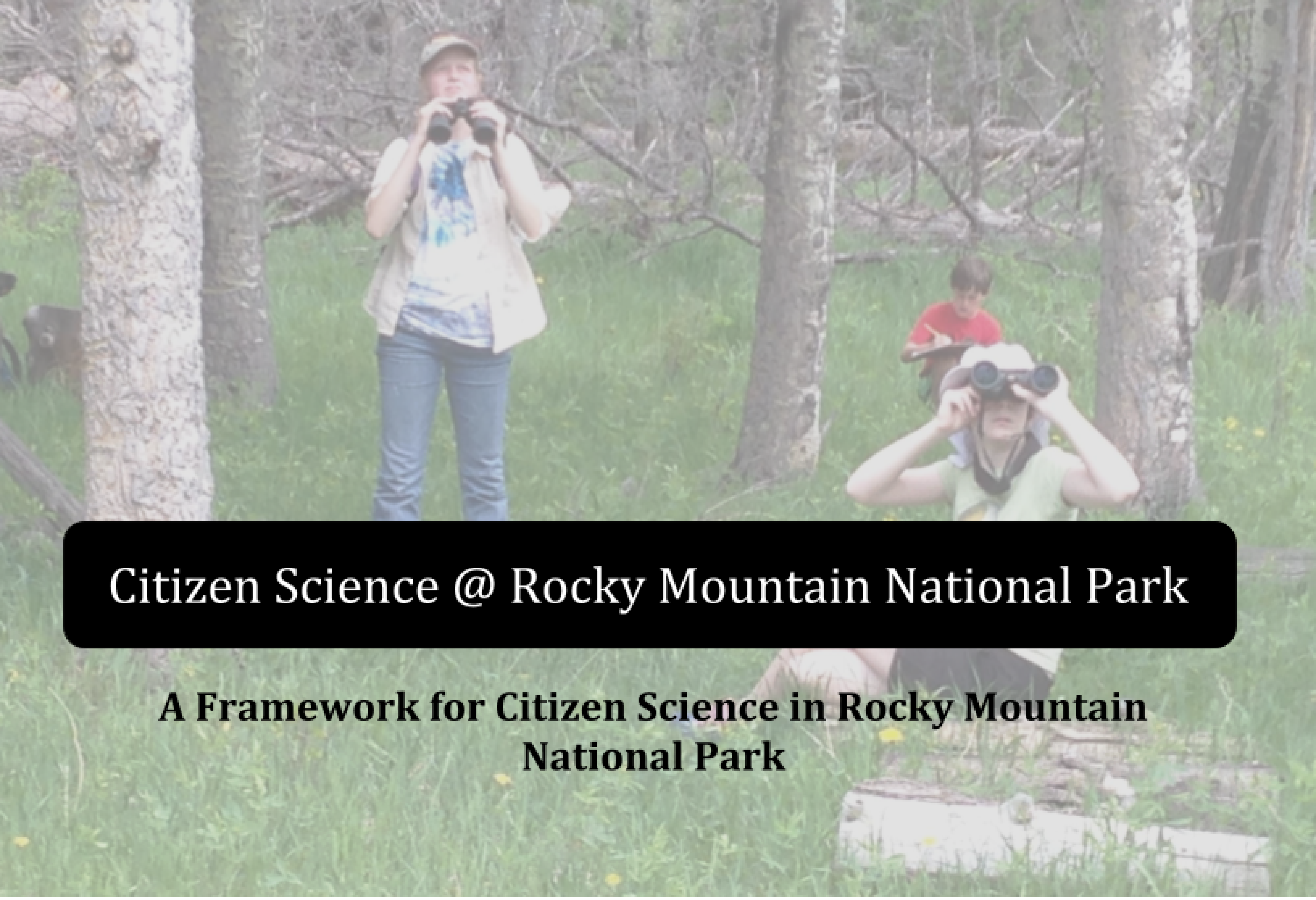

Citizen Science @ Rocky Mountain National Park

A Framework for Citizen Science in Rocky Mountain National Park

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A Framework for Citizen Science in Rocky Mountain National Park

A Report for Rocky Mountain National Park

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Summary

This report provides Rocky Mountain National Park (RMNP) with a framework and strategic plan to effectively identify, assess, design, implement, and evaluate citizen science projects and future project opportunities. The report offers a big picture view of past and current citizen science projects at RMNP, provides summary statistics as a baseline for tracking projects along with impacts and outcomes, and makes recommendations for park managers to strategically plan and implement a comprehensive citizen science program. These recommendations are tailored to help guide the design and implementation of future citizen science projects in the Park. An overarching recommendation is for RMNP to develop a dynamic, interactive, real-time, database-driven web portal to track citizen science projects at RMNP annually. This portal would enable efficient monitoring of projects, participation, impacts, and outcomes along with participant demographics, motivations, and perceptions to facilitate and streamline the creation of a dynamic dashboard (Figure 1) and annual reports for reporting progress moving forward.

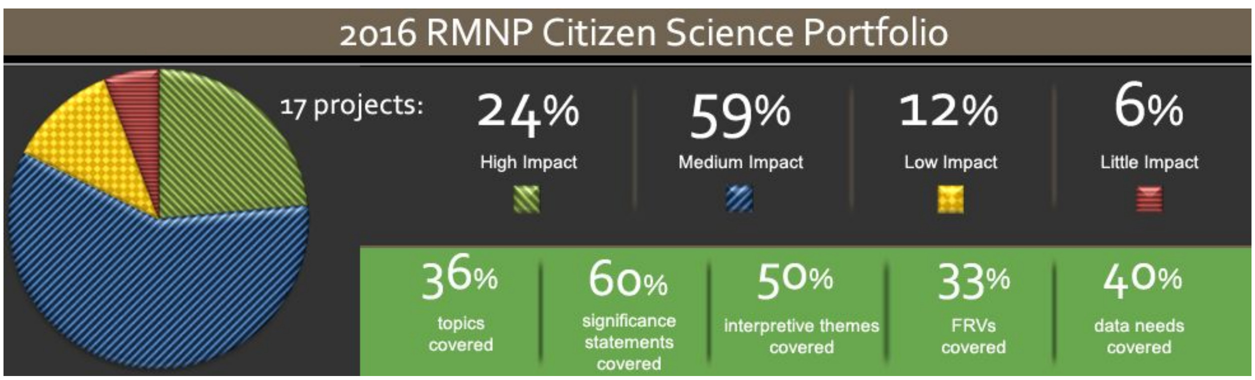

Figure 1 - A dynamic dashboard showing a breakdown of current 2016 citizen science projects (21) at RMNP and the proportion of these projects assessed as having high (24%), medium (59%), low (12%), and little (6%) impact along with percentages of citizen science projects covering core park topics (4%), significance statements (60%), interpretive themes (50%), Fundamental Resource Values (FRVs; 33%), and identified data needs (40%).

Once established, such a portal would foster internal RMNP staff and external stakeholder engagement with citizen science. The portal would allow internal staff to view and enter metadata for citizen science projects at RMNP while allowing the public and other stakeholders to view and learn about citizen science projects at the Park. Park staff with certain permissions could see summary reports while the public could become more engaged with the citizen science program through increased awareness of project participation opportunities. This portal could be structured much in the same way that the CitSci.org platform is structured - serving as a host and online presence for citizen science projects and providing data management and archival services where new project coordinators create projects, enter metadata, and have approved participants enter data directly into the portal. Project details could more easily be kept current, and with new dynamic sharing capabilities - these project details could even be shared seamlessly with other online project directories and advertising lists such as SciStarter.com and the federal listing of citizen science projects (www.citizenscience.gov). We strongly recommend keeping track of (and reporting impacts and outcomes for) citizen science at RMNP moving forward and developing this type of portal to facilitate such reporting[1].

Additional recommendations include considering projects related to water quality, partnering with the RiverWatch program, adding projects on key park resources such as trails and even historic building and artifacts, and including more social science / human dimensions of natural resource projects such as projects that assess visitor perceptions of Park resources. We recommend reaching out to the Alpine Algal Bloom Monitoring Project as another pre-existing project that has its own mobile app that may be of particular interest to RMNP as a potential new project for 2017. In all projects implemented, we recommend linking them more closely with RMNP 'place concepts' through project materials that emphasize people's affinity for places and emotional attachment to special places within RMNP as per the recommendations in Newman et al. (2017). Finally, we recommend developing a student internship program that engages graduate students as project coordinators for citizen science projects at RMNP.

Introduction

The term citizen science refers to participation of the general public in scientific research. It is an innovative approach to solve problems and answer questions by involving and engaging members of the general public; it can take several forms depending on the degree of participation (contributory, collaborative, and co-created; see Bonney et al. 2009 and Shirk et al. 2014). When designed and implemented rigorously, citizen science projects can extend the spatial and temporal scale of data availability (Loss et al. 2015, Theobald et al. 2015), increase social-ecological resilience (Shirk et al. 2012), improve scientific literacy (Trumbull et al. 2000, Brossard et al. 2005, Crall et al. 2012), accelerate conservation decisions (Cushing et al. 2005, Danielsen et al. 2005, Reid et al. 2009), and inform natural resource management decisions (Danielsen et al. 2005, Conrad and Hilchey 2011). Specifically, Danielsen et al. (2005) identified four generalized benefits and outcomes of citizen science related to natural resource management and participant empowerment, including: (1) improved communication between government and local stakeholders, (2) increased knowledge and changed attitudes and behaviors among those participating, (3) better adherence to regulations and policies by community members, and (4) empowerment of local stakeholders. Similarly, Conrad and Hilchey (2011) identified four related benefits, including: (1) making science and the environment more available to the public, (2) making local stakeholders more engaged in ecosystem management and policy discussions, (3) increasing participant scientific literacy, and (4) building social capital in communities in which citizen science and/or community based monitoring efforts are carried out. Effective citizen science is therefore not only a way to collect and access data, but also a way to make the lay public more familiar with the

[1] Note - our research team focuses on developing these types of portals and are more than happy to discuss further

particularities of conducting science and managing natural resources while promoting its importance (Irwin, 1997; Schlossberg & Mattia, 2003; Devish & Veestraeten 2013).

Despite these anticipated impacts and outcomes, such benefits only come to fruition when citizen science projects are effectively designed, implemented, and evaluated. To be effective, citizen science projects must be designed, managed, implemented, supported, and evaluated intentionally and strategically. This is especially true for RMNP where stakeholders are diverse. Some stakeholders, for example, are ephemeral with respect to the duration and frequency with which they interact with park resources, others are regular repeat visitors, and still others are key local actors with more stake in Park management such the US Forest Service and the communities of Estes Park and Grand Lake. Despite this diversity, the purpose of this report is to provide RMNP with a framework and strategic plan to effectively identify, assess, design, implement, and evaluate citizen science projects and future project opportunities. This report aims to provide a big picture view of current and past citizen science at RMNP and offer recommendations for Park managers moving forward in strategically planning a comprehensive citizen science program. We hope these recommendations help guide the design and implementation of future citizen science projects in the Park.

Background

Citizen science is not new (Miller-Rushing et al. 2014) and similarly this phenomenon is not new at Rocky Mountain National Park. The Park has a long and successful history of engaging volunteers in a variety of aspects of park management, operations, and citizen science activities. Beyond existing volunteer programs such as the Elk Bugle Corps, Bear Lake traffic monitoring, and volunteer guest assistance at the Beaver Meadows Visitor Center and Alpine Visitor Center focused on management and operations, RMNP also engages diverse members of the public as volunteers in citizen science endeavors. Categories of projects include high school citizen science projects, projects administered through the Continental Divide Research Learning Center (CDRLC), local co-created and collaborative projects, and contributory nationwide programs implemented locally within RMNP. Below we provide an inventory of past and current projects to provide an overall context for the citizen science that is, and has been, occurring at RMNP.

Inventory of Past and Current Citizen Science Projects

To the best of our knowledge, there have been 21 citizen science projects conducted at RMNP as of the writing of this report (Table 1). The first citizen science project known to occur within RMNP was the Audubon Christmas Bird Count (CBC) which started in the Estes Valley and RMNP in 1953. The Estes Valley and RMNP have been one of the areas counted (and sampled) within the CBC for 63 years. Several teams are organized to run various routes (transects) in the Park. There are a large number of wintering birds in the Park and in Estes Park. As an example, in 2002, 48 different species were recorded, with 3,451 individuals counted[2]. In contrast to this national contributory project, the first individual-led, co-created project, now referred to as the Brey and Mason Butterfly Population Study, started in 1994 and focused on butterfly diversity and populations. In this case, Richard Brey approached the Park in 1994 with an idea to conduct butterfly research. He connected with Dr. Paul Opler - a preeminent lepidopterist of the Rocky Mountains - to outline project goals and get started. What began as a 5 year bottom-up, co-created project to develop baseline indices of the Park's butterflies grew to become a unique record of mountainous butterfly communities spanning 15 years. The Park also hosted the 2012 National Geographic BioBlitz as part of a decade of species inventories in national parks. Nearly 200 scientists joined forces with the public to count plants, insects, mammals, birds and other creatures that inhabit the Park. The initial species count at the closing ceremony was 489 total, with a passing bald eagle raising the count to 490. The 24-hour inventory period (noon-to-noon) over two days added one lizard, nine insects and 13 non-vascular plants to the Park's species list and officially confirmed the presence of the big brown bat (*Eptesicus fuscus*) within RMNP. Additionally, The Plains to the Park Summer STEM Camp allowed for student research at Rocky Mountain National Park as a joint partnership between St. Vrain Valley School District (SVVSD), RMNP, and the Estes Institute. Students from Westview Middle School were part of a research team led by Dan Cribby and a Video Production Team led by Dave Kline. Finally, to answer the questions: Are Dragonflies good bioindicators of Mercury levels? and How much mercury is present in the water bodies of RMNP?, the Continental Divide Research Learning Center (CDRLC) brought a nationwide mercury dragonfly study to RMNP over the past two summer seasons. This permitted project is in partnership with the University of Maine and over twenty other parks. In this project, citizen scientists collect dragonfly larvae in the Park to be tested for mercury levels. These are just a few of the projects that have been conducted at RMNP thus far (see Table 1 for a complete inventory).

Table 1 – Inventory of citizen science projects and programs (past and current) at Rocky Mountain National Park along with the dates for each project, a description, and a brief assessment (*) of the degree to which projects benefits and/or contributes to Park scientific ( ), management ( ), interpretive ( ), educational ( ), and outreach ( ) goals classified and symbolized as having little impact ( ), low impact (-L), medium impact (-M), and high impact (-H) on these goals (broadly). *Assessments were determined by careful examination and expert author interpretation of project goals and objectives obtained from available project materials. Project sources included Park staff, Internet searches, Web of Science searches, and the author's knowledge of existing projects. Current (2016) projects are shown in bold.

Rocky Mountain National Park Citizen Science Project Inventory			
Project Name	**Dates**	**Description**	*
Christmas Bird Count	1953-2016	The Estes Valley and Rocky Mountain National Park have been one of the areas counted within the CBC for 63 years. Several teams are organized to run various routes (transects) in the park. There are a large number of wintering birds in the park and in Estes Park. For example, in 2002, 48 different species were recorded, with 3,451 individuals counted (https://www.nps.gov/romo/christmas_bird_count.htm)	-M

[2] https://www.nps.gov/romo/christmas_bird_count.htm

Brey and Mason Butterfly Study	1995-2016	Brey and Mason Butterfly Population Study. This study is being conducted by a couple of researchers in the park studying butterfly populations. There is not really much engagement with other participants we are aware of besides the participation of these two dedicated volunteer citizen scientists.	-M
Hummingbird Survey	2003-2016	Engelmann Hummingbird Study. Fred and Tena Engelmann have been studying hummingbird populations for some time in the park. This is really good science on these birds. This project is essentially conducted only by them, though they engage other participants through classes offered through Rocky Mountain Conservancy	-H
National Geographic BioBlitz	2012	Two days of exploration and documentation in Rocky Mountain National Park captured a vivid snapshot of the plant and animal diversity in the Rocky Mountains. The park hosted the 2012 National Geographic BioBlitz as part of a decade of species inventories in our national parks. Nearly 200 scientists joined forces with the public to count plants, insects, mammals, birds and other creatures that inhabit the park. A companion festival at the Estes Park Fairgrounds celebrated biodiversity and tallied up the numbers. This event added several species that had not been previously documented in the park. The BioBlitz was part scientific endeavor, part festival, and part outdoor classroom. Participants combed the park, recording as many plant and animal species as possible in 24 hours. More than 5,000 people, including over 2,000 school children, participated in the event. The initial species count at the closing ceremony was 489 total, with a passing bald eagle raising the count to 490. A 24-hour inventory period (noon-to-noon) over two days added a lizard, nine insects and 13 non-vascular plants to the park's species list. The big brown bat was officially confirmed at the 2012 BioBlitz. The 2012 BioBlitz also focused on personal discovery and understanding in the park. For a group of Denver based fourth graders, it was the ultimate field trip and the first time in a national park for many of those students.	-H
Dragonfly Mercury Study	2014-2016	How much mercury is present in the water bodies of RMNP? This is one question citizen scientists are currently helping to answer. The Continental Divide Research Learning Center (CDRLC) brought a nationwide mercury dragonfly study to RMNP over the past two summer seasons. This permitted project is in partnership with the University of Maine and over twenty to sixty other parks. Citizen scientists collected dragonfly larvae in the park to be tested for mercury levels. Dragonfly larvae have long life cycles and act as bio-indicators of what is in the water, including mercury. This study is part of ongoing citizen science research that is evaluating the utility of dragonfly nymphs (or larvae) (Odonata: Anisoptera) as indicators of mercury status in ROMO. Data are being used to develop hypotheses regarding whether mercury varies with odonate nymph body size or by family; or whether a site's landscape setting drives variability in mercury in odonate nymphs. ROMO currently uses students from Eagle Rock School who enroll in an Aquatic Ecosystem class which provides education and has the larvae collection as part of the curriculum. About 6-8 students participate in the citizen science project and usually a few end up presenting the information to park staff	-H
Eagle Rock Class - Fire Ecology	2012	http://eaglerockschool.org/rocky-mountain-conservancy-citizen-science-enhancing-scientific-literacy/ Citizen science projects are intended to enhance scientific literacy of the participants and improve the overall stewardship of park resources. Park managers develop scientifically sound practices then train volunteers to use these techniques and	-L

		collect information for resource related projects. These programs allow participants to experience the park while also helping to address important management questions. Students participate in a variety of projects at RMNP.	
Limber Pine Conservation	2012-2016	http://eaglerockschool.org/rocky-mountain-conservancy-citizen-science-enhancing-scientific-literacy/ and also see this link: http://www.fs.fed.us/rmrs/people/aschoette Limber Pine Population Protection and Cone Collection Study. This project started in conjunction with the USFS in hopes to take a proactive approach to the invasion of white pine blister rust which is known to kill large population of 5-needle pine (ie Limber pine). Seeds from the cones are stored at the National Seedbank Laboratory in Fort Collins for possible future restoration projects, or at the USFS Dorena Genetic Resources Center in Oregon to be tested for resistance to the invasive White Pine Blister Rust.	-H
Jon Achuff's Glacier Studies	2001-2016	https://www.nps.gov/romo/citizen_science.htm; In 2001 Jon Achuff began a study of glaciers in RMNP - hoping to answer a simple question - Are glaciers retreating? Geoscientist Jon Achuff has studied this area and believes the entire Longs Peak Boulder Field is moving on a glacier. His research is time consuming and strenuous, requiring him to carry delicate equipment in all seasons more than seven miles to the research site. Similar monitoring efforts would have cost the park or its partners approximately $35,000.	-M
Pikas In Peril (and NextGen Pika Patrol)	2010-2016	A student citizen science effort to gather baseline data on the current distribution of pikas, pika habitat and collect pika scat. Teachers may register to participate with their students. This project has never quite got off the ground. Contact person is: Emily Kellagher. Might be a way to engage students from Estes Park Middle School and High School as it is geared towards students. See https://www.nps.gov/orgs/1778/pikas-in-peril.htm and https://www.nps.gov/romo/learn/nature/pikas.htm	-L
Elk Population Ground Counts	2016	Citizen scientists conduct a monthly elk survey across 3 consecutive dates, driving pre-determined routes in the park and town in the winter and park only in the summer. Citizen scientists count and classify elk (age and sex) and count the total number of collars. These data are used to estimate the winter elk population size, population trends, and elk use of the winter range in the summer. Observations are conducted from the road and typically require minimal hiking.	-M
Raptor Monitoring	2016	Citizen scientists conduct regular 4 hour surveys at several sites from March 1 - July 31 to assess the presence of raptors in climbing closure areas. Raptor ID experience is beneficial but not required. Select citizen scientists with raptor experience may also visit historic nest site and territories and look for evidence of breeding activity. High school age students and above are welcome to participate. Site accessibility ranges from no hiking to intense backcountry hikes. The park has 37 active raptor citizen scientists, 15-20 of these citizen scientists monitor raptors regularly.	-M
STEM Academy Wildlife Camera Monitoring / Plains to the Park	2014	STEM Academy is a group of 12-15 students ranging from middle to high-school from St Vrain School District that participate in a two week summer project called Plains to the Park. This project helps train 'Citizen Scientists' in the ecological field research techniques necessary to monitor the ecological health of the Endovalley/Fall River drainage in ROMO. The two week course features multiple days in the Park, conducting field research focused on wildlife and plant communities of the park. Students have classes at Westview where they learn the protocols used by scientific researchers as well as days of field research in the park. Students document their work following standardized methods (e.g. game cameras, water quality monitoring and wildlife	-M

		transects) used by professional researchers. In addition, a separate team of students work to document the entire process in a filmmaking project. The film crew follow the scientific research team and help make videos to communicate their work. Details here: http://wms.svvsd.org/updates/plains-park-documentary-film-making-2016	
Creating GIS Sound Maps	2016	The project goal is to locate, record, and map anthrophonic, geophonic, and biophonic sounds to create GIS sound maps of Rocky Mountain National Park. This acoustical record has the potential to serve as an acoustical benchmark for how the park sounded in 2015. Five University of Northern Colorado (UNC) Geography/GIS students assist the PI with field sound recordings and GIS development to create a soundscape/citizen science curriculum for use in K-6 classes modeled after Purdue's YELL program (Your Ecosystem Learning Laboratories). The PI's GIS students will be given course credit for summer research work while participating in engaged field work and curriculum development, creating potential partnerships with ROMO personnel that might lead to future internships or careers	-M
Carbon and Ozone Monitoring - Bear Lake and Fall River Corridor	2016	In a partnership with the Estes Park Environmental Center, this is a a project where student groups monitor carbon and ozone levels from Estes Park up the Bear Lake and Fall River corridors. Data are collected using digital monitoring packs. This is a new project for 2016.	-M
Costa Rica Science Exchange	2016	The Costa Rica science exchange is an opportunity to make global scale preservation a reality through citizen science projects and conservation issues that both CR and RMNP are facing. This program also provides exposure for today's youth to better understand conservation and science. This is done through student exposure to various resource stewardship and science projects during their time in both locations. Projects included: (1) Vegetation surveys, (2) Water quality monitoring and testing, (3) Migratory Bird Transects, (4) Trail Cameras to document wildlife movement, and (5) Wildlife Observations. Students are able to interact with various staff and mentors in both locations allowing for a more personal and professional relationship to be cultivated. This experience also demonstrated the power of communicating through the language of science since a language barrier between hosting RMNP staff and exchange students existed. Students present at the end of the week on group experience and what they learned. The group also shares some of their cultural traditions by providing authentic Costa Rican food. Furthermore, student from Estes Park present to the town on their experience. One major outcome is that although each area is separated by 1000's of miles similar conservation issues and approaches exist.	-M
Forest Changes and Migration Study	2013	This project consists of resampling subalpine forests plots that were originally sampled in 1972 and again in 2013. Within each plot all trees greater than 4 cm are identified, counted, measured, and recorded. These data can then be analyzed for change over time or to look at the potential for species migration	-M
Clark's Nutcracker Tracking	2016	The citizen scientists are involved in initial trapping of nutcrackers as well as with attachment of glue-on model radio tags. The majority of their time, however, will be devoted to tracking nutcrackers by using receivers and antennae. Once they track a nutcracker, they will mark the bird's point using a GPS, describe the bird's behavior in terms of foraging, caching, and other (perching, preening, calling, etc), and collect more GPS points as the bird moves.	-L
Project BudBurst	2014-2016	http://budburst.org/parks-rmnp. Over 900 native and over 100 non-native vascular plant species are found in the Park	

		and project budburst has partnered with RMNP to engage volunteers to help monitor 10 focal plants, including: Alpine forget-me-not (Eritrichium nanum), American pasqueflower (Pulsatilla patens), Chokecherry (Prunus virginiana), Colorado blue columbine (Aquilegia caerulea), Darkthroat shootingstar (Dodecatheon pulchellum), Kinnikinnick (Arctostaphylos uva-ursi), Moss campion (Silene acaulis), Ponderosa pine (Pinus ponderosa), Quaking aspen (Populus tremuloides), and Woods' rose (Rosa woodsii)	
The Summer Solstice Bird Count	2014-2016	This project occurs in June each year as close to the solstice as possible. Citizen Scientists survey routes similar to the CBC inside and outside of the park within a 24 hour period for bird diversity and abundance. The project is a collaboration between the Rocky Mountain National Park and Monteverde National Park in Costa Rica. Both parks share data to study the migratory patterns of neotropical birds. Both parks share data to study the migratory patterns of neotropical birds	-H
Glacier Photo-monitoring Project	2016-	This project will document glacial changes using monumented photo points that the general public can access once the project is finalized.	-M
Jim Westfall's Aspen and Willow Photo Point Monitoring	2013-2016	Aspen and willow repeat photo point monitoring project	-M

From a topical perspective, these projects focus on a variety of topics, including: wildlife (e.g., elk, raptors, birds, dragonflies, pikas, camera monitoring, etc.), plants (e.g., Limber pine, forest changes, plant phenology, etc.), soundscapes, and air quality. Today (in 2016), the RMNP citizen science portfolio consists of 17 citizen science projects studying elk, raptors, hummingbirds, butterflies, Limber pine, soundscapes, wildlife, carbon, ozone, forest changes, American pikas (*Ocotono princeps*), Clark's nutcracker (*Nucifraga columbiana*), plant phenology, and bird diversity (Table 1; listed below), including the following 2016 citizen science projects:

1. Elk Population Counts
2. Raptor Monitoring
3. Engelmann Hummingbird Study
4. Brey and Mason Butterfly Population Study
5. Limber Pine Population Protection and Cine Collection Study
6. Creating GIS Sound Maps of Rocky Mountain national Park
7. Dragonfly Mercury Project
8. Carbon and Ozone Monitoring of Bear Lake and Fall River Corridor
9. Costa Rica Science Exchange (vegetation, water quality, migratory birds, and wildlife)
10. Forest Changes and Migration Study
11. Pikas in Peril
12. Clark's Nutcracker Tracking
13. Project BudBurst
14. Christmas Bird Count
15. Summer Solstice Bird Count
16. Glacier Photo-monitoring

17. Aspen and Willow Photo-monitoring

An overview of all citizen science projects (including these 17 projects in 2016) at RMNP through time is shown in Figure 2. This longitudinal view of citizen science at RMNP allows us to visually see overlap and continuity across projects conducted and implemented at RMNP. By visualizing projects in this way – we see that the number of simultaneous projects being implemented in any given year has steadily increased over time. Just this year, in 2016, there were the most concurrent citizen science projects running at the same time (17) of any year having citizen science projects in the Park and there were several years where only a few projects were implemented. This trends presents both opportunities and challenges for the Park. While having many projects affords the Park to expand the spatial and temporal scales of data collection and interpretation, it also presents challenges associated with managing more volunteers and more projects - tasks that require significant Park staff time and resources to manage effectively.

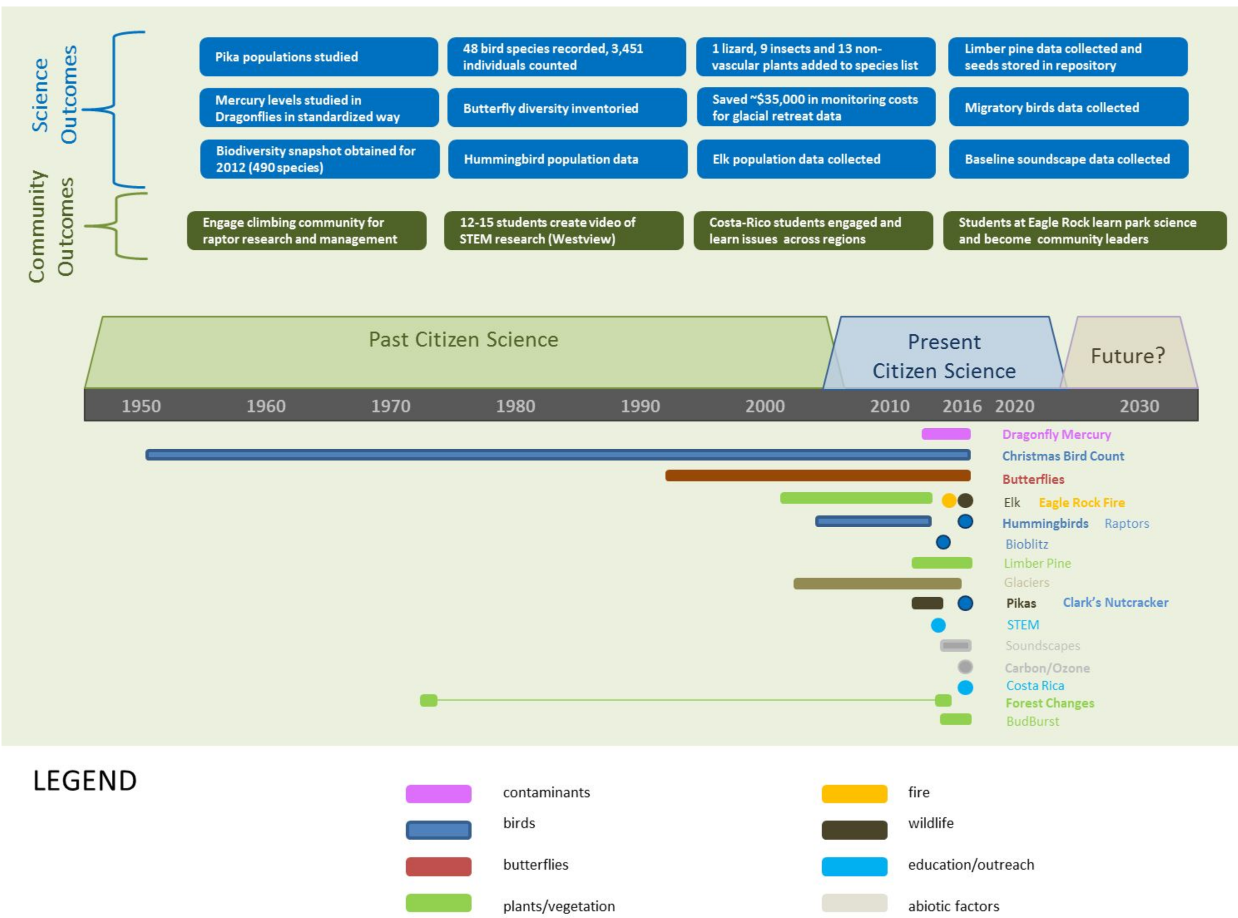

Figure 2 - A long-term view of citizen science at RMNP through time. Past and current projects are presented along a timeline and key outcomes of these projects (scientific and community outcomes) are listed. This longitudinal visualization depicts years of active citizen science and years of inactive citizen science at RMNP. Colors for individual projects correspond to topic/theme of the project, including: pink

(contaminants), dark blue (birds), red (butterflies), green (plants/vegetation), brown (wildlife), grey (abiotic factors), bright blue (education/outreach focus), and orange (fire).

The longest running citizen science project at RMNP is the Christmas Bird Count - a project that has been running since 1953 and continues today. The second longest is the forest changes study (intermittent) and the butterfly diversity study followed by the glacier study. Elk, hummingbird, and raptors studies have also been lengthy in duration. There are several ecological, scientific, and pragmatic reason to opt for fewer longer term citizen science projects. First, citizen science projects take the most resources in the design and first few pilot years of implementation. Once up and running and refined, the resources required to maintain them decrease to some degree. Second, long term studies in ecology are needed for long term monitoring and often provide rich data for effective decision making. Third, volunteers gain proficiency when returning year in and year out for participation. However, a few drawback to long term projects include the challenges associated with long term volunteer retention and a lack of new projects to entice and recruit new volunteers. Given this, we recommend that the Park focus on maintaining a few core citizen science projects long term but mixing this suite of project offering with new projects that are responsive to unique and time-sensitive Park management issues that often arise.

Assessment of Project Relevance, Impact and Outcomes

Regardless of breadth and longevity of past and current projects - what is RMNP gaining from these projects? Beyond identifying the success stories (and challenges) associated with each project at RMNP, it is also important to assess the impacts and outcomes of citizen science projects for Park goals and objectives. What is RMNP gaining from implementing these projects? Are the data generated helping to inform resource management decisions? Is the current portfolio of projects the most relevant for RMNP? What gaps exist in RMNP science, management, education, and outreach needs that are not being filled by citizen science and to what degree can strategically chosen and well-crafted citizen science projects help meet these needs in the future?

To address these questions, it is important to identify the primary scientific, management, and community (outreach/education/engagement) outcomes arising from citizen science projects at RMNP. A brief overview of these outcomes is shown in Figure 2 and include both scientific outcomes and community outcomes. Scientific outcomes arising from citizen science at RMNP include: a better understanding of pika populations, identification of mercury levels in Dragonflies via standardized methods, a biodiversity snapshot obtained in 2012 (490 species identified), 48 bird species recorded and 3,451 individuals counted via the CBC, butterfly diversity inventories, hummingbird population data, new species added to species lists (1 lizard, 9 insects, 13 non-vascular plants), ~$35,00 savings in monitoring costs, improved elk population data, limber pine data collection and specimen preservation, migratory bird data collection, and baseline soundscape data generation (Figure 2). Community outcomes include engagement of the climbing community, STEM video production, engagement of costa-rican students, and engagement with Eagle Rock and St. Vrain students. Additionally, to determine what RMNP is getting from citizen science projects, it is also important to identify what the Park needs with respect to its scientific, management, and education goals and objectives to be able to compare the benefit, impacts, and outcomes of citizen science projects to these goals, objectives, and needs, thus generating a gap analysis.

To determine the areas most important to the Park, we first identified which **topics** have dedicated management plans in place at RMNP (as one surrogate/indication of importance of topic) and then evaluated these management plans with respect to existing citizen science projects (Table 2). This lens (topics having management plans with related citizen science projects) provides one rubric for assessing the 2016 RMNP citizen science portfolio relevance to Park needs. There are eleven topics having associated management plans currently in use at RMNP, in addition to the overall Master Plan and overall Foundation Document (see the Overview and Complete Document) (Table 2).

Table 2 – Inventory of topics having management plans with related citizen science projects and programs (2016) at Rocky Mountain National Park.

Rocky Mountain National Park Topics, Management Plans, and Citizen Science Projects		
Topic	**Plan**	**Citizen Science Project(s)**
Water Quality	Annual Water Quality Reports	Dragonfly mercury
Bark Beetles	Bark Beetle Management Plan	❌
Horse Use	Commercial Horse Use Plan	❌
Elk & Vegetation	Elk and Vegetation Management Plan	Elk population ground counts
Fire	Fire Management Plan	Eagle rock fire
Climbing	Guided Climbing Strategy	❌
Invasive Plants	Invasive Exotic Plant Management Plan	❌
Land Protection	Land Protection Plan	❌
Trails	Trail Plan	❌
Restoration	Vegetation Restoration Plan	❌
Wilderness	Wilderness/Backcountry Management Plan	Soundscapes, Glacier photo-monitoring

Of these eleven topics, only 4/11 (36%) have active citizen science projects related to them that could contribute scientifically to understanding these topics when designed and implemented strategically. Thus, there is an opportunity for RMNP resource managers to meet with citizen science practitioners and more closely couple the citizen science offerings at the Park to management priorities. This rubric offers one view of potential new citizen science projects to seek out and consider implementing. This lens (the lens of topic/management needs) might serve as a good rubric against which to vet and or filter future citizen science project ideas and opportunities.

This approach identifies gaps that are poised for considering new citizen science project opportunities. For example, water resources remains a topic of interest for Park managers, yet the 2016 citizen science portfolio does not offer a water-related citizen science project. Opportunities exist to reach out to the Colorado RiverWatch program and/or the diverse community based water monitoring community to identify, devise, design, implement, and evaluate strategic water quality monitoring projects in RMNP in the future. However, note that RMNP sometimes refrains from offering a citizen science project option when there are other researchers addressing a given topic (e.g., Rocky Mountain I&M is currently conducting a multi-year study on water quality throughout the park). Ultimately the Park will look at current ongoing research conducted by external, internal, and citizen science researchers and actors and identify gaps. This being noted, it would be good for RMNP to pick up topics and implement citizen science projects after existing research projects end. Additionally, use of this lens (topical) can itself be limiting because, although no management plans might exist for certain topics, other topics might also offer important opportunities for citizen science projects at RMNP - such as the existing offerings (e.g., dragonflies, pikas, butterflies, etc.) and new opportunities such as repeat photography; visitation; restoration success; light pollution; noise pollution; visitor use, attitudes, and behaviors; recreational use; and other ecological topics such as soil diversity, erosion, and disease ecology.

A second indication of areas important to the Park involves evaluating Park significance statements. Significance statements express why Park resources and values are important enough to merit national park unit designation. Statements of significance describe why an area is important within a global, national, regional, and system-wide context. These statements are linked to the purpose of the park unit, and are supported by data, research, and consensus. Significance statements describe the distinctive nature of the park and inform management decisions, focusing efforts on preserving and protecting the most important resources and values of the park unit[3]. The significance statements identified for Rocky Mountain National Park are shown in Table 3 (in no particular order). This provides a second rubric (lens) through which to assess current annual citizen science project offerings and potentially identify new project ideas relevant to these significance statements.

Table 3 – Park significance statements and related citizen science projects and programs in 2016 at Rocky Mountain National Park (RMNP).

RMNP Significance Statements and related 2016 Citizen Science Projects	
Significance Statement	**Citizen Science Project(s)**
1. Rocky Mountain National Park provides exceptional access to wild places for visitors to recreate and experience solitude and outstanding scenic beauty. Trail Ridge Road, the highest continuous paved road in the United States, and the extensive trail system bring visitors to the doorstep of a variety of wilderness-based recreational opportunities	soundscapes

[3] https://www.nps.gov/romo/learn/management/upload/ROMO_Foundation_Overview.pdf

2. Fragile alpine tundra encompasses one-third of Rocky Mountain National Park, one of the largest examples of alpine tundra ecosystems protected in the contiguous United States	
3. Glaciers and flowing fresh water carved the landscapes of Rocky Mountain National Park. The park is the source of several river systems, including the Colorado River and the Cache la Poudre, Colorado's first and only designated wild and scenic river	glacier photo-monitoring
4. The dramatic elevation range within the park boundary, which spans from 7,600 feet to 14,259 feet and straddles the Continental Divide, allows for diverse terrestrial and aquatic ecosystems, varied plant and animal communities and a variety of ecological processes. The park is designated as a United Nations Educational, Scientific, and Cultural (UNESCO) international biosphere reserve and globally important bird area, with portions of the park's montane, subalpine, and alpine ecosystems managed as research natural areas for scientific and educational purposes	CBC, etc.
5. The mountainous landscape of Rocky Mountain National Park has drawn people to the area for thousands of years. Visitors can see remnants of the different ways people have used this land over time, ranging from prehistoric big game drives to dude ranching to recreational tourism	

Of these five Park Significance Statements, 60% (3 out of 5) have related citizen science projects. Thus, a few opportunities exist when using this rubric approach for RMNP staff to seek new projects that more systematically inform all five of these significance statements and that are intentionally designed to address / monitor these significant resources. One notable opportunity is the alpine tundra - a resource that might make for a good citizen science project. For example, the Park might wish to create a project that engages hikers in white tailed ptarmigan (*Lagopus leucura*) population studies to devise species distribution models following the methods of Jackson et al. (2015) whereby opportunistic hiker observations were shown to be comparable to machine-learning methods.

A third way to frame areas important to the Park is through an interpretive lens/rubric. The following interpretive themes for Rocky Mountain National Park were developed by park interpretation and management staff, with participation by representatives of the Rocky Mountain Nature Association, the park's primary education partner:

Table 4 – Park interpretive themes and related citizen science projects and programs in 2016 at RMNP.

RMNP Interpretive Themes and related 2016 Citizen Science Projects	
Interpretive Theme	**Citizen Science Project(s)**

1. Diverse natural ecosystems provide opportunities to understand the interconnectedness of the natural world and foster stewardship	
2. Rocky Mountain National Park's spectacular mountain wilderness provides opportunities to connect to the natural world through recreation, enjoyment, learning, and spiritual renewal	soundscapes
3. National parks like Rocky Mountain National Park serve as a resource benchmark and play an important role as an international outdoor laboratory where changes can be monitored and the health of the planet can be assessed	all 2016 projects exemplify this theme
4. Human use of this land has evolved over time and reflects landscape values and use from American Indians to early settlers to today's visitors	

Fifty percent (50%) of these interpretive themes have related citizen science projects in 2016.

A fourth way to identify areas important for RMNP is by reflecting on the Park's identified Fundamental Resources and Values (FRVs). Fundamental Resources and Values are those features, systems, processes, experiences, stories, scenes, sounds, smells, or other attributes determined to merit primary consideration during planning and management processes because they are essential to achieving the purpose of the park and maintaining its significance[4]. The preeminent responsibility of Park managers is to ensure the conservation and public enjoyment of those qualities that are critical (fundamental) to achieving the park's purpose and maintaining its significance. These qualities are called the Park's fundamental resources and values. Fundamental resources and values are closely related to legislative purpose, and are more specific than significance statements. Fundamental resources and values help focus planning and management on what is truly important about the Park. If these resources and values are allowed to deteriorate, the Park purpose and/or significance could be jeopardized. This distinction is made to ensure FRVs receive specific consideration in Park planning processes, because of their relationship to the Park's purpose and significance. The following FRVs have been identified for Rocky Mountain National Park of which 33% have related citizen science projects in 2016:

- Access to wild places – The exceptional access to wild places available in Rocky Mountain National Park increases the relevancy of the park and fosters stewardship by providing urban escape, recreational opportunities, and linking visitors back to nature. The park's high-quality roads, trails, and shuttle systems bring visitors to the doorstep of wilderness and help support a high quality visitor experience.
- High-elevation Ecosystems – The high-elevation ecosystems of Rocky Mountain National Park represent a dynamic interaction of southern Rocky Mountain landscapes. The park's alpine

[4] https://www.nps.gov/romo/learn/management/upload/ROMO_Foundation_Overview.pdf

tundra, a component of this confluence, is iconic throughout the Intermountain West and holds international significance.

- Wilderness character – Ninety-five percent of Rocky Mountain National Park is designated as wilderness, and this vast and steep landscape strongly exemplifies the qualities that comprise wilderness character. The largely pristine and primitive landscape provides opportunities for personal challenge and a natural haven for flora and fauna to thrive.
- Headwaters of the Continental Divide – Headwaters provide a source of clean fresh water to four major river systems, including a 14-mile wild segment of the Cache la Poudre Wild and Scenic River, the Big Thompson River, and the iconic Colorado River. Water has defined the landscapes of the park and is integral to the three major ecosystems (alpine, subalpine, and montane) and some of the park's rarest habitats (alpine lakes, fens, bogs, riparian willow and aspen communities). Headwaters lakes and streams support unique communities of aquatic, riparian, and terrestrial species.
- Ability to experience a wide variety of recreational opportunities – Rocky Mountain National Park is a premier Colorado destination that provides an exceptionally wide range of recreational experiences for a diverse group of users. Diverse visitor opportunities can include high elevation experiences along the Continental Divide National Scenic Trail, strolls around Bear Lake, climbs up lofty Longs Peak, and wildlife viewing and scenic driving along Trail Ridge Road.
- Traces of human footprints on the landscape – Rocky Mountain National Park's landscape has been a magnet for people through time. Visitors can still experience the remnants of these peoples' diverse uses, ranging from Paleo-Indian big game drives, to extractive activities and dude ranching, to early tourism and recreational activities that led to the popular support for the area's designation as a national park.

Finally, known data needs are fifth way to elucidate the areas of primary concern for the Park and potential avenues to explore citizen science in ways that help meet Park needs. Fortunately, RMNP has created a list of known data needs which we can use to compare to data collection opportunities presented by current and prospective citizen science projects. Currently, the Park has identified 16 data need and four issues (Table 2), including:

- Visitor activity information, including type of activity and use of facilities/trails/etc.
- Day-use visitation statistics, including the Longs Peak trailhead, trails, and summit.
- Visitor-safety data, currently underway as part of a four-year project to analyze accidents, trends, and safety messaging
- Extent of invasive species within the park, both flora and fauna.
- **Maps** of migration routes for avian and other species that traverse the park
- **Beaver** habitat and needs, including how beavers reoccupy disturbed lands.
- **Climate** change research to follow monitoring of subalpine and montane ecosystems and species of concern.
- **Potential** effects of limber pine loss in the park
- **Climate** change research to follow monitoring concerning aquatic and terrestrial habitats and species of concern.
- Taxonomy and distribution of extant trout populations based on current genetic information.

- **Water** quality for heavy metals.
- Archaeology surveys for the remaining unsurveyed sections of the park.
- Vulnerability assessment for cultural resources.
- Infrastructure assessments for Perry Cabin (Sprague Lake), Trail Ridge Road remnant (Lake Irene), and Wigwam Tea Room.
- Historic American Buildings Survey/Historic American Engineering Record (HABS/HAER) for fire lookout on Shadow Mountain

Issues:

- congestion and visitor use management issues in key sections of the park, including Bear Lake and the Longs Peak parking and campground area
- overall parkwide transportation issues
- adapting management to changing ecosystems due to climate change and other factors, such as nitrogen deposition
- the need for data and better understanding of backcountry uses

Table 4 – Comparison of identified data needs /issues with and without related citizen science projects. Red icons (✖) symbolize no past/present citizen science projects have addressed this need, yellow icons (✔ -f) indicate that few projects address this need, blue icons (✔ -s) indicate that some project address this need, and green icons (✔ -m) indicate many projects are well suited to address this need.

RMNP Data Needs / Issues Comparison with Citizen Science	
Data Need	**CitSci?**
Visitor activity information (type of activity and use of facilities/trails/etc.)	✖
Day-use visitation statistics: Longs Peak trailhead, trails, and summit	✖
Visitor-safety data	✖
Extent of invasive species within the park, both flora and fauna	✖
Maps of migration routes for avian and other species that traverse the park	✔ -m
Climate change research: monitor subalpine/montane ecosystems, species of concern	✔ -s
Potential effects of limber pine loss in the park	✔ -m
Climate change research: monitor aquatic/terrestrial habitat, species of concern	✔ -f
Beaver habitat and needs, including how beavers reoccupy disturbed lands	✖
Taxonomy and distribution of extant trout populations	✖
Water quality for heavy metals	✔ -s
Archaeology surveys for the remaining unsurveyed sections of the park	✖
Vulnerability assessment for cultural resources	✖
Infrastructure assessments: Perry Cabin, Lake Irene, and Wigwam Tea Room	✖
HABS/HAER) for fire lookout on Shadow Mountain	✖

When looking at these data needs and the current citizen science portfolio, we see a mismatch in current project data collection and data needs (Table 4), but also some excellent examples matching projects with known data needs. For example, a stated data need is the “Potential effects of limber pine loss in the park” and the 2016 Limber Pine Population Protection and Cone Collection Study is well suited to provide baseline data necessary to address this need. However, 67% (10/15) of the data needs identified do not align with current citizen science offerings and 33% (5/15) have projects that address them. Some of these data needs lacking current citizen science projects may make excellent citizen science projects while others will not. For example, visitor activity information, day use statistics, extent of invasive species (common conspicuous species only - see Crall et al. 2011), and possibly trout and archaeology surveys might be suitable whereas visitor safety data, beaver habitat and needs, taxonomy of trout, infrastructure assessments, and HABS/HAER might not be well suited.

Regardless of lens used to look at Park needs (e.g., topics per Park management plans, Significance Statements, Interpretive Themes, Fundamental Resources and Values; FRVs, and/or data needs) and the degree to which citizen science projects are addressing these needs, there it is also important to assess how well citizen science might be suited to needs not currently being addressed. An excellent rubric to do so is the rubric developed by Pocock et al. (2014) that looks at factors such as the simplicity of data collection protocol, resource availability, scale of sampling, complexity of protocol, and motivations of participants (Figure 3) required. We recommend that the Park first identifies needs to be addressed (as per above) and use the rubric below (Figure 3) to vet possible projects that might be well suited to each need not yet well addressed. When looking for new citizen science projects that might fit identified needs well, the Park can either find existing projects or create new ones. We look at existing projects nationally and locally/regionally next.

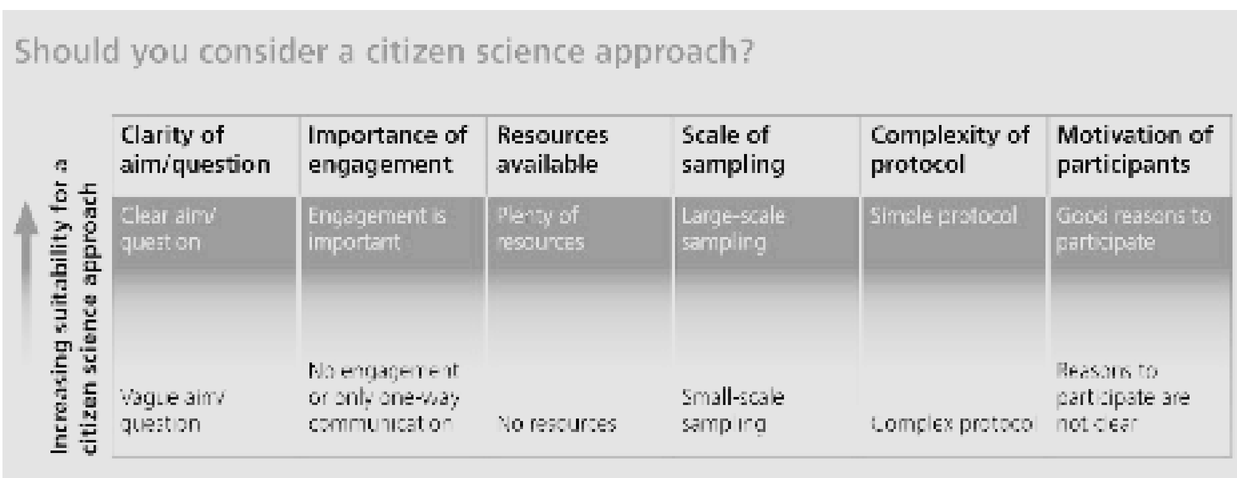

Figure 3: Example decision framework for citizen science from Pocock et al. (2014). These are guidelines, not rules - not all criteria must be met, and creative solutions may be found to increase suitability. Note that scale of sampling can be either spatial or temporal, and includes a degree of granularity. Community based monitoring, for example, provides data over a relatively small spatial scale but can provide greater resolution of observations within that space and over time that may otherwise be unfeasible.

Nationwide Program Evaluation

Among common national programs – which fit best with RMNP and why? What projects seems to be working and what projects are not working? Which of the nationwide programs might be the best fit for RMNP? What factors might be important to help RMNP narrow down which programs and projects to look into and consider implementing?

These are difficult questions. There are, of course, numerous popular and well-supported national projects and programs available that can be implemented and adopted by national parks generally and RMNP specifically. When searching for existing projects, a good resource to use is SciStarter.com. Using this resource and our knowledge of existing national programs, we identified a few national projects that might be of interest to RMNP (below) and a few local / regional projects that may also be of interest and relevance to the Park (next section).

A good initial list of example nationwide projects (albeit not comprehensive) includes:

- Nature's Notebook (Phenology, Climate Change)
- Project BudBurst (Phenology, Climate Change)
- CoCoRaHS (Precipitation)
- eBird (Birds)
- Christmas Bird Count (Birds)
- RiverWatch (Water)
- GLOBE at night
- The SMAP/GLOBE Partnership: Citizen Scientists Measuring Soil Moisture
- iNaturalist (biodiversity / future bioblitz events)
- CitSci.org - a diverse platform that can support any topic project

Some of these national projects have more direct relevance to RMNP than others. For example, it might be interesting and particularly relevant to install several CoCoRaHS rain gauges in the Park and enlist volunteers to monitor them daily (or augment volunteer monitoring of gauges with Park staff monitoring) to get a better picture of micro-scale precipitation variability within the Park. This approach might help inform Park managers of climate changes locally while also engaging local volunteers (perhaps even K-12 students) in science through an existing and ready-made program that is well supported, easy to accomplish, and relevant to a variety of Park data needs.

Local/Regional Program Evaluation

Local citizen science projects that may be of interest to RMNP include a recently established project (stated August 2016) called Alpine Algal Bloom Monitoring Project and led by Dr. Jill Baron that is designed to engage hikers in taking photos of algal blooms in alpine lakes. This project has its own dedicated mobile app that syncs with CitSci.org for online data management and display. This project might be a good fit.

Recommendations

Moving forward, and given our assessment of past and current citizen science projects at RMNP, what steps can be taken by RMNP to elevate the value, utility, impact, outcomes, and overall importance of citizen science to the Park? We have identified and adopted five recommendations (steps) based on published frameworks[5] that might help make the citizen science at RMNP more impactful.

Identify Goals, Objectives, and Needs

Research increasingly supports the notion that project design will influence project outcomes (Shirk et al. 2014), especially when possibilities are considered and goals are articulated up front to inform careful and intentional design focused on imparting specific outcomes – outcomes that can be intentionally designed for science, management decisions, and/or for participants. Goals should be ***specific***, ***realistic*** and ***relevant*** with respect to project scale, participant interests, and agency priorities (Shirk et al. 2014). Our initial work based on existing management plan topics, park significance statements, interpretive themes, Fundamental Resources and Values (FRVs), data needs, and issues is a first step towards this end. Additional work is still needed to more clearly identify relevant target audiences, project scales, and known participant interests and values among potential participants (visitors, locals, etc.).

Make goals, objectives, and needs *specific*

Identifying ***specific*** goals requires effective strategic planning and clear articulation of specific goals and related objectives, research questions, management needs, and data required. It also requires documenting your intent to use data for decisions and use cases about *how* data will be used to assist you in making management decisions (Newman et al. 2017). Examples of specific goals, objectives, research questions, and required data are shown in Table 1. Once specific needs are clearly articulated, how the outcomes of the research will be used can more readily be identified and documented. In the example in table 1, the how might be phrased as follows: Managers at RMNP will use data and results emanating from the "Keep Our Trails Healthy" citizen science project by using the results to guide decisions about whether RMNP trail crews should place waters bars at 30 degrees or 40 degrees from trail center and whether crews should sue rock or wood to build these water bars.

Table 1 – Hypothetical examples of specific goals, objectives, research questions, and required data along with associated management decision making needs that could be used in designing a citizen science project for RMNP entitled "Keep Our Trails Healthy." The more specific the goals, objectives, questions, and data required can be, the better the citizen science projects can be designed to meet specific needs at RMNP effectively.

Hypothetical Examples of Specificity in Goals, Objectives, Questions, & Needs

[5] Shirk J,Bonney R. 2015. Citizen Science Framework Review: Informing a Framework for Citizen Science within the US Fish and Wildlife Service. Cornell Lab of Ornithology, Ithaca, NY.

Goal: Reduce erosion on hiking trails

Objective: Replace water-bars with more efficient angle

Research Question: Is 30 degree angle more effective at reducing erosion than 40 degree?

Data: Treatment: Erosion data* on new 30 degree bars

Data: Control: Erosion data* on previous 40 degree bars

Research Question: Are rock bars more efficient at reducing erosion than wooden bars?

Data: Treatment: Erosion data* on rock bars

Data: Control: Erosion data* on wooden bars

Goal: Improve visitor hiking experience

Objective: Reduce number of hiker encounters

Research Question: Does number of hiker encounters impact hiking experiences

Data: observational data on number of hiker encounters

Data: corollary data on hiking experience (surveys)

*Note: Erosion data might consist of quantitative flow rates (cubic inches of water/cm following a specific simulated rainfall event), qualitative photographs of erosion evidence, measured sedimentation volumes down flow from water bars (e.g., area of sedimentation plume, etc.).

Make goals, objectives, and needs *realistic*

Setting ***realistic*** goals requires questioning assumptions about such things as who might use resulting data, whose goals should take priority, and what counts as success. Goals (for the short, medium, and longer term) should enable demonstration of success both internally and externally.

Make goals, objectives, and needs *relevant*

Tie citizen science at RMNP to relevant issues as outlined in our needs assessment approach (looking at topics with existing management plans, Park significance statements, Interpretive themes, FRVs, and data needs and issues). In addition, conduct more formal needs assessments periodically by engaging with stakeholders and potential citizen science practitioners and participants associated with the Park to co-create these goals, objectives, and needs with stakeholders. In this way - potential project leaders (e.g., citizen science practitioners) and participants both can devise relevant needs and project ideas in collaboration with Park scientists, managers, and interpreters. We recommend having meetings with these broad stakeholders once every five years to get buy-in and set a five year strategic plan for RMNP citizen science in motion.

Establish Capacity

The capacity of RMNP to support citizen science projects is an important consideration moving forward. How many projects supporting how many participants can realistically be managed by RMNP staff, collaborators, and partners? To what degree can RMNP scientists be involved in projects?

Assess volunteer management capacity

Citizen science is often presented as a low cost alternative that provides monitoring for baseline information that could be achieved via paid staff Fauver et al. 2016 *in prep.*). For example, Gardiner, Alley and Brown (2012) studied a beetle monitoring citizen science project using average cost per plot monitored. They compared verified citizen science (i.e., volunteer data is checked by researchers) to direct citizen science (i.e., volunteer data are not verified by researchers) and found that verified citizen science cost $40.29 per trap while direct citizen science cost $31.44 per trap. Another study surveyed 138 citizen science macroinvertebrate monitoring projects (Nerbonne and Nelson 2008). Of these projects, spending ranged from $1,000 per site to $0 per data collection site averaging $211. A comprehensive analysis of the EuMon (European Monitoring) project between 1993 and 2005 considered citizen science projects that addressed amphibians,reptiles, birds, butterflies, other insects, plants, and mammals (Schmeller et al. 2009) and found that it cost approximately 4 million euros (approximately USD $4,370,140) to facilitate 148,690 person-days. If we assume that one person-day is equal to eight hours, then the cost per volunteer hour is USD 3.67 (Fauver et al. in prep.). Finally, Tulloch,Possingham, and Joseph (2013) calculated the average cost of two methods for citizen science bird surveying over several years, compared using data collection hours and found that bird atlas monitoring programs had mean data collection hours of 186,500, and a mean cost of USD 10,133,500, or USD $54.34 per volunteer hour. The breeding bird survey projects surveyed had mean data collection hours of 147,900, and mean costs of USD $10,014,200, or USD $67.71 per data collection hour.

These costs vary drastically between projects, most likely due to the methods of volunteer management and data collection. In two projects which compared costs of citizen science versus professional monitoring, Gardiner et al. (2012) found that the cost of professionals was USD $126.62 per sticky card trap, more than three times the cost of a citizen science project. Although Schmeller et al. (2009) did not study a professional monitoring project, it these authors noted that to pay a worker for each of the volunteer hours it would have cost 13 million euros (approximately USD $14,238,900), or roughly three times the cost of the EuMon citizen science project. While project costs may differ greatly, these papers concluded that professional monitors cost approximately three times as much as citizen science volunteers, yet a study by Fauver et al. (2016, in prep) found that costs were comparable when comparing three projects in Colorado. Each project compared was managed by or are in close partnership with a natural resource management agency projects (e.g., the Front Range Pika Project and the City of Fort Collins Natural Areas Department) are still operational, while the third (Scott Miller Archaeological Survey) is no longer operational. Results from this study show a 1-2% savings using citizen science versus professional monitoring.

So, the upshot of all of this is that managing volunteers takes time and resources in the form of funding and staff. A few rules of thumb from our experiences working with the Front Range Pika Project indicate that a half time FTE is needed to manage a typically seasonal data collection oriented top-down project supporting on average 75 volunteers/participants and this half-time FTE typically manages project activities such as volunteer recruitment, training, training material development, field days, protocol development, volunteer management, technical support, scientific support liaison, data management, end-of-season gathering, and formative and summative program evaluation. However, there are a few tools that exist to help make volunteer management easier and more efficient. These resources include

SciStater.com (for recruitment and advertising and awareness/retention), CitSci.org (for data management), and iNaturalist for bioblitz events. Other resources to consider include volgistics for volunteer hour tracking, evite for invitations for trainings, and mailchimp for communications with project volunteers. Google forms, dropbox, and other similar resources can also help.

Increase technological capacity / infrastructure

Another opportunity in general is the use of technology in any of the gaps identify or current projects offered. Mobile apps are not being used in any of the current 2016 projects and there are many benefits to adopting technological platforms (both mobile and web-based) to grow citizen science at RMNP. The technological advances of the past 10 years have greatly expanded citizen science projects globally (Newman et al., 2014, Wiggins et al. 2011) and there are now excellent platforms and apps out there that might fit well with the goals and objectives and needs of RMNP scientists and managers. Yet this requires capacity and infrastructure. However,there are several platforms available that can provide free data management infrastructure and support such as CitSci.org (see www.citsci.org) , epicollect, liquid.io, and Anecdata.

Design & Refine

The steps of designing and implementing a successful citizen science project can be summarized as (1) form team and devise your research question/hypotheses, (2) refine protocol, (3) recruit participants, (4) train participants, (5) collect data, (6) analyze data, (7) retain participants, (8) and share results (Bonney et al. 2009; Fauver et al. 2016, *in prep*, Shirk et al. 2012). These steps are iterative and requirement continual refinement through traditional adaptive management processes (Figure 3).

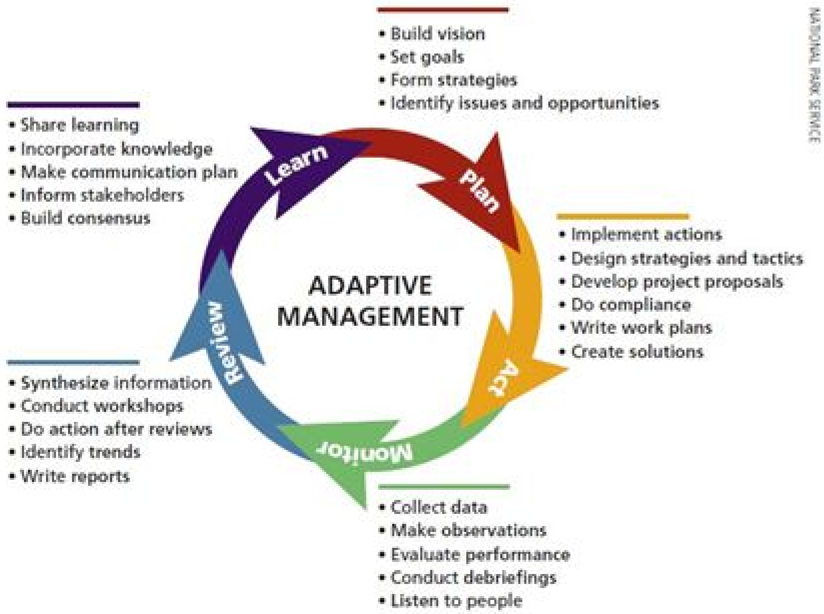

Figure 3 - Adaptive management processes.

Intentionally design/select projects

From the outset it is important to design and/or select projects intentionally to meet specific objectives and needs at RMNP (Shirk et al. 2012). Be clear about goals - are they scientific, monitoring-oriented, or educational in nature? Write clear and measureable objectives and devise a logic model with short and long term outcomes and impacts.

Implement projects intentionally for desired outcomes

Although there is much literature emphasizing intentional design in citizen science, it is equally important to consider the ways you intend to implement your project intentionally with defined outcomes in mind. For example, (Fauver et al. 2016 in prep) compared costs across three different implementation strategies used by three citizen science projects: (1) training prior to data collection and supervised data collection, (2) training concurrent with data collection and supervised data collection, and (3) training prior to data collection and unsupervised data collection. These authors hypothesized that choice of implementation strategy will relate to a project’s annual fixed costs (costs that do not change with additional volunteer data collection hours) and annual variable costs (costs that increase per volunteer data collection hour). Fixed and variable costs are important because a project with high fixed costs and low variable costs can increase in size (or 'scale up') more cost effectively than a project with low fixed costs and high variable costs. The authors found that when calculated as a percent of a project’s total budget, the project implementing strategy ‘A’ (training prior to data collection and supervised data collection) had the highest fixed costs and lowest variable costs, the project implementing strategy ‘B’ (training concurrent with data collection and supervised data collection) had the lowest fixed costs but the highest variable cost per additional data collection hour, and the project that implemented strategy 'C' (training prior to data collection and unsupervised data collection) had moderate fixed costs and moderate variable costs. Understanding the effects of implementation strategy on a project's budget is essential when designing and implementing a successful citizen science project. These intentional implementation considerations can affect the cost/benefit of your project (Fauver et al. 2016 *in prep*). Be sure to consider both design and implementation.

Manage

Few best practices have been documented for some of the more procedural tasks of managing a citizen science project. Attention here, however, can be critical for sustainability, with the need to anticipate and respond to ongoing needs of participation, data management, and expectations of all partners. Managing ongoing citizen science projects takes time and resources. Some things to consider when managing your project include staff support time, costs associated with ongoing management (fixed and variable costs), policies associated with volunteer management (privacy and personally identifiable information (PII), etc.), and sensitive data.

People management

Managing people is critical to project success. Be sure to be transparent, communicate often, and share results back with volunteers. Research shows this last step of sharing what has been learned is critical.

Data management

Data management is the process of controlling (and organizing) the information generated during your project (Penn State University Libraries 2013). This includes the development, execution and supervision of plans, policies, programs and practices that control, protect, deliver and enhance the value of data and information assets[6]. Data lifecycle management (DLM) is a policy-based approach to managing the flow of an information system's data throughout its lifecycle: from creation and initial storage to the time when it becomes obsolete and is deleted. In citizen science, many data lifecycle activities occur in parallel to the tasks and steps of the scientific method (Figure 1). But before we delve into the data lifecycle and associated tasks, activities and steps, why is it important to manage data, anyway? Effective and efficient data management:

- facilitates data collection, compilation, and sharing
- makes data more understandable and reusable
- avoids data loss
- facilitates easy analysis and visualization
- meets grant requirements
- enables replication of research
- ensures the legacy of your project long into the future
- facilitate serendipitous discoveries
- streamline the identification of outliers and errors

[6] DAMA-DMBOK Guide (Data Management Body of Knowledge) Introduction & Project Status" (Note: PDF no longer available online at https://www.dama.org, current version available for purchase).

- increase the rigor of scientific (and hence citizen science) research
- save time and money

These are just a few of the many benefits of effective data management. In general, it is important to manage data because doing so will benefit you and your collaborators, will benefit the scientific community, and journals and sponsors want you to share your data (Strasser et al. 2011).

Central to the process of data management is the data lifecycle – the stages of project data management that occur throughout your entire project from start to finish and beyond (Figure 3). This lifecycle is important because it guides the decisions you make regarding data throughout your project. The data lifecycle reminds you about important steps needed to organize information with the goals of analysis, visualization, sharing, and reuse in mind. To accomplish such organization, the lifecycle consists of eight stages: Plan, Collect, Assure, Describe, Preserve, Discover, Integrate, and Analyze (Figure 1; Michener et al. 2011, Strasser et al. 2011, DataONE 2014). Stage 1 (plan) involves writing a Data Management Plan. A Data Management Plan describes the data that will be generated and how it will be managed, documented, archived, and made accessible throughout its lifetime. Many federal granting agencies now require Data Management Plans for research projects before awarded funding. The contents of the Data Management Plan should include[7]:

- types of data to be authored
- standards to be applied (e.g., format and metadata content)
- provisions for archiving and preserving data
- access policies and provisions
- plans for eventual transition or termination of data (if relevant)

By following this data lifecycle, you position your data well for repurposing, reappraisal, and reuse by yourself and others to make new discoveries and prevent the 'normal degradation of data' (Figure 3). The key is to pay attention to each of these steps at the beginning and continuously throughout your citizen science project. Waiting until your project ends – a common mistake - is too late. Once good data management practices have become routine, many benefits suddenly emerge. Robust data management must be part of any citizen science research project, and the full engagement of specially trained personnel is indispensable for success (Rüegg et al. 2014). Ultimately, science based decision making may hinge on your data management, analysis, and visualization techniques chosen and applied.

[7] See www.dataone.org

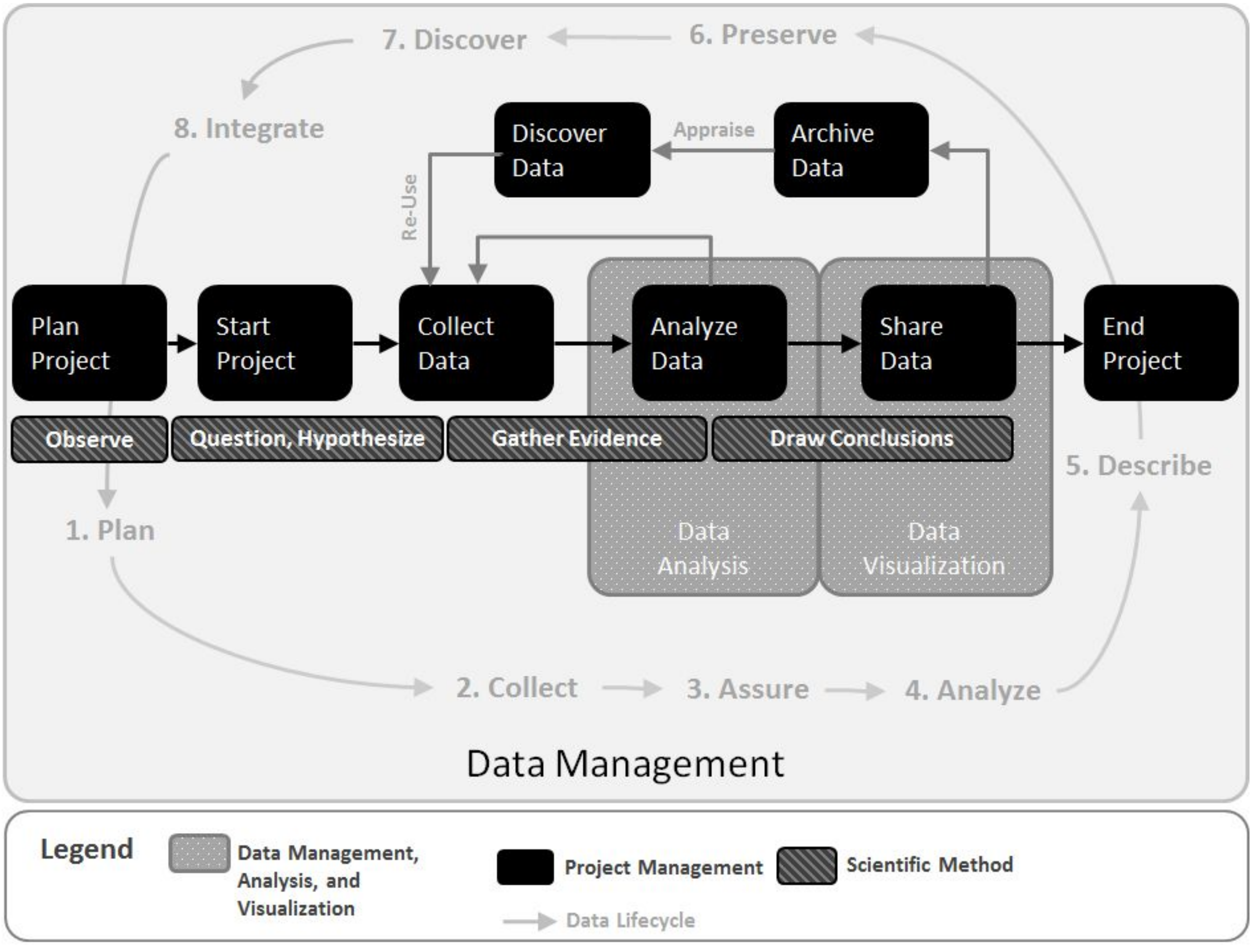

Figure 3 - The data lifecycle illustrating how the work of managing, analyzing, and visualizing data (the foci of this chapter) relate to project management and the scientific method. Opportunities for appraisal, reuse, repurposing, and reappraisal of data are shown along with the important, yet often forgotten, project management activities of data discovery and data archival. Adapted from University of Virginia Library (2014) and DataONE (2014a).

Apply, Evaluate, and Adapt

We recommend that RMNP devise formative and summative project evaluation strategies to better enable assessment of the effectiveness of projects. A good place to start would be by following the guidelines put forth by Tina Phillips and colleagues at the Cornell Lab of Ornithology in their Program Evaluation Handbook (footnote/cite). Applying this evaluative framework to all projects (and organizing metadata about all projects into an online data management platform (citsci.org like portal complete with maps and directories of projects through time) will help.

Be transparent

From the outset it is important to be up-front and transparent about how data are generated, how they will be made available, and how they are going to be used. Regular feedback should be provided both on what the research is showing and on ways the data or research results are being used. Partners and participants should be able to see how citizen science is being used to inform decisions, and ideally have access to the data and analyses. Openness and transparency can require investments in infrastructure and in time – it is worth considering this in terms of an investment towards community/participant trust, ongoing participation, and perhaps even unique insights or actions (Shirk et al. 2014). There will be circumstances where full transparency and openness will raise concerns or may not even be possible. For example, location data for endangered species often need to be obscured. They can also at times be contentious, or carry legal implications. There is a particular set of issues to consider when data have direct management or policy implications, such as for species management, habitat restoration, or game harvest. Transparency and openness can raise concerns about unanticipated and potentially unsanctioned data usage (Shirk et al. 2014).

Be agile and nimble

Adaption is also critical. Adaptive management is one way to frame the iterative process of project design and redesign. The cyclic nature of the approach is designed to facilitate continuous learning, improvement, and adaptation, to ensure that the effectiveness of project activities improves over time, and that activities can respond to changing needs and conditions (Williams et al. 2009). Other tools include logic models and conceptual diagrams. For background on how to approach and plan for evaluation in citizen science, with a particular emphasis on learning outcomes, see Phillips et al. (2014).

Conclusions

This report provides Rocky Mountain National Park (RMNP) with a framework and strategic plan to effectively identify, assess, design, implement, and evaluate citizen science projects and future project opportunities. The report offers a big picture view of past and current citizen science projects at RMNP, provides summary statistics as a baseline for tracking projects along with impacts and outcomes, and makes recommendations for park managers to strategically plan and implement a comprehensive citizen science program. These recommendations are tailored to help guide the design and implementation of future citizen science projects in the Park. An overarching recommendation is for RMNP to develop a dynamic, interactive, real-time, database-driven web portal to track citizen science projects at RMNP annually. This portal would enable efficient monitoring of projects, participation, impacts, and outcomes along with participant demographics, motivations, and perceptions to facilitate and streamline the creation of a dynamic dashboard (Figure 1) and annual reports for reporting progress moving forward. We hope that this report helps provide a few ideas to consider for Park staff when creating a Park-wide citizen science program in the years to come.

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