Community Involvement to Increase Monitoring Capacity for Climate-Sensitive Resources

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Climate-driven changes in environmental conditions and disturbance patterns have informed predictive models with expected distributional shifts of forest habitat types (Fornwalt et al. 2024) and myriad changes for vulnerable biophysical resources across ecosystems of the Front Range of Colorado (e.g., Colorado Parks and Wildlife 2015; Smith 2024; White 2024). Strategies for managing these forests adaptively in a changing climate are more likely to realize desired outcomes when decisions are based on relevant and current data (see Moir and Block 2001). Although natural resource monitoring programs generating data often require substantial investments of time and labor (Lovett et al. 2007), community science and crowd-sourcing data collection can expand monitoring capacity for climate-sensitive biophysical resources (McKinley et al. 2017). Limited agency staff and funding for routine monitoring and field data collection justifies engagement of interested public groups who can make valuable contributions to resource management (i.e., community science). Community science projects can permit monitoring of critical resources that otherwise would not be possible or extend the spatial and temporal scale of monitoring (McKinley et al. 2017). Managers may find employing community science particularly useful for examining sensitive biophysical resources that may change under altered climate conditions (e.g., Chandler et al. 2017). In addition to increasing capacity to collect data, by recruiting volunteers, managers can better deliver information to the public, connect greater numbers of the public with the mission of the U.S. Department of Agriculture, Forest Service, and increase the public value of national forests, which will likely be crucial to managing forests adaptively in the face of climate change.

Community science has been in existence for decades and successful programs have capitalized on the interests of nature enthusiasts. Beginning in the early 1900s, the Audubon Society began the Christmas Bird Count as a means to understand the diversity and trends of birds within the United States (Butcher et al. 1990; Stewart 1954). Other efforts to engage the public in the science and management of our natural resources have been developed and promoted in more recent times to examine, for example, nesting birds, invasive plant species, pollinators (see Bonney et al. 2009). Some of those efforts are more broadly accessible through the internet (e.g., Gallo and Waitt 2011) and others through more local engagement with specific conservation (e.g., Firehock and West 1995) or community-based forestry groups (e.g., Ballard et al. 2008). Regardless of the platform, interested community members are likely accessible for those managers and scientists willing to invest resources in managing such programs and able to pique the interests of the public.

Monitoring encompasses a broad spectrum of environmental measures used for informing land management decisions and is also used to evaluate management actions (Lovett et al. 2007). The burgeoning number and diversity of community science programs in recent years (MacPhail and Colla 2020) provide ample opportunity for natural resource managers seeking to build or expand monitoring capacity (see table 1). Community science can aid both managers and scientists to collect far more observations than possible with professional staff, which in turn can be used to improve knowledge of the natural world and develop decision support tools (McKinley et al. 2017). For example, when crowd-sourced observations are coupled with precipitation gauges, the accuracy of models characterizing peak flows on ungauged watersheds was improved across space and time (Starkey et al. 2017). Other hydrology-related programs focus on water quality monitoring at regional or national scales, yet with the advent of relatively low-cost dataloggers there is more opportunity for using volunteer scientists for hydrologic monitoring (Buytaert et al. 2014; Njue et al. 2019). Capitalizing on the enthusiasm of birders, Cornell Lab of Ornithology's eBird program has surpassed over 1 billion bird observations globally (eBird 2021), leading to improved distribution models for numerous migratory bird species (Sullivan et al. 2014), while their backyard Nestwatch program has improved understanding of reproductive biology of birds (e.g., Bailey et al. 2020) and how climate change is altering reproductive success of conservation species (e.g., Callery et al. 2022). Other community science programs have improved early detection of forest insect and disease occurrence, allowing for rapid and targeted management responses (e.g., de Groot et al. 2023; Mair et al. 2016). Several community-based forestry programs employ aspects of crowd-sourcing data collection to adaptively create management prescriptions and monitor outcomes (Ballard et al. 2008), which can link to the monitoring emphasis in the 2012 Forest Service Planning Rule to examine the effects on species diversity and hydrologic function (USDA FS 2012). Through the Collaborative Forest Landscape Restoration Program (CFLRP) of the Forest Service, project teams often rely on community-based monitoring of restoration outcomes (Schultz et al. 2012), one of which on the Uncompahgre National Forest uses community scientists to help collect data used to evaluate wildfire risk reduction (McKinley et al. 2017).

Within the Front Range mountains of Colorado, one ongoing community science project occurring on the Arapaho-Roosevelt National Forests is part of a global monitoring effort on ungauged streams. Trained volunteer scientists use the Stream Tracker application (Stream Tracker 2021) on smart phone devices to collect presence/absence data on streamflow to better understand hydrology of seasonally, flowing nonperennial streams (fig. 1). Volunteers report on streams encountered along popular hiking trails as well as those streams infrequently examined along forest road networks. Since 2017, community scientists have reported stream flow data across 222 sites in numerous intermittent streams within the Arapaho-Roosevelt National Forests. Since the project's inception, more than 100 volunteers have recorded well over 5,000 streamflow observations globally (Stream Tracker 2021). Such observations have improved insight into the seasonality of streamflow under current climate conditions, supported the development of streamflow duration models for ungauged streams, and helped volunteers to learn how their monitoring contributes to broader scientific understanding and aids management decisions.

Table 1—Examples of community science monitoring programs that operate at a broad national scale and regionally within the central Rocky Mountains.

National monitoring programs	Fields of study	Program links
eBird	Bird distribution Phenology of birds	https://ebird.org/home
iNaturalist	Plants, invertebrates, birds, reptiles and amphibians, fish, mammals	https://www.inaturalist.org/
The USA National Phenology Network	Phenology of plants and animals	https://www.usanpn.org/
Monarch Larva Monitoring Project (MLMP)	Occurrence in Monarch butterflies	https://mlmp.org/
Nature's Notebook	Track seasonal changes in plants and animals	https://www.usanpn.org/natures_notebook
NABat	Occurrence of bats in space and time	https://sciencebase.usgs.gov/nabat/
Project Budburst	Seasonal changes in plant life cycles	https://budburst.org/

Regional monitoring programs	Fields of study	Program Links
Stream Tracker	Hydrology of ungauged streams	https://www.streamtracker.org/
Riverwatch of Colorado	Water quality	https://coloradoriverwatch.org/
Mountain Studies Institute	Noxious weed mapping Bighorn sheep monitoring PikaNet	https://www.mountainstudies.org
University of Wyoming Biodiversity Institute	Mullen Wildfire Community Science Initiative Rocky Mountain Amphibian Project Wyoming BioBlitz	https://www.wyomingbiodiversity.org/index.php/community-science
Colorado Pika Project	Records observations of Pika	https://pikapartners.org/
CoCoRahs (Community Collaborative Rain, Hail, and Snow Network)	Observations of precipitation in rural and remote areas of Colorado	https://www.cocorahs.org/

Figure 1a-b—Photographs of community scientists performing field work to aid Forest Service resource managers: (A) Trout Unlimited volunteer locates and retrieves stream temperature datalogger (photograph by Tom Lindsey, Trout Unlimited); (B) Stream Tracker volunteers make repeat observations (dry versus wet) of streamflow presence in ungauged stream (courtesy photos by Kira Puntenney-Desmond, Colorado State University).

Other community science efforts on national forests in Colorado include assisting in evaluation of land-use impacts, animal abundance, and physical habitat conditions. In southwestern Colorado, range condition assessments performed by local ranchers help to add more data points and bolster information from the limited number of surveys that agency staff are able to complete (USDA Forest Service 2021). Using the U.S. Geologic Survey North American Bat Monitoring (NABat) program, volunteer scientists are monitoring roost sites on the Pike and Routt National Forests, which has helped document declines in bat populations in other regions of the western United States (Rodhouse et al. 2019) and helps multiple agencies acquire bat monitoring data needed for better managing conservation challenges facing imperiled bat species across North America (Reichert and Soileau 2020). In return, volunteers learn about the ecological and economic importance of bats and contribute to improving management. Within alpine ecosystems, interested public help the White River National Forest and agency partners monitor American pika abundance and occupancy due to the species' importance in the ecosystem and vulnerability to climate change outcomes (Front Range Pika Project 2021). Trout Unlimited volunteers have helped staff on the Arapaho-Roosevelt National Forests to deploy and retrieve stream temperature dataloggers (see fig. 1), resulting in a substantial increase in the number of streams with year-round temperature monitoring, which will ultimately help managers evaluate where stream temperatures are warming in response to climate change and develop sound conservation approaches for climate-sensitive aquatic species (e.g., cutthroat trout *Oncorhynchus clarki* subspecies, Susan's purse-making caddisfly *Ochrotrichia susanae*).

Community science programs can provide information over broader geographic and longer time scales than most land management monitoring programs (McKinley et al. 2017). The advent of mobile computing and utility-based applications available on smartphones has given rise to several platforms capable of streamlining data workflows and, thus, supporting community science initiatives (Newman et al. 2012), many of which have assembled data sufficient for broad-scale assessments that show spatial and temporal shifts in species distributions at regional scales (e.g., Parmesan et al 1999; Sullivan et al. 2014). Whereas some community science projects have developed specific applications (e.g., eBird 2021; StreamTracker 2021), other data collection platforms, such as Epicollect (2021) and Survey123 (2021), are highly customizable to address a range of community science topics and facilitate easy deployment of trained volunteers. Once useful community science projects are developed and adapted, smartphone applications such as these are helpful in managing data and allowing participants to see their observations and track progress.

Even lack of time, funds, and expertise for taxonomic identification of diverse or rare species are challenges that may be particularly amenable to community science projects in conjunction with species identification applications (e.g., Ožana et al. 2019; Sullivan et al. 2014). The iNaturalist application (2021) applies an algorithm to suggest species identifications of photographs to assist with identification, which is followed by confirmation from trained scientists to obtain research grade data. Public engagement by collecting photo observations in National Forests followed by uploading to iNaturalist may allow for development of species lists and distributions. One such effort used iNaturalist on Forest Service lands in Arizona to examine observational trends in 34 plant species in space and time, identifying five plant species that might need improved conservation on Federal lands (Souther et al. 2021). Similar efforts may empower community members to become familiar with the diversity species on National Forests, developing strong interests in certain taxonomic groups and contributing to increasing knowledge about rare species.

Developing and managing community science projects requires a commitment of resources and time in the form of training volunteers, developing platforms and organization structures, and real costs to agencies and organizations; however, many successful community projects report positive returns on invested agency resources. The European-developed Freshwater Watch (2021), which aims to compare aquatic ecosystem dynamics (e.g., water quality, biodiversity) across a range of land-use impacts, returns on average 6 hours of data collected by volunteer scientists per hour of instruction and engagement by lead agency scientists and managers (Thornhill et al. 2016). In the case of stream temperature monitoring on the Arapaho-Roosevelt National Forests, a modest amount of training and direction (e.g., 7 days per year) provided from Forest Service biologists to volunteer scientists who steward datalogger networks yields more than a doubling in the density and extent of monitoring sites (AR-NFs, 1996-2024, unpublished data) and a cumulative equivalent of more than 1,000 hours of labor. For web-enabled programs (e.g., Stream Tracker), where simplified streamflow presence or absence data can be collected on a smartphone application without specialized equipment and self-guided training for volunteers, the return on investment in training volunteer scientists can yield high rates of return as volunteers contribute data across time and space once they become familiar with recording observations in the application. However, such programs often work best and generate the most accessible data repositories when sufficient paid staff are available to manage incoming data (MacPhail and Colla 2020) and monitoring programs are built in collaboration with community groups (Conrad and Hilchey 2011).

Well-managed community science programs can provide large volumes of data for monitoring changing environmental conditions on national forests and where those changes are occurring rapidly or are muted, which will likely enable managers to prioritize actions for their most critical of resource concerns in a more informed manner. Although initiating and overseeing a community science project does take time, the engagement can be mutually beneficial. Volunteer scientists can provide much needed data, particularly for climate-sensitive biophysical resources, while experiencing new activities that are important for managing natural resources. Engaging community members in management can increase public awareness of resource management issues and inspire members of the public to take action in meaningful and beneficial ways, helping to create a culture of shared stewardship, and connecting people to the land (MacPhail and Colla 2020). Community science not only can help forest managers improve data collection across spatiotemporal scales and make more informed conservation decisions, but also serves to engage sectors of the public in those decisions and foster public engagement (Aceves-Bueno et al. 2015; McKinley et al. 2017). Further, ample reviews of effective community science programs and existing datasets (e.g., Buytaert et al. 2014; Conrad and Hilchey 2011; de Groot et al. 2023; MacPhail and Colla 2020; Njue et al. 2019; Silvertown 2009) are available to help national forest managers develop community science programs and acquire crowd-sourced information instructive for managing climate-vulnerable biophysical resources. More resources about using public participation to support management needs are available at the USDA Forest Service Citizen Science website (USDA FS 2021).

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