Socially Networked Citizen Science and the Crowd-Sourcing of Pro-Environmental Collective Actions

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Abstract The social Web has changed the nature of human collaboration with new possibilities for massive-scale cooperation in such important endeavors as scientific research and environmentally important collective action. While first generation citizen science projects have successfully used the Web to crowd-source environmental data collection, "next generation" citizen science practice networks combine crowd-sourcing, joint sense of purpose, and soft institutional governance with the distributed intelligence and efficacy of online social networks. Here we tap into evolutionary theory and social psychology to generate hypotheses for how such "next generation" citizen projects can best support pro-environmental behaviors like habitat restoration and energy conservation. Recent research on the evolution of cooperation highlights the potential for reputational mechanisms and scorekeeping to foster cooperation in online social networks. Nested bordered tug-of-war models suggest that challenges that elicit between-group competition will increase within-group cooperation. Based on social psychology, we note that increased levels of interest and cooperation can be fostered by social norms comparisons in combination with visually compelling representations of individual and collective benchmarks. Finally, we explore how properties of social networks themselves enhance the spread of behaviors through the three degrees rule, homophily, social contagion, and the strength of weak ties. In an age where environmental toxins, habitat loss, population growth, and climate change threaten our future health and survival, we present testable hypotheses and argue for the importance of field experiments to better understand the nexus between the social self, group identity, social networking effects, and potential for supporting collective action via the social Web.

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1 Introduction

The Internet has revolutionized how we learn, invent, and cooperate by decentralizing communications and providing opportunities for individuals to create and display content to an unlimited audience. Given its ability to engender massive collaboration, social learning, and collective intelligence (Boyd and Ellison 2008), the Web presents unprecedented opportunities to understand the human potential for cooperation. The question we raise here is whether, by combining the power of social networking with the sense of purpose found in citizen science, we can provide a new level of support for cooperation within the context of pro-environmental behaviors like energy conservation and habitat restoration. We raise this question at a time when scientific collaborations are occurring over the Internet at previously unprecedented scales, not only in the conservation arena but in a wide variety of disciplines from mathematics with Tim Gowers' Polythmaths blog, where people collaboratively tackle new mathematical proofs (Gowers and Nielsen 2011), to biochemistry, with the game-like citizen science project, Fold.it, whose participants recently discovered a new protein that regulates infection by the Simian AIDS virus (Khatib et al. 2011). The Internet's ability to build large, networked, communities, showcasing the collective impacts of people's contributions and efforts, make the Web the most important tool in history for collaboratively managing public goods.

From an evolutionary standpoint, rapid societal changes in how we cooperate, learn, and invent are fascinating. New models suggest that these changes might go so far as to facilitate more equitable distributions of public goods and avert the tragedy of the commons, even in such difficult arenas as climate change and loss of biodiversity (Bimber et al. 2005). This chapter begins with the premise that science literacy alone does not lead to behavioral change (Osbaldiston and Schott 2011). We explore models and empirical work at the forefront of understanding the social and psychological dimensions of human behavior and place these within the context of the influence of social media. What levels of cooperation are possible in a world made small by Internet-based social networks (Watts and Strogatz 1998), and how might integration of ideological and knowledge networks (e.g., environmentalist and science learning networks) support scientifically informed attitudinal and behavioral shifts? Given that people are influenced not just by friends, but by friends of friends of friends (Christakis and Fowler 2009), how does bringing people within three degrees of separation of a large number of others influence our potential for massive collective action? And can that influence help to support the behavioral change required to address dire environmental problems?

Specifically, we focus on the potential for collective action in citizen science environments that bring both crowd-sourcing approaches and social networking to bear on conservation actions. We consider "first generation" citizen science to be a form of crowd-sourcing with weak institutional governance in which self-selected participants tend to buy into institutionally defined goals and protocols (Wiggins and Crowston 2012). Most current citizen science projects are "first generation" in that they support a joint sense of purpose but do little to connect participants with each other. In contrast, electronic practice networks are "self-organizing, open activity systems focused on shared practice that exists primarily through computer-mediated communication" (Wasko and Faraj 2005). We define "next-generation" citizen science practice networks as having properties of both: (1) channeling a sense of purpose through weak institutional governance, which provides specific goals and protocols for the crowd-sourcing of science-based activities and (2) forming electronic practice networks that allow participants to engage in self-organized cooperative activities via social networking. We propose that when such citizen science practice networks are designed with a collective sense of purpose and with an understanding of barriers to and facilitators of pro-environmental behavior, they will provide new opportunities to manage environmental goods, including common-pool resources, like oil, gas, and water, as well as public goods, like climate, air quality, and biodiversity, which can be shared by everyone.

Progress towards understanding how the Web can be used to support and sustain collective action can only be made by engaging in cross-disciplinary thinking and research. Here we investigate the intersections between the fields of evolutionary biology and social psychology, hoping to stimulate their incorporation into new models and empirical studies of how socially networked citizen science can facilitate collective action. We explore these questions by focusing not on the scientific goals of citizen science but on the ways in which projects can be designed to support scientifically informed environmental behaviors and the scaling-up of individual conservation actions. We pursue this question with the idea that personal shifts in behavior are necessary to our collective future, require social support, and are critical precursors to shifts at higher levels of groups and institutions (Ostrom and Cox 2010).

We bring to this work the basic framework of levels of analysis, seminal to evolutionary studies of social behavior in human and nonhuman animals. We assume that only behaviors that confer inclusive fitness advantages to individuals will be maintained in populations, recognizing that individuals gain by passing on their alleles through both descendant and nondescendant kin (Hamilton 1964). Studies of fitness advantages comprise the ultimate or functional level of analysis, while studies at the proximate level of analysis seek to understand fitness-enhancing mechanisms. While proximate mechanisms may at times appear unselfish, we assume they will only evolve if they positively influence inclusive fitness of individuals. Just as individuals can gain by passing on their alleles through both descendant and nondescendant kin (Hamilton 1964), so can they gain when apparently altruistic acts are repaid by others (Nowak 2006).

In this chapter, we first describe the history of "first generation" citizen science projects and the transition to "next generation" citizen science practice networks, as exemplified by YardMap, which literally puts environmental behaviors on the map. We then highlight the special properties of social mapping environments. Finally, we describe research on collective action and pro-social behavior to derive hypotheses and recommendations for how electronic citizen science practice networks can be designed to support environmental behavior.

2 The Transition from First Generation to "Next Generation" Citizen Science to Support Ecological Research, Conservation, and Management

Citizen science encompasses the many ways in which the public collaborates with professional scientists to conduct a research. Within the context of conservation, first generation citizen science often takes the form of crowd-sourcing to collect large quantities of longitudinal data on the distribution and abundance of organisms across their ranges (Howe 2006). In the USA, birds have played a key role in the development of citizen science methodologies since 1900, when Frank Chapman at the American Museum of Natural History launched the Christmas Bird Count. This and other large-scale citizen science efforts have contributed to scientific understanding of the impacts of human-caused climate and habitat change on birds, and are currently the only way to gain an understanding of the impacts of changes in the distribution and abundance of animals and plants at large and conservation-relevant geographic scales (Dickinson et al. 2010a).

Starting in the 1990s, the Cornell Lab of Ornithology (the Cornell Lab) pioneered the use of Geospatial Web applications to collect citizen science data online, producing dynamic mapping visualizations and developing new computational approaches to analyzing patterns in the data (Sullivan et al. 2009). Today the Cornell Lab engages upwards of 200,000 people who contribute observations to a small, strategic set of projects. These projects set the modern standard for crowd-sourcing of data collection on wild birds as important sentinels for the impacts of environmental change.

Environmental research using citizen science data has uncovered emerging patterns and enabled new public understandings of the leading environmental challenges of the twenty-first century (Dickinson and Bonney 2012). Here we extend this work by asking what "next generation" citizen science might look like and what it might be able to accomplish in the conservation arena. Obvious impacts of connecting participants through social networking include expansion of the public knowledge base and increased potential for social learning. But the most intriguing question is whether socially networked citizen science has a vital role to play in collective actions that could alter the trajectory of "wicked problems" like loss of biodiversity and climate change (Dickinson et al. 2010b; Mankoff et al. 2007; Paulos et al. 2008).

The example we focus on here, called YardMap, is both a citizen science project and a test environment for psychological, sociological, and evolutionary hypotheses for how socially networked citizen science, specifically, and electronic practice networks, generally, can support environmental collective action. YardMap is an online mapping application designed to support and display the activities of individuals within a large, socially networked conservation community. It is focused on managing or restoring habitat for birds and reducing carbon emissions (Fig. 1). While the primary focus in YardMap is on individual (or single family) actions, the cumulative impacts of behaviors like energy use and habitat restoration

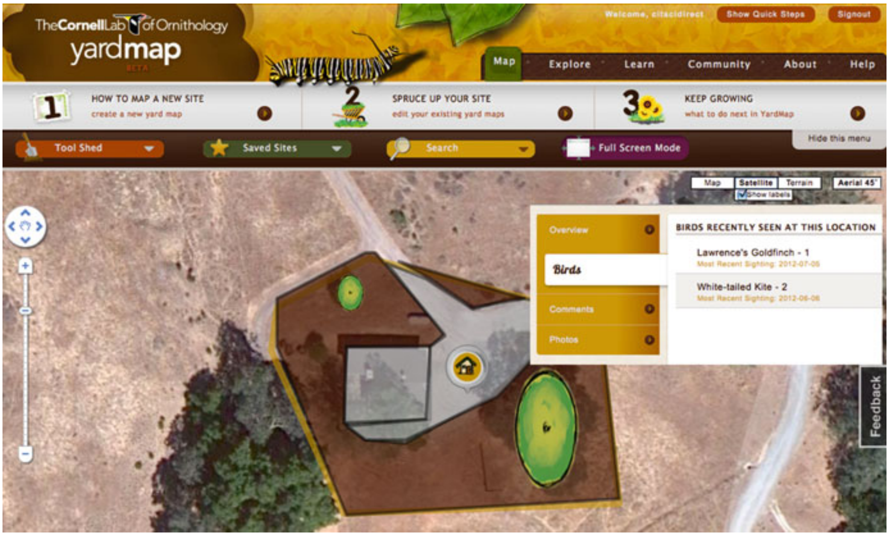

Fig. 1 YardMap application, showing a map with an open site window. Each site and object within a site has an associated information window that feeds comments to and is navigable from the social network

can be significant. For example, Dietz et al. (2009) named 17 simple household actions that, with little in the way of economic or time costs, could save an estimated 123 million metric tons of carbon per year with national, collective implementation. These actions include simple activities like keeping tires properly inflated, cleaning the refrigerator filter once a year, and installing a programmable thermostat. Collective adoption of these practices would represent a decrease of 20 % in household direct emissions or 7.4 % of USA national emissions, a reduction roughly equivalent to the total annual emissions of France.

Individual (or family) scale habitat management for wildlife may also have important cumulative impacts. Daniels and Kirkpatrick (2006) showed that while both landscape-level and garden-level habitat quality predict the presence of Australian bird species in urban environments, small-scale variables, for example, planting natives were stronger predictors of occupancy than the larger, landscape-level variables, like intensity of urbanization. While this pattern suggests that backyard manipulations have a significant impact on Australian bird distributions, the pattern may be the result of spatial clumping of similar gardens, either because people of similar taste and resources tend to live in close proximity or because neighbors engage in imitation and status seeking (Warren 2007). Such spatial autocorrelation would be indicative of potential for strong cumulative impacts of many small, local, and garden-based manipulations. YardMap is designed to observe the behaviors underlying such patterns (e.g., imitation) as well as the patterns themselves, and because YardMap data are integrated with bird-monitoring data, the wildlife outcomes of human behavior and garden-based manipulations can be measured directly.

In 2009, we embarked on creating the YardMap citizen science Web application to support online community involvement in residential conservation practices (Fig. 1); as a "next generation" citizen science platform it is also designed for future tests of hypotheses for which interventions succeed in generating increased levels of cooperation in these two important pro-environmental contexts: energy conservation and habitat restoration.

3 YardMap as an Example of a Citizen Science Practice Network

YardMap is an electronic practice network that allows participants to create, label, and discuss practices by tracing or dragging polygons and objects onto a Google map and commenting on them. The application has a full social network, defined by Boyd and Ellison (2008) as any Web-based service that allows people to (1) create a profile, (2) list others with whom they share a connection, and (3) browse those connections. YardMap allows participants to describe and converse about their mapped conservation practices in a closed social network and to feed news about their practices to Facebook and Twitter to draw others into the project. It also provides educational information relevant to habitat-bird conservation and reduction of carbon emissions with smart tools that point participants to relevant local resources (Fig. 2). Each thing people do in YardMap becomes part of YardMap's database, allowing for longitudinal studies of behavioral change.

Social networking can be built on any form of social connection or interaction, and in the case of YardMap, the connection is rooted in the shared activities of providing information and ideas on personal conservation practices. Activities include sharing self-created maps that display all kinds of choices about use of outdoor spaces and creative, sustainable solutions to common backyard problems (*Where do I put the compost pile? Which natives do well on a step incline?*).

4 The Added Value of Geocollaboration Tools

YardMap is also a form of "geocollaboration" (Hopfer and MacEachren 2007), an area ripe for growth on the Web given its huge potential for creating new pools of knowledge enabling communities to make decisions and organize activity broadly. The emergence of the geospatial Web in the mid-2000s has made projects like YardMap possible (Scharl and Tochtermann 2007). Technologies that enable laypersons to have convenient access to all kinds of georeferenced information are changing the role of maps across the world. Opportunities for "map hacking" (Erle et al. 2005) put control of map-making directly into the hands of the general public. YardMap attempts to access a level of detail about habitat composition and

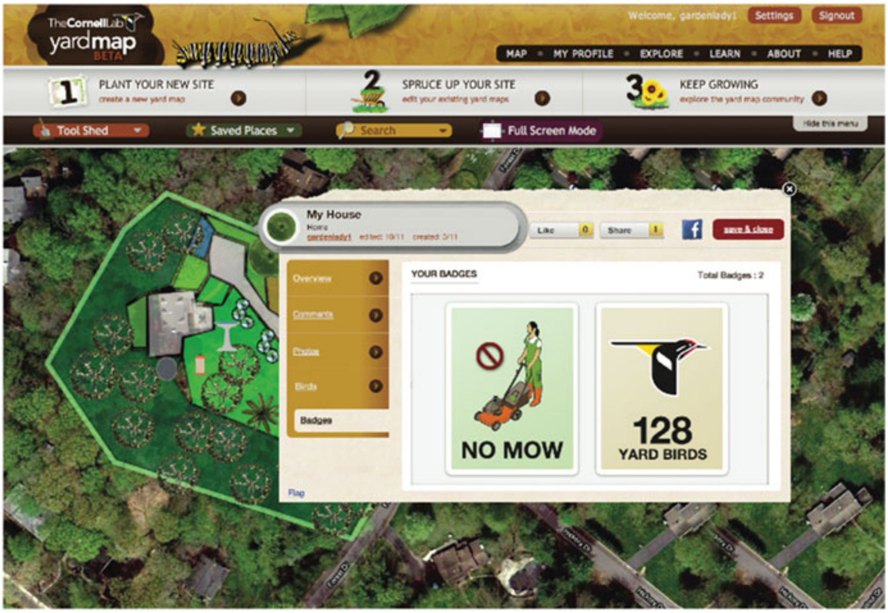

Fig. 2 YardMap showing cooperative and achievement-based badges displayed in a site window

sustainability practices that typical geographic information systems (GIS) cannot. The types of micro-habitat information collected in YardMap are unprecedented and *depend* on the practices and expertise of individuals, many of which occur at a scale invisible to GIS (Poore 2003), but are still potentially meaningful to birds (Lerman and Warren 2011), insects (Tallamy and Shropshire 2009), and carbon emissions (Dietz et al. 2009).

Maps are particularly amenable to rich, collaborative discussions via social networking. Research has shown that groups have a tendency to make suboptimal decisions because they spend time repeating information already known to all group members rather than utilizing their unique expertise to build a more robust knowledge base from which to make choices (Stasser and Titus 1985). Hopfer and MacEachren (2007) argue that maps help to eliminate this communication bias by *explicitly linking knowledge contributions with geographic objects/locations*.

Map annotations also have the advantage of acting as shared mediating artifacts, sometimes referred to as boundary objects, which orient users, even those with differing cultural knowledge and perspectives, to a common goal. In YardMap, there are many potential layers of map-based artifacts, from an individual tree to a visualization of many YardMappers' efforts to collaboratively create contiguous parcels of viable habitat. Theoretically, homophilous groups will form around these artifacts based on common interest and a desire to collaborate or share information.

Every mark on the map provides an extra-linguistic addition to the collaboration. Text annotations or "notes" and status updates in YardMap provide rich descriptions (e.g., information about intended plans for creating bird habitat or descriptions of how someone managed the transition to more natives in their backyard). Photographs give static detail-rich information (e.g., an image of a tree someone is trying to identify). Drawings, such as habitat polygons and site-lines in YardMap, help to immediately orient collaborators without the use of specialized, extra language. Tags, like information about pesticide use or mowing habits, standardize the vast array of relevant language into accessible ‘bits’ that become a common lexicon for collaborators coming together for the very first time. These function as straightforward advertisements or “badges” of yard accomplishments (Fig. 2).

Taken together, the entirety of the YardMap’s public map comes to represent the collective knowledge base of a community involved in the behavior of creating more sustainable yards and lifestyles. Because of how it is designed, it also reflects the normative behaviors of YardMap participants. As a whole, it is designed to become richer in knowledge resources than the sum of individuals’ contributions, likely reflecting both collective intelligence (Woolley et al. 2010) and minable social data (Hill and Terveen 1996). As such, YardMap is an environment that lends itself to exploration and implementation of a wide range of ideas on how online communities can foster collective action.

5 What Game Theoretic Models and Behavioral Games Say About Human Potential for Collective Action

Collective action models have their roots in the zero-contribution thesis of Olson (1965) and in Hardin’s (1968) tragedy of the commons, both of which assume that all individuals act as selfish rationalists (rational egoists). Early models included the N-person “Prisoner’s Dilemma” game (so named by Dresher 1961) and indicated that rational egoists acting exclusively out of self-interest always do better by defecting rather than cooperating. The Prisoner’s Dilemma is a nonzero sum game (one player’s gain is not necessarily another’s loss), and it is not strictly a cooperative game because players do not interact. The conclusion of these early models was that cooperation will not happen unless individual contributions to a collective action are externally regulated by coercive sanctions, laws, and institutions (Hardin 1968).

Predictions of these early models were not supported by real-life observations nor by a variety of behavioral economics experiments in which participants made decisions about how many “lab dollars” to contribute, knowing that lab dollars represent some fraction of actual dollars they potentially receive at the end of the experiment. Instead of failing to contribute, which would be the optimal decision for a self-interested player, participants tended to contribute between 40 and 60 % of their resources in single-shot Prisoner’s Dilemma games (Ostrom 2000). Still, cooperation is limited and in iterated, multiple-trial Prisoner’s Dilemmas of finite length, individual contributions decay over time with more than 70 % of participants contributing nothing at all in a salient last round. Even more telling is the observation that people increase their levels of cooperation as they learn and develop a better understanding of how the game works; if they were only self-interested, rational egoists, this would not be so (Ostrom and Ahn 2008).

Many environmental problems are best classified as social dilemmas in which public or fully sharable goods are freely available to noncooperative free-riders. Their solutions require a large crowd to cooperate towards a common goal, and they are characterized by conflict between the public interest and the private interests of individuals. Building on the idea that people are more generous than predicted by early, more restrictive models of cooperation, there has been a gradual movement to introduce a wide range of possibilities for pro-social behavior, beginning with allowing the sorts of interactions that permit people to choose whether and with whom to cooperate (Ostrom 2000). The most important component of second-generation models of collective action is that people are allowed to be "conditional cooperators," eliminating the assumption that everyone is a selfish egoist. The second most important component is that they allow partner choice (Noe 2001).

Pro-social tendencies are evident in observations that people are more likely to cooperate when they believe others will do so, especially when face-to-face communication is added to the mix (Ostrom 2000). Today, many aspects of human pro-social tendencies have been variously accounted for in models of social dilemmas and in behavioral games (the empirical tests of the models). Qualities that variously influence levels of cooperation include cognition (e.g., framing and anchoring; what is most salient) (Critcher and Gilovich 2007; Rand et al. 2009; Tooby et al. 2006) whether or not participants are known to each other; whether they will have opportunities for repeated interactions and reputational display (Barclay 2004; Griskevicius et al. 2010b), leadership effects, visibility of social norms, (Chalub et al. 2006); and whether competition, rewards, or punishment are introduced (Ostrom 2000; Milinski et al. 2006). All of these characteristics can potentially influence cooperative outcomes in electronic social networks.

Models of social dilemmas now typically allow for conditional cooperation in which cooperative tendencies vary among individuals and depend upon whether the actor believes that others will cooperate (Milinski et al. 2002). Unlike first generation models, they are built upon an understanding of checks and balances, including social rewards that appear to govern pro-social behaviors across cultures (Ostrom and Ahn 2008). In a broad sense, second-generation models frame the problem of collective action within the context of social capital, trust networks, and the potential for interpersonal, rather than institutional, rewards and punishment. In a few cases, they even consider *future* benefits of cooperation, such as averting climate change (Santos and Pacheco 2011).

Research on cooperation has yielded general results supporting the idea that, under the right circumstances, cooperation can persist in decentralized communities facilitated by pro-social interactions (Ostrom 2000). In such cases, top down interventions, such as government policies can interfere with, rather than augment, collective action (Montgomery and Bean 1999). On the other hand, we suggest that soft connections to institutions and small "effective group sizes," such as occur with socially networked citizen science, may be very helpful in supporting collective action.

Recently, we have seen a proliferation of evolutionary models that address cooperation and whose outcomes could be influenced by interventions in electronic practice networks. For example, the nested, bordered tug-of-war model places cooperation within the context of intergroup dynamics and has shown that levels of within-group cooperation increase with increasing between-group competition (Reeve and Holldobler 2007). This suggests that interventions that increase between-group competition, in, say, energy conservation, would theoretically increase overall conservation outcomes (Table 1). Another class of models focuses on indirect reciprocity, where altruistic actors receive benefits not directly from recipients but from the observers of their acts (Nowak and Sigmund 1998). This form of cooperation is particularly relevant to electronic practice networks and would be enhanced by providing opportunities for people to display their actions and by providing tools that calculate reputation scores (Table 1) If future benefits are important (Santos and Pacheco 2011), then visualizations that make future gains salient could increase cooperation in electronic practice networks (Table 1). Together, these ideas suggest that building electronic, citizen science practice networks based on new developments in collective action theory, which focus on social rewards and punishment, will extend thinking beyond the simple benefits of the efficiency of social networks (Hampton 2003) to illuminate the Web's potential to support collective action. While considerable attention has been paid to how top-down and institutional structures can support collective action, we are only beginning to investigate how the network structures in decentralized communities matter. Next-generation citizen science clearly provides opportunities for seeding citizen science practice networks with theoretically and empirically informed social drivers of cooperation.

6 How Proximate Mechanisms Can Engender Cooperation in Citizen Science Practice Networks

Before we examine social networking's capacity to augment the potential for collective action, it is essential to understand social and cognitive barriers to pro-environmental behavior and to consider how they can be accounted for in the design of "next generation" citizen science practice networks. Citizen science participants are self-selected. This is important because even when people report having favorable attitudes towards conservation, such as we might expect of people joining pro-environmental citizen science projects, acting on these attitudes and values proves difficult (Kallgren et al. 2000). Increasingly complex cognitive models recognize that people do not make decisions based on information alone, but also weigh social and economic factors (Hines 1987). For example, someone might hear that letting a lawn "go wild" is better for birds, but while she recognizes a connection between a wild lawn and saving songbirds, she is also thinking about her neighbor's negative reaction to her wild lawn and the cost of returning that lawn

Table 1 Testable hypotheses for interventions that will increase pro-environmental behavior in citizen science practice networks

Nature of intervention	Hypotheses for what interventions will increase pro-environmental actions
Provide opportunities to interact socially over map objects	Interacting over map objects and annotations will lead to formation of homophilous groups around those map objects and will orient even those with different cultural knowledges and perspectives towards a common goal
Create opportunities for competition to increase cooperation	Creating opportunities for homiphilous affinity groups within YardMap to compete with each other will increase within-group cooperation, based on the nested tug-of-war model of Reeve and Holldobler (2007)
Make future collective gains salient	Creating tools that allow individuals to witness the future collective gains of their actions will increase individual expression of pro-environmental behavior
Self-efficacy hypothesis	Launching challenges with visible and specific benchmarks for individuals will increase expression of pro-environmental behavior
Collective efficacy hypothesis	Launching challenges with visible and specific comparison tools and benchmarks showing the group's collective impacts will increase individual expression of environmental behavior
Reputational display	Providing opportunities for individuals to advertize their pro-environmental actions in the social network through tagging and badges will increase their expression of pro-environmental behaviors
Score-keeping mechanisms	Providing reputational scores for participants using a page-rank-like system or like/dislike and making these scores visible in the social network will increase expression of pro-environmental behaviors
Metrics of allowing	Providing participants with the number of followers they have and making the number of followers visible within the social network serves simultaneously as a visible metric of leadership and gives participants a sense of the reputational consequences of their behaviors; expression of pro-environmental behaviors and leadership (contagion of behaviors) will increase with the number of followers
Visual symbols of following	A picture of eyes next to number of followers will increase individual expression of pro-environmental behaviors; images of eyes have been shown to increase levels of donation to a communal coffee till in comparison with control pictures of flowers (Bateson et al. 2006)
Combine social norms comparisons with benchmarks	Visual images that show where people are relative to social norms, and that simultaneously show benchmarks or goals that are more ambitious than the social norm, will increase expression of pro-environmental behavior and shift the social norm in a more favorable direction (see YardMap pyramid in Fig. 3)

to its tamed state when she has to sell the house (Kurz and Baudains 2011). As human beings respond to social, not just material consequences of their actions, social support for conservation action is likely to be important. This suggests that the current design of YardMap, which allows individuals to "like" each other's actions, will increase enactment of "green" behaviors.

Self-efficacy, which correlates closely with identity and self-esteem (Schwartz et al. 2005), is widely recognized as an important driver of behavioral change. Research indicates that people in the USA believe they have little self-efficacy when it comes to influencing the environment (Gupta and Ogden 2009). Such beliefs lead people to assume that responsibility for environmental conservation must fall to larger entities, such as government or business (Wray-Lake et al. 2010). Activities focused on problems, rather than solutions, may exacerbate this. For example, calculating a carbon footprint, as is popular on myriad websites these days, may reinforce feelings of insignificance. We suggest that launching challenges with specific benchmarks and providing mechanisms for people to track their progress relative to explicit goals, will increase sense of self-efficacy in YardMap (Table 1). We also hypothesize that emphasizing group efficacy will enhance feelings of self-efficacy and support pro-environmental behavior in YardMap. For example, YardMap attempts to mitigate a lack of self-efficacy by providing scientifically informed statistics and information on the collective impacts of specific actions and by enabling participants to invite others to join in. As increasing numbers of people begin to adopt beneficial practices, the collective impacts can be displayed in compelling visualizations (Table 1).

In Web social networks, projects aimed at generating change must consider the potential to shift social norms, which profoundly influence what people are likely to do. Altruism itself is a social norm; thus, campaigns that foreground messages about environmentalism as a shared, social value should find some success in motivating behavioral change (Goldstein et al. 2008). The norm of reciprocity also appears to maintain social relationships across cultures, and thus should be a powerful motivator in pro-environmental contexts (Cialdini and Goldstein 2004). These and other ideas have been the focus of a series of experiments placing signs in hotel rooms to see which sorts of messages will get people to participate in hotel towel reuse. When the hotel made a donation to an environmental organization before inviting guests to reuse their towels, reuse rose to 42.5 %, compared to 30 % for appeals based more generally on cooperation, social responsibility, or the environment (Goldstein et al. 2007). This suggests that norms of reciprocity are somewhat effective at increasing rates of hotel towel reuse. In a later study, appeals highlighting descriptive norms were similarly successful (44 % reuse), in this case, letting people know that 75 % of the hotel's guests reused their towels. The more substantial increase to 49.3 % was not seen until researchers invoked commonality by producing signs saying that 75 % of people staying in "this hotel room" have reused their towels (Burger et al. 2004; Goldstein et al. 2008). In YardMap, similar effects may be achieved using smart, spatially aware tools that show sustainability achievements of nearby others.

While the hotel towel study demonstrates the power of social norms at eliciting cooperation, another study involving energy consumption illustrates a key drawback of social norms comparisons. While enabling customers to see their energy use in comparison to their neighbors' use altered consumption, high-use households showed strong movement downwards towards the norm, while low use households showed a tendency to increase their energy use when they could see that they were using less than the average amount. This demonstrates that simple quantitative comparisons can have a leveling effect, keeping the population in the vicinity of the existing social norm, rather than shifting both the population and the social norm in the desired direction. We suggest that this leveling effect may be ameliorated in YardMap by using visualizations that combine social norms comparisons with directional benchmarks (Table 1, Fig. 3) or by combining images of social approval (e.g., a smiling face) with visual representations of the most pro-environmental benchmarks.

As Rosenberg (2011) notes, people do not change their behaviors based on new information or fear appeals but by encountering a new peer group with which they can identify and within which social norms and new behaviors are seen as "really cool" and even heroic. Given that people are highly influenced by comparison with others (Frank 2011), a key question as yet unresolved is how social comparison can facilitate shifting of social norms and whether social norms shift more rapidly in electronic practice networks than in offline communities. In YardMap, campaigns that make competition and social comparison of "greenness" salient may drive increased investment in pro-environmental behaviors with challenges, such as, "How green can you be?"

7 Designing Citizen Science Practice Networks to Support Pro-Environmental Behavior

The design of citizen science practice networks to support pro-environmental behavior is an area ripe for empirical research. We propose that pro-social tendencies necessary to support collective action are activated once participants are (1) linked to one another within an online social network, (2) can witness what others are doing, and (3) can display their actions socially through e-friendships. These provide opportunities for social identity and normative influence, as well as reputation maintenance, formation of trust networks, and delivery of social rewards and punishment required to prevent free-riding (Table 1). We also suggest that properties of social networks, themselves, will augment the potential for collective action at meaningful scales.

On online social networks, spread of behavior can be influenced by the sheer number of connections people have, the visibility of their connections, and the ability to form very specific connections based on similarity (homophily) or status (e.g., centrality in the network) (Ostrom and Ahn 2008). While electronic practice

Fig. 3 Dynamic tool showing YardMap participant where he or she fits relative to low, average, above average, and top participants

networks like YardMap will likely be quite homophilous, it remains to be seen whether they can achieve the critical mass to make a difference. When people have a large number of connections, they tend to have high exposure, and so they become influential; in addition to this, some individuals are behavioral opinion leaders, while others have outsized influence because they are connected to a few key leaders whom they can influence (Easley and Kleinberg 2010, p. 513). On the other hand, individuals also tend to be most strongly connected to similar others and they will tend to share a large proportion of overlapping friendships with such people (McPherson et al. 2001). This fosters the maintenance of cooperation in social networks simply because people are more likely to connect with and imitate others like them (Durrett and Levin 2005). Research in social psychology has shown that compliance is more likely to occur among similar people, even when the shared trait is as simple as a first name, a fingerprint, or birthday (Burger et al. 2004). It is possible to distinguish influence-based contagion from homphily-driven diffusion, and this becomes important in determining which design strategies will counter versus facilitate the spread of behaviors (Aral et al. 2009). A hypothesis in need of testing is whether adding tools that allow participants to form homophilous subgroups will increase diffusion of cooperative behaviors in citizen science practice networks like YardMap or whether the entire network is so homophilous that its structure has little influence (Table 1).

While strong ties among similar individuals are certainly important in creating "bonding" social capital, people interacting in large, electronic social networks also tend to have weak ties to a large number of less familiar individuals. Such bridging social capital helps to generate rapid diffusion of information and behaviors throughout the larger network (Backstrom et al. 2006), while also tapping into diverse skills and opinions, which likely fosters the emergence of collective intelligence and innovation (Woolley et al. 2010). Given that YardMap taps into gardening, a popular hobby that crosses socioeconomic and cultural barriers, there may be more potential for bridging social capital than would exist in social networks focused only on sustainability.

In the end, network density may be even more critical. The density of networks on the whole is thought to increase the potential for collective action (Marwell et al. 1988). This is corroborated by recent simulations suggesting that high levels of cooperation can be achieved, even without reputation maintenance, if the benefit: cost ratio of cooperation exceeds the average connectivity (Ohtsuki et al. 2006).

The transparency of electronic practice networks can enable pro-social mechanisms known to generate and maintain collective action, including group identity, reputation, social capital, and normative behavior. Various models of collective action suggest that reputation and opportunities to detect cheaters promote cooperation (Hauert et al. 2002). Additionally, we know from social psychology research that activities that give people a sense of purpose and belonging, or opportunities for identity-building and reputation maintenance, also facilitate cooperation (Griskevicius et al. 2010a). Understanding the nature of online reputations and the potential for deception is thus critical to assessing the potential for collective action in electronic practice networks.

Reputation may be established and communicated broadly within social networks, not only through direct connections (friends) but also along a variety of paths to friends of friends, but success of online collective action will depend on the accuracy of reputational information and the trustworthiness of individuals. In face-to-face social networks, the accuracy of information about people degrades as it becomes second-hand information, often leading to more extreme impressions and, potentially, judgments (Gilovich 1987). In contrast, in online social networks, information about an individual is usually replicated precisely as it is conveyed from friends to friends of friends through sharing tools. This should allow reputations to be transmitted more accurately than in "real life."

Most modern models of cooperation rely on trust and indicate that the potential for cooperation is enhanced by reputational display and scorekeeping tools (Nowak and Sigmund 1998). Early on, social networking tools provided opportunities for "referral trust" in which individuals could recommend others as trustworthy (Artz and Gil 2007). But contexts for trust differ, for example, a participant in YardMap could score high in terms of interpersonal trustworthiness and low in terms of the accuracy of plant identifications he or she conveys. Much of the emphasis on trust has been on trustworthiness of information, but a variety of tools, including computational metrics, have been developed to combine different aspects of reputation into a single score. These include tools that rank interpersonal trustworthiness based on people's position in the social network, for example, their degree or their degree weighted by the trustworthiness of their connections as sorted and assigned by the PageRank algorithm (Hogg and Adamic 2004). Refinement of such methods will continue to improve precision and accuracy of various metrics of trust and trustworthiness in social networks (Table 1).

Game theoretic models have shown that accessible information on reputation makes social interactions more efficient; this efficiency could be amplified in social networks, especially given the high speed of transactions (Raub and Weesie 1990). Mechanisms that allow participants to assess trustworthiness and that do not allow cheating seem feasible in online social networks and will likely be required if electronic practice networks like YardMap are to foster collective action (Table 1). Social networking tools can also summarize information about the behavior of others via computational algorithms (e.g., scores of trustworthiness, Hogg and Adamic 2004). When actions are reported and displayed in a highly visual Web interface, they are potentially searchable and visible to all, which can aid collective action (Table 1). Additionally, the ability to pay rewards and mete out punishment offers significant, unrealized potential to foster collective action; evidence suggests that in online interactions involving markets (Bolton et al. 2004), negative feedback has more impact than positive feedback, but this idea has recently been contested within the context of collective action (Rand and Nowak 2011). Despite evidence that deception occurs in social networks just as in real life (Toma and Hancock 2012), we argue that the social Web has sufficient corrective potential to enable the proximate mechanisms required to generate massive collective action.

8 Shifting Attitudes, Behaviors, and Social Norms within Electronic Practice Networks

Despite extensive, expensive efforts aimed at getting people to adopt pro-environmental practices, we have seen few major collective shifts in behavior (McKenzie-Mohr and Oskamp 1995). This is true despite the massive proliferation and public adoption of Web 2.0 technologies in the last 10 years. It is not for lack of trying—there are *countless* websites devoted to "going green." We suggest that one problem has been a lack of integration of research from evolutionary biology and social psychology to inform the design and development of such Web interventions. Exploring the interaction of social networking with proximate mechanisms governing collective action can help to test and guide design principles for citizen science practice networks.

Here we illustrate such design principles using the new citizen science project, YardMap.org, which entered beta testing with the public in 2012. We propose that the potential for cooperation is enhanced by combining social network features with features that enable the full range of behavioral mechanisms that support cooperation, based on previous models and experiments (Fig. 2, Table 1). These mechanisms not only include reputational drivers of cooperation but also acknowledge that between-group competition can lead to increased within-group cooperation (Reeve and Holldobler 2007). Projects like YardMap can be used to conduct “field experiments” within electronic practice networks to measure which mechanisms are well supported and to examine the outcomes of cooperation through electronic tracking of conservation behaviors, social network structure, and the form and nature of interactions within the networks.

In Table 1, cited throughout, we highlight recommendations for further research to test hypotheses for which interventions or design features will support cooperation in pro-environmental contexts. Citizen science practice communities like YardMap, when informed by evolutionary and social psychology, serve as real life labs for testing interventions that are thought to promote collective action while simultaneously testing the impacts of scientifically informed pro-environmental practices. Our synthesis of research suggests that projects will do best to employ tactics that promote normative visibility in combination with benchmarks (Fig. 3), emphasize to users that their actions are both socially and practically valuable, and show how the cumulative impacts of participants’ actions can be significant (Table 1).

The question of how the Internet might help in the effort to manage collective actions is an important one, especially within the context of the dire environmental problems of the twenty-first century. Evidence suggests that the most fruitful course will be to structure online environments to allow for expression of the full range of proximate pro-social mechanisms that have promoted cooperation and altruism throughout human evolution.

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