and record-keeping. Sensors placed on inhalers, such as those developed by Propeller Health, allow passive, objective collection of when and how frequently patients use their medications. When paired with a smartphone, these sensors can track the geographic location of inhaler use and corresponding weather and air quality data at the time of use. These data can then be transmitted to mobile apps and online platforms, which help display the information and provide insights on patterns of use and associated environmental triggers, all in real-time. By simply continuing to use their inhaler equipped with a sensor, patients now have access to a more complete picture of their medication use and symptom experience. With a tool like this at their disposal, patients have new opportunities to experiment, learn, and discover new insights and trends about their health experience and expand the knowledge of community level asthma burden.

An exciting project in Louisville, Kentucky, has begun to use Propeller Health's sensor technology, paired with the growing citizen scientist movement, and a supportive and forward thinking municipal government, to engage citizens in helping to better understand and address asthma within the community. In recent years Louisville has been ranked in the top 20 "most challenging places to live with asthma" in the US and was named the #1 "Spring Allergy Capital" (AAFA). A whole host of social and environmental factors make Louisville and the surrounding Jefferson County difficult for the residents with asthma. As Louisville sits in the Ohio River valley, pollution from nearby coal and oil-burning industrial facilities and car emissions can accumulate, reducing the air quality and creating conditions that can trigger asthma symptoms. Reduction in tree canopy and rising temperatures also contribute to making Louisville a challenging place for residents with asthma to live, work, and

play. On top of this, a recent health report by Louisville Metro Public Health and Wellness highlights a variety of additional social factors such as poverty and unemployment rates that limit access to healthcare and opportunities to lead healthy lives. The combination of these factors contribute to the high prevalence of asthma in Jefferson County, where over 10% of the population has asthma and asthma is the 4th leading cause of hospitalization.

Leaders in Louisville have grown concerned with the burden that asthma places upon the health, economic vitality and quality of life in their city, and recognize that it is a very important problem that needs to be addressed at the community level. Despite a strong commitment to improve the health of its citizens and to address the larger asthma burden, city leaders have been limited by the data available to track asthma within their community. Currently the city relies upon healthcare utilization data to assess the burden of asthma, however these data only offer information about where and how frequently residents go to the ER or hospital, not where they are experiencing asthma symptoms. In order to better understand local factors that impact asthma, city leaders have sought innovative approaches to collect data in a way that provides a more real-time and precise picture of citizens' experience with asthma. In 2012, the City of Louisville, including Mayor Greg Fischer and Chief of Civic Innovation, Ted Smith, formed a public-private collaboration with Propeller Health and three local foundations including the Owsley Brown Charitable Foundation, Norton Healthcare Foundation, and the Foundation for a Healthy Kentucky, to find out whether an innovative asthma surveillance program that equipped local citizens with sensors to collect real-time data on inhaler use could help improve citizens' daily symptoms and directly inform local policy decision-making.

Working closely with stakeholders across various sectors, this pilot program aimed to engage citizens of Jefferson County



IMPROVE ASTHMA, TOGETHER

Louisville is one of the highest asthma cities in the U.S.
A new community program wants to solve this problem using Propeller smart connected inhalers.

Interested in getting your free smart inhaler?

Receive a sensor for your inhaler

We have a limited number of sensors available to the community at no cost, thanks to generous funding from the Robert Wood Johnson Foundation, the nation's largest philanthropic organization focused on public health.

Sign up above to see if you're eligible for a FREE sensor!

Figure 6. AIR Louisville website. AIR Louisville <https://www.airlouisville.com/>

in collecting data to support their own asthma management, and to help fill the data gap on asthma burden at the community level. Over the course of 13 months, local citizens volunteered to be a part of the pilot program. Citizens were recruited through a number of avenues including Walgreens Pharmacies, community programs like the Family Scholar House, community events such as Healthy Hoops, and specialty clinics like Family Allergy and Asthma. By the end of the recruitment period, 140 citizens had volunteered to use the Propeller sensor for a year. During the year of data collection, the 140 citizens continued living their lives as they normally would—working, going to school, and playing in the community and taking their medication as needed. Each time citizens in the program took their medication the sensor captured the date, time, and number of puffs, and if the citizen had a smartphone, the location of use. These data were presented back to citizens in the form of a mobile application and web-based dashboard, both of which provided information on their current

level of asthma control, medication adherence, personalized education, and the community burden of asthma.

Armed with a passive data collection tool and the analytical capabilities available on the app and dashboard, citizens had a new, data-driven opportunity to improve their asthma management and to support efforts to improve the breadth and scope of asthma surveillance data available in Jefferson County. At the individual level, the citizens in the program became more informed and aware of their asthma—from identifying specific asthma triggers to tracking their medication use—citizens benefited greatly from their involvement in the pilot program. Participants also benefited from the data collection efforts of their fellow citizens who were involved in the pilot program as their data could be shared at an aggregated, de-identified level to show where others in the community were experiencing symptoms. In this way, residents had access to valuable information beyond the scope of their own

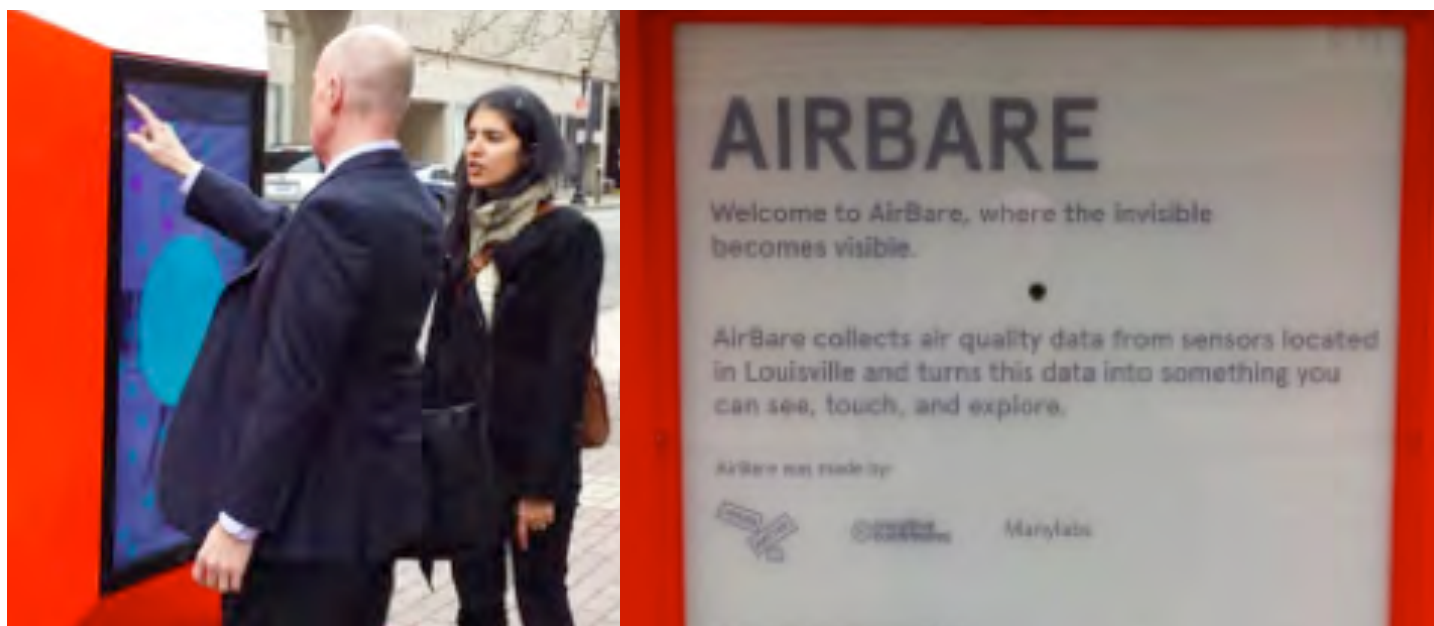


Figure 7. AirBare. Future directions: citizen health scientists contribute asthma data to nationwide efforts.

experience, which could help inform them about environmental risks present in the community.

At the community level, citizens contributed significantly to filling the surveillance data gap. Over the course of the program, the citizens' sensors collected thousands of inhaler use events and tens of thousands of person-days of data. This data collection method has led to the creation of the largest, most detailed database of asthma inhaler use in existence. By combining the aggregated, de-identified data with local socioeconomic and environmental data layers, city leaders were able to see patterns emerge about where, when, and why we see clusters of asthma activity across Jefferson County. Further, the sensor data paired with local data layers allowed city leaders to begin to test associations, identify specific social and environmental drivers of asthma, and ultimately see the great potential these data offer for informing city plans and strategies aimed at reducing asthma burden.

The pilot program's promising results inspired leaders to explore opportunities to expand the program in order to reach a larger segment of the Jefferson County population with asthma. Thanks to a grant from the Robert Wood Johnson Foundation, an expansion of this pilot program, AIR Louisville (www.airlouisville.com), is currently underway with the goal of recruiting more than 2,000 participants, making it the largest citizen-science, community-focused asthma program ever implemented. AIR Louisville involves the City of Louisville, the Mayor's office, the Institute for Healthy Air Water and Soils (IHAWS), Propeller Health, Louisville Metro Public Health and Wellness, the Community Foundation of Louisville, local employer partners, such as Brown-Forman and Papa Johns, local health plans such as Passport Health Plan, and local

asthma specialty clinics, such as Family Allergy & Asthma. The collaborative program is adding new partners every day.

The primary goals of AIR Louisville are to improve citizens' asthma self-management, to reduce asthma-related healthcare utilization and cost, to identify regional environmental drivers of asthma and to use the citizen-generated data to directly influence Louisville's policy-making and intervention strategies. More specifically, city leaders are interested in using these data to help determine where to focus their attention and funding in order to have the most meaningful impact on asthma burden. For instance, using the pilot program data, city leaders in Louisville have begun to explore what the specific impact of improving air quality could be for residents with asthma. How many asthma attacks could be prevented if specific intervention were implemented to address the most relevant environmental triggers in the community? Where should the city plant trees within the county to have the greatest impact reducing asthma symptoms? These questions, among many others, can be explored in greater detail thanks to the aggregated, de-identified data collected through the AIR Louisville program. In this way, this data-driven approach for reducing asthma burden at the individual and community level can offer city leaders new opportunities improve the health and well-being for all of its citizens.

This direct connection between data collection and policy decision-making will strengthen the ties between citizens' health experience and meaningful policy action. Accordingly, using the sensor and corresponding mobile app and dashboard, citizens in this program are able to play a larger role in the data collection and discovery process, both in terms of better understanding their own self-management and gaining valuable insights on drivers of asthma within Jefferson County. The larger community is also



able to benefit from this program thanks in part to the work of AIR Louisville's nonprofit partner, IHAWS, which is distributing a number of micro air pollution sensors across Louisville to capture more detailed data about air pollution levels. These data will be displayed on IHAWS open-source, open data portal to increase transparency and public awareness. A public art installation called AirBare, located in downtown Louisville, combines the air quality data with the citizen-generated inhaler use data to display a real-time look at air quality in the city and how this can impact asthma. Making these data publicly available through visualizations in the AirBare art installation, citizens throughout Jefferson County have the opportunity to become more aware of local drivers of asthma and see the value and insights that citizen-generated data can provide local city leaders.

With the promising results and potential of the program in Louisville, there is great interest in expanding this type of citizen-science, community-focused asthma program to additional locations across the country. Earlier this year, Propeller Health announced that it would build a national Asthma Risk Map for the United States, through which citizens can track how climate change may affect the frequency and severity of respiratory disease. Using the program in Louisville as a model, the company expects to partner with city leaders and local stakeholders to equip residents with sensors to collect crowd-sourced data on the time and location of inhaled medication use in cities around the country. Fueled by the citizen-generated data and using predictive spatial modeling techniques and open government data resources, Propeller Health will aim to identify areas in US cities where the impacts of climate change will likely be felt most acutely by people with chronic respiratory disease over the next 10 to 100 years and beyond. In this way, citizens will not only contribute to better understanding their own self-management and burden in their own community, but also help drive greater understanding and valuable insights related to the health impacts of climate change at a national scale.

Conclusion: promise of citizen science for chronic disease management and prevention

Advances in technology have begun to open the door for broader community participation in tracking chronic diseases. With sophisticated digital health tools in the hands of citizens, we are only just beginning to see the promise of how improved data collection and analysis tools can empower citizens to play a more significant role in informing their own self-management, enriching the understanding of chronic disease phenotypes by sharing their data within patient social networks, and guiding policy action. As key investigators of their own health experience, citizen health scientists are redefining the role that patients can play in advancing the treatment and understanding of chronic diseases, and substantially informing and rapidly moving chronic disease research forward.

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Chris Hogg, MBA, is a digital health advocate interested in how new forms of health data are changing the relationship between physician and patient. As COO, he leads the company's San Francisco office with an emphasis on product, data and implementation. Prior to Propeller Health he co-founded 100Plus, a mobile health company using personalized analytics to promote healthy behaviors, which was acquired by Practice Fusion in 2013. At Practice Fusion he built a data science group that created data products leveraging the company's 80+ million patient clinical database. Prior to 100Plus Chris led the Cardiovascular Commercial Strategy group at Gilead Sciences. Chris holds a Degree in Molecular and Cell Biology from Brown University and an MBA from The University of Chicago.

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For the Love of Trees



Valerie Magnuson
Executive Director of Louisville Grows, Inc.

“When we plant trees,” says Nobel Peace Laureate Wangari Maathai, “we plant the seeds of peace and seeds of hope. We also secure the future for our children.”

In the center of the fastest rising heat island in the United States, in late July, a group of Louisville teens attended the second Youth Forestry Course presented by Louisville Grows. Each participant would be assigned a route of 20 trees that they would commit to visiting twice during the summer months. During their rounds they would encourage homeowners and businesses to take responsibility for the care and maintenance of their trees through conversations and handwritten notes on the back of door hangers: “You’re tree looks really healthy! Please remember to fill your TreeGator (the green irrigation bag zipped at the base of the tree) once a week to help your tree thrive.” They would collect data on 8 indications of tree health such as the absence of mulch, the presence of weeds, soil moisture at planting sites and indicators of tree health such as bark damage, broken branches, suckers and the absence of leaves and enter it into Google Drive. By the end of the training, they would know when a tree needed to be replaced, how to measure soil moisture with a pencil, and communicate informed observations of the natural world to Louisville Grows staff. Citizen Science! This critically important work of volunteer Summer Inspectors allows Louisville Grows to keep detailed records on 1000+ trees planted through the program since 2013.

This Citizen Forestry 102 ‘Summer Inspector’ course was one of many presented through the neighborhood based reforestation program Love Louisville Trees. In 2013, 2014, and 2015 the program trained over 160 youth and adults in tree care,

maintenance, and volunteer management and data collection. In the next ten years, Louisville Grows will train hundreds more Citizen Foresters, and they, in turn, will train thousands of volunteers during planting events. Soon, Citizen Foresters who have completed both the 101 and 102 courses will have the option of becoming Community Foresters who plan and coordinate planting events under the supervision of Louisville Grows staff. The long-term program goal of a Citizen Forester on every block and a Community Forester in every neighborhood would result in the democratization of knowledge throughout the Louisville community. Since each tree planted provides benefits that extend beyond the edge of the yard or street where it’s planted, it makes sense that the work of reforesting our neighborhoods should be the work of the society at large.

During the July training, the instructor paused the presentation to ask why trees are important. The teens were participants in the Advocacy in Action program and had spent the summer learning about the local food system and sustainability as employees of Louisville Grows. “To keep our streets cool and reduce crime? To keep our air clean? To give us oxygen?” Yes, the instructor replied, but there’s more. A study conducted in 1984 showed that patients with a view of nature recovered faster and requested fewer pain medications than patients with a view of a brick wall (Ulrich 1984). Tree canopy coverage is strongly correlated with income levels; lower income communities have lower percentages of tree canopy coverage with serious implications for the health of the children and adults living there (Schwarz et al. 2015). Tree planting in lower income communities can help achieve equitable distribution of urban tree canopy and should be recognized as the pursuit of environmental justice, even if we’re

not talking about justice and equity distribution as volunteers go door-to-door speaking with residents. Instead, the economic benefits of planting a tree such as a 30% reduction in utility costs and a 10% increase in property values are promoted to appeal to resident's self interest.

Louisville Grows incorporated in 2009 and became a federally recognized 501(c)(3) non-profit organization in 2012. In the beginning the organization worked to assist community groups in the creation of community gardens and orchards by providing volunteer labor, funds, sample garden contracts, and garden designs. In 2011, the organization took a leap and signed a 5-year lease with Louisville Metro Parks on a 5-acre property in the Shawnee neighborhood. The former tree nursery became 'The People's Garden' in 2012: a mixed-use urban agricultural demonstration site with orchards, market gardens, 6000 sq. feet of greenhouse space, and a thriving community garden. In early 2013, Louisville Grows signed a second lease on a 1-acre property in the Portland neighborhood to build a community garden, market garden, play space, and peach orchard. That was the year the owner of Limbwalker Tree Service was on the hunt for an organization to make something from a logo design that had been gifted to them by a local design firm. Love Louisville Trees facebook page and t-shirts preceded the program by about one year. Chris O'Bryan had come across Friends of Trees while visiting Portland, Oregon, and had been awed by their capacity to plant thousands of trees with volunteer power. He saw their program as a model for the creation of a similar program in his hometown. When he approached Louisville Grows, the organization was at first hesitant to take on such a large project so early in its development, but the need for increased tree canopy and the potential to get thousands of citizens (and non-

citizens) involved in the effort won them over. No one else was doing the work, and it aligned with their mission to build a just and sustainable community in Louisville, KY through urban agriculture and environmental education. Louisville's first Citizen Forestry Course and Neighborhood Planting Event would take place shortly thereafter in the fall of 2013.

Long standing organizations like Friends of Trees, the Greening of Detroit, and TreePeople provided access to training manuals and Chris used his skills as Certified Arborist and President of the Kentucky Arborists Association to help Louisville Grows adapt them into a training manual for Love Louisville Trees. Soon, twenty-eight residents from across Louisville were gathered in an unheated former army barracks in the center of the Portland Neighborhood to become Louisville's first Citizen Foresters. During the 2-hour classroom portion, attendees learned the basics of tree anatomy, planting, and how to interact with volunteers during planting day events. During the outdoor portion, Chris went through each step of the tree planting demonstration to prepare participants to provide the same



demonstration to their group of volunteers. “Step one, gather your tools....step two, determine your planting location, it should be marked with a white x....step 3, look for BUD flags or markings indicating where the utilities are located.....” Finally, the burlap and wire basket lay in a tangle with tree tag and twine and the future was planted. Attendees took turns leading the others through the planting steps with the next trees with their manuals as guide. When all was said and done, the Citizen Foresters, sporting new long-sleeved Citizen Forester swag, could plant trees and, perhaps more importantly, teach others to plant trees like Certified Arborists.

Louisville Grows Citizen Forestry program and those like it allow residents to work towards a greener, more sustainable future through active participation. The science practiced by Citizen Foresters is practical. Over time the data collected by Citizen Foresters through the Summer Inspector program informs the type of trees planted by Love Louisville Trees. These adjustments happen quickly. Trends are recognized and examined, and the organization might discover that certain species of trees shouldn’t be planted in easements or others do particularly well. Citizen Forestry is science everyone can participate in. In the 2007 Urban Tree Canopy Plan for Louisville, the authors concluded that one of the major limiting factors in the city’s ability to address the tree canopy issue was the lack of community involvement and support, and that increasing canopy will depend on the inclusion of residents and neighborhood associations. The 2015 study of Louisville’s Urban Tree Canopy showed that Louisville is currently losing 54,000 trees per year. In order to reach the 40% canopy target recommended by American Forests, a citywide movement (or, as some have said, a Treevolution) is needed to bring together stakeholders from the most affected neighborhoods, the school systems, funders, NGOs and governmental organizations to work collectively to care for our city’s existing canopy.

The value of ecological resources, especially in urban environments with high concentrations of human habitants, are often ignored or downplayed in favor of development; a few people make a short term gain at the expense of the many. When thousands of trees are removed, taxpayers must either pay to replace the ecological services once provided by the trees for free or suffer the consequences to public health. This Tragedy of the Commons plays out on the global stage and in our local communities, and can only be counteracted with movement building and through participation in programs that work to rebuild and protect shared resources like Love Louisville Trees. Plenty of evidence exists showing the link between tree canopy and human health. When the Emerald Ash Borer swept through Michigan killing millions of trees, researchers saw a spike in deaths from cardiovascular disease and respiratory illness at a rate of an additional 24 deaths per 100,000, or, 24000 deaths (Donovan 2013). If these rates are consistent across state lines, the current loss rate of 54,000 trees per year in Louisville should result in an additional 12,000 deaths annually! In Michigan, this rise in mortality was greater in wealthier populations that had previously benefitted from high canopy percentages in their neighborhoods. In Louisville, the California neighborhood already has the highest rate of heart disease among all Louisville neighborhoods and one of the lowest tree canopy percentage covers for a residential neighborhood at 12.9% (Arno, Rock 2014). More work needs to be done to raise awareness on the link between tree canopy and public health and the services provided by trees in our communities, but the good news is that Love Louisville Trees is already making headway.

A literal and figurative sea change is coming and both are related to climate change. There’s never been a time when Citizen Science was more needed or relevant. Without the broad scale involvement of the general public serving as advocates, stewards, and Citizen Foresters, the canopy in our global and





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local communities will continue to decline. People are motivated to participate out of fear for the future, curiosity, or a number of other reasons, but the greatest motivator of all is love. Love for our children who deserve to breathe clean air, love for our neighbors who struggle to pay their utility bills and suffer from asthma or heart disease, and Love for Louisville's Trees.

The teens inspected a row of Red Maples along Montgomery St. and found an insect was damaging the bark of multiple trees. They noticed a tree planted in a particularly wide stretch of easement was benefitting from the extra space and was much larger than its neighbors. Across the street, a man turned off his lawn mower near a small Yellowwood planted in 2013, and the youth crossed the street to inspect it. After pulling out the weeds they asked the man about the tree. "This tree was planted for my mother who passed. We call it by her name." The teens suggested that the tree might need some water, and waited as the man dragged his garden hose over and began filling the TreeGator. The instructor asked "Why do you think this tree is thriving here in the front yard of this house, while trees of the same species, planted at the same time, are struggling?" "This tree has more room to grow." The youth answered. "And Love."

Valerie Magnuson is a former full time organic farmer and the current (and so far, only) Executive Director of Louisville Grows Inc. The mission of Louisville Grows is to grow a just and sustainable community in Louisville, KY through urban agriculture, urban forestry, and environmental education. Find out more about our work at www.louisvillegrows.org.



Sensor Networks and Community Data: Building Knowledge around Local Air Quality

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Introduction

Over the past two years we have been working with residents and city officials to implement a distributed multi-sensor network to collect real-time data on air pollutants and to share that data with the general public. Air pollutants have significant impacts on human health, yet residents often have either misconceptions or limited knowledge of the pollutants, their causes, and impacts (Committee on Environment, 2013). Our goals have been to improve resident's knowledge and awareness regarding the impact, and how air pollutant levels shift and change based on a number of geo-social variables such as neighborhood demographics, tree cover, time of day, weather conditions, and impervious surface cover. In this article we describe our efforts, the technology of low-cost air quality sensors, the challenges we have experienced, what we have learned regarding residents understanding of air pollutants and what the future may hold for implementing and using low-cost sensing technologies to engage residents in science.

Why air quality?

Air pollution is one of the most serious and widespread environmental threats to urban populations (Cohen, 2005). Level of air pollutants vary among and within urban areas, but all people living in cities are exposed. Infants, young children, seniors and people who have lung and heart conditions are especially affected, but even young, healthy adults are not immune to harm from poor air quality. To evaluate the quality of the air, under the Clean Air Act, the Environmental Protection Agency (EPA) sets acceptable limits, monitors, and regulates air pollutants across the United States using expensive but highly accurate sensors. Six major pollutants are monitored, including ground-level ozone, nitrogen oxides, carbon monoxide, particulate matter, sulfur oxides, and lead. While all six are harmful to human health and the environment, ground-level ozone and particulate matter are the most widespread and of particular concern for human health (Environmental Protection Agency, 2014). The concern regarding the impact of poor air quality on humans has resulted in research that has improved our understanding of the health impacts of exposure to air pollutants. We now know that air pollutants are linked to greater risk of asthma, respiratory

symptoms and disease, cardiovascular disease, lung cancer, and mortality (Environmental Protection Agency, 2014; Sax, Zu, & Goodman, 2013; World Health Organization, 2014). In fact, according to the The World Health Organization an estimated 3.7 million premature deaths worldwide in 2012 were caused by exposure to outdoor air pollutants (World Health Organization, 2014). In recent decades, changes in regulations, technology, and practices have led to improvements in air quality in several large cities (Parrish, Singh, Molina, & Madronich, 2011). In addition, clean air laws and regulations, particularly in the United States, have improved the air quality in most major United States cities, but there remain several pollutants in the air at levels that are harmful to health. In many cases these pollutants are at higher levels in low-income and communities of color. For example, according to the EPA, in 2010 roughly 143 million Americans lived in areas that exceeded the acceptable limits of at least one of the six pollutants (Environmental Protection Agency, 2015). Unfortunately, it is often communities of color and those with low education and high poverty that face the greatest health risks due to elevated levels of air pollutants (Faber & Krieg, 2002).

Rise of local sensor technology

To monitor air quality pollutants, cities have relied on geographically sparse networks of stationary and expensive measurement stations that provide very precise and accurate readings of air pollutants. However, researchers are finding that air quality can vary greatly over relatively small scales since the air pollutant concentration in a specific place depends predominantly on local emission sources such as traffic patterns and local biophysical conditions (i.e. wind patterns, the amount of impervious surface cover, tree cover) (Britter & Hanna, 2003). Consider, for example, the differences in air quality between a local tree-filled park and a bus depot three blocks away. As a result of this variability, the conventional approaches of using air quality monitoring based on networks of static and sparse measurement stations is not very effective at identifying fluctuations in air quality throughout the day. Consequently, most cities are unable to easily identify "hotspots" or areas where a particular air pollutant is problematic. In recent years, the miniaturization of sensors coupled with decreasing cost and increasing popularity of low-cost microcomputers such as Arduino



and Raspberry PI have enabled the development of low-cost air quality monitoring stations. Even though these new low-cost sensors tend to produce lower quality data, they have the potential to be distributed across an entire city. This will allow for large scale spatial data collection at resolution that is impossible with the traditional (and more expensive) stationary sensors.

Pollutant	Measured In
Temperature	degrees Celsius (°C)
Humidity	Percent (%)
Carbon monoxide (CO)	parts per billion (ppb)
Nitrogen dioxide (NO ₂)	parts per billion (ppb)
Dust (Particulate Matter – PM 1.0)	Particle Counts per 283 milliliters (PCs/283 ml)
Ozone (O ₃)	parts per billion (ppb)
Volatile Organic Compounds (VOCs)	parts per million (ppm)

Despite the significant data integrity challenges, the air sensor technology market is rapidly expanding with new sensors that cost anywhere from a few dollars to a few tens of dollars. In fact, the IHS (a leading environmental technology company) has declared that 2015 is the “Year of the Environmental Sensor” (Bouchaud, 2015) with China leading the way. But a significant question remains whether there is value in collecting less accurate data because the accuracy of the data is correlated to how and in what ways these low cost sensors are best used. Despite the concerns regarding low-cost sensors, the idea of ubiquitous sensing is attracting attention from the air quality management community and many urban health professionals (Kumar et al., 2015). As a result of this increasing interest, there are many, small, portable and lower-cost measurement devices using sensors that have entered the market with a wide variety of potential uses including measuring air quality in a neighborhood, school or near sources of air pollution such as highways and industrial facilities where air quality is a concern. For the past two years with support from the National Science Foundation (Grant DUE #1244936), we have been exploring the educational aspects of the data that is collected from these low-cost sensors. Specifically, in this article we report on our work in using one of the larger networks of air quality sensors, the Air Quality Egg (<http://airqualityegg.com/>) sensor network.

Air Quality Eggs

What are Air Quality Eggs?

Air Quality Eggs (AQEs) are devices that allow local air quality to be monitored through the collection and broadcast of sensor data. These devices consist of two separate components that are wirelessly tethered by a Radio frequency (RF) signal. The Data Egg uses a microcontroller, an Arduino shield, to collect air quality information through built-in sensors – at regular intervals – and then broadcasts this information to the Base Egg via an RF signal. Upon receiving the air quality information from the Data Egg, the Base Egg then uses an Ethernet connection – a wired LAN connection – to publish this data on Xively, a website that allows for open data monitoring of IoT (Internet of Things) devices.

What are the pollutants measured by Air Quality Eggs?

For the work discussed here we used the first generation Air Quality Egg. This version of the Air Quality Egg is equipped with a Data Egg that has four built-in sensors to monitor temperature, humidity, carbon monoxide, and nitrogen dioxide. Additional sensors that monitor dust (particulate matter), ozone, and volatile organic compounds can be purchased separately.

What are the strengths and weaknesses of Air Quality Eggs?

The Air Quality Egg is a relatively low-cost device, costing approximately \$180 for the basic four-sensor version, making it affordable when compared to industry-standard air monitoring devices (like the EPA sensors which are thousands of dollars). In addition, the Air Quality Egg provides *local* air quality data for residents through easy online access for data monitoring, collection, or analysis. By using the Air Quality Egg, residents can gauge and identify the extent of air pollution in their neighborhoods in a simplified manner.

However, the relative low cost of the Air Quality Egg also leads to certain disadvantages, particularly when it comes to sensor readings. Variation in temperature can cause an increase in data fluctuations – leading to decreased precision and accuracy – for the gas sensors that monitor CO and NO₂. Furthermore, the Base Egg requires a wired Ethernet connection – for uploading data to Xively – which limits where the system can be placed because the distance between the Base and Data Egg cannot exceed a certain range (this issue has been resolved with the imminent release of the second generation of air quality egg). The placement of the system is also affected by the requirement that an outdoor power socket be available (for the Data Egg).

Limitations of Air Quality Eggs:

During our research with Air Quality Eggs in Boston, we observed certain limitations when it came to providing residents with these devices. While the Air Quality Egg system was easy to setup and use, it proved to be challenging for most people to fully setup the system without assistance (not Plug-and-Play). In addition, the Air Quality Egg system tended to stop collecting and publishing data after a certain time period and had to be reset / rebooted quite often.



As far as monitoring air quality, residents were also confused by the amount of data and options that were available on the Xively website (for their respective AQE system). The Xively website ended up being too technical for residents who just wanted a basic understanding of the level of pollution in the air around them. When residents were able to simplify data, such as viewing it on a map, they often misunderstood or misinterpreted the variation in data across different Air Quality Eggs. It was this concern that led us to develop a set of GIS-based visualizations to support residents in interpreting the data.

Our Project

We provided Air Quality Eggs to community volunteers throughout the city to place outside their homes, schools, or workplaces. The collected air quality data was then transmitted to an open-source website (xively.com) where the data was graphed and manipulated, but most importantly could be downloaded as an excel file for more in-depth analysis and visualization. We knew the GPS coordinates of the data egg collector locations and by coupling their GPS location with the wealth of other GIS data that is readily available such as land cover use, census data, tree cover, economic, and demographic data, our project team used geospatial analysis techniques to create visuals that supported residents in asking questions of the data. For example, a resident could ask: “Does a relationship exist between Ozone levels and tree cover in a particular neighborhood, and if so what is the nature of that relationship?”, or “Does a relationship exist between Nitrogen Oxide levels and income levels and if so what is the nature of that relationship?”, or “Does land cover use impact how Ozone concentrations change over time?”

To visualize the data, the city was divided into sections based on geographic and physical characteristics such as highways, a river, urban centers, and population density. In order to account for variation across sensors and present the data in a visually understandable manner, the readings from the multiple sensors in each section were combined to create an average value for each pollutant in the different sections. The levels were assigned color gradients to create ‘heat maps’ of the pollutants across the city. The maps were then displayed on the front window of a local bookstore through the use of touchfoil technology. A touchfoil is a thin plastic film that is installed on a window and turns the window into a touchscreen, permitting people to manipulate the digital display while standing outside (See Figure 1.) This allowed bookstore customers and passing pedestrians to interact with the air quality data and compare the air quality maps to other aspects of life in their city (land use, tree cover, traffic patterns, read more at: <http://www.fastcoexist.com/3031162/citizen-air-quality-sensors-cover-the-places-governments-cant-reach>).

Drawing on the shift from deficit to dialogue models of science communication (Holliman & Jensen, 2009; Stilgoe, Lock, Simon & Wilsdon, J. (2014), the touch foil display did not present the project teams’ analysis of or conclusions drawn from the data. Instead, basic information was provided on the science

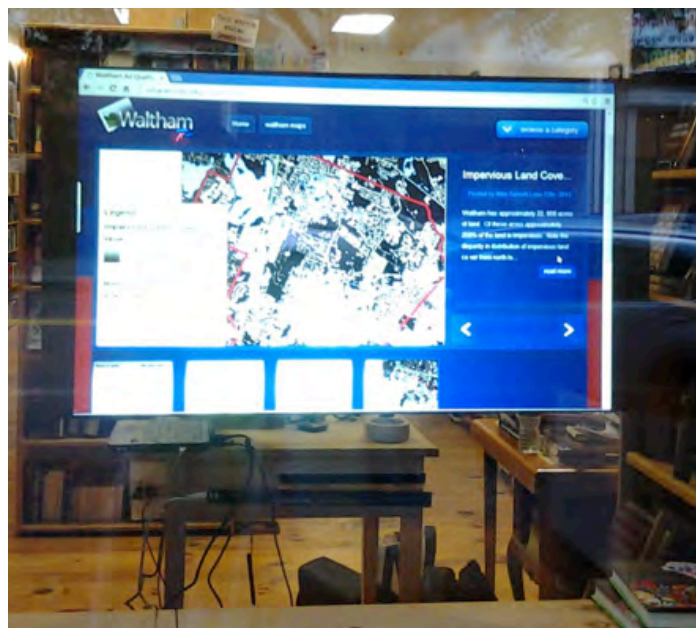


Figure 1: Touchfoil on bookstore window.

behind the data (i.e. what the compounds are) and how to read the maps, and guiding questions were offered to encourage users to make their own comparisons and draw their own conclusions from the data. Additionally, quiz questions embedded in the display asked users their opinions about air quality in their city, whether they thought anything should be done by the community related to air quality, and what they thought any actions could be.

While the technology does not yet allow for free response or message board style dialogue (typing on the touch foil is prohibitively difficult through typical double pane glass), it was our hope that providing access to the data and drawing on users’ expertise on life in their community would encourage dialogue around the issue of air quality and how to take actions to improve air quality. Future iterations of the project will ideally include the ability for users to add local knowledge to the maps (i.e. “The sequence of traffic lights at this intersection makes it so cars have to wait for a long time to get through... maybe that contributes to the higher levels of pollution in that area”) or make suggestions for improving air quality in particular neighborhoods (i.e. “There’s some open space around this parking lot where bushes could be planted to increase green space”).

Locally based, locally used data

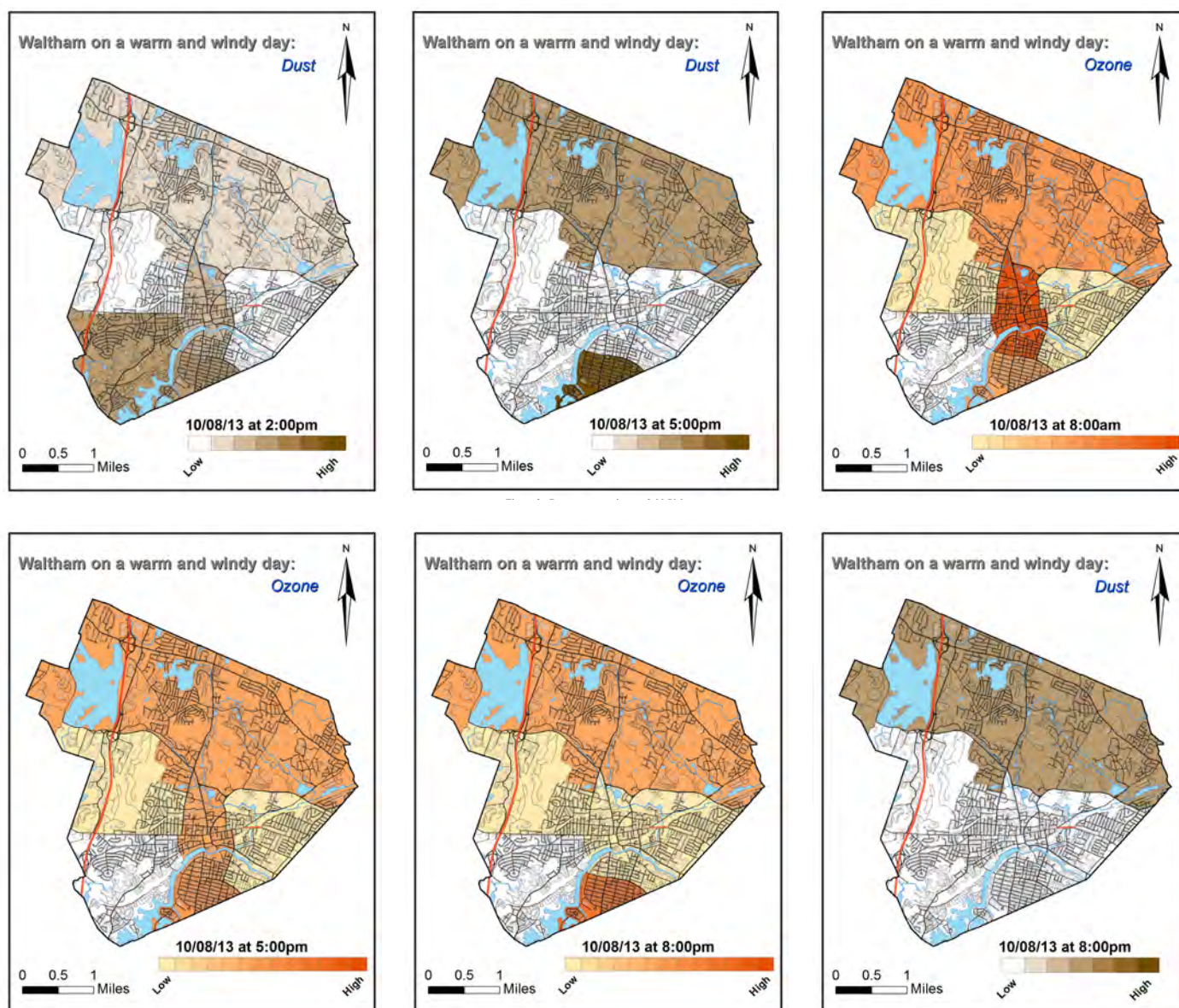
Our project was similar to typical citizen science projects, in that community members were engaged in collecting and contributing data to a larger project, but the purpose, nature, and use of the data were somewhat different than is common in citizen science projects. The term ‘citizen science’ refers to “public participation in organized research efforts” (Dickinson & Bonney, 2012, p. 1) around science topics. In a typical project, a research question is identified, methods of data collection determined, volunteers sign up to collect data, then the data is



analyzed by scientists and published in the scientific literature. These projects have a long history in the United States, with the Audubon's annual Christmas Bird Count—run every year since 1900—representing the oldest continuous project (National Audubon Society, 2013). Initially projects focused almost entirely on the science, though in recent years projects have begun to include goals related to education, scientific literacy, attitudes towards science, and public participation and engagement with science (Trautmann, Shirk, Fee, & Krasny, 2012). Although there is a great deal of variation among projects in terms of scale, topic, and degree of public participation (Bonney et al., 2009a), in most projects members of the public contribute time, energy, and data towards the ultimate goal of building scientific knowledge (Dickinson & Bonney, 2012).

In contrast, the goal of our project was not to create a data set for the purpose of building scientific knowledge, but rather to foster engagement and dialogue among community members

about the air quality in their community. The variations and inaccuracies of the data from the low-cost air quality eggs, compared to the higher-cost, high quality sensors, make the data less useful for monitoring or researching air quality. However, while the data from the air quality eggs cannot give precise readings on the levels of pollutants, the relative highs and lows across the city can spark discussion around which areas in the city experience higher pollution, as well as potential causes or methods for improving local air quality. This project is grounded in both the Participatory GIS (geographic information systems) movement (Jankowski, 2009) and the rising interest in citizen participatory sensing (Kuznetsov & Paulos, 2010). These two initiatives revolve around the concept of engaging the public and eventually leading to the public's participation in the use of data for increased community involvement in issues that impact their lives. The visibility and availability of data may initiate conversation around local air quality, but community members





investment in and knowledge of their community are necessary to generate knowledge building, motivation, and action around improving local air.

Learning, Design, and Outcomes

Our research agenda drew heavily upon the recent work of Bevan and Michalchik (2012) in that we explored how and in what ways community members interacted with and learned from their participation in the project. According to Bevan and Michalchik, the developmental features of an informal science learning experience are critical to what a learner takes away from the experience. Complementary, the literature on museum learning represents the most coherent body of free-choice science learning research to date (Falk & Dierking, 2012). This research base has been extremely important in helping the field move forward around what engages people in informal settings. However, there is a gap in the research on technology-based, free choice learning among adults (Haley, Goldman, & Dierking, 2005), due in part to methodological obstacles in conducting research on a “non-captive” audience (Falk & Dierking, 2012). In the research portion of our work we focused on how community members participated in the project. This focus fills a gap in the existing research literature and, we believe, provides us with insight regarding which aspects of the project were effective at fostering engagement and dialogue.

A core aspect of our work has been an examination of what residents are learning when they interact with the visualizations. To this end, our primary research questions were:

1. What do residents learn about trees and air quality content as they interact with the touchfoil content?
2. What were the primary reasons why a resident participated in the project and why did they stop and interact with the touch foil or host an air quality data egg?
3. How are people using the touchfoil to interact with the data?
4. What do people think or talk about related to their local air quality while using the touchfoil?

To explore these questions we conducted observations of people using the touchfoil and interviews with users and egg-hosts. Additionally, we embedded quiz questions in the touchfoil interface asking users about their knowledge and beliefs related to air quality.

One of the first touchfoil installations was on a busy street in a diverse area with many restaurants with the surrounding area being predominantly Hispanic. We have had 512 quiz results submitted from 450 distinct users (however, it is difficult to tell how many of the users are repeat visitors other than through extrapolation using our observations). We also have 55 residents

who are currently hosting air quality eggs through the Boston metropolitan region with 30 of those residents in the same town as our first touchfoil location. It is these 30 residents who have been most active on e-mail, attending talks at the bookstore and encouraging others to visit the touch foil. With these numbers in mind we briefly describe our outcomes and what we have learned regarding the implementation of the program.

What have we learned?

Through our internal research and external evaluation we learned that: (1) residents consider air quality a very important environmental issue and value learning about it but are not sure about the nature of air quality problems and how the different pollutants impact human health, (2) residents’ interest was focused on what the air quality was around the place they live. In fact, as of this writing we have 50 residents hosting eggs at their home and 45 of them noted that they wanted to know what their children were breathing, (3) the touch foil technology was a draw to attract residents to learn about air quality because it was a “cool” piece of technology but more importantly we have found the maps and visualizations were the key in sparking discussions around why various neighborhoods had different levels of pollutants.

Finding 1: Residents are deeply interested in the quality of their air but have little knowledge of what causes air pollution or the primary sources of air pollution. They wished to not only improve their own understanding of air quality but wanted to contribute to a larger project to improve the collective knowledge of air quality of their community. For example, of the 350 responses to the question: “Have you heard of ground level ozone?” only 50 users responded with yes, 25 thought they had heard the term before, whereas the remaining responses were negative.

Finding 2: Residents were primarily interested in learning about air quality in the places they live, and wanted to spread the word about local air quality. The principal driving factor for participation in the project was that they simply wanted to know what their children were breathing as noted in this e-mail:

I am excited to host an egg. I live on a busy street on the south side of the city and didn’t give much thought to the air till we had children and now I worry about what they are breathing and would like to be able to help and lead a program to clean up the air.

In essence, many residents are envisioning the project as a way of getting the word out to their friends and neighbors through the touch foil about the quality of the air. This is an interesting result in that the residents who are hosting eggs are basically the data collectors but they see themselves as critical and central to the process with their data potentially leading to action because their data is public.



Additionally, what is unique regarding the touch foil interface is that nearly every user that was observed approached the touch foil alone and interacted with the content without interacting with others. However, in many of our interactions with users of the foil they would note that they were going to go home and share what they learned with their spouse or roommates and tell them to visit the foil to “play with the data”. This also played out on social media as after each time the foil was turned on, the number of social media posts related to the foil increased. These posts focused mostly on sharing something they read on the foil about air quality and most included a comment about “how cool” the technology was. In addition, our external evaluator found that residents who had visited the foil or were hosting an air quality egg had told, on average, nine other people about the project.

Finding 3: Residents who visit and interact with the foil are first drawn to the technology but manipulate it due to the topic. What has been particularly surprising is how much time users spend answering the quiz related questions. Generally we are finding that users are spending approximately 4 to 5 times longer when they engage with the quizzes than when they look at other parts of the interface. Residents spend an average of three minutes interacting with the images on the foil but considerably more time when posed questions about the data. This is in contrast to what recent research suggests is the typical family time spent at a science exhibit (Kiesel, Rowe, Vartabedian, & Kopczak, 2012). We are finding that the technology, coupled with an engaging content area does create a context in which a resident’s attention is focused, which can set the stage for deeper analysis by the resident and discussion with others later. In terms of visual design, we have learned that residents find it difficult to interpret layered data on the foil but by comparing and contrasting visuals side by side and creating a pathway for residents around environmental conditions, they were better able to interpret the results. However, as time progressed and we placed additional touch foils in libraries and grocery stores we learned that the calibration of the touch foils were too time consuming for the businesses. Adjusting to this challenge, we shifted to a large touch panel which only required the owners of the stores to turn it on. This approach proved considerably more successful and was easier to use for both residents and touchfoil hosts.

Challenges and the Future

It is a particularly exciting time for residents and urban dwellers as new technological developments in environmental sensing open up opportunities to examine the environment in ways that up to now were either too expensive or too difficult due to lack of data. However, this excitement should also be tempered because of the number of technical challenges that still need to be solved. One of the most important is the reliability of the measured air pollution data. To date, our experience with the air quality data shows that levels fluctuate significantly over the course of a day and as a result the data needs careful analysis to

determine if an event was real or an artifact of the lower quality sensors. Another challenge is that most low-cost sensors have a limited life span which is usually on the order of a few months to at most a few years. There is current work being undertaken to better understand the hardiness and longevity of the emerging low-cost sensors but there are a number of uncertainties (i.e. battery life, calibration time, lifetime under different weather conditions). However, perhaps the biggest challenge is how to help the average person understand the data that these many sensors are collecting. For example, much of the data is still fed to servers and websites that are best navigated by people with a high level of comfort around exploring and manipulating large data sets. However, the typical resident is most interested in the air quality around them and is most interested in having access to a very easy to use interface that shows air quality in real time and how it is changing so they can plan accordingly. Lastly, if the field is to mature and truly become participatory in nature we will need to determine ways that residents can provide ground-truthed observations and data in a way that complements the voluminous data from a ubiquitous sensor network. Only by engaging the residents where the sensors are placed and giving them a sense of ownership over the data will the data become useful for policy and planning purposes. If residents are not fully engaged, the data is likely to become part of a large data repository which has value, but that value is limited.

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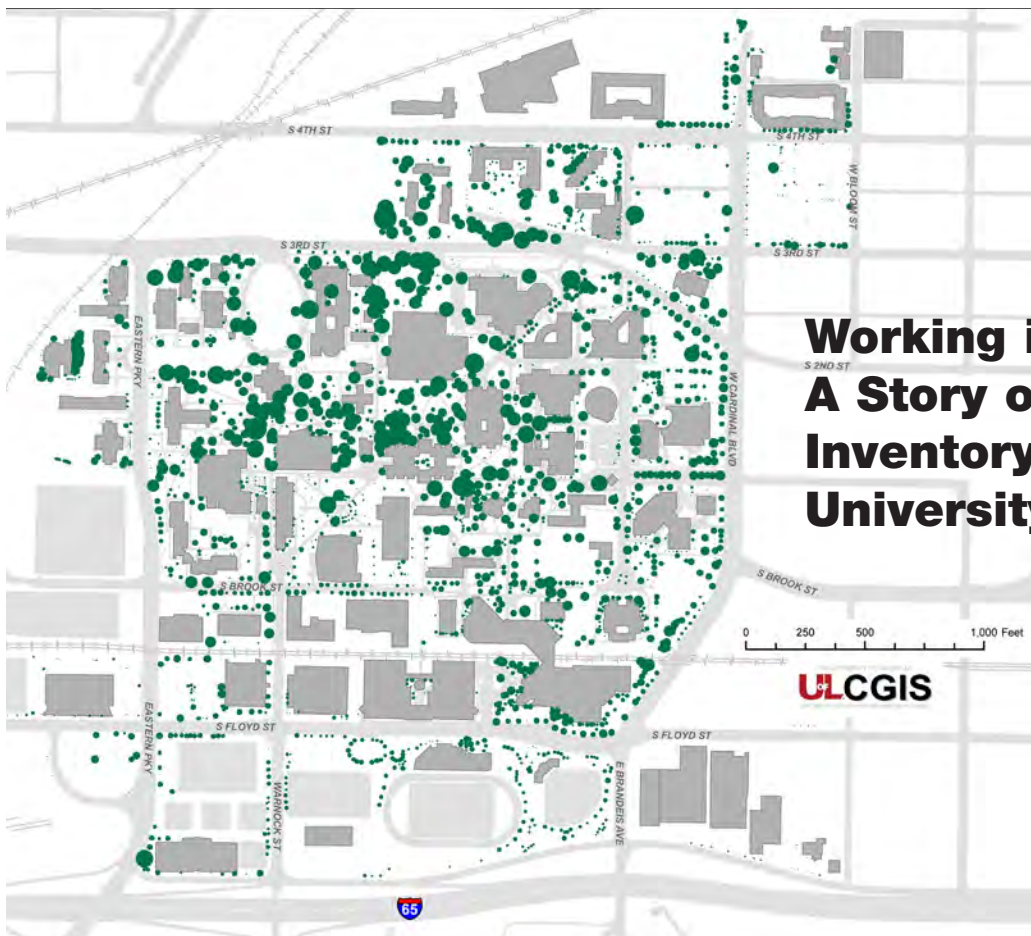
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Working in the Forest – A Story of Campus Trees: Inventorying Trees at the University of Louisville

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The Belknap campus of the University of Louisville is located in the heart of Louisville, Kentucky. The majority of the 22,500 students attending and 6,800 faculty and staff working at UofL (2014 Factbook) use this campus. This 274-acre campus contains seven colleges, associated classroom and administrative buildings, four dormitories, as well as the Rauch Planetarium and Speed Art Museum. Ten student housing complexes surround the Belknap Campus, with four more in progress. All intramural and many university athletic fields also lie adjacent to Belknap Campus.

This story is not about the campus buildings, though, but about the trees that surround them. One will find as much variety in trees on UofL's Belknap campus as anywhere else. Over 2,400 trees and 130 tree species make up this urban campus forest. This urban forest ranges from majestic Oaks standing over 100 feet tall in the center of campus to the horticultural varieties of Redbuds and Cherries recently planted around dorms and athletic parks.

Trees serve very important ecosystem functions, and in an institutional setting where people are in high density, trees can have profound effects on their lives. Not only do trees provide Oxygen, but also cooling shade for people and even buildings. Trees help generate breezes and reduce erosion from rain and runoff. They also provide many psychological benefits, helping to reduce stress and improve overall mood.

In an effort to better understand the trees making up UofL's urban forest, I recruited undergraduates attending the University of Louisville to help me complete a census of all campus trees. This work began in the fall of 2010 as a citizen science project, and is still going on in 2015. The University itself has supported this survey, and the Physical Plant, Biology Department, Geosciences Department, and Center for GIS all have contributed to and will continue the survey project. In 2010, UofL sought and was awarded Tree Campus USA status. This project was begun independently but quickly was brought under the oversight of Campus Sustainability.

Initial Campus Tree Survey

The survey of campus trees started in the fall of 2010, with students from Dr. Parker's Environmental Biology course and his lab, where I was research coordinator. The students were able to gain class points for engaging in this citizen science project. I trained each student volunteer in how to measure a tree. The techniques taught included standard Diameter at Breast Height (DBH; 4.5 ft. from ground) measuring and measuring canopy width across two perpendicular axes with a counting wheel. The biology undergraduates in my lab were also taught these techniques, along with the use of an altimeter to measure height of a tree and basic tree identification skills. Some Environmental Bio. students who showed a high degree of interest were also taught basic tree identification skills.

Tree Facts

- Trees recycle oxygen, and help remove air pollutants (Escobedo & Chacalo, 2008)
- Trees shade buildings and help generate wind, reducing cooling costs (Akbari, 2002; Sawka, Millward, McKay, & Sarkovich, 2013)
- Trees help reduce stress and improve mental health through increasing the 'naturalness' of an area (Grahn & Stigsdotter, 2010; Taylor, Wheeler, White, Economou, & Osborne, 2015)
- Trees increase the property value of homes in most cases (Pandit, Polyakov, Tapsuwan, & Moran, 2013)
- Most people feel we need trees, want trees around them, and feel cities need more trees (Camacho-Cervantes, Schondube, Castillo, & MacGregor-Fors, 2014)

Groups of 3-5 Environmental Biology students were led by someone from my lab, and I supervised all groups. Each group contained one person who collected all data on simple datasheets. We created time slots for Env. Bio. students to show up, based on my availability and the availability of people in my lab. This meant that for some time slots as many as 3 groups were active at once, all working in the same area. To prevent duplication, all trees were marked on maps provided by the Center for GIS and enumerated by a senior lab person or myself. Then all trees were flagged ahead of active groups and flags collected once a tree was surveyed, with flagging reused when possible.

Each group divided labor, so one person collected DBH, one or more did canopy width, and one person collected the data. The group leader measured tree height. Individuals were able to participate in all roles, and those interested in learning tree identification helped me ID trees as I supervised. Lab undergraduates entered all data into an excel database. Approximately 25 Env. Bio. students and 4 undergraduates from my lab helped measure, map, and identify 1,102 trees on the central Belknap campus over two semesters. Once all data was entered, I worked directly with some students both from the spring 2011 Env. Bio. class and my lab to perform measurement checks and assure all data collected contained the smallest margin of error possible.

I also wanted to discover more information about our campus forest, so I sought out formulae to calculate other factors. As we did not collect core samples from any trees to determine age, some values were unavailable. But I inserted formulae for calculating green and dry weight of a tree, and calculated the amount of Carbon in each tree as well as the amount of CO₂ sequestered over a tree's lifetime. I also calculated a horticultural value for each tree, using the method pioneered by David Nowak (1993, 2002).

Expanding the Scope

The next step in this process was to expand our influence, and incorporate more interested parties. We had already made initial

contact with the Geosciences department which provided us with detailed maps of campus. Geosciences and the Center for GIS had a strong interest in the tree project, as well as building a stronger partnership. This partnership created more opportunities for undergraduate volunteer efforts immediately and into the future.

Once we had measured and verified all trees, we contacted Geosciences professor and Center for GIS director Bob

Forbes, who had been our previous contact. Bob then identified undergraduate volunteers from one of his classes to collect GPS points for all 1,102 trees surveyed. We provided him with our maps to coordinate tree numbers, and all trees were GPS'ed over the summer of 2011. These data points were linked with all the data in GIS, and an initial Google Earth layer was created to demonstrate the tree survey.

The next group I established contact with was grounds management. Grounds management, a part of the Physical Plant, is responsible for planting all new trees and works to maintain mulching schedules and disease/pest treatments (like the emerald ash borer). They typically engage in two planting cycles each year, working to increase the size of the campus forest and replace any lost trees. In the summer of 2011, they provided planting maps and species lists of newly planted trees. Biology major volunteers, as part of my lab, helped add these new trees to the existing database, and in the process we established a partnership of mutual benefit with grounds management. This addition involved numbering the new trees, then obtaining height and canopy width. Each was purchased at a standard DBH, and we knew the species from the planting list.

Biology and non-biology major volunteers worked to maintain the surveyed areas of campus through the spring of 2012. The tree survey became a continually updated project, and was used as a platform to teach others both how to measure and how to identify trees. This citizen science project began to gain more interest and momentum, and helped the Campus Tree Advisory Committee to better understand and manage UofL's trees.

Second Campus Tree Survey

Up to this point, the tree census had only focused on the main body of the Belknap Campus, and had not tallied many of the surrounding athletic parks and off-campus dormitories. So, once again in the fall of 2012, Environmental Biology students were asked to contribute time as citizen scientists. So began the second phase of the tree survey. In total, an additional 20 Env.

Biology students and 6 undergraduates from my lab contributed time mapping and surveying trees as well as recording data. The training process occurred much the same as the first time, although this time around the lab undergraduates were able to do a bit more.

The second phase of the tree survey continued through the fall of 2012 and spring of 2013, adding all the athletic and dormitory buildings around campus. The first step was mapping all the trees in new areas of campus. This posed a much greater challenge due both to the greater density of smaller trees, as well as to the fact that areas surveyed were much further apart. The new areas were broken into four chunks, representing the four sides of campus. Each side had a crew tasked with completing that region, and when finished, each crew double-checked the work of the other. Mapping involved using paper maps to locate and number each tree on-the-ground, looking at the trees and creating appropriate spacing and placement.

After all trees were located and subsequently numbered, surveying began. The same information was collected as before; DBH, tree canopy width along two axes, height, and species ID. During this new survey it was much harder for me to stay with the teams, as they were further spread out. To remedy this, I worked directly with a few of my lab undergraduates and 4 Env. Bio. students to measure a subset of trees. I used this as a more rigorous training opportunity to develop team leaders that could operate independently. All of the volunteers received more background information into sampling theory and methodology to create a stronger understanding of the technique, as well as more detailed measurement parameters. Each of the four Env. Bio. team leaders was assigned a side, and my lab team leaders were available for any side. Several Env. Bio. students stayed on with the project into the spring of 2013 after their class was over to help complete as much of the second phase survey as possible.

Biology undergraduate volunteers worked in the spring of 2014 to finish the second phase of the survey. These were students who joined my lab just to work on this project, either for research credit or simply for experience. A biology intern, Jordan, worked in the summer and fall of 2014 to conduct a re-tally of all campus trees to add any newly planted trees and account for removed trees. During this time several extensive construction projects mandated the removal of over 60 trees. They also incorporated new dormitory developments and measured trees in areas previously inaccessible due to construction. The new total tree count included over 2,400 surveyed trees.

Over 45 undergraduate non-biology and 10 biology majors participated in this citizen science project. From the initial survey in 2010 to the final tallying in 2014, citizen scientists contributed more than 4,000 hours of work at all phases of the project. While this project took much longer than if a professional company had surveyed

campus trees, there was no associated cost to the University (saving an estimated \$19,000). The project itself served as an educational tool, and as a platform to promote environmental awareness and stewardship. The value of this project to the students was an added benefit of doing this survey project.

Supporting the Tree Survey

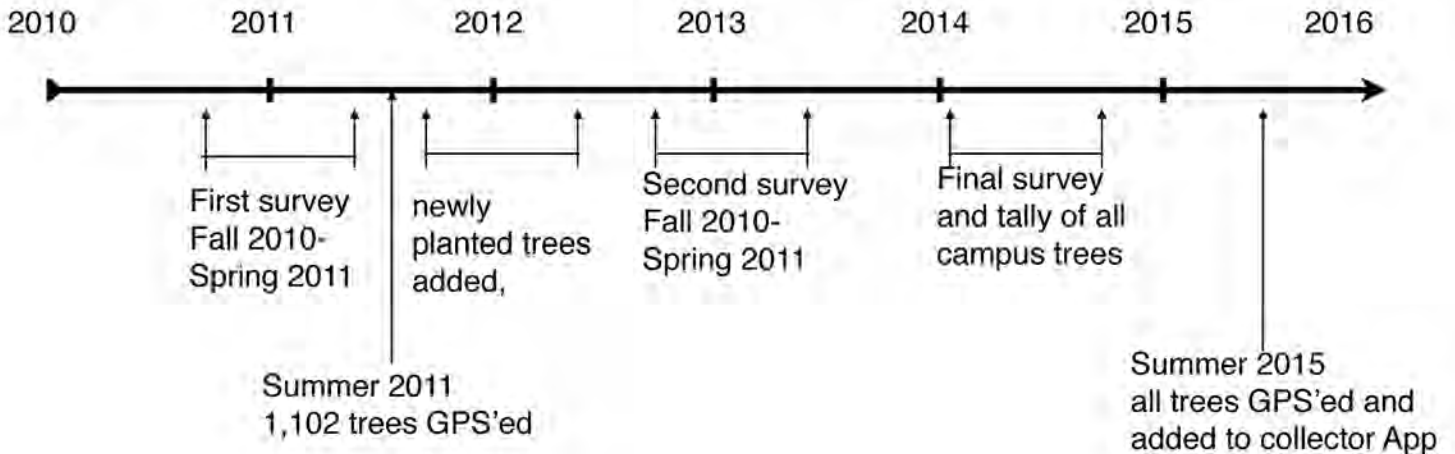
During the process of surveying trees around campus, we also worked to develop other methods of showcasing the tree database and creating outreach tools. One of these mechanisms was the creation of a phone App. In the spring of 2012, four Computer Engineering and Computer Sciences (CECS) seniors chose to help create a Tree App for their senior Capstone project. These four students worked directly with me and Dr. Parker on App design and functionality. The inclusion of these engineering students brought the citizen science project to the next level. This initial application, named the Tree Research Education and Exploration (TREE) App, provided a Google Earth-driven platform where anyone could locate a tree based either on the tree number or the physical location of the tree. A user could see all the information gathered about the tree, including some basic phenological components.

To support this App, we found a student volunteer to collect data on each tree species. This volunteer identified if each tree species was native to Kentucky or the US, and if an alien species, identified its native range. I also taught this volunteer how to determine which parts of the year leaves and flowers emerged for each species, and what kind of fruit or seed each tree produced. All of this information was collected for every tree species, and linked with each tree of that species in the database which in

Historical Trees at UofL

Historical trees are clippings or propagules from trees growing at historical locations or tied to historical figures. They often represent very old trees.

- Harper's Ferry Flowering Dogwood
- Clara Barton Flowering Dogwood
- Robert E. Lee Chestnut Oak
- Isaac Newton Apple Tree
- Rutgers Hybrid Dogwood



turn is displayed for an individual tree when selected through the TREE App.

This App also contained a backdoor component for working with grounds management. The App created a portal through which each tree could have all mulching, trimming, fertilizing, etc. documented as to date and time, by whom, and with comments. Since the App was to be made available on the Android market, all grounds crews could use their phones to accurately record data on each tree as they worked. Crew leaders and the grounds superintendent could also see what trees each crew worked on and how long it took them to more efficiently plan future work. This metadata function of the App was designed to increase efficiency, save money and resources. Grounds management could use the feature of this App to more accurately care for the campus forest and manage resources.

The TREE App created a multi-user interface that connected the general public, tree research, and grounds management in an effort to increase public knowledge of the campus forest, while also increasing institutional knowledge of the campus forest. Unfortunately, when the Capstone project ended, the App was not complete. Enter the Geosciences Department.

Geosciences and Department for GIS

But not all was lost; interest in the App's functionality remained strong. Bob Forbes, the Director of the Center of GIS, was responsible for the initial GPS data point collection through his undergraduate volunteers. He remained involved in the tree survey project through the Campus Tree Committee, as well as through map contributions and general interest. As he and I discussed the future of the tree survey, we realized Geosciences was a natural home for the database, along with Biology. And Bob thought he could find a way to create a new App. We started by making sure all surveyed trees were added to GIS.

Once a third and final set of maps were completed and checked over in the fall of 2014, I provided Bob and the GIS

department with all of my maps for conversion to GPS points. At this stage, only the original 1,102 tree had GPS points, and the rest of the 2,450+ trees surveyed were marked as numbered points on paper maps. Geosciences students worked by hand in GPS to accurately add each new data point to the tree survey database. The Center for GIS employed two students to manually add each point in AGIS, adding to the original tree database layer. This task was completed through the spring of 2014.

In the summer of 2014, I worked with the two Center for GIS students, Faye and Fernando, to assess the completed map and address any errors inherent to this kind of work. We resolved all issues they had noted through the process of adding the trees, and made sure all the numbers matched up correctly with tree information. Some of this work required going on campus and checking the location of trees, as well as species and size. Over the course of the summer, all tree numbers were linked with their respective data and a completed map took shape in GIS.

Concurrently, DJ Biddle in Geosciences had created a new collector App. Collector for ArcGIS is an App-based map service through ESRI, which DJ had used for other projects. This collector App features much of ArcGIS's functionality in an easy-to-use interface, and can be customized for specific tasks and applications.

Our Collector App uses the tree database I constructed enlisting Environmental Biology student volunteers, volunteers in my lab, GIS graduate students. The collector App allows for new trees to be added as they are planted, and trees to be removed from the database as they are removed in real time. Nearly all the features and functionality of the original App will be included in this new App, with a more user-friendly interface. The App will be available to anyone who wants to explore the campus forest. Maintenance crews and others conducting research on trees can add or modify columns to log any information for trees, creating an ever-evolving database that pays homage to the work of citizen scientists.

Top 5 trees on the University of Louisville's Belknap Campus, by weight. DBH represents the diameter of each tree at ~4.5 feet. Green weight incorporates the weight of all roots, leaves, branches and the trunk. Dry weight removes the weight of water, based on % water content of each species. Tree values are based on Nowak (1993, 2002). Parentheses next to values represents position in top 10 rank for each tree.

Species	DBH (in)	Height (ft)	Canopy Diameter (ft)	Green weight (tons)	Dry weight (tons)	\$ Value
Pin Oak	65.24 (3)	115.0 (3)	58.9	87.69 (1)	65.33	51,995.00 (5)
Shumard Oak	62.52 (5)	115.0 (2)	75.5	79.55 (2)	59.27	49,867.00 (7)
Black Oak	54.84 (10)	125.0 (1)	86.7 (3)	66.53 (3)	49.57	43,910.00
Northern Red Oak	63.96 (4)	84.4	84.9 (5)	61.11 (4)	45.52	50,870.00 (6)
Northern Red Oak	54.96 (9)	98.3 (7)	80.6 (9)	52.6 (5)	37.93	44,010.00

Additional Tree Survey Projects.

Along with the current tree database and the Collector App, I also worked with Erica Walsh, UofL's Marketing Manager, to create a tree tour of campus. This tour highlights some of the most impressive trees on campus, as well as trees with historical significance (InfoBox 2). The tour meanders around the Belknap campus, allowing tour-goers to experience all the campus has to offer. This tour is available online (<http://uoflblog.com/tree-tour>), and is used by student visitors as well as by those interested in campus goings-on to delve into another aspect of the University of Louisville.

Dr. Linda Fuselier, a Professor in the Biology Department at UofL, is also using the trees on campus for citizen science. Dr. Fuselier conducts a session in her lab for non-biology majors that collects information about trees on campus. We used the tree inventory to identify multiple representatives of about 20 species, and I created basic information sheets for each species. Groups of students are presented the species sheets and get to pick two species to collect data from. Students then collect phenological data such as if leaves and flowers are present/blooming, is fruit present, etc. This data is entered into an online database (https://www.usanpn.org/natures_notebook). This lab is repeated every semester, and continues to build on our knowledge of campus trees.

Bill Persons received his B.A. in Organismal Biology from the University of Louisville in 2010, and continued on at UofL as a Doctoral Student. Bill has served in the capacity of a Graduate Teaching Assistant, teaching Introductory Biology labs for both majors and non-majors. His doctoral research has focused on habitat selection of White-footed Mice (*Peromyscus leucopus*) in an urban park, and the impact of the invasive shrub Amur honeysuckle (*Lonicera maackii*). He successfully defended his dissertation in July 2015 and is working to finalize his written dissertation. The tree survey started out as a side project, but over the years has become almost as much of a focus as his dissertation research. Bill is married with a young daughter, and plans to work as a naturalist or wildlife biologist before returning to teach in academia.

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Butterfly and Moth Collecting: A Great Example of Citizen Science



Charles Covell

When I moved from Ohio to North Carolina in my 8th grade year, I already had the “collecting bug,” but was not a “bug collector” until a boy in my new Scout troop showed me the colorful butterflies on dressmaker pins that he had in a foot locker. To the possible disappointment of my philatelist father, I immediately changed from a budding stamp collector to an amateur lepidopterist. At the time, and for some time after, I did not think of myself as an amateur scientist but an avid collector vying with my friends - now three in number - for new species to add to my growing cigar-box collection. These were beautiful objects to catch, spread, identify, and arrange for others to see. During early high school years, this pursuit took the place of “cruising,” which occupied some of my classmates. This hobby might have burned itself out were it not for a visit to the United States National Museum in Washington D.C. while visiting my grandparents in the summer after my passion for butterflies began.

An article in a 1927 issue of *National Geographic Magazine* (Showalter, 1927) informed me that a huge private collection of butterflies had been acquired by the National Museum. I assumed that this collection was on display, and so was keenly disappointed when I arrived only to find there were no butterflies on display at all. None.

A guard explained that the collections were kept in office areas where curators cared for them and used them for research. The guard called Mr. William D. Field, the curator of butterflies, and arranged for me to meet him and see some of the huge collection of butterflies held in cabinets behind locked doors. As Mr. Field and I became acquainted, I took the next step necessary in becoming a scientist: learning to prepare specimens on special thin insect pins and adding a small label telling where, when and by whom the specimen was collected. “Without data, the specimen has no scientific value,” he told me. He also encouraged me by giving me a couple of glass-topped insect boxes, a supply of insect pins, and information about books and other aids to building a useful collection. On a visit the following year, he told me about a society recently formed: The Lepidopterists’ Society. I joined in 1951 at age 15, and have been an active member ever since.

The Lepidopterists’ Society is international, but members are dominantly North Americans. Founded by two graduate students at Harvard in 1947, the Society has as its main purpose to “...promote the scientifically sound and progressive study of Lepidoptera by: (1) distributing a periodical on Lepidoptera; (2) facilitating the exchange of specimens and ideas by both the professional worker and the interested amateur in the field.” (lepsoc.org website). What a perfect platform for the launching of a major example of citizen science! This statement has guided me through my personal journey from first collection through 40 years as a college professor and 11 years as a part-time curator of a major museum collection.

The founders of the Society both went on to become “professionals,” in that the collection, preservation, and study of butterflies were part of their jobs. One, Charles L. Remington, became a professor and curator of Lepidoptera at the Peabody Museum, Yale University. The other, Harry K. Clench, became curator of invertebrates at the Carnegie Museum of Natural History, Pittsburgh, PA. Remington was the first editor of the publication, “Lepidopterists’ News,” which published articles including descriptions of new species of moths and butterflies. Today, the Society has a scientific *Journal of the Lepidopterists’ Society*, plus a news magazine, “News of the Lepidopterists’ Society.” Long scientific treatises and checklists have appeared occasionally as *Memoirs of the Lepidopterists’ Society*. Membership remains a mixture of amateurs and professionals at varying degrees of time dedicated to the study of moths and butterflies.

While at first I was determined to maintain Lepidoptera collecting as a “scientific hobby,” it all changed for me after my second year as an English teacher in a Virginia boys’ school. I found myself as a summer assistant to Roger Rageot, the naturalist at the Norfolk, VA Museum. Together we tramped the Great Dismal Swamp where I got back into butterfly collecting. That summer I had Army Reserve duty at Ft. Knox, KY, and was able to drive my car out on a two-day journey with an overnight stop at Blacksburg, VA. I wanted to find a well-known spot for the Northern Metalmark butterfly near there, and ended up in the office of Dr. James McD. Grayson, head of the new Entomology



Department. In addition to the needed directions, I was invited to attend VPI and earn an MS degree in Entomology. This I did the next summer, and stayed on for my PhD. From there I became a faculty member in the Biology Department at the University of Louisville (1964 - 2004). While there I built the existing insect collection from about 40,000 to 250,000 specimens and taught introductory organismic biology and several courses in entomology. A friend and I initiated the Society of Kentucky Lepidopterists in 1974, and members have included a number of people of all ages who have enjoyed our field trips to many Kentucky parks and other areas to collect, photograph, and “watch” butterflies and moths. In addition to several young people, there have been nature-lovers from the Kentucky Society of Natural History, hobbyists, and the several “professional” biologists who serve the essential role of basing the organization in institutions such as universities and museums. The symbiosis envisioned by the founders of the Lepidopterists’ Society is the means by which experienced biologists teach techniques and impart knowledge to the amateurs, and by which the amateurs do field and other work to augment the efforts of the professionals. Besides the enjoyment of field and meeting activities imparted to members of all parts of this spectrum, there are valuable scientific works published that might otherwise never see the light of day. In one example, members of the Society of Kentucky Lepidopterists helped immeasurably by providing the data on which a work listing all known butterflies and moths of Kentucky was produced (Covell, 1999). In addition, several amateur lepidopterists have produced major works on their own, and published significant papers on various aspects of insect science. Some of the most productive “citizen scientists” I have known, made or still make their living in diverse fields other than the profession of entomology: law professor, mathematics professor, state small-craft inspector, sanitary inspector, general contractor, copy machine technician, sewer district employee, pest control operator, dentist, physician, and others.

At present, I work part-time at the McGuire Center for Lepidoptera and Biodiversity at the Florida Museum of Natural History, Gainesville, FL. Here we have combined the collections of several units of the University of Florida and the Florida Division of Plant Industry with the largest private butterfly collection, the Allyn Museum of Entomology, into holdings of several million specimens. In curating part of the vast moth collection, I find that the collections have been built mostly by amateur collectors: citizen scientists. Some sought nothing beyond a fine collection; but others wrote books on state butterflies or opened new pathways to the life histories and habits of part of the approximately 12,000 species of Lepidoptera in North America, and over 125,000 species worldwide. Through volunteer workers, both young and mature, at the McGuire Center, more new amateur recruits are being brought into the never-ending work of building and studying the moths and butterflies of the world - many of which are not yet named. Professional curators and advanced amateurs carry out the

mentoring process without which advancement in the field would not be possible.

While I was lucky to be able through the help of several important people in my life to turn my hobby into a professional career, there are many whose contributions are limited to the collection and proper documentation of specimens. While I have focused on butterfly and moth collecting, there are lesser numbers who make important contributions to other areas of entomology, with several “charismatic” groups of insects being their choice: beetles, dragonflies, true bugs, and insects in general. Then there are those who are interested in gems and minerals, botany, ornithology, aquatic biology, and many other areas such as astronomy and ecology. Some of our major scientific treatises in all disciplines have been contributed by amateurs who have followed their interest to levels ranking with those of scientists who have made their living in their chosen disciplines. Richard Heitzman, a postal worker from Missouri, and his wife published *The Butterflies and Moths of Missouri* based on their years of collecting both butterflies and moths in that state. Amateur moth specialists Loran Gibson and Don Wright teamed up with a young professional Todd Gilligan to author a book on a group of interesting moths of the Midwest (Gilligan, Wright and Gibson 2009). And many, like me, have begun as “rank amateurs”, progressed to a certain level of experience and productivity as “citizen scientists,” and finally have found themselves able to be fortunate enough to join the universities, museums and laboratories as professionals.

When I look back on my experiences over 65 years with butterflies and moths, I realize that I was lucky indeed to discover this line of endeavor. As a hobby, it was perfect. There is the beauty of the specimens, perfectly spread, arranged in neat rows, with variation to study. Athletic activity can be a major aspect as one hikes into remote mountains or rain forests in pursuit of specimens. Friendly competition is sometimes there





as collectors or “watchers” vie to outdo their collecting pals. Photography and art are a major aspect of the pursuit of colorful and strangely shaped Lepidoptera as images for books and articles. Scientific illustration of anatomical structures are needed to help characterize species by describing them. Fellowship with colleagues has always been important to me; I have had friends worldwide with interests similar to mine. The sense of contributions to science can be a major motivation, especially as one progresses in knowledge and experience. Collections and observations are important in conservation biology, faunistic surveys of parks and preserves, and research into the effects of climate change as species become more or less common in an area studied over a period of many years.

Yes, amateur entomology like other areas of natural history can only lead to eventual careers as professionals. However, positions in museums and universities for full-time pursuit of one’s interests are generally uncommon. More than likely, a person who wishes to “go pro” finds himself or herself lucky to have a job where the exact subject of one’s passion can be pursued only in part - as a professor, wildlife biologist, water quality analyst, or some similar public servant. More than likely, though, it is enough to reach an advanced level of knowledge and experience to contribute to a chosen discipline in science as an amateur - a citizen scientist.

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Charles V. Covell Jr. was born in Washington D.C. in 1935, and grew up in Virginia, Ohio and North Carolina. He earned a BA in English from the University of North Carolina in Chapel Hill in 1958 and taught in a boys’ day school for two years. He attended graduate school at Virginia Tech, receiving the MS in 1962 and the PhD in 1965 in Entomology. In 1964 he joined the Biology faculty at

the University of Louisville where he taught entomology and organismic biology until 2004. He then moved to Gainesville, FL, where he has been working part-time since 2004 at the McGuire Center for Lepidoptera and Biodiversity - a branch of the University of Florida. Charlie is married to Elizabeth Gore Barnes (1958), and has three grown children and one grandchild. He has no plans for retirement.

Hobby Birder and Citizen Scientist



Kathy Dennis

Birding. A hobby in which individuals enjoy the challenge of bird study, listing, or other general activities involving bird life.

Birder. The acceptable term used to describe the person who seriously pursues the hobby of birding. May be professional or amateur.

Ornithologists. Scientists who study every aspect of birds, including bird songs, flight patterns, physical appearance, and migration patterns. Usually is a professional.

Citizen Science. Public involvement in the inquiry and discovery of new scientific knowledge. A citizen science project can involve one person or millions of people collaborating towards a common goal. Typically, public involvement is in data collection, analysis, or reporting.

Why do I like to watch birds? They are beautiful. Their colors and songs always raise my spirits. They are everywhere. I can see them from my kitchen window, the parking lot at the grocery, or I can travel to a relaxing natural setting like the mountains or the beach. I can watch them in the company of other birders, or just by myself. They manage to survive against incredible odds and they can FLY! But most importantly, they are indicators of the health of our planet. If something bad happens to them, it will eventually happen to us too.

The earliest birders were hunters. They observed birds, and other wildlife, learning their habits in order to hunt and eat them. Survival was their goal, rather than enjoyment. Birds were also part of their religious and medical lives. Myths and legends taught morals based on stories starring birds. Ancient Romans foretold the future based on bird entrails, and no one started a new endeavor without good omens found by the auger. The Native

Americans on this continent studied birds, but they did not record any of their findings.

As Europeans settled North America, they too were interested in birds as a food source, or to stop the potential damage they might do to a farmer's crops. Why would anyone care about the well-being of birds? When Passenger Pigeons migrated over an area, they took hours to pass over a single spot, darkening the skies and rendering normal conversation inaudible, while their droppings were as thick as snow. There were so many you could kill them just by shaking a stick as they flew over. They were an endless resource. I doubt the word "extinct" even existed at the time, yet by 1914 the last living Passenger Pigeon died in the Cincinnati Zoo.

The earliest naturalists were all self-taught men; self-taught because no one "studied" the flora and fauna in order to teach others about it. There were no text books, field guides, or binoculars. The tool of a naturalist interested in birds was a trusty shotgun. "A bird in the hand is worth two in the bush." Not just a saying, but a rule to live by if one wanted to learn about birds in the 18th and 19th centuries. To study it, one "collected" the bird by shooting it, then preserving it with taxidermy for additional observation. The more data (i.e. birds) one collected, the more one learned.

Consider bird migration. For thousands of years, everyone knew some birds disappeared when the seasons changed, while others remained all year. Where did they go and how did they get there? Aristotle was the first to claim that Kites, Doves, Storks, and Larks all spent the winter in hibernation. In European countries, songbirds were believed to wait on the shores of the Mediterranean until the storks arrived and the small birds could be ferried across. Aristotle can be credited for another lasting theory on where birds went in winter – he believed one species



morphed into another. The simultaneous disappearance of one species with the sudden appearance of others caused the famous philosopher, as well as many others throughout the years, to combine the two. Redstarts molted and became robins. In 1703 it was thought by some that birds migrated to the moon for winter. A fifty-page pamphlet, published anonymously by 'A Person of Great Learning and Piety,' claimed the journey to the moon takes sixty days, during which birds do not have to eat, and mostly sleep on the wing. Well, why not? There was no real data to show otherwise.

Ah, but in the 21st Century we have lots of scientific knowledge, right? Well, I'd say we have a good start, but still have plenty to learn. Scientific studies rarely have enough money, enough time, and enough people to gather enough data to really satisfy the person heading the study. When the subjects of a study (such as birds) are widespread and move around throughout the year, there aren't enough grad students to search them out. But now scientists can enlist the aid of civilians, as it were, to help fill that last shortage. The ornithologists at the Cornell Lab of Ornithology have enlisted large numbers of amateur birders to collect their data using computer software and the Internet.

How many birders are there in this country? In 2011, the U.S. Fish & Wildlife Service published a pamphlet on *Birding in the United States: A Demographic and Economic Analysis*, which can be found online at <http://www.fws.gov/southeast/economicImpact/pdf/2011-BirdingReport--FINAL.pdf>. According to this study, in 2011, there were 47 million birdwatchers (birders), 16 years of age and older, in the United States— about 20 percent of the population. What is a birder? The National Survey uses a conservative definition. To be counted as a birder, an individual must have either taken a trip one mile or more from home for the primary purpose of observing birds and/or closely observed or tried to identify birds around the home. 88% of these (or some 41 million people) were backyard birders. The greatest number are in the 55+ age category, with higher income and education levels having the highest rates of participation. People in rural areas or small towns and cities are more likely to bird than those in large metropolitan areas. People identified as birders in this report said that they took an active interest in birds— defined as trying to closely observe or identify different species. But what is the extent of their interest? Their "avidity" was measured by the number of days spent bird watching.

Birding can be a simple, inexpensive hobby, needing only a window with a bird's eye view and perhaps a pair of binoculars. Or, it can be part of a multi-billion dollar "industry."

Birders love to keep lists of the birds they have found; a backyard list, a county or state list, a list from a trip to a national park or summer vacation spot. The

ornithologists at Cornell Lab of Ornithology and the National Audubon Society asked themselves, "Bird lists? Isn't that like data? Could we get them to share all that data somehow?" Thus was born the concept of eBird in 2002 – a computer program that allows the birder to record his/her observations, including the date, location, time, number of observers and of course, how many birds of each species were seen, online in real time at www.eBird.org. Since so many now use smartphones, there is also an app called Birdlog for both iPhone and Android, allowing the birder to keep records of the birds seen while still in the field without trying to remember what that person saw hours earlier.

eBird's goal is to collect vast numbers of bird observations made each year by recreational and professional bird watchers. It is amassing one of the largest and fastest growing biodiversity data resources in existence. For example, in May 2015, participants reported nearly 10 million bird observations from around the world! The observations of each participant join those of others in an international network of eBird users. eBird then shares these observations with a global community of educators, land managers, ornithologists, and conservation biologists. In time these data will become the foundation for a better understanding of bird distribution across the western hemisphere and beyond.

Some scientists reading this might question the validity of data collected by non-scientists. How do we know the observer identified the bird correctly? What if that person exaggerated the numbers seen? Can amateurs really be trusted? Every record submitted goes through a verification process using both

Chart 10. Trip-Related Expenditures
(Total Expenditures: \$14.9 billion)

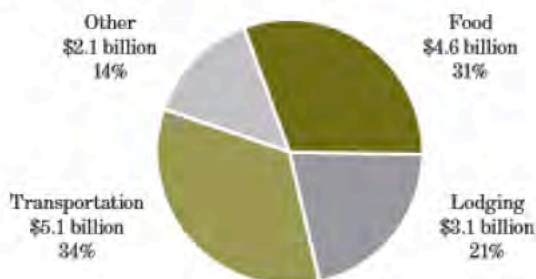
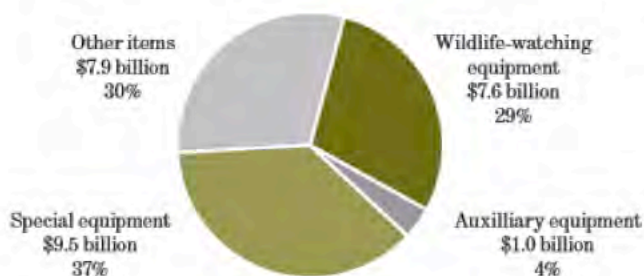
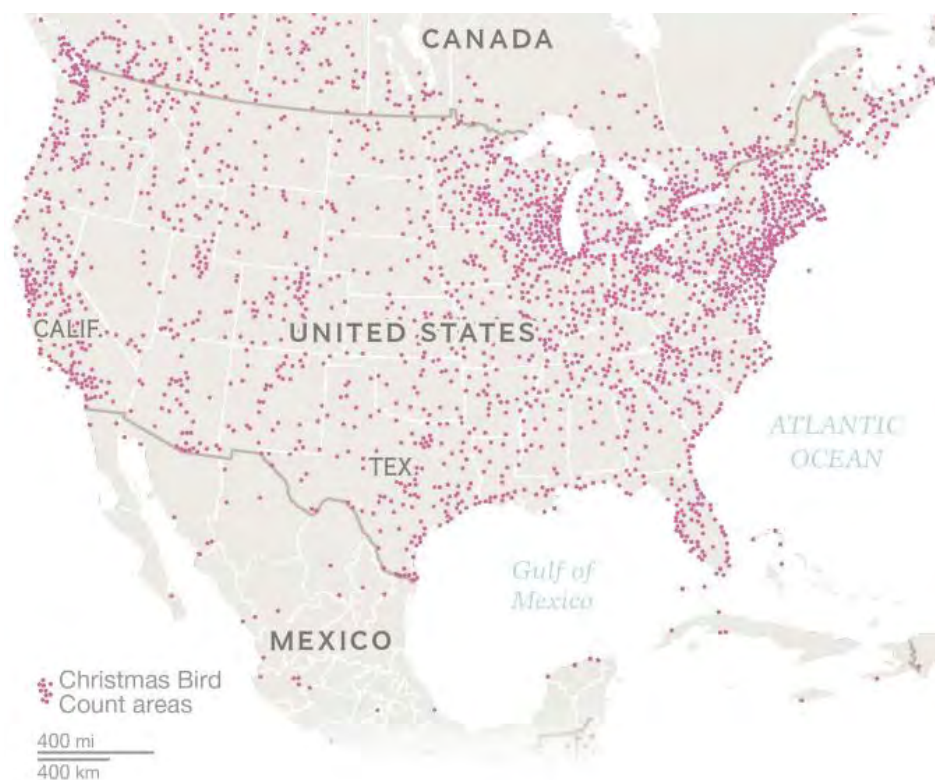


Chart 11. Equipment Expenditures
(Total expenditures: \$26.1 billion)





2015 GBBC Statistics



Checklists Submitted:
147,265

Total Species Observed:
5,090

Total Individual Birds Counted:
18,726,079



automatic computerized filters and a network of local experts. If a rare bird is reported, or a common bird at an unusual time or location, eBird will question the observer about it. The eBird program encourages the observer to make comments supporting the ID, describing habitat, behavior, etc. to help confirm the identification. The data is worthless if it cannot be trusted.

In addition to their day-to-day birding activities, birders participate in mass birding events such as the Christmas Bird Count, Project Feeder Watch or NestWatch, and the Great Backyard Bird Count sponsored by the national Audubon Society and the Cornell Lab. On four days in February each year, for example, anyone can join the Great Backyard Bird Count. Instructions are easily found online. In 2015, records submitted from 100 countries counted almost half the species in the world. By counting at the same time each year, scientists can analyze the numbers of each species and watch trends of increases, or more often, decreases for a given area.

So what happens after the birder submits the data? When a person submits a checklist to eBird, that observation becomes available to the global community of researchers, educators, conservationists, birders and anyone else with an interest in birds. A list of publications by scientists who have used the eBird data, highlighting ways in which eBird data are being put to use, can be found at <http://ebird.org/content/ebird/about/publications/>. The data is always available without charge to anyone who requests it.

Chris Wood of the Cornell Lab of Ornithology addressed a recent conference of the Kentucky Ornithological Society. He told the group of one study with farmers in California. By showing them when certain species of shore birds were migrating through their area, the farmers were persuaded to change the timing in which they flooded their rice fields. It benefitted them and the birds. The Cornell Lab has developed software which displays a moving depiction of migrating birds. The animated occurrence maps make the presence or absence of any bird species come to life as they migrate across their range.

We know the world is in trouble. The speed of climate change is so fast that creatures like birds will have a hard time trying to adapt. Is there anything that can be done? We won't really know without the data showing exactly how the birds are being affected, and citizen science such as eBird will provide that data. Remember, whatever happens to the birds may happen to us eventually.

Kathy is retired from the IT Department of a Louisville Law firm, and is now a professional volunteer. She spends her time volunteering at Creasey Mahan Nature Preserve in Goshen, KY, managing their website and teaching nature classes. Her favorite activity is the time she spends at Raptor Rehabilitation of Kentucky, Inc, caring for the raptors and taking them to educate the public about their importance. In her spare time, she is the past president of the Beckham Bird Club, and the newly elected president of the Louisville Audubon Society. With her husband, Dick Dennis, she enjoys traveling around the county to add new birds to her life list.

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