Citizen Participation in the Biological Sciences: A Literature Review of Citizen Science

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Abstract

The growth of citizen science over the past decade is shown by the increasing number of references to the topic tracked by bibliographic databases such as the Web of Science. The current survey examines the literature on citizen science in the biological and environmental sciences. A number of projects have studied insects and pollinators, avian migration, invasive species, horticulture, marine species, phenology, wildlife behavior, and ecosystems. The projects share a number of themes: including field study of distributed populations, questions about data accuracy, and benefits for the public such as improving public participation in science, expanding the number of people making science and technical decisions, promoting informal science education, and the connecting science to citizenship. Further research into citizen science across a wider range of disciplines is needed to fully understand this emerging phenomenon.

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"Citizen science [is the] participation of the general public in scientific research" (Couvet, Jiguet, Julliard, Levrel, & Teyssedre, 2008). The continuing development of the internet and other communication technologies over the last 20 years has contributed to the growth of citizen science projects in a number of different disciplines. The current paper reports the results of a literature review of current citizen science projects.

Some scientists argue that we are entering a new era of scientific discovery, a data-intensive "fourth paradigm" of scientific investigation. In this new paradigm scientists are recording, and analyzing massive amounts of data from new observation and simulation tools (Gray 2009). Citizen science is a tool for cost effectively collecting and analyzing the vast amounts of new data generated by data-intensive science (Bonney et al. 2009; Silvertown 2009).

Citizen science is a volunteer activity based on the four dimensions described by Cnaan, Handy, and Wadsworth (1996). Citizen scientists participate out of choice instead of coercion, nor do they receive monetary compensation. Activities can be carried out for organizations or individually. The intended beneficiaries of citizen science are widespread and may encompass the individual participant who learns more about science while being involved in a project, to the scientist who is running the project, and finally to the wider world that may benefit from the outcome of the research.

The methods used for the paper followed the traditional structure of a thematic literature review. A variety of common bibliographic databases, including Web of Science and Google Scholar, were search for the phrase "citizen science" and synonyms. References from relevant papers were examined for further possible articles on the topic.

Literature Review

Understanding the distribution of citizen science projects must begin with a brief discussion of the structure of current scientific research. A number of efforts have been made in the field of scientometrics to map and/or measure the different disciplines of science. Klavan and Boyack (2009) synthesized 20 of these projects into a "consensus map of science." They identified 16 scientific research areas: mathematics, computer science, physics, physical chemistry, chemistry, engineering, earth sciences, biochemistry, biology, infectious diseases, medical specialities, health services, brain research, psychology, social sciences, and the humanities. Four of these areas are mentioned in all 20 maps of science they surveyed: mathematics, physics, chemistry, and biology.

The following literature survey focused on two of the major areas identified by Klavan and Boyack: biology, and the earth sciences. A brief section sets the historical context for citizen and amateur science.

Historical Context

The participation of non-scientists in scientific research is not a new phenomenon. Before the professionalization of science in the 19th century a lot of scientific research was conducted by amateurs (Mims III, 1999). Many early scientific discoveries and inventions were made by amateurs in a variety of fields ranging from astronomy, to physics, to biology, and beyond (Gregory & Miller, 1998; Silvertown, 2009). Significant scientific figures, such as Robert Boyle or Charles Darwin, may be considered, by today's standards, to have been non-professional scientists (Shapin, 1994). The development of professional scientific practice and the concomitant growth of institutions, such as universities and professional associations, accelerated in America during the 19th century and continued to gain ground into the 20th century (Holmfeld, 1970).

"Citizen science" as a term-of-art began to be applied to amateur projects in the mid-1990s (Irwin, 1995). The term was used to indicate a growing concern with the participation of non-scientists in expert decision and policy making. Increasing public participation was seen as a beneficial way to incorporate more people into the complex design of science and technological systems.

The use of non-scientists to collect scientific data can be traced back to the 19th century. Prominent scientific projects that extend over such long periods of time include: the Audubon annual bird count (Silvertown, 2009), the Ontario phenology database (Futter, 2003), and the American Association of Variable Star Observers ("History of the AAVSO | AAVSO," 2010).

Biological Sciences

When studying ecosystems and conservation practice, the use of citizen science is helpful but limited. Because ecosystems are complex and subtle changes can alter the whole community of organisms and environment, the reliability of citizen science is questioned; very specific data collection methods must be taught in order for citizens to record observations of indicator species whether botanical or animal. Data collected by students of White Oak stands showed that students' data correlated with trained scientists, but more specific and detailed data collection should remain in the hands of the professionals (Galloway, Tudor, & Haegan, 2006). The California Sea Grant asked citizen scientists to count the population of spawning grunion along the coast of California, and to collect water samples that would later be tested for factors affecting grunion spawning (Martin, 2008).

The geographic range that citizen scientists occupy has assisted in a study of pest resistance; citizen scientists scour forest terrain in search of resistant species standing in pest-infested woodlands. Volunteers give program coordinators their location, the growing conditions, and arrange plant cuttings for future propagation; the pest-resistant species can then be bred to produce a progeny with a resistant strain (Ingwell & Pressier, 2011). Master gardeners were trained to inventory street trees in their community; which led to a grant that effectively enhanced the community by planting appropriate trees that lend shade and increase pavement longevity, act as storm water catchers, avoid power line interaction, and decrease death rate of trees through professional planting (Prochaska & Hoffman, 2010). Other projects are assessing the progeny of the American and Chinese chestnut as a possible pest-resistant Chestnut strand to repopulate forests (Antill, 2011) and Cornell University is leading a project to study the Viburnum Leaf Beetle (Viburnum Leaf Beetle (VLB) Citizen Science, Cornell University. (n.d.).).

Phenological studies need citizen scientists and have depended on their data collection throughout history. “Volunteers have documented seasonal events for more than a century, and scientific studies are benefiting from the data” (Mayer, 2010). Ice development, break-up, and ice-free days has been recorded in Southern Ontario by citizen scientists since 1853 (Futter, 2003). Project Budburst involves volunteer monitors in the surveillance of phenophases; citizens record their observations into the website’s database, which can be accessed by scientists and researchers to build theory, management practice, and understand the changes that are occurring within our ecosystems (Henderson & Havens, 2008; Meymaris, Henderson, Alaback, & Havens, 2008). The National Phenology Network also uses volunteer scientists to record changes in plant and animal lifecycles; the data is entered into an online database called "Nature's Notebook," so that phenological data such as nesting, leaf emergence, and pollination can be accessed in one place (Miller-Rushing, 2010).

When it comes to identification of species, it is important for citizen science project coordinators to include training and/or plant id pamphlets to increase the accuracy of reporting (Crall et al., 2011). The Invaders of Texas citizen science program detects the arrival of invasive species, maps the local terrain with invaders, and encourages researchers to use this data to better understand the dispersal of invasive plant species within Texas borders (Gallo et al., 2010). Adirondack Park has instilled a citizen science project to assist park rangers with the inventory of non-native, invasive species (Brown et al., 2001). Scholars survey 128 citizen science programs studying invasive species and they propose a public database where all of the projects could deposit their findings; centralized data sharing and standardization are offered as a prototype for improving data collection (Crall et al., 2010). In Japan, citizen scientists are used to observe the spatial spread of invasive bee species so that management practice can be developed based on the collected data (Kadoya et al., 2009).

Invasive plant species can also be spread through the mobility of pollinators, though generally their seeds are swept by the wind or caught by a roving mammal. Citizen scientists are able to assist in scientific research by luring pollinators with desirable plants to count local populations, recording quantities of individuals over a wide terrestrial range, associating food preference, and measuring nectar production for phenological changes and trends. The Great Sunflower Project is a citizen science operation that entices wild bees to a universal species, the Lemon Queen Sunflower, to assess the population and distribution of species within urban environments (Great Sunflower Project). The California Pollinator Project authored a guide that is an invaluable resources for volunteer data collectors (Ullmann et al., 2010). HoneyBeeNet uses the weighing of bee hives on a daily basis to track nectar collection (Vizcarra, 2010). A study comparing non-professional and professional data collection confirmed that citizen scientists are excellent resources for expanding knowledge of pollinators over space and time, saving money on monitoring, and educating the public about conservation and ecological issues (Kremen et al., 2011).

There are several prominent citizen science efforts that follow the migration patterns of monarch butterflies. Scholars used Journey North's data of overwintering monarchs in the southern United States to determine what climates Monarchs can survive in during winter (Davis et al., 2005; Howard et al. 2010). Other projects have studied the prevalence and transmission of protozoan parasites among butterflies. These observations show the role that humans play in altering migration patterns through habitat destruction, climate change, and decimation of breeding grounds; management of these activities helps reduce the change to ecosystems that depend on Monarchs (Bartel et al., 2011). A study using the citizen science project The Fourth of July Butterfly Count's annual data reveals a drastic decrease in the types of butterfly species visiting the observation site; the scholars suggest habitat alteration and variance in land use as the culprits of the decline (O'Brien et al., 2011).

Citizen scientists' core strength when studying avian species is their wide geographic range. Because most birds are migratory, studying avian change in migration locations or timing, population of endangered species, extent of pathogen invasion, and diversity of species within certain regions is difficult and expensive for professional scientists because they lack mobility.

Many birds that breed in Eurasia overwinter in India creating the need for the Migrant Watch citizen science monitoring project (Quader et al. 2007; Sharma, 2008). The wide geographic range that is signature for citizen science groups can be used to assess disease variance; volunteers look for the hallmark signs in flocks of House Finches to evaluate the changes in population and prevalence of Mycoplasmal Conjunctivitis within the droves (Altizer et al., 2004). Great Britain has been intellectually profiting from the movement of using citizens' private property as observatory sites. Homeowners are documenting the types, the frequency of visits, and the migratory cycles of populations of wild birds that can be perceived on their land (Cannon et al., 2005). Data about the relationship between birds and their adaptation to development is valuable in creating and maintaining land within cities that sustains native bird populations. There is a case study that focuses on the Tucson Bird Count (TBC) program and the Park Monitoring Program, who both utilize citizen scientists to survey various sites to determine the distribution and abundance of birds in this urban setting (McCaffrey, 2005). Data from three longstanding citizen science databases the Christmas Bird Count, Project Feeder Watch, and Breeding Bird Survey was used for verifying the complicated, competition dynamics between House Finches and House Sparrows (Cooper, 2007).

The main avenue for citizen participation with marine life is observation of population and biodiversity. Volunteers participate by diving or snorkeling, and are educated to observe and identify species; the citizen scientists must document populations, location, timing, and oceanic state during observation (Maurin & Peck, 2008). A study of the marine life within Italian waters created a volunteer-sightings-based index of marine biodiversity (Goffredo et al., 2010) and seahorse populations (Goffredo et al., 2004). It has been found that after additional dives, the accuracy and consistency of data is increased to the level of professional data collection (Darwall & Dulvy, 1996). Citizen scientists also record marine species population, reproduction timing, and evidence of fishery encounters and damage. A common, though little studied shark, the whitetip reef shark is the emphasis for a community volunteer project that uses photography as an alternative method for data collecting (Whitney, Pyle, Holland, & Barcz, 2011). Often a flagship species will be used as the focus of a study in order to garner interest and increase the number of volunteer participants. The North Carolina Sea Turtle Project uses sea turtles to attract citizen scientists to a conservation project that will hopefully give the volunteer a greater understanding and compassion for marine conservation as a whole (Mallos, 2010). Dolphin populations are being observed in Suriname to increase awareness about conservation and possible detrimental practices that can affect the dolphins like harbor expansion and dredging of the river (Pool, 2010).

It has been said that community monitoring done by citizens offers the public an exciting opportunity to participate in research and to share in a highly valuable learning experience (Lee, 2007). Citizens have been utilized within wildlife monitoring programs to gather data about wildlife presence in urban environments or to assess population near proposed developments in many regions. The Mianus River Gorge Preserve Backyard Coyote Project started to promote community awareness by involving citizens in the documentation of coyote presence through surveys, worked to educate the public in understanding the coyote, and discussed how to prevent a piece of land from being particularly appealing to the animal (Weckel, Mack, Nagy, Christie, & Wincorn., 2010). Volunteers use GIS web programs, phone service, highway monitoring, interviews, and tracking to understand wildlife movement and land use. Road Watch in the Pass, a citizen science project, focuses on wildlife observations along a part of highway that has a proposed expansion (Lee, Quinn, & Duke, 2006). The mountain pass monitored by the Cascade Wildlife Monitoring project has presented enough sound data to convince the government to fund crosspaths and set aside land in the surrounding area for preservation (Moskowitz & Watkins, 2007). Often the data that the citizen scientists collect affects legislation, land management, development of wild areas, and highway expansion.

Discussion

The distribution of peer-reviewed papers across the biological disciplines reviewed in this paper is fairly even. Insects and pollinators contributed 9 papers, avian and invasive species 8 papers each, horticulture 7, marine and phenology 6, wildlife 5, and ecosystems 3. All of these areas show one of the major benefits of citizen science, distribution across geographic areas and time periods. In fact this may be the largest benefit of citizen science projects and part of the reason why field sciences have been the first to adopt citizen science methods.

The problem of accurate data collection is a core concern for scientists who wish to assure that the data they are using for their studies is sound and the conclusions drawn are based on sound scientific information (Delaney, Sperling, Adams, & Leung, 2008; Galloway et al., 2006; Martin, 2008). Analysis of data accuracy among citizen scientists indicate that they can be as accurate as professional scientists given the correct training and appropriate incentives (Nerbonne, Ward, Ollila, Williams, & Vondracek, 2008). The overall concern with data accuracy is an indication of the relative novelty of citizen science as a method for scientific discovery. Until citizen science becomes an accepted scientific protocol it is likely that practitioners will still need to justify the use of non-experts for data gathering and analysis.

Traditional laboratory based sciences, such as microbiology, have yet to adopt citizen science on any significant scale while other biological sciences, especially those that require field observations, have been quick to adopt citizen science. Whether laboratory sciences can benefit from citizen science is an open question. The further development of technology may help laboratory scientists harness the power of citizens for data processing, if not data collection.

There are also potential benefits of citizen science in improving public participation in science (Trumbull, Bonney, Bascom, & Cabral, 2000), expanding the number of people making science and technical decisions (Feenberg, 1999), promoting informal science education (Gibbs & Berendsen, 2007), and the connecting science to citizenship (Suomela & Allard, 2012).

Citizen science continues to grow in importance and significance. A search for the phrase "citizen science" in the Web of Science database shows consistent growth over the past decade, from 3 citations in 1997 to 44 in 2011 (see figure 1). The environmental and biological sciences have already benefited from adopting citizen science. Other sciences may benefit from citizen science in the future.

The current survey suggests a number of future research directions. Further literature research needs to be done on the use of citizen science in the other major areas of science. Other areas may use different terminology for the same phenomenon of soliciting help from non-participants.

Conclusion

The study of citizen science is valuable in order to understand the interactions between experts and non-experts. It also benefits science communication and decision making. The need for improving science education has been recognized by many experts both in and outside of citizen science (Bonney, et al., 20009; Brossard, Lewenstein, & Bonney, 2005). One of the main goals of the public understanding of science movement and other science-technology and society research programs over the past 20 years has been to investigate the connections between non-scientists and scientists (Gregory & Miller, 1998). Increasing the knowledge of the general public is believed to be one of the best ways to incorporate their input into democratic decision making about matters of technical and scientific policy (Feenberg, 1999).

The current review has surveyed the development of citizen science in the biological and environmental sectors of science. It has revealed a growing interest on the part of many scientists and social science researchers in the topic of citizen science. If current trends persist the topic of citizen science will become increasingly important over the next decade.

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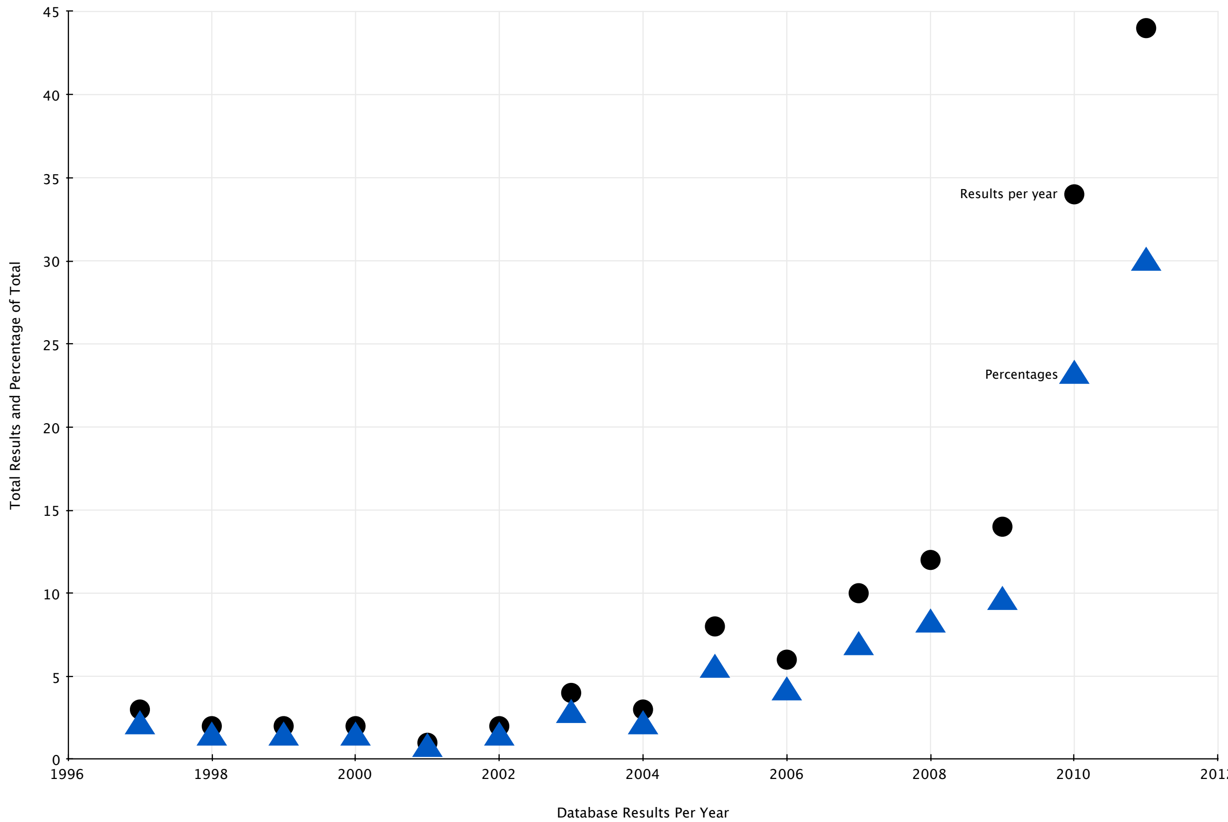

Figure 1 : Number of references to “citizen science” in Web of Knowledge per year. 1997-2011. Source Thompson-Reuters.